enforcement process. Early fears that Canadian and U.S. legal systems were not amenable to enforcement have been dispelled by successful systems in Vancouver, Edmonton, Calgary, and San Diego. Edmonton is particularly revealing in that it started with a barrier system but within 2 years converted to self-service as an economic measure. In all 4 SSBF systems, evasion is now at or below 1 percent and is well below anticipated levels. Machine maintenance varies from satisfactory to very good. Vandalism has been shown to be a minor problem. The legalities of ticket inspection and enforcement have proved workable under different jurisdictional and legal systems. The protected benefits of added security and information services offered by enforcement staff have exceeded all expectations.

Any city that can adequately control and administer parking meter enforcement should be able to handle self-service. The self-service, barrier-free, proof-of-payment system has often been labeled as an "honor system." In fact, increasing fraud or potential for fraud on conventional transit fare collection systems makes these more of an "honor system" than self-service. Not only is SSBF clearly the preferred option for new LRT systems in a wide range of passenger volumes, but it may also have merit for use on the entire transit system. It now appears that Portland, Oregon, will be the first to implement this systemwide. The results could have a major impact on the entire future of transit fare collection in North America, which is still geared to concepts dating from when fares were a nickel and labor cost 15 cents an hour.

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San Francisco Muni Metro: Operating Issues and Strategies

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The advent of a light rail vehicle system presented the San Francisco Municipal Railway (Muni) with new challenges associated with operating a high-speed subway system. The Metro, as the system is known, is a subway and surface operation on five existing streetcar lines in San Francisco. It carries about 120 000 passengers per day. Muni was able to run extensive tests with its new fleet of LRVs before starting revenue service to check operating characteristics, especially the ability to couple and run as a multi-car train. Muni's start-up strategy for a gradual phase-in of LRV service provided opportunities to learn about a far more complex operating environment than traditional streetcar operation. It became apparent in the early operational phases that a traditional schedule approach was unworkable. Before full-scale operation began, it was decided to abandon the usual schedules and use a "dynamic schedule." By headwaying the cars and providing a pool of fallback operators, it was hoped to maximize the use of the LRVs and help meet the ever-increasing demand of Metro passengers. This headway and fallback system was refined to help Metro break the turnaround bottleneck at the Embarcadero Station, which limited the system's capacity. In addition, a central trainmaster at Van Ness Station improved the consistency of service. The headway and fallback system's shortcomings include partially developed crew dispatching and trainmaster procedures and stacking of outbound trains caused by system saturation.

The five existing Muni streetcar lines are all that remain of an extensive network of electric street railways that once served most areas of San Francisco. Most of these lines were discontinued before or immediately after World War II. The 44 miles of double track in the five existing lines survived principally because of their exclusive rights-of-way, which were not, and are not, readily convertible to motor bus use.

Three of the five streetcar lines (K, L, and M) use the Twin Peaks Tunnel, which was completed in 1917. One of the lines (N) uses the Sunset Tunnel, completed in 1928. The fifth line (J) partially uses an exclusive right-of-way parallel to Church Street. Before the completion of the subway, all five lines used the same tracks for more than 2 miles on Market Street. At Duboce and Church Streets, in the Upper Market area, two of the lines separate from the other three: The N Line proceeds west to the Sunset district; the J Line serves a portion of the Mission district; and the K, L, and M lines travel through the Twin Peaks Tunnel to serve, respectively, the Ingleside, Parkside, and Ocean View districts.

This is the surface portion of the existing Muni streetcar network that has been transformed into a light rail vehicle system called Muni Metro. The primary objective of this modernization was to provide significantly improved speed, capacity, comfort, reliability, and safety to the patrons of the existing streetcar system.

One of the major improvements provided by the Muni Metro has been the replacement of 2 miles of surface street operations on Market Street with nearly 5.5 miles of subway. This subway includes four stations in downtown San Francisco—shared by occupying the upper level of the BART subway—plus three new Muni Metro-only subway stations along Market Street. In addition, one subway station is to be remodeled in the Twin Peaks Tunnel, and one new station is at West Portal.

