Portland LRV

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The Banfield light rail transit (LRT) project is the outgrowth of years of planning to improve the transportation conditions on the rapidly growing east side of the Portland metropolitan area and includes rebuilding of the existing Banfield freeway and construction of a new LRT line, 15.1 mi long, from downtown Portland to the suburban community of Gresham.

In 1973 and 1976 the Federal Highway Act was amended to permit the transfer of Interstate highway monies to other transportation projects including mass transit projects. During this time the proposed Mt. Hood freeway in southeast Portland was withdrawn and the bulk of this money was made available to support transit corridor projects. Planning studies were started in 1976, and the UMTA alternatives analysis process was completed in the summer of 1979 with Banfield as the priority corridor and light rail as the preferred mode. The preferred alternative included rebuilding of a portion of the existing Banfield freeway. The final environmental impact statement was approved in the summer of 1980. The first capital grant from UMTA was received in September 1980 for right-of-way (ROW) acquisition, and in December 1980 UMTA issued Tri-Met a "letter of intent" to fund the project in its entirety. Final design was initiated in 1981 and construction was under way by 1982. Table 1 gives the major project milestones.

Because of the freeway rebuilding and the use of Interstate transfer funding sources, the overall Banfield LRT project is being managed under joint arrangement of Tri-Met and the Oregon Department of Transportation (ODOT). In general, ODOT is directly responsible for the freeway rebuilding and Tri-Met for the transit portions although there are many areas of overlap and shared responsibility. The Banfield LRT project is the first rail transit project to be undertaken by Tri-Met, which currently operates an all-diesel bus fleet of about 700 buses.

The LRT line will encounter a variety of ROW conditions, including downtown city streets, the median of an existing bridge, a side ROW adjacent to a one-way city arterial, a freeway ROW, a median ROW in a county arterial, and a railroad ROW. Two-thirds of the line will be at grade with numerous street crossings, and one-third will be fully grade separated adjacent to the Banfield freeway. There are no subway sections. With minor exceptions, vehicular traffic will not be permitted to share the LRT ROW and will be physically separated by small curbs and other protective measures. Along the at-grade segments, the light rail vehicles (LRVs) will generally either have the opportunity to preempt traffic signals in order to optimize operations through intersections or will have gated protection. For construction purposes, the LRT line has been broken into seven contracts.

The downtown Portland segment imposes the majority of ROW and operational constraints found along the whole line. Block lengths are short (normally only 200 ft property line to property line) and therefore limit overall train length; streets are narrow (normally 60 ft property line to property line) and therefore require tight turning movements. There are also tight vertical and horizontal clearances where the line runs under the ramps and between the piers of two existing bridges. The downtown alignment includes a one-way loop on two adjacent streets.

The steepest grade will be approximately 7 per-

TABLE 1 LRT Project Milestones

Date	Milestone
1976	Planning studies
1977	Planning studies
1978	Tri-Met selection of LRT Preliminary engineering started
1979	Local jurisdiction selection of LRT Alternatives analysis completed
1980	Environmental impact statement completed ROW acquisition started
1981	Final design started LRV contract awarded
1982	Maintenance facility contract awarded TES contract awarded 1st ROW construction contract awarded
1983	Signals contract awarded ROW contracts awarded Maintenance facility completed
1984	1st LRV arrived in Portland 1st ROW contract completed 1st TES and signals segment completed
1985	LRV delivery completed
1986	Open for revenue service

cent for 600 ft, and there are several grades of 3 to 5 percent. The minimum horizontal radius is 82 ft.

There will be 25 stations, yielding an average spacing of 0.6 mi. In the downtown segment, station spacing will be only 500 ft to 800 ft, and the longest station spacing throughout the line will be about 1.7 mi and will occur in the grade-separated segment. Station platform length will be approximately 200 ft, and platform height (for boarding) will be low level, approximately 8 in. from top of rail at all stations. There will be island platforms and left-hand, right-hand, near-side, and far-side platforms depending on ROW conditions. A self-service fare collection system with off-vehicle validation is planned. Accessibility for handicapped persons will be provided by a wayside lift, which will be mounted on each station platform and will raise from platform level to LRV floor level.

