South Yorkshire Supertram

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Sheffield, with the surrounding metropolitan area in the county of South Yorkshire, has become the second city in the United Kingdom to reintroduce trams and the first city to plan for extensive street running. To be built in eight phases, the South Yorkshire Supertram system is to have the first phase completed by the end of 1993; the entire project, by 1995. Of its total 20 route-miles, about 10 mi will have on-street running, 8 mi will have segregated track adjacent to roadways, and 2 mi will be on converted British Rail track. The 25 double-articulated, low-floor vehicles, designed to carry 250 passengers, will operate on 5-min headways most of the day. The bulk of the funding for the project, which is estimated to cost $400 million (U.S.), comes from the central government with a limited amount contributed by property developers and other real estate interests.

Situated in the metropolitan county of South Yorkshire, the city of Sheffield was once the heart of the British steel industry. Its name is known worldwide through the production of special steels and fine cutlery. Sheffield entered the first tram age in 1873 when a private company operated horse-drawn carriages. Electric trams were introduced in 1896 when the city took over the system. The system ultimately expanded to some 100 route mi. However, the system was gradually abandoned over the years and finally closed in 1960. Sheffield is now the second city in the United Kingdom to reintroduce the tramcar and the first with extensive street running over the route.

With the rationalization of the steel industry in the United Kingdom, many of the steel mills in the lower Don Valley area of Sheffield were closed down. This area is being redeveloped under a central government initiative by the Sheffield Development Corporation for recreational, leisure, shopping, business, light industry, and residential purposes. Major new sports and athletics stadiums and an olympic-sized swimming pool were constructed in time for the World Student Games held in Sheffield in July 1991. Line 2 of the South Yorkshire Supertram network is being constructed through the lower Don Valley, linking the new Meadowhall retail malls with the stadiums and the city center.

Sheffield reconsidered the benefits of a modern light rail transit (LRT) system in the late 1970s and early 1980s, and finally, when route alignment and other parameters were agreed on, steps were taken to obtain the necessary acts of Parliament and royal assent without which construction cannot take place.

Funding is provided almost wholly by the central government with a limited level of private contribution from property developers and other real estate interests. South Yorkshire Supertram Limited (SYSL) was then formed as a wholly owned subsidiary of the Transport Executive to construct, operate, and maintain the system. Following prequalification processes, a number of international companies and consortia submitted bids for the separate contracts to design and build the infrastructure and the rolling stock. Siemens Plc was awarded the rolling stock contract for 25 double articulated vehicles. Balfour Beatty Power Construction Limited (BBPCL) secured the contract for the construction of the network, including the civil engineering, trackwork, overhead contact system (OCS), power supply, maintenance depot, and tram signaling and control system. Some of the utilities are realigning their services under separate arrangements with SYSL; road traffic signaling and ticket equipment are also separate, direct contracts.

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SUPERTRAM SYSTEM

Predominantly a double-track system, the 20-route-mi Supertram network will consist of two lines that form three radial routes joining together in the city center (Figure 1). Some 10 mi of the route will have on-street running, 8 mi of segregated track will be sited adjacent to the roads. whereas the remaining 2 mi will run on converted British Rail track. The terrain for much of the Supertram route is hilly; design includes gradients of up to 10 percent.

Supply to the overhead contact system will be at 750 volts (V) direct current (dc), and the present requirements are for 12 substations. Maximum operating speed is 50 mph, with lower limits on-street and at intersections. The 25 light rail vehicles (LRVs) are bidirectional, double articulated units, each about 115 ft long by 8 ft 8 in. wide. An innovative feature of the LRV is its low floor, allowing boarding from very low platforms, eminently suitable for in-street use. They are designed to carry 250 passengers and will have a service frequency of 5 min in each direction throughout the major part of the day. Sufficient flexibility is built into the system to provide special high-frequency services to accommodate major events at, for example, the Don Valley Stadium.

The system will be constructed in eight phases. The northeast radial (Line 2) will be Phase 1, due for completion by the end of 1993, and will provide a 5-mi link between the city center and the large shopping complex at Meadowhall in the northeast of Sheffield (Figure 2). This route takes the line along the Don Valley redevelopment area and links with the Transport Executive's new transport interchange at Meadowhall, which brings together all transit modes within a single facility. The remaining seven phases (Line 1), 15 mi long, will run from Middlewood in the northwest to Halfway in the southeast. Lines 1 and 2 will meet on the delta junction and viaduct structure near the city center. The whole project is due for completion in 1995.