In addition to the subway improvements, the surface operations of Muni Metro were upgraded: The aging track and power distribution facilities were repaired or replaced; facilities were provided to aid the separation of rail traffic and vehicular traffic; and additional passenger-loading islands were constructed.

One hundred new U.S. standard light rail vehicles (SLRV) were procured for service on the Muni Metro. These vehicles were built by the Boeing-Vertol Company under a contract signed in 1973. The cars are capable of speeds up to 50 mph, are articulated to facilitate curves in streets, and have steps adjustable to high and low. High steps accommodate the standard design of high platforms in the subway stations; low steps meet the pitch of standard traffic islands and street stops.

METRO TASK FORCE

Although it was in the works for a number of years, the pieces of the Metro System really began to come together with the creation of the Muni Metro Task Force, established in 1978. The Task Force consisted of a small number of staff members and a director, Farrel Schell, who had the responsibility for recommending and expediting the timely completion of actions necessary for the successful inauguration of Muni Metro service.

The Task Force worked with other members from all Muni departments, Public Utilities Commission Bureaus, and other city agencies that had direct line responsibility for various aspects of Metro implementation. This Task Force concept proved to be an effective management tool in coordinating and directing the efforts of so many different departments and agencies working to bring the Metro into operation.

COUPLING ISSUE

Could Muni couple LRVs safely? Because the system lacked experience in coupling cars, some safety-related concerns were raised, such as hazards inherent in coupling, the hazard of coupling on a grade at Duboce Portal, and the risk of "fall-on-board" types of accidents. These potential hazards were quickly dispelled after Muni acquired the LRVs and tested the coupling procedure during the test and acceptance program. Muni learned that it could couple LRVs without incident.

Muni Metro's system components were designed to allow coupling. As proposed, coupling would be accomplished at the two entrances to the subway. Three lines, K (Ingleside), L (Taraval), and M (Ocean View), would couple into trains at West Portal Station. Similarly, J (Church) and N (Judah) cars would couple at Duboce Portal and proceed into the subway as a train.

It was hoped that peak headways on individual lines would be about 4 minutes, with trains from the two subway trunks merged alternately at the subway junction. They would operate on a 2-minute combined peak headway to the Embarcadero Station terminal.

This operational strategy built high capacity around the use of multi-car trains despite a relatively long 2-minute headway. (Market Street surface streetcar operations ran on a 50-second headway.) In fact, the physical design of the Embarcadero Station Terminal facility effectively prevented turning trains around in less than 2 minutes. Thus, subway capacity was limited by the terminal capacity, not line capacity.

This type of scheduled operation has never been implemented. A number of factors contributed to its demise. A major factor was the operation of the LRVs on the surface: They proved to be much slower than expected. It quickly became evident that a 4-minute peak headway, given the number of LRVs Muni had purchased, would be impossible to obtain.

The reliability of such a schedule was based on the almost-perfect arrival of cars at the coupling locations, so trains could be dispatched at regular intervals. Delays at coupling locations were inevitable unless timely arrival of cars from outer terminals could be assured. With LRVs operating on the surface in mixed traffic, this became an impossible task. In addition, early service was plagued by numerous delays caused by car disablements on the street. These frequent disablements ruined any chance of regular arrivals for coupling. Once the coupling cycle was broken, "short trains" would be dispatched before all scheduled cars arrived. This caused haphazard outbound schedules, which then contributed directly to problems of scheduled coupling when these trains arrived back at the coupling point off schedule.

Although Muni chose not to use the "scheduled" coupling, it devised a method of coupling that was not tied to scheduled arrivals. The procedure of coupling and sequencing cars is discussed later in this paper.

TEST AND ACCEPTANCE PROGRAM

Before any of the new LRVs went into revenue service they had to prove themselves in the test and acceptance program. Each vehicle was required to provide well-documented proof that, under simulated revenue conditions, it was able to perform up to specifications.

Each vehicle had to show 30 "good" days of service. A "good" day meant that, if in revenue service, the vehicle would not have to be removed from revenue service due to mechanical problems. Areas that received extensive testing were braking rates (service and emergency), acceleration rates, and the propulsion system. This program used the combined efforts of Louis T. Klauder and Associates, a Muni engineering consultant, and the Muni operations and engineering departments.

