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COST SAVINGS POTENTIAL OF MODIFICATIONS TO THE STANDARD LIGHT RAIL VEHICLE SPECIFICATION

Prepared by

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FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
Urban Mass Transportation Administration
Office of Technology Development and Deployment
Office of Rail and Construction Technology
Washington, D. C. 20590

PREFACE

This report describes an assessment of the Standard Light Rail Vehicle (SLRV) specification to determine whether the relaxation or modification of some requirements could result in a significant reduction in vehicle costs.

The assessment was sponsored by the U. S. Department of Transportation (DOT), Urban Mass Transportation Administration (UMTA), through the Office of Rail and Construction Technology of the Office of Technology Development and Deployment. The work was performed by N. D. Lea and Associates, Inc. under contract to the Transportation Systems Center of DOT. Boeing Vertol Company, Louis T. Klauder and Associates, and Kaiser Engineers also contributed significantly to the assessment in an advisory role under separate contracts with the Transportation Systems Center.

The assistance of Thomas L. Wolgemuth, Manager, Engineering of the Chicago Transit Authority, and members of his engineering staff, was especially helpful in providing independent judgments of potential cost savings as a check against the engineering cost estimates prepared for this study. Valuable assistance was also received from Dr. Hermann Zemlin and Mr. Meyer-Plate who arranged to have Studiengesellschaft Nahverkehr mbH and the Verband Öffentlicher Verkehrsbetriebe of the Federal Republic of Germany review potential areas of cost savings.

In addition, Jeffrey Sisson of the Massachusetts Bay Transportation Authority assisted in identifying and assessing the value of potential cost reduction areas.

The study project manager also wishes to acknowledge the assistance of Jeffrey Mora of the UMTA Office of Rail and Construction Technology, Office of Technology Development and Deployment who, as the representative of the sponsoring agency, provided continual encouragement and support. Jason Baker of the Transportation Systems Center also provided invaluable technical assistance based upon his many years of experience with light rail transit operations and engineering.

Special acknowledgement is also due Charles Phillips of the Transportation Systems Center, who as TSC technical representative provided continual guidance and support and invaluable assistance interfacing with the several contractors supporting this effort.

It should be stressed that, notwithstanding the considerable assistance from all of these individuals and groups, the final judgments in this report are those of N. D. Lea & Associates, Inc., and do not necessarily agree with those of each cooperating organization.