The cost estimate for the overall Banfield LRT project is approximately $308 million and the transit portion is approximately $207 million. The vehicle contract represents approximately 12 percent of the total transit portion. As of April 1985, the project is 95 percent committed and nearly 70 percent expended. Opening for revenue service is planned for the fall of 1986.

LRV PROCUREMENT

As the Banfield LRT project began to move from the planning stage to federal project approval, a determination was made by Tri-Met that procurement of the LRVs should receive a high priority in the overall schedule. LRV procurement was expected to be the single largest dollar amount contract in the entire project, and an early execution of that contract was sought in order to serve as a forcing function for the rest of the project.

Predesign studies, wayside conditions, and operational preferences had determined the basic type of vehicle to be procured--a large, articulated, double-sided and double-ended car--and in early 1980 Tri-Met, with the assistance of the consulting firm of Louis T. Klauder and Associates, embarked on a process to procure the LRVs and related equipment and services. Tri-Met sought a procurement that would be competitive, conform to UMTA regulations, and yield an LRV based on proven design. After research of then-existing and planned rail car procurements, Tri-Met elected to use the now familiar two-step procurement process.

The first step of the process included issuance of a performance-oriented request for technical proposal (RFTP) by Tri-Met, submittal of technical proposals by interested proposers, and evaluation of those proposals and determination of acceptable proposals by Tri-Met. The technical proposals contained no prices or references to prices.

The second step included issuance of the invitation for bid (IFB) by Tri-Met only to acceptable proposers, submittal of bids, award of contract by Tri-Met to the lowest bidder, and contract performance.

Before the RFTP was officially released, an extensive industry review was conducted and comments were received from numerous car builders. Four proposals were eventually received, and after a 4-month evaluation two were found acceptable. These were from Bombardier of Canada and Siemens of the Federal Republic of Germany. Proposals were evaluated on two principal bases:

- Management arrangement and qualifications of the proposer, and
- Technical merits, proven design, and suitability of proposed LRV for Tri-Met's requirements.

In addition to rail car manufacturing experience, a prime consideration in evaluating the proposer was continuity from design to fabrication. Licensing arrangements were permitted, and even encouraged, as long as they offered a sufficient degree of designer review and authority over fabrication and thereby increased conformity to proven design and reduced untested design deviations.

The number of vehicles required by the contract was fixed at 26 for all bidders. This number was based on passenger loading projections, vehicle performance, expected vehicle size, and other factors. It was acknowledged and accepted that there could be small variations in passenger-carrying capabilities among the bidders, but such variations were minor.

Bids were received from Bombardier and Siemens in May 1981, and Bombardier offered the low bid as follows:

Price for 26 LRVs at $775,521 each	$20,163,546
Spare parts, tools, training, and technical support	1,498,666
Total bid price	$21,662,212

Contract provisions additionally allowed for escalation according to U.S. Department of Labor indices and specified formulas. Contract award was made in September 1981.

DESIGN AND FABRICATION PLAN

Bombardier, Mass Transit Division, of Quebec, Canada, is Tri-Met's contractor for the supply of the 26 LRVs, specified spare parts, manuals, training, and technical services. One requirement of the RFTP process was that the management arrangement for the contract be unambiguous, and such has been the case. From Tri-Met's point of view, all matters pertaining to the contract--whether design, fabrication, performance of subcontractors, or adherence to contractual terms and conditions--are solely the responsibility of Bombardier.

For the Tri-Met contract, Bombardier is operating under a license from the Belgian firm of Constructions Ferroviaires et Métalliques, conveniently known as BN. BN is the overall designer of the Portland LRV, particularly the car body structure and trucks. In addition, under separate contracts, BN acts as a subcontractor and supplies Bombardier with certain components such as the truck frames, articulation, door panels, and gearbox assemblies. For the Portland car, Bombardier elected to assume certain design responsibilities such as interior finishing and car wiring to a greater degree than it had done before on other contracts.

The Portland LRV is basically a stretched and otherwise modified version of the pre-Metro cars built (partially) by BN for Rio de Janeiro in the 1970s. Truck and articulation design are derived from the Rio car and from other BN designs such as those for the Manila LRV.

