line appears on the surface to have an LRT right-of-way, both now provide streetcar service. The only anomaly is Pittsburgh, in which there are two LRT lines, a slow but largely off-street route (Mt. Lebanon), and a true streetcar line. It does not appear coincidental that the Pittsburgh system in its present state and at its typical trip time of 31 min has the smallest daily ridership of any CBD-oriented system except Newark and Shaker Heights, which pose special problems of urban and transit system development.

Some systems, such as the Shaker Heights Rapid Transit and the lines in Philadelphia's western suburbs, must be fast so that typical trip times are not unduly long. Speed, however, is not everything. The four systems in the group that have a $\overline{V}$ between 18 and 22 km/h (11 and 14 mph) include two heavily used CBD-oriented operations—Boston's Green Line and Philadelphia's subway-surface lines. Typical trip times for these systems are about 20 min. More importantly, these lines connect vital elements of the urban core with each other and with residential areas. For the latter, the trunk-and-branches configuration allows most riders to have a single-vehicle ride.

The currently operating LRT systems serve the kinds of medium- to high-density urban and suburban areas that future development may well have to emulate as decreasing amounts of fossil fuels, especially petroleum, make it more and more expensive to sustain the automobile-oriented spread-out style of life. This process might be called the Europeanization of American cities. Given the role that LRT plays in many areas of Europe and the vitality of the cities thus served, such a trend might be more acceptable than we now think. Certainly, the quality of life along Boston's Green Line supports this notion.

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Operational Idiosyncrasies of a Subway-Surface System

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The objectives of this paper are to acquaint the reader with the behind-the-scenes activities that constitute the day-to-day operations of Philadelphia's subway-surface system and to pinpoint techniques and methods that new systems could adopt to avoid some of the problems SEPTA faces. The paper discusses daily operations, service interruptions, training, accident prevention, and support activities. The problems discussed are accompanied by a discussion of the solutions adopted or those that would be adopted if there were adequate funds and local cooperation. Specific recommendations for new systems are summarized.

A daily rider of Philadelphia's subway-surface system might describe a typical journey as follows:

I live close enough to the car line to walk to the stop, and I usually only wait a short time before a streetcar arrives. I get on board with the other people and, if I'm lucky, I find a seat. During the 20-minute ride I usually either read the paper or just watch the signals in the tunnel flash by. At 15th Street I get off and make my way to my job; normally I arrive before my next-door neighbor, who drives to work.

Our passengers probably never give a thought to the many behind-the-scenes activities that make their safe arrival possible. I wish to describe these activities here and provide an introduction to one of the most efficient ways of moving people—the surface-subway operation of the Southeastern Pennsylvania Transportation Authority (SEPTA). I will first review the history of the system and then discuss daily operations and service interruptions, considerations for training and for accident prevention, and support activities.

HISTORY OF THE SYSTEM

Some historical background will place today's operation in perspective. Subway construction fever gripped Philadelphia at the turn of the century, and numerous companies were chartered. One of these, the Market Street Elevated Railway Company, advanced a plan for a route to connect the western suburbs with the center city. The track was to be elevated from 69th Street to the Schuylkill River, cross that river on a new bridge, and then go underground to the Delaware River via City Hall.

An interesting feature of the scheme was that West Philadelphia streetcars would climb up on the bridge to join the El before both trains and trolleys began the underground trip to and around City Hall. El trains were to operate as expresses in the two center tracks from the Schuylkill River to City Hall. The trolleys were to operate on the two outer tracks and make local station stops at 24th and 19th Streets.

The surface-car subway, operated by the Philadelphia Rapid Transit Company (PRTC), was opened in December 1905, before the El's completion. Trolleys crossed over at 19th Street to use the El tracks and temporarily stub ended at 15th Street. In early 1907 the streetcars were shifted onto their own tracks entirely and routed around City Hall, looping under the newly opened El. The eastern terminus was and is Juniper Street Station.