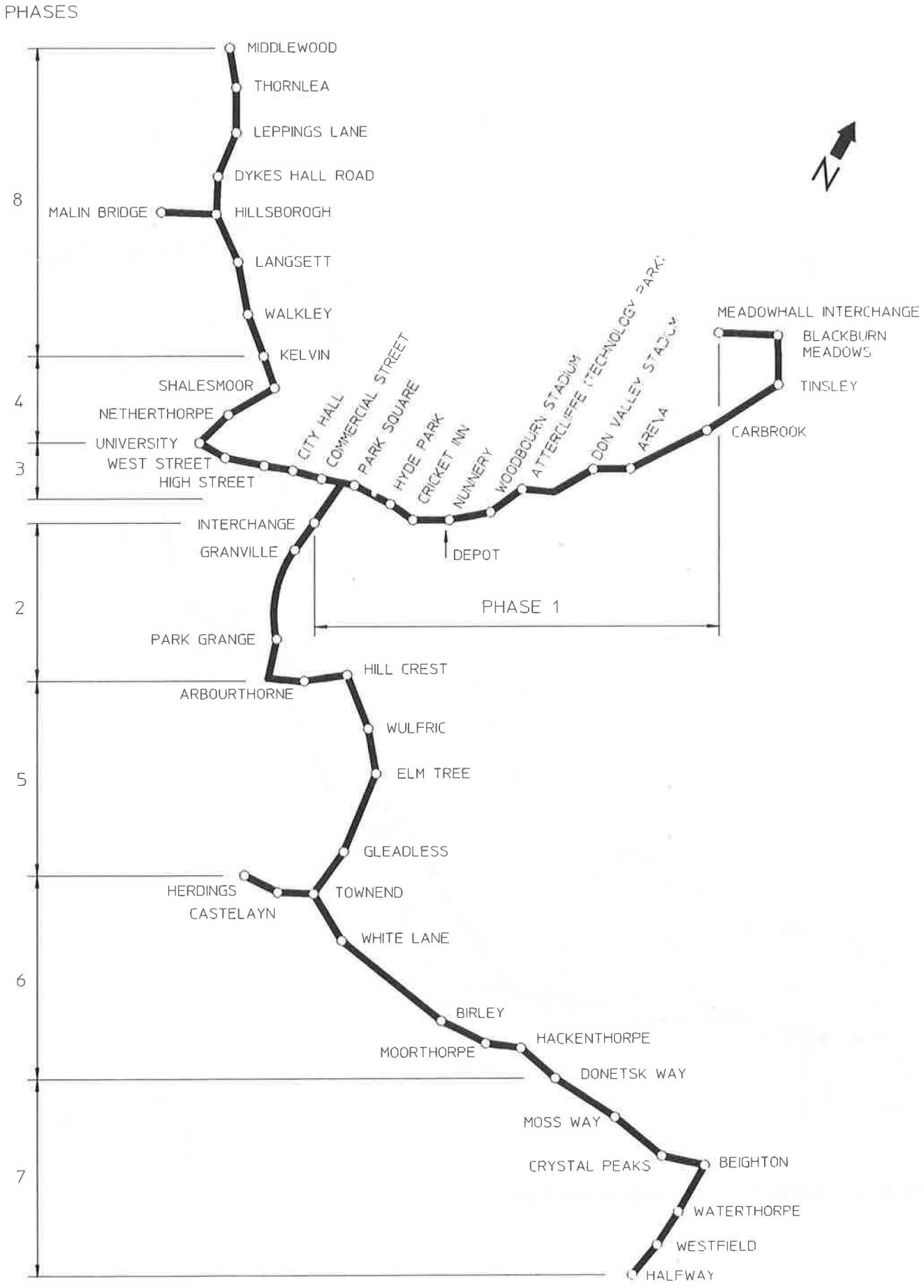

FIGURE 1 South Yorkshire Supertram routes and phases.