Propulsion system design and supply of hardware are by the Brown Boveri Company (BBC) of Switzerland through its North American subsidiary. The Portland traction motor is based on the BBC motor for the Breda LRVs in Cleveland, although there are significant differences. The switched resistor propulsion control system is based on that of certain Swiss railways, particularly the Sankt Gallen-Appenzeller (SGA) railway.

Several other components (pantograph, door operators, slewing ring, suspension, and so forth) are French or German in design and manufacture, making the Portland LRV overall very much European in origin. This transfer of European technology to the North American setting has sometimes exposed philosophical differences and otherwise made life interesting.

Major car body subassemblies such as the roof, side walls, and parts of the underframe were fabricated at Bombardier plants in Quebec. Originally, Bombardier proposed to assemble the car shell at its main plant in La Pocatiere, Quebec, before shipment to a new plant in Barre, Vermont, for equipment installation and final assembly. However, early in the contract Bombardier proposed and Tri-Met agreed to allow underframe and shell assembly also to occur in the Barre plant. Welding capabilities had to be significantly upgraded at Barre and brought to American Welding Society (AWS) standards because significant structural assembly work had never been done in that plant before.

All equipment installation, car wiring, interior finishing, painting, final assembly, and static testing are accomplished at the Barre plant. Trucks are also assembled and wired there.

However, Bombardier's main engineering forces are located in Quebec, and in the author's opinion this physical separation of engineering and production is at best tolerable and at worst detrimental to the smooth production of such a complicated piece of equipment as a modern LRV.

In the final analysis, design of the Portland LRV has been shown to be less proven than anticipated at the proposal stage and although applicable experience of the manufacturer at a corporate level has been adequate, unforeseen learning curve problems have been persistent at the actual production plant. These problems may be due to insufficient transfer of experience from plant to plant.

MAJOR CONTRACT MILESTONES

As previously stated, the contract was awarded in September 1981. Fabrication of the first underframe was started at Barre in the fall of 1982, and the first shell assembly was put together in December 1982. The first car was articulated in the spring of 1983, and the car body strength test was performed in Ontario, Canada, in June 1983. Trucks were set under the first car in the fall of 1983, and Car 101 was first moved under its own power in November 1983. Table 2 gives a summary of the major LRV contract milestones.

By mutual agreement between Bombardier and Tri-Met, two of the first cars (101 and 103) were sent to the Transportation Test Center (TTC) in Pueblo, Colorado, for proof-of-design testing during the period December 1983 through March 1984. Car 103 continued to Portland and was the first LRV to arrive in April 1984. Car 101 was returned to a newly completed test track at the La Pocatière plant for further testing. Car 102 was the first LRV shipped directly from Barre and it arrived in August 1984. Testing in Portland has been under way since September 1984.

TABLE 2 LRV Contract Milestones

Date	Milestone
September 1980	Request for technical proposals issued
December 1980	Technical proposals received
March 1981	Acceptable proposals determined
May 1981	Bid
September 1981	Contract signed
October 1982	1st underframe fabrication started
December 1982	1st shell assembled
Spring 1983	1st articulation, undercar equipment, and interior equipment installed
June 1983	Car body compression test performed
Fall 1983	1st trucks installed
November 1983	Car 101 moved under its own power
December 1983	Car 101 shipped to TTC for dynamic testing
April 1984	1st car (103) arrived in Portland via TTC
August 1984	1st car (102) arrived directly from Barre
September 1984	LRV testing started
Fall 1985	Delivery completed

As of April 1985, thirteen cars (half the order) are on site in Portland, seven cars are substantially assembled in Barre, and all car shells are completed.

Delivery of all 26 cars is now planned for the fall of 1985 or about 1 year behind the original schedule.

LRV DESCRIPTION AND PERFORMANCE

The Portland LRV is a six-axle, single articulated car that is double sided and double ended. There are four double-wide, low-level doors per side. The car is approximately 89 ft long, 8 ft 8 in. wide, and 90,000 lb in weight (empty). There are 76 seats and room for 90 standees (at 4 people per square meter) for a design capacity of 166 passengers. Crush capacity is 256 passengers total. Table 3 gives a summary of the major LRV system requirements.