In addition to testing the vehicles, Muni used the test and acceptance program to develop a new operator's training program that provided instruction in operating in a high-speed subway environment, knowledge of the signal system, troubleshooting vehicle problems, and emergency procedures.

The test and acceptance program allowed Muni to test the LRV's capability to sustain regular programmed in-service coupling, which was to be an important feature of Muni's operating strategy. All tests showed that in-service coupling could be accomplished safely and without damage to the LRV's couplers.

Projected operating schedules called for LRVs to operate on a 4-minute surface headway. However, tests of the LRV in surface operation showed that it was significantly slower than PCCs, due primarily to slow door cycles and a 3-second delay from the time power is called for and a brake release is achieved. Given the slower surface operating characteristics, it became apparent that Muni would not be able to operate on a 4-minute headway.

The test and acceptance program allowed Muni to "season" the cars before actual revenue service began. In addition, it provided the time and experience to develop new operating rules and procedures for the subway and to familiarize operators, supervisors, and maintenance personnel with the many new Metro features.

PHASE-IN STRATEGY

Metro service did not begin all at once on all five lines. Muni had decided on a phase-in strategy because subway operation was both new to Muni and far more operationally complex than Muni's traditional mode of streetcar operation. The phase-in strategy provided hands-on experience and opportunities to learn. Phasing was also a response to the fact that various components—new track and electrification facilities, station fare equipment, etc.—were not all available at the same early date as a single line could be placed into service.

The phasing-in of Metro service proceeded as follows:

- Phase 0 was a preliminary operating phase that introduced the LRVs to the public and provided surface operational experience.
- Phase I began on February 18, 1980, with the N (Judah) line operating with LRVs in the subway in revenue service. Five downtown stations were open.
- Phase II added 2-car trains in revenue service on June 11, 1980, from Embarcadero Station through the Twin Peaks Tunnel to just west of West Portal Station. All nine stations were in use.
- Phase III added on December 17, 1980, the M (Ocean View) and L (Taraval) lines to Metro service. (Headway and fallback scheduling began with this phase.)

- Full operation was inaugurated on June 17, 1981, when the J (Church) line began Metro service. Metro service operates 5 days a week from 4:30 a.m. to 12:30 a.m.

FULL-SCALE OPERATION

When Metro began full-scale operation with all 5 lines running in the subway, the operational plan attempted to respond to a number of problems encountered during the last phases of operation. One serious problem was the capacity of the Metro system. Although there are no entirely accurate ridership figures available, estimates from the data of the automated fare collection equipment and passenger counts of the schedules department indicate that ridership began increasing with the very first phase of Metro. At present Metro carries about 125 000 to 140 000 riders per day, with large concentrations (about 15 000) during the morning and afternoon rush hours. As noted previously, the Embarcadero Terminal (stub-end operation) limited the system capacity to 30 trains per hour if each was turned around in 2 minutes. So Muni decided to run as many multi-car trains as possible to accommodate rush-hour crowds. To accomplish this, it was necessary to couple at the Portals.

To accommodate large numbers of passengers waiting on station platforms, and to avoid overcrowding, it was decided to stop trains at certain predetermined platform locations. Therefore, the Twin Peaks lines (L, M, and K) used the westernmost platform stops, while the Duboce trains (N and J) used the mid-platform stops. In this way passengers were not crowded to one end of the station platforms.

Once Muni had these discrete stopping locations that assisted in queueing passengers and reduced confusion about where to wait for a certain train, it had to guarantee that the train consist would be consistent. In other words, the headway system did not guarantee a particular pattern for train arrival at the portals. As discussed, dispatching three separate lines from diverse terminals and running in mixed traffic produced random arrivals. So when three LRVs would arrive at West Portal Station, inbound, they could be in any order—i.e., K-M-L, L-M-K, L-K-M, etc. Therefore, a transit line coordinator not only coupled trains together but also sequenced them; that is, he would assign them a predetermined order. In this way Metro cars were portal-controlled. Coordinators at both subway portals performed these functions: coupling LRVs, sequencing them, and distributing them to the proper line.