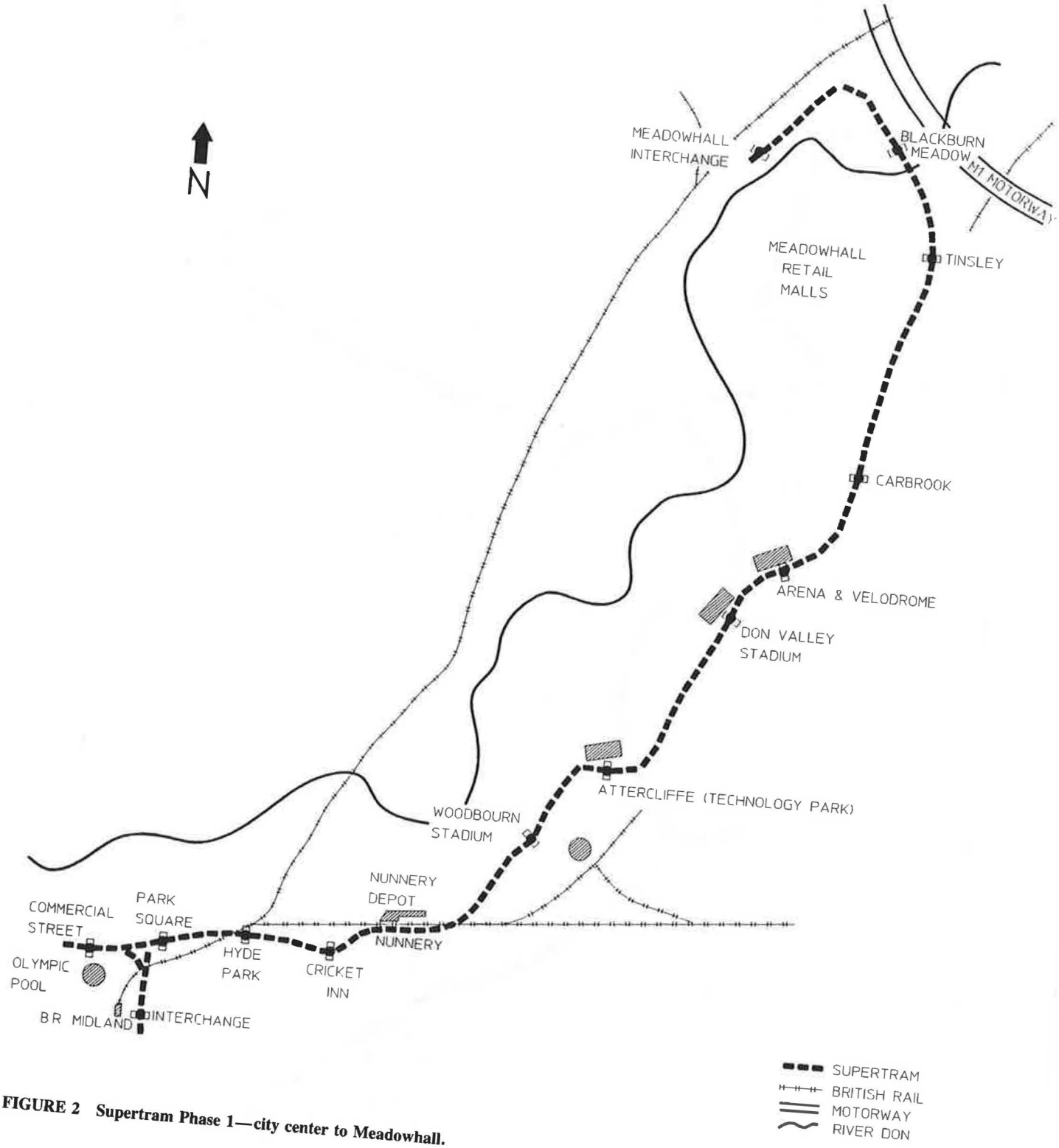

FIGURE 2 Supertram Phase 1—city center to Meadowhall.

Interestingly, the majority of recent new and planned developments in commercial, industrial, retail, and residential facilities are along the light rail route.

Finance

The funding for the project comes mainly from central government. A major portion of the estimated cost of $400 million (U.S.) is to be funded by direct capital grant aid with the bulk of the remainder from authorized borrowing by the Regional Transit Authority. Private investment from local businesses that are likely to benefit from access to Supertram is also captured in the total financing package. Supertram will thereby only need to service its operating costs with no capital debt burden. A condition of central government's agreeing to provide finance is that the LRT system will be privatized in due course and then be operated and maintained without revenue subsidy for a concession period of 30 years. The capital assets will remain in the public ownership of the Transport Executive.

Client's Structure

The task of coordinating the project on behalf of the South Yorkshire Passenger Transport Executive (SYPTE) is SYSL's consultant, Turner and Townsend Project Management Limited (TTPM). TTPM is coordinating the building process using Kennedy Henderson Limited for the tramway electrical and mechanical disciplines and the Design and Building Services (DBS) consultancy for the technical specification design approval, supervision of civil and highway works, together with design of some structures and retaining walls, mainly on Line 2.

Both before and during the construction process, detail consultation with owners of property fronting the system has been undertaken so that the layout can accommodate the needs of the local people. This public consultation process is being handled by an independent consultancy. A fourth agency will provide architectural and landscape services to the project management team. The overall structure of the Supertram project team is shown in Figure 3.

TECHNICAL ASPECTS

Civil Works

Consulting engineers were commissioned by BBPCL to carry out the detailed design work on alignment and structures. Although the client's documents generally identified the locations where structures were envisaged, the nature and extent of such elements were left largely to BBPCL to determine within parameters laid down in the contract. The basic alignment involves a total of 30 structures ranging in scale from modifications to existing subways to a nine-span, 980-ft-long reinforced concrete viaduct.

The three structures forming the Park Square delta area were designed by the DBS consultancy on behalf of the client. The design of the remaining structures was included in BBPCL's scope, although at certain locations the client indicated a preferred form of structure.

Vertical alignment was substantially fixed by the street running nature of the system, and by the position of at-grade street crossings and headroom clearances for new and existing structures.

The geology of the area was such that coal-bearing measures could be expected near the surface with areas of drift found in the Don Valley where Line 2 was to be built. A geological study provided a detailed breakdown of the further requirements for site investigation involving boreholes up to 150 ft deep and test pits with in situ and laboratory testing as necessary. The extent of shallow mine workings and positions of shafts and other voids were identified, such that structure design could incorporate treatment of such features.

BBPCL clearly recognized the potential impact of major construction works within substantially urbanized areas and so maintained a close liaison with their consultant throughout the design. This ensured that the form of the structure and its major components would be suitable to minimize the effects of construction on the day-to-day life of the city.

Viaducts

The system contains two major viaducts, at Sheffield Parkway and Norfolk Park. The former structure was designed by DBS on behalf of the client and consists of a six-span, 970-ft-long viaduct carrying twin tracks. The structure crosses the four lanes of Park Square's traffic circle, a major intersection on the city's road system, and subsequently runs parallel and immediately adjacent to the westbound lanes of the Sheffield Parkway. The structure is of post tensioned reinforced concrete construction using precast segments erected in balanced cantilever methods. The precast solution provides benefits to the overall construction period and minimizes the disruptive effects associated with constructing a major viaduct over a key thoroughfare.

The Norfolk Park viaduct is a BBPCL-designed structure based on a steel composite bridge construction. The 1,000-ft-long viaduct is founded over a substantial portion of its length in the slopes of an existing cut adjacent to British Rail main lines. At its southern end the structure passes over Norfolk Park Road and a private car park before running back onto the embankment. The original design for the viaduct was an in situ constructed reinforced concrete box-type structure with a retaining wall. However, limited access and the constraints imposed when working adjacent to an operational railway led BBPCL to alternative design solutions in the form of reinforced earth embankments and steel composite bridge construction. Ultimately technical and commercial considerations showed the steel composite design coupled with a conventional reinforced concrete retaining wall to be the most suitable solution.