Almost as soon as the subway opened, PRTC advanced plans to extend it. One such idea called for a surface-subway distribution loop in the center city. It was to run from City Hall via Broad, Walnut, Fifth, and Arch streets and back to City Hall. Some of the stations on Arch Street were actually started. Also proposed was a tunnel to replace the Schuylkill Bridge, and an extension of the subway into West Philadelphia. The tunnel under the river was actually dug in the 1930s but, like the distribution loop, fell prey to the constant bickering between the city and PRTC.

It was not until 1955 that a joint extension underground of the El to 44th Street and the trolleys to portals at 36th and 40th streets opened, replacing the bridge at last. Unfortunately, the surface-subway alignment was dictated by urban renewal, University of Pennsylvania expansion, and cost considerations. The initial cost savings have been negated many times over because the twisting tunnel alignment reduces schedule speeds, causes rail and wheel wear, requires more signaling, and results in an ever-present potential for car collisions. Where possible, new systems should minimize curves.

DAILY OPERATIONS

Today five routes originating in the western fringes of Philadelphia make up the system (Figure 1). These routes operate 90 cars and carry an average of 60 000 passengers each way daily. The headway in the subway during peak hours is a very close 30 s. Route 10 operates out of 64-year-old Callowhill Depot and enters the subway at 36th Street near Market. The other four lines operate from Woodland Depot, which dates from the horsecar era of the 1860s.

The surface portion of the system has conventional street running with its attendant hazards of traffic congestion and service delays (Figure 2). Traffic signal preemption for streetcars has been suggested to the city by SEPTA but to date has not been implemented. There is one section of private right-of-way on the outer end of Route 36, but it is subject to interference from cross traffic. The final unprotected turn into traffic to reach the terminal gives the operator quite a challenge. This is one of the places where preemptive signals, such as those commonly used in Europe, would speed service and provide safer operation. Loops at the ends of lines should always include bypass capability for scheduling flexibility and for passing disabled cars.

The four lines that enter the 40th Street Portal activate a preemptive traffic signal that stops automobiles crossing in front of the tunnel. The automobile traffic presents a serious accident hazard and delay potential, so the city plans to reroute traffic and restrict the area around the portal to transit only.

When the car enters the subway, the operator faces an abrupt change in light levels that affects his or her vision. We are exploring the possibility of installing yellow transitional lighting just inside the portals of both the surface-car and rapid transit tunnels. New tunnels should be designed to minimize the impact on operators of such changes in light level.

Most of the tunnel is lighted only by widely spaced incandescent bulbs, but the stations are bright. This poses another vision problem for operators entering and leaving stations. Some sections of the tunnel have been modernized with fluorescent lighting, and we are studying the feasibility of installing roof-mounted car headlights for better visibility in the tunnel. Light levels should be uniform throughout the tunnel.

A three-aspect block signal system regulates car progress everywhere in the tunnel except in the old section between 22nd and 15th streets. In this area, safety depends on the operator's vision and alertness. Techniques used to maintain this alertness are discussed later. To increase station capacity, a call-on system is used that enables the following car to move into the station while the first car is still loading or unloading. This practice does increase the likelihood of car collisions, and we closely monitor its use.

The signals are numbered to help the operator quickly identify his location. All eastbound signals are even numbered, and westbound signals have odd numbers. By mentally adding a zero to the signal number, the operator also knows the house number on the street above him. Thus, MS 211 is located at 2110 Market Street. This system greatly aids the Radio Room personnel who dispatch help to an operator.

Since the majority of passengers disembark and load at Juniper Street Station, we use a sliding gate to increase car capacity there. In the morning rush, a supervisor positions the gate so that four cars can unload simultaneously before each moves beyond the gate to the paid area to load. In the evening rush, the gate is positioned to allow four cars to load at once in the paid area.

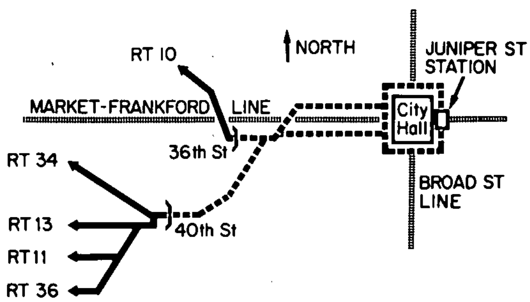
Lighted signs at 15th Street West Plaza Station and automatic ones at Juniper Street Station direct passengers to the berth at which cars on a given route will stop. A sign in the tunnel outside the entering end of the station tells the operator at which berth to stop.