N. D. LEA & ASSOCIATES, INC.

Thomas J. McGean
Project Manager

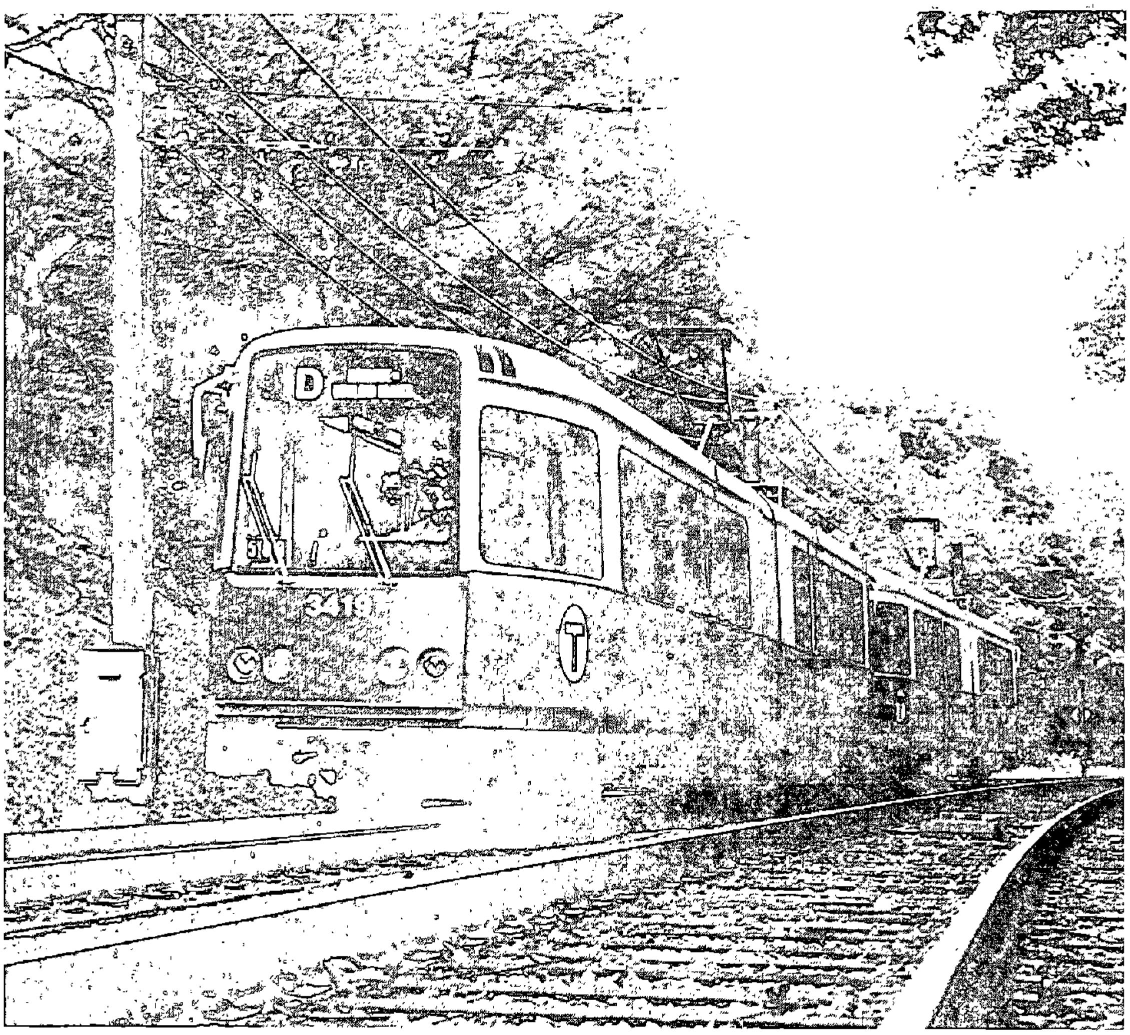
TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)



TWO-CAR BOEING VERTOL SLRV TRAIN OPERATING IN BOSTON

1.0 INTRODUCTION

In late 1971, the Urban Mass Transportation Administration (UMTA) and the San Francisco Municipal Railway (MUNI) rejected bids of approximately a half million dollars per car for new light rail vehicles as being excessive. To obtain economies of scale, UMTA sponsored the development of a Standard Light Rail Vehicle (SLRV) specification to be used by all transit authorities requiring this type of equipment. The specification was developed by the Massachusetts Bay Transportation Authority (MBTA) with the assistance of MUNI, the Southeastern Pennsylvania Transportation Authority (SEPTA), as well as other light rail systems and consultants.

The first use of the standard specification was a joint procurement in November 1972 by the MBTA and MUNI for 230 new light rail cars. The successful bid by Boeing Vertol was approximately $300,000 per car - apparently offering clear evidence of the value of standardization and volume purchasing. Yet, barely five years later, the same Boeing car was bid to the Greater Cleveland Regional Transit Authority at over three quarters of a million dollars. The successful bid on this procurement was from an Italian firm at a price of $645,000 each for eighty-foot long articulated cars. There is considerable concern within UMTA and the transit industry over this escalation in costs, and the question has been raised whether a simpler light rail car might not sell for a more reasonable price and be easier to repair and maintain. To a certain extent this may reflect a somewhat nostalgic attachment to the venerable and simple PCC car developed by the Electric Railway Presidents' Conference Committee - yet there is no discounting the increasing complexity of recent designs. According to a recent UMTA sponsored state of the art review of light rail transit, "As transit operators have demanded improved performance, greater passenger comfort and improved maintainability of the newer equipment, the number, complexity, and cost of the various components carried onboard the LRV have increased."

It would seem timely to re-examine the approach to specifying light rail equipment with the purpose of determining whether performance and technological innovation have been overemphasized without adequate concern for the impact upon costs.

1.1 PURPOSE AND SCOPE OF THIS REPORT

This report documents the results of such a study sponsored by the Department of Transportation, to determine whether the elimination or relaxation of some features and requirements in the Standard Light Rail Vehicle specification could result in a significantly less expensive car. The primary concern has been to reduce vehicle-first costs without major sacrifices in either performance or life cycle costs.