Bridges

The contract requires nine bridges to be constructed. The two bridges in the Park Square area have been designed by DBS and are intended, together with the Sheffield Parkway via-

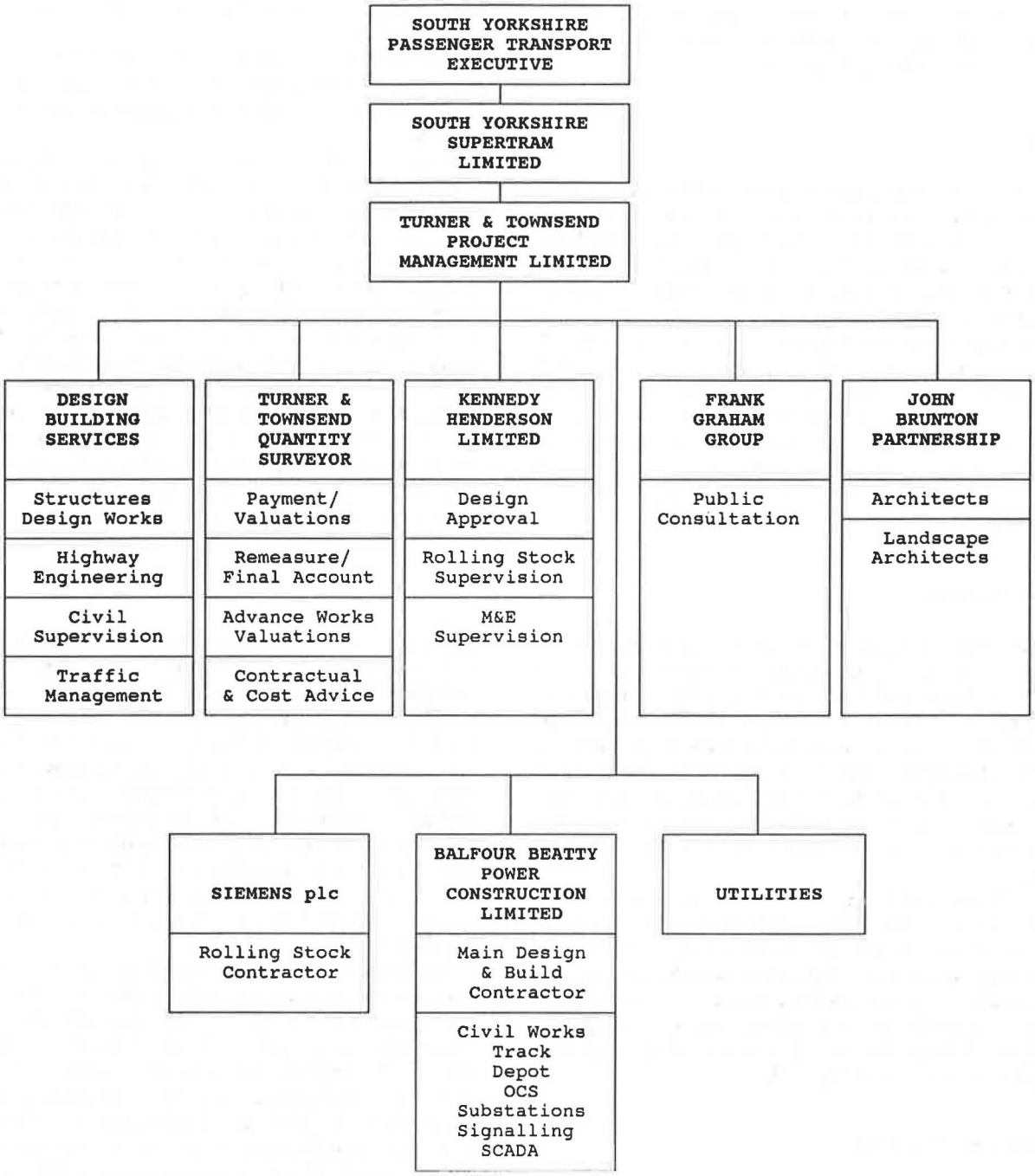

FIGURE 3 Supertram project team.

duct, to present an aesthetically pleasing solution to this highly visible core of the route. The Commercial Street Bridge is a three-span, 360-ft-long structure crossing the four lanes of the Park Square traffic circle with a 240-ft-long center span.

The bridge is of steel composite construction with simply supported side spans and a bow girder center span, all supported on pile foundations through fill to bedrock. BBPCL's major consideration on this structure has been to develop a construction method that provides maximum flexibility of work consistent with the need to maintain traffic flows on the traffic circle. This has resulted in the superstructure being preassembled in sections, adjacent to the bridge site, and lifted into place at night and during weekends. The method has required substantial temporary intermediate supports, the locations of which have been specifically chosen to minimize the reduction in roadway width during construction. The program and methods of working have been developed with the intent of progressing from the ends of the structure, again to reduce disruption to traffic.

The second bridge in Park Square is a 114-ft single-span structure of precast, post tensioned reinforced concrete construction. The geometry and form of the structure dictated

that the precast units, weighing 50 tons each, be supported on temporary trestling spanning the live roadway section. Limited headroom was available beneath the box for temporary support.

The eight bridges within the Don Valley section of the route are BBPCL designed. Cricket Inn Road bridge is a single span structure carrying the twin tracks over an existing rock-faced railway cut. At the eastern abutment, the existing ground level and geology permit a conventional reinforced concrete foundation to be formed on the shallow bedrock. However, at the western abutment, the ground level is significantly lower and close to old coal-working areas. The bridge foundations will therefore be extended below the coal-working levels with mass concrete fill placed to form a suitable bedding for a conventional reinforced concrete foundation. The 154-ft-span superstructure is designed as two pairs of braced steel girders with a reinforced concrete deck slab. The girders will be preassembled adjacent to the bridge site and launched into position during railway possession periods. This minimizes the number of railway possessions required and reduces construction time.