While this was a fairly routine job during base periods, the job got significantly more complex during morning and afternoon peaks when the coordinator had to ensure that all pull-outs were assigned their proper line and then were depleted after the peaks were over. This meant managing the difference between 61 base-period cars and 82 peak-period cars.

In January 1981, when the last of the Metro lines, the J (Church), went into subway operation, the decision was made to inaugurate a headway and fallback operation of Metro. By using this "dynamic" scheduling system it was hoped that Muni could move more riders with the existing LRVs. Since Muni could not have more cars, the ones in service had to be put to more productive use. Of course, a traditional schedule with operators tied to vehicles did not allow for this. It seemed hard to justify a $300 000 vehicle not working because the operator needed a break or because the schedule had recovery time built into it to allow for any delays incurred while running to the outer terminal.

The two components of the headway and fallback schedule work together to reduce schedule recovery time and allow the operator time out of seat, while keeping the vehicle working. Another feature of the headway system is the ease of adjustment by the transit line coordinator supervising the line when delays occur.

Each of the five Metro lines is monitored by a transit line coordinator (TLC) positioned at some point on the line. These TLCs work in two shifts, providing coverage from 6 a.m. to 10 p.m. During this time TLCs give each outbound car a leaving time from the outer terminal that keeps cars spaced at 6-minute intervals. TLCs work to keep LRVs moving by giving only a minimal amount of "recovery time" (about 1-3 minutes) at the terminal. If problems occur, the TLC, who is in radio contact with Muni's central communications, uses switchbacks at various locations along the line to restore disrupted service.

If the LRV is kept moving in service, when do the operators get a break? Operators get their break at the Embarcadero Station terminal. When an LRV reaches Embarcadero Station, the operator who brought it from the outer terminal gets off and a new operator takes the car for its next trip. The operator who has just been relieved then becomes part of the pool of operators and waits until he is called for his next trip. The fallback is designed to give operators a break of 8 to 11 minutes. In the case of multi-car trains, the entire crew is replaced with fallback operators.

The implementation of the fallback system meant that an operator might not work the line he had signed on. The new union contract in fiscal year 1980-1981 allowed Muni to have this flexibility within certain limits; that is, operators could make up to three trips on other than their primary line.

The fallback system solved a problem experienced by many operators in the early phases of Metro who found themselves late at the outer terminal and unable to get a break at all. With fallback, some break was guaranteed.

By headwaying the LRVs and using fallback with the operators, Muni was able to keep the LRVs moving. Schedule department estimates indicate that this system allows Muni to maintain capacity with 6 to 8 fewer cars in the base period and 12 to 14 fewer cars in the peak periods than would be required with normal schedules. This "saving" is critical, since Muni is currently limited to its existing 100-car fleet and is dealing with a high-technology vehicle that has proved to be maintenance-intensive.

The Embarcadero Station terminal was still the limiting factor in the Metro system. In fact, the job of dispatching crews at Embarcadero compounded an already laborious and complicated turnaround process. Thus the crew dispatching at Embarcadero was to remain there only until a permanent structure and office could be constructed at Montgomery Station, which is one station west of Embarcadero.

By moving the fallback to Montgomery, Muni attempted to break the bottleneck at Embarcadero by putting the relief operator on the train at Montgomery. Then the operator would ride in the inactive cab and prepare it for its next outbound trip. Once at Embarcadero, with operators in each cab, the LRVs were more quickly activated for their outbound trip, passengers were loaded, and the train dispatched. The operator who had just finished his trip would ride back to Montgomery and join the fallback pool.

The operation of the fallback at Montgomery has proved successful in reducing the time required to turn trains around at Embarcadero. All trains can be ready to be dispatched in 90 seconds or less.

Simultaneously with the move to Montgomery, Muni operations managers addressed the problem of one-sided service in the subway. The line sequencing and distribution control at the portals was moved to Van Ness Station, the first station receiving trains from both trunks. The transit line coordinator here had the job of sequencing the trains and distributing them to the proper line. Thus the TLC had control of all the trains entering the system. Trains were still coupled at the portals to reduce the number of units in the subway and help provide increased capacity during peak hours.