Before these two stations were modernized, the berthing positions were changed from moment to moment according to which car was next due in. Standard berthing positions were introduced to eliminate the accident hazards of people darting into the track area or shoving their way through the limited waiting space to reach the proper berth. I can recommend constantly changing berthing only if the station is properly designed to safely handle passenger ebb and flow.

Passengers normally pay fares to the operator when they enter the trolley, but at the two busiest stations, Juniper and 15th Street West Plaza, cashiers are used. Cashiers collect fares for a few hours at Sansom Street Station during the heavy influx of school children from that area. The 30th Street Station cashier handles both local (subway-surface) and rapid transit (Market-Frankford) traffic. Once he or she is inside the cashier controls, the passenger is directed by means of color-coded turnstiles to the correct line. Because the surface-subway is integrated with the subway-elevated lines, certain joint operational techniques are employed. At 15th Street West Plaza Station, the cashier admits passengers for both the surface-subway and the Broad Street subway lines.

At Juniper Street Station, a blue train-arrival light comes on during the very late hours to alert a trolley operator that an El train has arrived at the adjacent 13th Street Station and that the operator must give passengers enough time to descend the stairs to reach their cars. Stationmen are assigned to the Juniper and the 15th street stations in the evening peak hours to provide center-door loading. This lessens station dwell time.

Figure 1. Schematic map of Philadelphia subway-surface system.