The basis for the review has been the Standard Light Rail Vehicle Specification, as originally prepared and released through the National Technical Information Service of the U. S. Department of Commerce. This specification differs from a subsequent version which defines the SLRV as it was actually built by Boeing Vertol for the MBTA and MUNI. While the review process concentrated upon the original specification, there are areas where there have been significant changes in the "as built" version which have been noted and the implications discussed.

It is important to emphasize that this study does not represent a review of the Boeing Vertol light rail car, nor is it a value engineering study of improvements which could be made in the design and production of that vehicle. The scope of the investigation is strictly limited to identifying and analyzing items in the specification which may have the result of increasing car costs. Design choices or production techniques selected by the supplier are outside the scope of this report.

1.2 STUDY METHODOLOGY

The approach taken to identify and quantify potential cost reductions was premised upon two considerations. First, since the light rail specification is a voluminous and detailed document, an organized and disciplined technique was required to filter out and identify the more promising opportunities from the myriad of possibilities. Second, since such a process inevitably must involve judgment, the methodology had to actively solicit the views and opinions of a diverse group of individuals and organizations with experience in light rail transit. The approach selected employed a rigorous line by line review of the light rail specification which identified a list of 640 possible cost reduction items. Each of these items was discussed in formal interviews with engineers from Boeing Vertol, resulting in a refined list of 180 items. The 180 items were then subjected to in-depth review by a number of light rail experts, using a combination of structured interviews and an analysis of numerical rating forms completed by these experts. The MBTA, Louis T. Klauder and Associates, Kaiser Engineers, and Boeing Vertol participated directly in the process. Assistance was also received from the Transportation Systems Center of the Department of Transportation (DOT), Office of Rail and Construction Technology of the UMTA Office of Technology Development and Deployment, the German firm Studiengesellschaft Nahverkehr mbH (SNV), the German Verband Öffentlicher Verkehrsbetriebe (VÖV), and the Chicago Transit Authority. While all of these organizations provided invaluable expertise and assistance, it should be emphasized that the final judgments in this report are those of N. D. Lea & Associates, Inc. (NDL), and do not necessarily agree with those of each cooperating organization.

NDL analysis of information provided by these experts resulted in the selection of twenty cost reduction areas as having maximum promise. Detailed estimates were then prepared of the savings in vehicle first cost from these changes, based upon a typical one hundred car order.

1.3 OUTLINE OF THE REPORT

This report consists of six chapters plus three appendices. Chapter One contains a general introduction. Chapter Two is an executive summary of the report, also containing all conclusions and recommendations.

The next chapter presents a general overview of factors affecting light rail vehicle costs in order to place the limited scope of this particular investigation into proper perspective. There are many factors which affect car costs which are outside the scope of this study. These include the need to subcontract major portions of the car buy, the effect of inflation, economies of scale based upon order size, standardization, vehicle capacity, and general business conditions.

This overview is followed in Chapter Four by a thorough explanation of the study methodology used to identify changes to the specification with promise of reducing costs. Chapter Four describes a Technique for Assessment by Structured Interviewing (TASI) developed by NDL, which proved to be quite useful in obtaining and processing the views of a variety of light rail experts in an efficient and orderly manner.

Chapter Five reviews the major areas for cost reduction identified through the interview and survey process. In addition, areas which originally appear promising, but were discarded after further investigation, are also included. Areas for cost reduction have been divided into nine sections as follows:

a) design and manufacturing constraints
b) level of complexity and sophistication
c) operational factors
d) reliability and maintainability
e) testing requirements and standardization
f) documentation requirements.

g) passenger comfort
h) dynamic performance
i) clarification of requirements

Chapter Six contains a quantitative analysis of the savings which can be obtained by implementing the twenty most promising specification modifications, assuming a procurement of one hundred cars. The section includes a cost breakdown for each of the changes. In addition, aggregate cost savings are provided for three example cars which incorporate the cost reduction suggestions in varying degrees.

Finally, the Appendices include the detailed results of the NDL evaluations of interviews and rating forms received from the various light rail experts who participated in this study.

2.0 EXECUTIVE SUMMARY

This report represents the results of a review of the Standard Light Rail Vehicle specification to determine whether the elimination, modification, or relaxation of some requirements could result in a significant reduction in vehicle costs. The primary concern has been to reduce vehicle first costs without major sacrifices in either performance or life cycle costs.