The Sheffield Parkway bridge is a 107-ft-long skewed structure carrying twin tracks across a main dual roadway. The client's preferred solution was a reinforced two-span concrete box-type structure with the central pier situated within the median of the road. BBPCL provided an outline design of such a structure but offered an alternative solution based on steel composite construction, which had a number of advantages.

- The depth of the superstructure would be reduced, thus lowering the height of the adjacent embankments with consequent financial and schedule benefits;
- The need for a central pier would be eliminated; and
- The amount and nature of traffic management associated with this form of construction would be significantly lessened.

The alternative solution was subsequently approved.

Woodbourn Road bridge carries twin tracks over British Rail tracks and is adjacent to an existing bridge. The design incorporated reinforced concrete spread footings founded on bedrock with the underlying faulted rock removed and replaced with mass concrete where necessary. The exposed elements of the structure have been designed to match the adjacent bridge. The 92-ft single-span superstructure is designed using precast, prestressed concrete beams launched into position during a limited number of railway possession periods.

The system is carried over the Sheffield and South Yorkshire canal on an arch-type of bridge. The arch form was retained as it complemented a similar structure located nearby. The type of structure chosen imposed considerable technical demands because of the large loads on the thrust blocks. Bedrock was identified as lying close to the surface and no shallow mine workings were evident. However, historical information suggested that mine shafts were present in the area of the southern piers. Provision was made within the design for capping of shafts, and the bridge was to be founded on spread footings based on rock. The structure crosses the canal over a deep cut with rock-faced batters. Access at the bottom of the batters is extremely limited, resulting in construction access at the ends of the bridge. BBPCL opted to use a steel composite superstructure to allow the arch to be preassembled in sections and lifted into position using large cranes. This method obviated the need for the substantial temporary support works required for a similar type of structure in concrete.

The Darnall Road bridge is a single-span, 62-ft-long structure that carries the route over a local side road. Foundation design incorporates the removal of shallow mine workings with mass concrete fill replacement, the reinforced concrete footings then being founded on the rock. The superstructure was designed as two pairs of steel girders supporting a reinforced concrete deck slab to minimize the need for traffic management on the highway below.

The River Don bridge will use the substructure of an existing British Rail bridge, but the superstructure will be replaced in its entirety. The bridge is a three-span, 180-ft structure with intermediate piers in the River Don. The existing substructure was strengthened with capping beams. To minimize the weight imposed on the substructure, a steel composite superstructure was adopted. The continuous steel girders are preassembled in pairs behind the abutment and launched across the river, thus resolving the problem of limited access for the large cranes required for lifting.

Retaining Walls

Retaining walls were required at various locations along the route and total nearly 1 mi in length, ranging in height from 3 to 33 ft. Generally the walls are of reinforced concrete founded on spread footings on the relatively shallow rock. For ease and speed of construction, standard panel lengths of 33 ft have been adopted, thus allowing maximum reuse of formwork systems. The route at Hillsborough Corner takes a sharp turn to extend to Holme Lane. To achieve an acceptable track radius at this point, it was necessary to widen the corner to maintain the roadway width and to carry the realigned road over a weir of the adjacent River Loxley. This will be achieved by constructing a retaining wall and a reinforced concrete slab on piers spanning the weir. The geology of the area showed a 16- to 33-ft layer of sand, cobbles, gravel, and boulders overlying bedrock. It was necessary to provide bearing piled foundations for the structure at this location. All retaining walls are being faced with brickwork or masonry to blend with existing facades.

Underpass

At Brook Hill, the route crosses a large traffic circle that forms a major intersection of the city's road system. Crossing at grade is not possible because the required tram priority could not be achieved and an elevated crossing with headspan clearance could not be provided with an acceptable vertical alignment. An underpass solution was consequently chosen. Various forms of structure were considered, but the limited depth of material above the roof of the underpass ruled out conventional tunneling or corrugated steel structure solutions. A reinforced concrete box design has, therefore, been adopted. The geology of the area shows approximately 8 ft of fill overlying bedrock (mudstone and siltstone), the top 3.6 ft of which is highly weathered. The structure is thus founded within rock on conventional reinforced concrete bases.

Construction of the 450-ft-long tunnel and 300-ft-long approaches will be undertaken using cut and cover methods.

This will be carried out in stages, to maintain traffic flows at the traffic circle, with completed sections backfilled and restored to provide diversionary routes for traffic. A significant part of the excavations will be through rock of varying states of weathering. The exposed rock faces will be rock bolted.

General

The construction of an LRT system clearly is a major logistics exercise in dealing with existing utility equipment, identifying, designing, and implementing traffic management measures necessary to construct the works, and reinstatement or regrading of the existing highway system along the route.

Throughout design and construction, BBPCL has maintained close liaison with the local authorities and utilities. The necessary service diversions have been planned within the overall program such that, wherever possible, areas are clear of utilities prior to the start of construction.

Similarly a close liaison has been maintained with the Local Highway Authority to determine the most suitable form of traffic management for the various phases of construction. These have ranged from long-term diversionary routes to short-term temporary measures for lifting of bridge beams and so forth. These systems were developed early so that the public has been notified well in advance of any disruptive situation. BBPCL has similarly worked closely with the local authority to identify areas where construction activities bring potential conflict with established pedestrian routes and to implement suitable alternative arrangements.