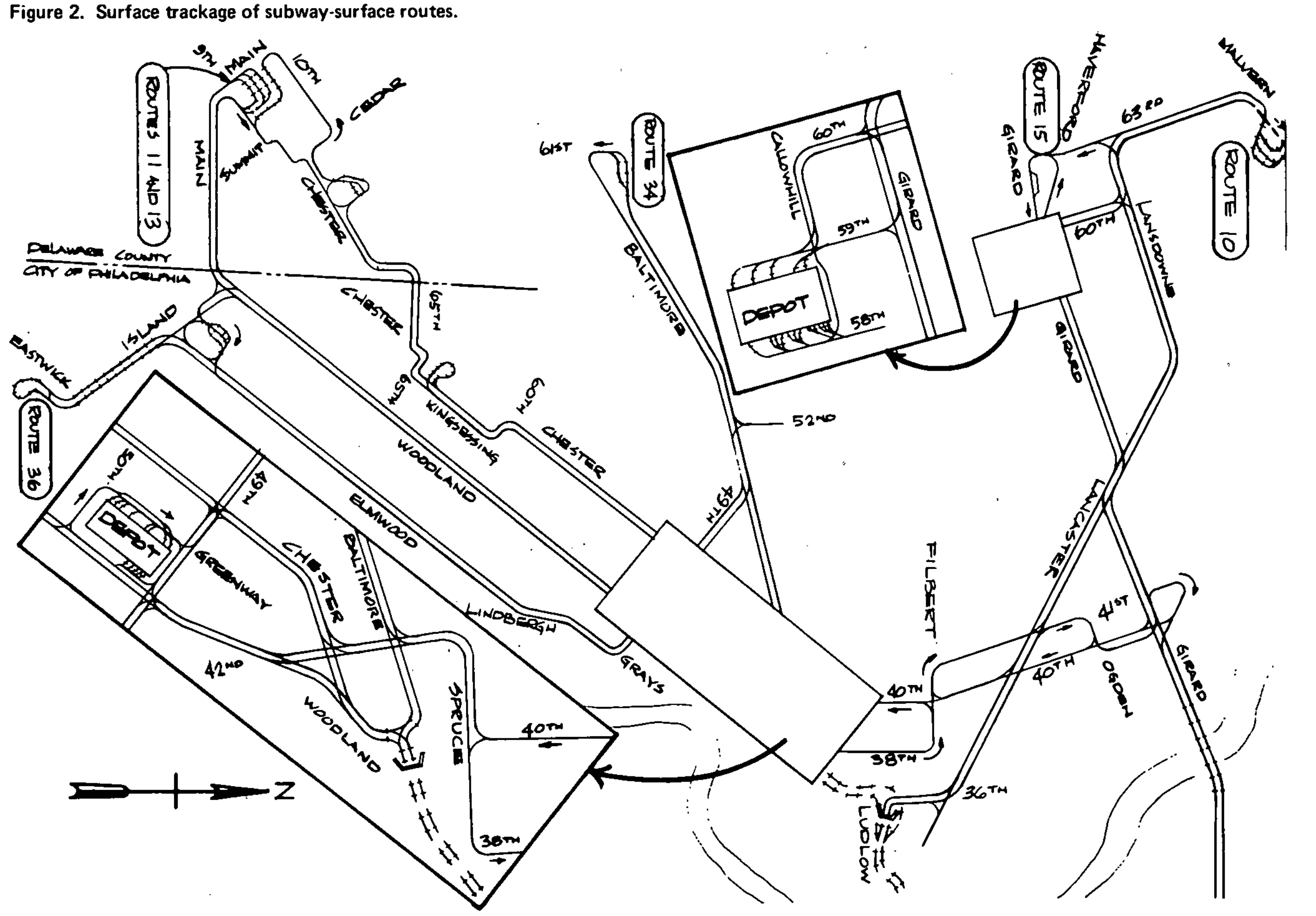


SERVICE INTERRUPTIONS

Since our streetcars are not equipped with radios or train telephones, an operator faced with a delay, mechanical breakdown, or other problem must call the control center, Radio Room, from the nearest telephone and then follow instructions. In the tunnel, telephones are located on the walls. A grant request is being prepared for funds to enable us to equip the cars with radios.

Radio Room personnel pass on to the operator instructions from the street supervisor or, if the delay is in the tunnel and is of major consequence, turn jurisdiction over to the subway-elevated train dispatcher. Street supervisors use radio-equipped automobiles but can conserve air time by calling in on telephones strategically placed at the portals. During delays, instructors who are not engaged in the training of students frequently join supervisors to clear the track as quickly as possible. Both aim to minimize the impact on passengers riding

Figure 2. Surface trackage of subway-surface routes.



trolleys that are immediately behind the crippled car or that must be cut to restore the operating schedule.

Today's social problems unfortunately have a direct impact on transit operations. Fare disputes sometimes necessitate police intervention, and certain cashier booths have switches to turn on a police-request light located at the street entrance to the station. At times, the streetcar operators are faced with the dangerous problem of unruly and perhaps violent passengers. To assist the operator in alerting police along the route, some trolleys have been equipped with a revolving amber help-needed light. These lights are, however, difficult to see in the daylight and have not been in operation long enough to provide a final evaluation of their worth. The help-needed light does serve another function in the subway. If the car breaks down, the operator turns on the amber light before leaving for the nearest telephone, and the reflection off the walls makes the light even more visible. Operators of trolleys going in the opposite direction can then alert the first instructor or supervisor they encounter. In the joint-operation section of the tunnel, Market-Frankford subway-elevated operators who spot the amber light call the train dispatcher immediately on their train telephones.

Fire boxes, fire extinguishers, and emergency exits are located together throughout the subway. Most are placed adjacent to the telephones. Telephones are kept locked to prevent vandalism, and operators carry a special key. We hope to place arrows on the walls, so that when an operator leaves the car to find a telephone he or she will immediately know which direction to take to reach the nearest telephone. The present private telephone system will shortly be replaced by Bell System telephones whose locations will be standardized to facilitate finding them in an emergency.

The use of trolley poles rather than pantographs results in all-too-frequent dewiring and torn overhead wires. Emergency crews are on call and are directed into the subway through the nearest station.

Each operator is issued a flashlight for his or her own and the passengers' safety in the tunnel. Supervisory personnel have flashlights equipped with fuse testers to facilitate trouble shooting. Although the all-electric Presidents' Conference Committee (PCC) cars have interior emergency lights that are powered by the battery, PCC cars with air brakes do not. A disabled, dark car can produce a panic situation. All new cars, whether they have air brakes or are all electric, will be equipped with adequate emergency lighting.