TABLE 3 LRV System Requirements

	Requirement
General type of car	6-axle, single articulated double-sided, double-ended, 4 low-level doors per side
Length	89.14 ft over coupler faces
Width	8 ft 8 in.
Empty weight	90,000 lb ± 3%
Seats	76
Standees	90 minimum at 4 persons per square meter
Minimum horizontal radius	82 ft
Dynamic clearance	5 ft 7 in. from track centerline on tangent track
Overhead voltage	750 V DC nominal 525 to 875 V DC operating range
Track gauge	4 ft 8½ in.
Acceleration	3.0 mph/sec ± 5% at AW0 to AW2 10 sec to 25 mph 40 sec to 50 mph Constant performance from 600 to 825 V DC
Top speed	55 mph
Normal service deceleration	3.0 mph/sec ± 5% at AW0 to AW3 from 45 to 5 mph
Dynamic brake failure	Complete service run at 30 mph limit with 3.0 mph/sec ± 10%
Emergency brake	4 mph/sec to 6+ mph/sec average
Jerk limit	3.0 mph/sec squared maximum
Slip/spin efficiency	40% in acceleration and 75% in deceleration per specified procedure
Noise	70 dB(A) to 75 dB(A) per specified conditions

The car is designed for single-unit or multiple-unit (MU) operation in consists of up to four LRVs. Tri-Met has tested no more than two-car consists to date.

The track gauge is standard 4 ft 8 1/2 in. and the overhead voltage is 750 V DC nominal. The LRV operating range is 525 to 875 V DC.

The required minimum horizontal curve radius is 82 ft, and the minimum vertical curve radius is from 200 to 300 ft depending on whether crest or sag conditions apply.

The car body is constructed of low-alloy, high tensile strength (Corten) steel. Spot welding is primarily used for fabrication of the side walls and roof; construction of the heavier underframe and the shell assembly uses metal inert gas (MIG) welding techniques.

The floor structure includes corrugated sheet metal, treated plywood, and rubber flooring and has successfully passed the flammability requirements of an ASTM-E119 test. The seats are cushioned on stainless steel frames, and the interior uses melamine-type panels with some fiberglass sections.

The trucks are welded steel structures from BN with rubber primary and secondary suspensions, inboard bearings, one brake disc per axle, and resilient wheels. The primary suspension is a rubber toroid (doughnut) from Clouth, and the secondary suspension is an inverted chevron with alternately stacked plates of rubber and metal. The resilient wheels are from Penn Machine/Krupp and have a tire and hub separated by rubber blocks in compression to reduce wheel squeal on sharp curves. The center truck is not powered and is freewheeling. The motor truck is a monomotor design with a right-angle drive on each end, and the motor trucks are interchangeable. A flexible coupling from BBC-Sécheron (BBC) connects the gearbox to the axle. A single-race ball bearing slewing ring attaches the motor truck bolster to the car body, and the center truck uses a double-race slewing ring to permit both car halves to rotate relative to each other and to the truck.

The BBC traction motor is a four pole series DC motor with a continuous rating of 198 kilowatts and 280 amperes at 750 V DC and 1,780 rpm. The motor is self-ventilated.

The BBC propulsion control system employees a switched resistor arrangement with contactors controlled by an electronic control unit (ECU). There is no mechanical cam. The ECU is located in an underseat compartment in the interior of the car. The operator's handle or master controller has six distinct positions (rates) for motoring, six distinct positions (rates) for braking and coasting, and three positions to set maximum speed particularly for downhill operations. There are a maximum of 54 steps in motoring and 33 in braking, making for a relatively smooth ride without much notice of notching. Parallel operation of the motors is permitted in the two highest positions in motoring. Braking and accelerating resistors are roof mounted. A unique feature of the BBC control system is its rate feedback system. The system tries to satisfy the rate request from the master controller handle regardless of vehicle load or wayside conditions (e.g., grades). Thus there is no explicit load-weigh input for normal service propulsion control; instead the system uses the measured vehicle acceleration (deceleration) rate in a feedback loop as an implicit indication of passenger load.

Top speed of the LRV is 55 mph with an overspeed control set at 58 mph. The maximum acceleration is 3.0 mph per second and the car is required to reach 50 mph in 40 sec. Testing at TTC and Portland has indicated compliance with these requirements.

