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.