The normal procedure for handling breakdowns in the subway during rush hours is to immediately hook up and push the disabled car out. During off-peak hours and on the street, a trouble-shooting sequence is followed, and many times the problem is corrected by replacement of a fuse. Since delays in the subway cannot always be immediately cleared by pushing, we have emergency tools placed throughout the subway. These are periodically checked to ensure they are present and in working condition. In addition, great care must always be taken while making repairs in the joint-operation area because elevated trains may strike personnel who are engrossed in fixing the trolleycar.

Operator initiative plays an important part in keeping delays to a minimum, and often the disabled car is being pushed out before supervisory personnel reach the scene. SEPTA also has special hydraulic rerailing equipment that greatly assists in getting a trolley back on the track in minimal time.

Since the subway is a continuous loop with no cutbacks or crossovers, a car that breaks down eastbound would have to be pushed all the way out if it were not for a two-car spur adjacent to Juniper Street Station. This spur allows us to place the disabled car out of the way and fix or retrieve it during off-peak hours. Of course, a better solution would call for double-ended cars and frequent crossovers.

Procedures designed to clear the line as quickly as possible specify that all pushed cars go to Woodland Depot because it is closer than Callowhill. We use the Route 13 trackage on Chester Avenue instead of the more direct Woodland Avenue to avoid runaways on Route 11's steep hills.

Major accidents or derailments in the subway can make continued operation below ground impossible. When this happens, instructors or supervisors turn on pole-mounted amber lights located at the track switches for diversion routes. When operators see these lights they know they are not to enter the subway but instead take their passengers over a normally unused diversion routing to the 40th and Market El station. There the people can transfer to the trains to complete their trip to the center city. These diversion routes are also used for a few hours in the early morning each Thursday to let us close the subway to make uninterrupted repairs in the tunnel.

Unfortunately, we do not have a loop at the entrance to the 40th Street Portal, but an operator whose car has mechanical problems can, with the assistance of a supervisor or instructor, use the y-shaped track there to turn the car and return to the depot. This is not an ideal situation, since such an operation ties up the entrance. The city's plan to close 40th Street to all but transit will provide an opportunity to redesign the entrance trackage to include a loop.

The heavy ridership on the subway-surface lines makes it necessary to operate even while surface track is being reconstructed and roads are being paved. Temporary crossovers, temporary signals, and workers using walkie-talkies make this a safe, smooth operation and ensure minimum delays to our passengers. Major subway reconstruction, such as the shifting of the 15th Street Station platform, included provisions for cars to continue in service with only brief interruptions druing track tie-ins.

TRAINING PROGRAMS AND ACCIDENT PREVENTION

Delays occasioned by equipment breakdowns are serious but not as costly as those resulting from accidents. At SEPTA, the instructors in the Operational Training and Safety Division teach and follow up employees in both operation and accident prevention.

The initial 14-d training program stresses not only car operation, trouble shooting, and courtesy but techniques of accident avoidance. On-vehicle and classroom instruction are augmented by teaching aids, such as model boards, signal flash cards, and written examinations. Training stresses the operator's responsibility to anticipate such hazards as slippery rails where there are falling leaves. Follow-up training in defensive driving techniques is given to both new operators and experienced employees by instructors certified by the National Safety Council.

We keep employees informed about specific current problems through periodic distribution of handouts and the monthly issues of the four- to six-page Safety Sense Newspaper, which is specifically designed to provoke employee reaction and thought.

When they are not engaged in actual training, instructors function in many other roles. Follow-up rides are periodically taken with each operator to identify bad operating habits or poor performance. These rides also provide the opportunity to commend an operator for a job well done. Instructors must spend 15 min/d walking between stations in the subway. This serves several functions. The likelihood that an instructor may appear anytime and anywhere helps keep operators on their toes. In addition, instructors assist the Facilities Department by spotting and reporting out-of-order equipment, evidence of vandalism, and other problems. Finally, many breakdowns or delays are quickly cleared because an instructor was handy.