New York Air Brake (NYAB) provides the friction brake system that features a spring-applied, hydraulically released disc brake on each axle and track brakes on each truck for use in emergency stops. The disc brake system uses one pump and control valve per truck for redundancy and minimization of car plumbing. These three control units are car body-mounted, underfloor, and adjacent to their respective trucks.

Service braking is provided by dynamic braking on the motor trucks and supplemental disc braking on the center truck if necessary (for passenger loadings above approximately AW2). Dynamic and disc brakes are also fully blended on the motor trucks both during the initial instant (1 sec) of braking so the faster hydraulic can assist the slower electric brake and during the fade-out of the dynamic brake below approximately 5 mph. The maximum service brake rate is 2.5 mph per second from 55 to 45 mph and 3.0 mph per second from 45 to 5 mph for vehicle weights from AW0 to AW3 (211 passengers). Testing at TTC and Portland indicate compliance with these requirements. Both motoring and braking are protected by a spin/slide system that slows or reduces notching and dumps sand at the leading motor truck axles if necessary. The friction brake system is required to act as a backup and be able to meet a specified performance in the event of dynamic brake failure with a reduced top speed (30 mph) allowed.

Emergency braking is provided by disc braking on all trucks, track brakes, and automatic sanding. Spin/slide and jerk limit features are not present during emergency braking. A 4.0 mph per second to 6 mph per second rate depending on entry speed is required during emergency braking. Because propulsion (rate) control is effectively disabled during emergency braking, a separate load-weigh system is used to modulate emergency brake rate as a function of vehicle load.

Safety electric provides a 10 kw DC-to-DC converter which changes the 750 V DC input to a minimal 37.5 V DC output. This solid-state unit acts as a battery charger and in parallel with a McGraw NiCad battery provides the basic low voltage supply for various uses throughout the car. In addition to this 37.5 V DC supply, some systems (e.g., headlights or train radio) use dropping resistors or other converters to step the voltage down to 24 V DC or 12 V DC. The Soleq Corporation provides a solid-state inverter that uses the 37.5 V DC supply as input to create 120 V AC output to power the interior lighting, heating and ventilation (H&V) fans, and convenience outlets.

The door system is a swing plug design much like that on the General Motors Advance Design Bus and is provided by Faiveley of France, which also provides the pantograph. The door operator design is relatively new and is still under test. The train operator can control (open and close) the doors or "enable" the doors, which allows them to be opened locally by passengers pushing pushbuttons inside or outside the car. Separate control of the doors adjacent to the active cab is provided for use with the wayside lift.

Dellner of Sweden provides the fully automatic coupler that features a cantilever suspension, retractable electric heads, and a self-centering mechanism. Manual coupling, coupling on curves, and electric isolation are also provided.

Passenger compartment heating operates off the 750 V DC overhead supply and is protected by air flow switches and over-temperature devices. The H&V unit is mounted on the roof near the front of the car on each body half. A separate 750 V DC heater-blower unit is provided in each cab. Air conditioning was not required.

Each cab has a fully equipped communication system with radio to and from Central Control, public address (interior and exterior), intercom with other cabs, and radio from Central Control to public address. Provisions have been made for a passenger intercom to the train operator if the situation warrants in the future.

Cab controls are hand controls with the exception of the sander.

Certain portions of the Banfield LRT line will have track circuits and a block signal system with wayside signals protected by an automatic trip stop (ATS) system. The ATS system uses wayside permanent magnets and on-board antennas mounted on the center truck. Violation of a red signal can automatically bring the LRV to a stop at maximum service brake and index a counter.

The Portland LRV also carries a solid-state data recorder, purchased separately by Tri-Met and installed by Bombardier, that continuously records certain train-line input signals for purposes of testing, operator surveillance, and accident documentation.

IMPORTANCE OF SPECIFICATION

Car design and cost control measures begin at the specification stage, and there are obviously many dimensions to the importance of the effect of the specifications on design and cost of rail transit vehicles. A good specification does not a good car make, nor does a poorly written, weak, ambiguous, or incomplete specification guarantee equipment fraught with problems. However, in the authors' opinion the transit authority, consultant, and eventual customer can exert their greatest influence on the overall costliness of the car as a function of the contract documents developed.