By following an hour-by-hour guide that indicates how many cars should be working each line, the TLC at Van Ness would assign each of five lines the appropriate number of cars it needed to carry its passengers. When he gave the train its assigned destination the TLC would communicate with the crew dispatcher at Montgomery the consist of each approaching train. (It takes about 4 minutes for a train to move from Van Ness to Montgomery.) During this time the crew dispatcher would assign the crew for the train and the operator(s) would move out of the waiting room and move to the platform at Montgomery to meet the train.

Gaining control of both trunks at Van Ness has proved successful in a number of ways. Service is spread consistently to both trunks, thereby reducing the waiting time for most passengers. By improving the consistency of service, passenger complaints have been significantly reduced.

By working with all the cars, they are distributed in a regular fashion, and so the TLCs on the surface are provided with a more regular outbound flow of LRVs. This allows them to provide the 6-minute headway with a minimum number of switchbacks.

Finally, this system has reduced any large gaps on a particular line caused by a lengthy delay by spreading the available cars among the five lines. When the delay is cleared, the cars trapped behind it are redistributed to lines that may have received a reduced number of cars.

However, no system is without its problems. Although space does not allow an in-depth discussion, following are some of the problems Muni is working to solve:

- Developing new operator dispatching procedures, including deployment of adequate fallback relief, making reliefs, tracking operator trips, and identifying operators and cars.
- Managing changeover from headways to night schedules after 10 p.m.
- Stacking of outbound trains caused by breaking up large trains at Embarcadero to keep proper sequence.
- Proper distribution to lines when the Van Ness trainmaster has too few cars.

Even with these problems, it appears that the dynamic schedule will remain at Metro since it works to help Metro meet its ever-increasing demand.

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Base Specifications for Major Subsystems on the San Diego Light Rail Transit Project

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This paper provides information on the development of the base specifications for four major subsystems on the San Diego light rail transit project. These subsystems include transit vehicles, traction power, and signal and fare collection equipment. The plans and specifications were prepared from the operations plan and project design criteria.

On the San Diego LRT project, the plans and specifications of four major subsystems were prepared from the project criteria and were based on the features indicated in the operations plan. These features included a specified circuit time (roundtrip including both turnaround times), provisions for joint operation with freight trains, minimization of operating and maintenance staff requirements, a specific track plan, an indicated fleet size, absolute block limits, and a derivation of installed traction power capacity. The plans and specifications were developed with the philosophy of simplicity, use of proven equipment, and minimization of custom design; however, essential requirements were specified. Where such requirements were not mandatory and supplier or contractor ingenuity could contribute, the plans and specifications were open.

TRANSIT VEHICLE

The specifications of the transit vehicle may be considered in four parts. First, the vehicle had to have certain features and capabilities; second, the order would be for the fleet size; third, to minimize or avoid unexpected operating costs and difficulties, the vehicle design had to provide for maintainability; and fourth, provisions were made for elderly and handicapped (E&H) passenger access.

With regard to the vehicle features and capabilities, suppliers were required to supply their standard production vehicle, which would have to satisfy the following objectives:

1. The vehicle must meet the requirements of the California Public Utilities Commission General Order 143[1], which deals comprehensively with LRT operations and includes a subsection on vehicle design. It provides minimum requirements for safety equipment, including brake control, door controls, and warning lights, and requires structural integrity for protection in the event of collision.

2. Performance was specified in terms of a 75-minute circuit time. Plan and profile data were given to prospective suppliers to determine computerized velocity-distance-time profiles. To qualify, suppliers were required to submit the data along with their computed energy consumption projections.

3. Peak-hour patronage at the maximum load point required a 15-minute headway to service 1500 passengers per hour. The Metropolitan Transit Development Board (MTDB) looked for a practical standee space, and, as a result, the standing load was generally considered as 2 passengers for each seated at the time. Two-car trains were expected to handle this load. It may be noted that actual San Diego experience indicates that a maximum practical load is 150 seated and standing passengers per car.