Trackwork

General

The standard gauge track (4 ft 8 1/2 in.) consists of two types:

- Ballasted track for off-street running, and
- paved track for on-street running.

The request for proposals (RFP) called for flat-bottomed rail with a number of alternative specifications for both base plates and ties for the ballasted sections and grooved rail of cross-sectional area between 11.625 and 12.09 in.^{2} for the paved areas. The paved track support system was to be of concrete construction with embedment of the rails rather than mechanical fastening.

Final Trackforms

The final designs chosen after due consideration of the technical aspects, economic considerations, and the interface with the rolling stock were as follows:

Ballasted Track British Standard flat bottom section 80A wear-resistant grade-A rail mounted on concrete duo-block ties with Pandrol fastenings was chosen. Duo-block ties were chosen for economic reasons and to provide good resistance to lateral track movement. Switches are of a standard design mounted on timber ties. Ballast of at least 10 in. below the ties is provided by a no-fines, well-graded, bed of hard dense angular stone to National Standard Specification.

Paved Track For the on-street paved section plain track, 35G-TF grooved rail to French Standard NF F52 523 was chosen and, for standard switch construction, grooved rail to VOF Standard 785 (RI60) was chosen. The rails are embedded in a groove in the concrete paving using an elastomeric grout that

- Locates and fixes rails without the need for mechanical fastenings;
- Provides the rails with a resilient support for both passenger comfort and absorption of noise and vibration generated by the wheel/rail contact; and
- Provides electrical insulation to limit stray currents.

This type of design and construction was chosen because of its proven service record both in Europe and Hong Kong.

Drainage of the grooved track relies on special drainage boxes fixed to the underside of the groove. Run-off is channeled through ducts to the roadside surface water drains.

Rail Jointing Generally the system is designed as continuously welded rail (CWR) with fishplated joints confined to switches, depot, and tight radii curves. Rails are laid as 59-ft lengths and welded together using the alumino thermic process to form continuous lengths. Scarf-type expansion switches have been introduced at joints between CWR and fishplated tracks and over structural movement joints on bridges and viaducts. Rail lengths are destressed at a neutral temperature at predetermined lengths and welded together to form CWR.

Points Machines The switches on the main routes are designed to be trailing. Where facing points are installed, they have been designed to be switched automatically or manually.

Stray Current Protection The trackwork designs and materials have been chosen to provide the tracks with adequate insulation to meet the performance specification of 100 ohm·km single track between rail and earth and 10 ohm·km between single rails.

Measures adopted on ballasted tracks allowed for the following:

- Insulating rail pads and insulation between rail and clip,
- Leaving the ballast 1 in. below bottom of the rail,
- Use of CWR or bonded out rail, and
- Providing fault current return at substations.

For the paved track, the following measures have been adopted:

- Embedment of a grooved rail in an insulating material,
- Provision of an earth mat in the concrete track base under the rails and bonded out, and
- Jumper bonds across rails.

Where short sections of different trackform are provided, the rails are isolated from the surrounding supports to ensure no electrical continuity.

Depot

A depot facility to stable and maintain the 25 articulated trams is provided near the delta junction. The design allowed flexibility for trams to enter and exit the main lines at both ends of the depot.

Initially the maintenance schedule was to clean the inside of the trams daily, wash them two or three times a week, and inspect bodywork, chassis, wheels, pantograph, and general systems on a routine basis. Minor repair items would be carried out by depot staff, and major repair items would be done off site by contract. Subsequently the philosophy was changed, and the main workshop is now sufficiently flexible and well-equipped to do all but total rebuild. Specialist equipment includes a wheel lathe, water recirculating washer, sand filling equipment, engineers siding, casualty bay, jacking, and bogie jigging. Although space was restricted because of land availability, careful design allowed for a circular track from the end of the stabling lines into the main workshop, the minimum radius being down to 82 ft.

Infrastructure maintenance and warehousing are also based in the area together with the operations and driver control rooms and cafeteria facilities.

Overhead Contact System

General

With a large proportion of the route running on-street through the city center, aesthetic consideration has a major influence on the design of the overhead contact system (OCS) style, the assemblies, and the supporting structures.

OCS Style

Although simple catenary equipment could have been designed for short sections of the route in the outlaying areas, it was decided to use trolley wire equipment throughout as it provided a number of benefits:

- Visually less obtrusive,
- Uniformity of design and a saving in structure and component variety, and
- Absence of hangers simplifies construction and maintenance.

To meet the required current rating, twin 4/0 AWG cadmium copper trolley wires were used. Where 50 mph running is possible, the trolley equipment is auto-tensioned at 2 × 14 kN. Where the speed is restricted to a maximum of 30 mph, fixed terminations are used with tensions of 2 × 12 kN at 50°F. Maximum spans are 197 ft for the auto-tensioned equipment and 164 ft for the fixed equipment. At junctions, minimum radius curves, and other complex areas with speeds limited to 15 mph, the tension of the fixed termination equipment is reduced to 2 × 6 kN at 50°F and has a maximum span of 66 ft. In the depot area the equipment is similar, but has a single 4/0 AWG trolley wire because of the lower current requirements.

The equipment height varies according to the location. For on-street areas and in the depot, the height is governed by road traffic requirements with normal heights at supports of 19 ft 9 in. for auto-tensioned, and 20 ft 8 in. for fixed equipment. For off-street running, the optimum height of 18 ft 5 in. is used with an allowable minimum of 12 ft 6 in. To allow for abnormal loads, certain crossing points have a maximum height at supports of 21 ft 4 in., while the pantograph will have some reserve in its range, being designed for a reach up to 23 ft 0 in.