One of the first major decisions to be made in the procurement process is the type of procurement documents or specification to be used. This decision is influenced by the competency of the transit operator or procuring agency, the involvement of consultants, and the transit environment in which the procurement takes place. In the authors' opinion, a basic distinction exists between the conditions present for a "new start" system such as the Banfield LRT project and those for an existing rail transit property involved in rehabilitation or expansion.

For the new start system, historical constraints are not so prevalent. Obviously greater flexibility exists in defining technical requirements because there are no restrictions such as compatibility with existing equipment or need to couple with existing transit cars. To some extent vehicle-wayside interface can even be designed in concert. Thus a two-step, performance-oriented specification is a logical approach for a new start system, and such was Tri-Met's rationale in 1980 when the LRV procurement process was begun.

For an existing rail transit property with considerable experience and, probably, some equipment prejudices, a strictly performance-oriented specification may not be suitable. It may be more desirable and cost-effective in this case to specify hardware preferences in order to reinforce revenue-proven experience, to reduce spare parts inventory, and to promote interchangeability with existing equipment.

There are of course advantages and disadvantages to both the performance-oriented specification and the hardware specification. Too much flexibility could promote a tendency for experimentation and underreliance on proven hardware, and hardware dictates could promote ill effects from monopolies or retard innovation. Determination of the appropriate overall balance is probably best done on a case-by-case basis, and development of guidelines is beyond the scope of this paper except for the major premise that new start properties are probably best served by inclination toward performance-oriented specifications, with the caveats discussed hereafter.

Another major decision to be reached early in the procurement process and one which can obviously be contributory to the high cost of rail transit cars, particularly of LRVs, involves the uniqueness of the requirements, particularly general requirements such as car size, brake equipment, and door type. There has been for several years a tendency on the part of transit authorities to customize their major technical requirements. This tendency has been present not only in North America but also in Europe. For existing properties, this tendency is mostly understandable, but new start properties often make decisions to specify or allow certain types of equipment in combination with certain general car characteristics in lieu of actual proven interfaces. In many cases, virtually identical detailed performance requirements appear throughout several recent specifications, yet general requirements are often relatively widely variant. Whatever the actual reasons, the result, in a broad sense, is that in the last 10 years there has been a proliferation of different kinds and types of LRVs, in the United States and abroad, and little standardization despite the UMTA-funded attempt at such during the late 1970s.

In the spirit of the performance-oriented specification, the RFTP for the Portland LRV was permissive in many areas yet specific in others. For example, for the friction brake system, a hydraulic, an air, or an electric system was permitted with primary emphasis placed on meeting the performance requirements. The auxiliary power supply requirements allowed either rotating or static equipment. On the other hand, only a relatively small range of vehicle sizes was permitted, as opposed to specifying system carrying-capacity without regard for individual vehicle size, with the intention of forcing car builders to a common size and thus a common basis for bid. Also Tri-Met allowed only a switched resistor control system because of cost and complexity considerations.

Contractual terms and conditions are of course important specification-related elements that affect car costs. In the Portland procurement, there was a consistent attempt through the bid stage to inject specificity in the bid requirements and to reduce elements of risk for bidders. Mechanisms for these goals included requirement for the same number of LRVs of approximately the same size, development of a common spare parts list within the umbrella of differing allowable equipment, and inclusion of an escalation clause to compensate for effects of inflation over a multi-year contract. These goals of bid commonality (i.e., car size) and reduction of risk were held paramount even to that of allowing only identically proven equipment.

Although admittedly limited, Tri-Met's experience to date with the performance-oriented specification suggests that a desirable insurance for a transit authority is to include greater not lesser specificity in its requirements. Such specificity should not be limited merely to common performance parameters such as acceleration rate and top speed but should include applicable standards for materials, quality control, test procedures, and measurement techniques. More hardware specificity, not by brand name or manufacturer's name but by generic type, would have been desirable in the Portland specification. Sometimes seemingly minor items in a specification, or lack thereof, have ways of becoming important production or maintenance problems in the future. For example, specification of simple fasteners appears to not be exactly consistent with the loftier goals of a purely performance-oriented specification, is tedious to do, and is difficult to enforce. Yet mechanical fasteners and electrical terminations literally hold a car together and their importance should not be overlooked in any type of specification.