Besides working to assist operators, instructors run various checks of compliance with operating rules. The subway's block signals do not have trips, since an arrangement such as that used on the Shaker Heights PCC cars cannot be employed on street-running trolleys. Operators are sometimes tempted to lose respect for red signals, especially on time-zone lights. To minimize safety violations of this type, instructors periodically conduct signal checks during which the signal is held at red until the operator comes to a complete stop. Violators are suspended for a day for the first offense, and progressively stricter discipline is exercised thereafter. The possibility is being discussed of equipping new cars and the tunnel with an inductive-coil trip system such as that used in Belgium.

Our rules require operators to come to a complete stop at all facing point switches (except the air-brake-operated double-point switch in the subway) and to ensure that the switch is properly set before proceeding. Instructors conduct frequent switch checks. Interlocking switch and signal plants are possible accident sites, and operator adherence to safety rules at our one such location is reinforced by the use of a graphic recorder that can pinpoint signal or switch violations. This recorder in the 34th Street Tower is monitored by a signal maintainer.

The subway-surface system has only one railroad crossing; this is also frequently checked by instructors to see that operators stop and look before proceeding. The overhead wire at the crossing has a conductive net guard to catch the pole if a dewirement occurs. This allows the car to clear the crossing before the pole is rewired. Other safety aids are installed where needed, such as signs to warn of slippery rail. There is also a mirror at the portal so that an inbound trolley operator can watch in the mirror for automobiles behind outbound cars.

None of these efforts in itself will ensure accident-free operation but together they are very effective. SEPTA's greatly improved safety record attests to this.

SUPPORT ACTIVITIES

There are many activities and facilities necessary to support a subway-surface system, so I will mention only a few. Because our private right-of-way precludes the use of automotive vehicles to string or repair overhead wire, a tower car is employed. This car is also essential for repairs in the subway. Trash removal from the tunnel is facilitated by use of a work car. Other maintenance and repair functions dictate the need for crane and flatbed work motors. Car maintenance itself is accomplished at Callowhill Depot for Route 10 and at Woodland Depot for the other routes. A disastrous fire in late 1975 destroyed the Woodland Shop; we must now make do with a temporary prefabricated structure.

The future of the five subway-surface lines is assured. Specifications are being prepared for new light-rail vehicles to replace the tired fleet of PCC cars. A new depot and major maintenance facility have been designed to replace the antiquated Woodland Shop. Together these efforts will begin a new era in efficient transportation for the people of West Philadelphia. By then the joint efforts of the city and SEPTA to provide better security on the system for passengers and operators, eliminate graffitti, and in general raise the quality of service will have gone far forward.

RECOMMENDATIONS FOR NEW SYSTEMS

1. Use preemptive signals liberally for street running or private right-of-way with cross traffic, especially where turns are involved.
2. Plan the subway alignment to exclude or minimize curves; unavoidable curves should be made as gradual as possible.
3. Provide for transitional lighting where operators enter and leave the tunnel.
4. Provide uniform lighting levels throughout both stations and tunnel sections.
5. At terminal stations use sliding gates to increase loading and unloading capacity during peak hours.
6. Plan for the strategic, uniform placement in the tunnel of such items as telephones, extinguishers, fire alarms, and emergency tools.
7. Use arrows to indicate the shortest distance to such emergency equipment and make sure the tunnel has a concrete walkway for operator use and emergency evacuation of passengers.
8. Buy double-ended cars or cars with back-up controllers and place crossovers at frequent intervals in the trackage.
9. Provide for diversion of routes since even the most well-designed system will suffer blockages; it would be especially wise to include a loop at tunnel entrances if cars are single ended.
10. Ensure safety with simple block signals and car trips.

Traffic Engineering for Light-Rail Transit

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The development of safe and operationally effective designs for at-grade intersections and crossings for light-rail transit (LRT) is an issue central to the future deployment of the mode. This paper describes a design approach based on the performance characteristics of light-rail vehicles (LRVs) and the application of conventional traffic engineering hardware and design practice. At-grade operation of LRT introduces potential conflicts with motor vehicles and pedestrians at intersections, in streets between intersections, and at mid-block crossings. These conflicts are a source of delay and accidents for LRVs. Application of the appropriate conflict-control techniques must consider that modern LRVs have performance characteristics essentially similar to those of transit buses. There are four strategies available to the traffic engineer to eliminate or