Equipment Design

Wherever possible, the trolley wires will be supported by back-to-back cantilevers on central poles, hence minimizing the number of foundations and structures. The cantilevers are constructed from 1 5/8-in. diameter steel tube with fiberglass rod insulation of similar diameter and synthetic rope ties. The avoidance of large insulator sheds is more environmentally acceptable.

In situations where center poles are not acceptable, such as on-street running without a median, span wires will be suspended from side poles or adjacent buildings. The span wires are made from synthetic ropes, avoiding the need for cut-in insulation.

All equipment, with the exception of switches, is double insulated from the supporting structures. This avoids the need to earth-bond the structures to rails with the associated risk of corrosion in foundation reinforcement because of stray currents. At switches the structures are bonded to rails but are insulated from the foundations so that there is no current path.

The auto-tensioned equipment will have the balance weights located inside the anchor poles, and most of the switching will be indoors or in cabinets. These considerations help to minimize the visual impact of the equipment, protect it and contribute to safety.

Foundations and Structures

A range of standard side bearing foundations has been designed for the variety of ground conditions encountered in an urban situation. The foundations have a small cross section, typically only 2 ft to 2 ft 8 in. wide, except where unique designs are prepared.

The design of the supporting structures is influenced by aesthetic, engineering, and cost considerations. Stepped tubular poles are used throughout and have bolted base attachments to allow easy installation and replacement in the event of damage. The unsightly bolting will be hidden by a decorative trim. A requirement for a small number of special structures is anticipated, one known example being a large central pole at Park Square delta junction, from which an array of span wires will radiate.

Computer Applications

The use of computer-aided techniques in the OCS design is extensive. The static and dynamic characteristics of the equipment and the pantographs have been investigated and optimized using BBPCL analysis software. Structures and foundations are designed with spreadsheets and proprietary structural analysis programs, and almost all drafting uses computer-assisted drafting and design (CADD). The use of Moss CADD for installation design is increasing the level of integration of the various disciplines involved in the project. Survey data and the track alignments in Moss CADD are used directly by the installation design engineers without the need for extensive redrafting.

Substations

The original RFP specification was based on a power supply arrangement comprising an 11 kV ring main, feeding eight 1 MV substations spaced at regular intervals along the route. Seven of these substations had a single 1 MV transformer rectifier, and the remaining substation, which fed the depot as well as the main line, had two 500 kW equipments for increased security. The nominal voltage specified was 750 V dc with maximum no-load rectifier voltage of 700 V and a minimum pantograph voltage of 525 V in the absolute worst case. The system is generally required to be designed for vehicles operating at a maximum frequency of once every 5 min in each direction, although a reduced service may apply on certain parts of the route. The overhead equipment was originally specified as having a continuous current rating of 500 A root mean square (rms), and a resistance not exceeding 0.08 ohm·km at 20°C with the contact wire worn by 20 percent.

During the design phase, more detailed information became available. In particular

- The car manufacturer was selected, and the vehicle power characteristics were identified.
- Operational requirements were more closely defined.
- The types of equipment used for the power distribution were selected. These include 2,000 A semi-high-speed circuit breakers and transformers with dry-type insulation. The overload rating of the rectifiers is 150 percent for 2 hr and 200 percent for 1 min.
- A review of the power system was carried out. This involved the use of the BBPCL proprietary computer program, RAILPOWER, which simulates the operation of the vehicles running according to the defined schedule and calculates electrical parameters on a second-by-second basis. The wide range of digital and graphical output produced by RAILPOWER enables the system performance to be assessed quickly.

In light of this more detailed information, the design evolved such that the system currently proposed incorporates 12 600 kW substations, which feed twin 4/0 AWG cadmium copper trolley wire equipment. This is adequate to cater for the maximum continuous current requirement of approximately 600 amps per track. The system design is such that when a substation is out of service, continued operation is possible, albeit at a somewhat reduced performance level.

The trolley wires of the up and down tracks are not segregated electrically but are interconnected at regular intervals. This gives improved operational characteristics and a significant saving in energy thanks to regenerative braking. A significant saving in the capital cost is also possible because of the reduction in the amount of switch gear required. A further advantage is that the electrical sectioning of the overhead equipment is greatly simplified, particularly at junction areas.

Maintenance of the overhead equipment is simpler and safer because the problem of working alongside live conductors does not arise. Furthermore wrong-side running in streets full of general road traffic is, in any case, hazardous. The only disadvantage of this arrangement is that if the overhead equipment associated with one track fails, the other track is automatically taken out of service. The advantages of electrically common overhead equipment far outweigh the one apparent disadvantage.

Signaling and Control System

Different sections of the Sheffield Supertram system fall within each of the U.K. National Regulatory Standards for LRT categories:

- LRT 1: Street-running system shared with other users,
- LRT 2: Street-running, but not shared with other users, and
- LRT 3: Wholly segregated from other road traffic split as either—
  - —LRT 3A: Line-of-sight and not fully fenced, and
  - —LRT 3B: Fully fenced and under the control of an interlocked signal system.

On normal street-running the supertram operates on line-of-sight and obeys normal vehicle traffic signals redesigned to give priority to the tramway. Centralized urban traffic control is the only overriding authority. On LRT 3B the fail-safe interlocked signaling system operates on line-of-sight operation or, in the event of a clear track circuit in front of the train, a visual indication is given of a higher permissible speed. Lamp failures or faults revert back to line-of-sight operation, enabling the tramway to continue operation at safe driver-controlled speeds.