The authors do not presume to be able to draw conclusions about the effects on cost control of the level of specificity of technical requirements contained in the procurement documents. Too many factors are involved. As a general rule, however, the more specific and known an item or requirement is, the less controversial it will be and, possibly, the less costly after the fact. Both car builder and customer have less room for preferential interpretation.

SERVICE-PROVEN EQUIPMENT AND FACILITIES

In addition to the need for a clear and concise procurement document, the authors cannot overemphasize the importance of service-proven equipment; proven system interfaces particularly propulsion and brake and trucks; and, where possible, completing the assembly in an experienced and well-equipped facility. Each of these elements has significant impacts on car builder costs and final capital and operating and maintenance costs to the operator.

There is little question that a number of "off-the-shelf" designs, each capable of performing equally and of equal quality, would offer the ideal LRV procurement climate. However, in Portland as well as other current and prospective procurements such as San Jose, Sacramento, and Los Angeles-Long Beach there is not one car that can meet all of the requirements without some modification. This is due in part to local preference, state law (such as California Public Utilities Commission, General Order 143), and federal law (Buy America). Inevitably, it appears that there is almost always a struggle in the beginning of the procurement process between modification to the demand (i.e., the specification) and modification to the supply (i.e., truly service-proven equipment).

Because it is probable that the ideal case or perfect marriage between supply and demand can rarely happen, the operating property should attempt to use, and insist on the use of, a maximum number of service-proven systems while seriously reviewing its site-specific requirements for consistency with the available marketplace. Benefits to the operating property from reliance on service-proven systems include

- Known service history and repair procedures;
- Equipment similar or identical to that of other properties, which increases the possibility of parts availability in the long run;
- Potential for borrowing or sharing hardware if a crisis arises; and
- Lower end cost where new tooling and designs are not required.

The car builder, on the other hand, has a known quantity to integrate into the overall car and thus reduces his risk and cost, provided that such service-proven equipment is not excluded by the specification or provided that less expensive unproven equipment is not allowed.

On the basis of Tri-Met's recent experience, the authors would recommend taking this philosophy one step further, where possible, by insisting that systems with direct interfaces have been previously operated together.

As an example, two critical problems occurred in Portland as a result of using a new brake design or at least a derivative of an existing design that required substantial modification for the Portland application. The first occurred in the fitting of the brake equipment to the truck where physical interferences caused mounting and, later, operating problems. The other occurred when the propulsion supplier and brake supplier, who had no previous working relationship, experienced some mutual learning curve and coordination problems resulting in some delays to the car builder. The intent in citing these problems is not to point fingers but to illustrate by example the potential pitfalls of unproven interfaces. These problems have been responded to by all parties.

As a result of "Buy America" or local preference, many cars are being partially assembled in one facility with final assembly elsewhere. Although this practice is desirable in some cases and required in others, experience shows that it can be the source of problems and costs both for the car builder and for the operating property. In the Portland case, the car builder was allowed to transfer some of the work intended to be done in a facility with the most experience and know-how to a brand new, inexperienced facility and staff. Two major problems occurred: First, the skills required to do certain functions had to be learned and acceptability verified by test. This comes at the expense of the car builder or the authority, or both. Second, language or differences in standards, or both, create problems that would not have otherwise existed.

Further, the "secondary facility" may not be equipped to provide the testing facilities needed including water test rigs, testing equipment, and test tracks. As previously mentioned, this situation may also move much of the actual assembly away from the engineering design and support group. If anomalies occur, the reaction is slower and may require engineering staff and "expert" laborers to be temporarily transferred to the other site to rectify problems.

Finally, in the case of small orders, when one or two inspectors can handle the complete order, the overlap in work in two facilities generally requires increased staffing.

In retrospect, given the time between scheduled delivery and revenue service of the line and the problems that have occurred, Tri-Met might have been better served had it required a production prototype before commencing the fabrication of the fleet. This approach would have allowed for in situ design review and test, and modification where required, to only one car. The remainder of the production could be expected to proceed more expediently.

This approach can only be considered when schedule and resources permit and requires a protracted and probably expensive process on the part of the car builder to obtain and assemble single-item units. In theory the prototype car is highly attractive but in practice, in a small procurement such as Tri-Met's, it is an expensive proposition.