Overall control of the system is aided by a simple signaling control and data acquisition (SCADA) computer system, with video display set in the depot control room. The monitoring system currently covers selected areas such as substation traffic control and fault locations with radio control for instruction. Flexibility for control advancement is provided for future addition as the requirements develop.

COMMERCIAL ASPECTS

Planning

A fully integrated schedule, encompassing all the disciplines involved in the project, was produced to manage and control the project.

The network initially used for the project allowed for more detailed programming to be incorporated within it as information became available, and the design progressed. The Metier Management Systems Artemis 7000/386 software product is being used on the project because of its versatility and speed. The 7000/386 language is not particularly user-friendly, so Artemis Project 7000, a menu-managed system, is also being used. It is more user-friendly and, at the same time, the more complex and versatile 7000/386 language can be integrated with it to allow the production of reports tailored to site management. The system is being developed to incorporate design control; drawing register; variation order control; progress curves, overall, and for each discipline; delayed discipline; personnel resource scheduling; and construction labor histograms.

Cost Control

Whatever type of project is being undertaken, the contractor's key objectives must be to ensure that the project:

1. Is completed safely from the viewpoints of both the project personnel and the public,
2. Is built to the specification standards,
3. Is completed on time and to budget,
4. Makes an adequate profit for the contractor.

Only the third objective is dealt with here.

Limit of Authority

The project, because of its size, will have key managers who will answer for the project's financial performance. Thus it is essential for these individuals to have firm control over the expenditure and cash flows on the project with delegation to the appropriate level of their staff. These managers will also have the required delegated authority with respect to commercial contracts with the project's subcontractors and key suppliers, ensuring that the best technical and commercial terms are achieved in all respects.

Contract Reports

The contract requires two contract reports, each providing different types of information to different levels of the project staff. The first report is prepared weekly, enabling the line managers to determine whether or not they are operating efficiently in the field. This report deals with two key resources, labor and equipment. The project will be expected to achieve a level of productivity in the field in terms of completion of specific tasks, and these tasks will have a value of which the labor and equipment will be key elements. Having identified the tasks to be completed by means of a detailed program, they are then valued from within the overall budget for the contract. Each week the tasks are measured, valued, and compared with the costs. The line manager can identify the problem areas of low productivity and determine a course of action to rectify the problem. It is essential that this information is available on the Monday morning following the week of measurement and value. Although it might be considered that this frequency is too low, experience indicates that a weekly period is the most practical and manageable. Material control is not included on a weekly basis for reasons that will become apparent later.

The second report is prepared monthly and brings together all aspects of the project key elements of cost and value (e.g., construction labor, equipment, materials, subcontractors, staff, and site establishment).

This monthly report separately declares the cost and value against each of the above key elements and splits the individual cost and value against specific key elements (e.g., individual subcontractors or materials). It may be argued that, if the key elements have been procured within the values generated by the project, this level of reporting is not required. It is nevertheless essential that the management of the project be aware on a monthly basis of how each element is performing, both against the procurement declarations and the budget. If either one is showing slippage, then managerial decisions regarding the project's future can be made in terms of resource expenditure, reprogramming, and, if necessary, ensuring the client is kept well aware of the more serious effects on the project. Furthermore it is valuable in assisting the manager in deciding whether any systems put in place for material control, material reconciliation, weekly labor, and equipment cost and value reconciliations are having any effect, and if not, why not.

Budgets—Cost and Value to Completion

The project must have a budget in terms of both cost and value so that management can determine how the project is operating in the overall schedule. In some cases the budget assists management in making key decisions about scheduling and the use of personnel.

Once overall costs and value are determined, they are then analyzed against the project's monthly report to determine the financial effects on the project's physical performance (in terms of meeting milestones) and financial targets (in terms of procurement resource performance, such as material handling control, efficient utilization of labor and equipment).

Should the original budget be shown to be inappropriate through either under- or overachievement on the project program, then the budget must be updated. Frequencies greater than quarterly are not recommended.

Material Control

More than half of the project's cost and value is to be found within the material element. It is essential that this element is effectively managed by a control system. The system used was originally developed by BBPCL to control stock from point of sale to goods delivery.

The system has some sophisticated spin-offs in that it can also allocate to location, readjust for "as fitted" changes, and produce a number of used-on facilities. Coupling this with the need to monitor suppliers—inspection and testing, deliveries, and shipment details—the system can be almost a minute-

by-minute timetable or location chart of what is happening to the material from advice of order to erection in the line. The fact that certain elements are subject to a wastage and loss factor is also taken into account, so the system provides exceptional control for managing both costs and material movement.

The system itself was developed for use on a mainframe computer, but has since been modified for on-line terminal use. Further ongoing development will make it possible to revamp to UNIX, 386 desktop facilities.

Management of the material control system is possible at site level, but using the centrally based purchasing function within BBPCL's divisional offices secures maximum discount and flexibility of suppliers.

Visual display of the various elements, such as allocated requirements, order requirements, manufacturing dates, inspection details, shipment and dispatch details, received on site, in stock details, allocated to line, issued to line, loss details, and so on, assist the material controllers in maintaining an effective stores control procedure. Variance reports are produced for management control and information. Using this information with the sales analysis and cost reporting schedules, item pricing and material valuation became virtually automatic as part of the total material control system.

THE FUTURE

Unlike its continental neighbors, the United Kingdom has steadily closed down almost all its tram systems. Modern tram networks are now being enthusiastically promoted. No doubt when the South Yorkshire Supertram system has been completed and its quality service has been experienced, it will represent a powerful argument for the introduction of such projects in other cities in the United Kingdom.