Results of the study indicate that the trend towards more complex light rail vehicle designs has had a significant impact upon costs. It is estimated that changes in the specification could reduce car costs at least 16.5 percent without major impacts upon performance. Still greater emphasis upon simplicity such as specification of a uni-directional, all electric car with doors on only one side, could reduce costs by nearly 23 percent. Such changes, while significant, need not drastically impair performance. For example, the popular Frankfurt U2 car is all-electric, while the new Canadian Light Rail Vehicle as designed for Toronto is single-ended with doors on only one side.

This report does not represent a review of the light rail car built by Boeing Vertol, nor is it a value engineering study of improvements which could be made in the design and production of that vehicle. The scope of the investigation is strictly limited to identifying items in the specification which have the result of increasing car costs, and does not consider design choices or production techniques selected by the vehicle supplier and not constrained by the specification. Nonetheless, review of the Boeing car and drawings conducted in the course of this study suggest that such a value engineering effort would be likely to produce significant additional savings.

It is the judgment of N. D. Lea & Associates, Inc. (NDL) that a concentrated effort to rewrite the light rail vehicle specification to emphasize simplicity and economy of design, coupled with incentives to encourage value engineering by the supplier, could significantly reduce light rail car costs beyond 25 percent. If light rail is to be a realistic alternative to rapid rail and permit staged incremental development of rail transit, it is essential that the rolling stock not be a carbon copy in cost and sophistication of full scale rapid rail equipment. At present, the standard light rail vehicle is both more sophisticated and expensive than comparable rapid rail equipment. It not only has all the features of conventional rapid rail cars, but in addition has six axles instead of four, an articulation section, automatic track sanding, resilient wheels, and magnetic track brakes. These added features are often required by light rail service, but their cost should be offset by deleting some of the more sophisticated features of rapid rail cars which are not essential for light rail. In this manner, light rail can properly fulfill its potential as an intermediate capacity transit alternative.

2.1 APPROACH TO IDENTIFYING COST SAVINGS

To identify potential savings, NDL engineers reviewed the specification line by line, generating a list of 640 changes which might reduce costs. The review was "zero based" in that all items for which a service requirement could not be readily identified were recommended as candidates for relaxation or elimination.

The list of candidate changes was discussed item by item with engineers from the Boeing Vertol Corporation, who had actively participated in the design of the Boeing light rail car. Based upon their judgments concerning cost savings and performance impacts, the original list was reduced to a refined list of 180 items. These 180 items served as the basis for in-depth interviews with the Massachusetts Bay Transportation Authority, Kaiser Engineers, and Louis T. Klauder and Associates. In addition, rating forms containing these same items were subjectively evaluated in terms of both cost savings and service impacts by Kaiser, Klauder, and Boeing. Judgments concerning the cost reductions were also received from the German firm, Studiengesellschaft Nahverkehr mbH (SNV), the Verband Öffentlicher Verkehrsbetriebe (VÖV) and the Chicago Transit Authority, as well as from experts at UMTA and the DOT Transportation Systems Center. NDL analysis of the information provided from all these sources resulted in selection of twenty of the most promising areas for a detailed quantitative cost assessment.

2.2 PROMISING AREAS FOR COST REDUCTION

The SLRV specification dictates a sophisticated, high performance vehicle, when compared to the older PCC car. Features not found on the PCC cars include articulation, plug doors, remote operated destination signs, chopper control, air conditioning, a pantograph, slip/slide control in conjunction with automatic sanding, airbag suspension, automatic speed control, full communications, and provision for automatic diagnostic test equipment. In addition, most PCC cars were unidirectional while the SLRV is a bidirectional car. Many of these features provide important improvements in operational capability and should not necessarily be discarded. Further, some of these features, such as compressed air, are not explicitly required by the specification, but rather emerge as the practical solution to a variety of relatively stringent performance requirements. Nevertheless, it is evident that there has been a trend towards increasing sophistication and complexity in the specification of light rail equipment. The following are a number of the areas in which changes to the specification could serve to reduce car costs.

Design and Manufacturing Constraints

A number of the suggested changes related to design and manufacturing constraints imposed by the specifications upon the supplier. Restrictions on body contours and the requirement to use plug doors were cited as examples where it might be desirable to allow greater latitude for the vehicle designer. Other examples include the requirement for a 9/16 inch thick single piece windshield, and constraints on design of the articulation joint which preclude the use of a simple bellows for cover and protection.

Level of Complexity and Sophistication

Another area where specification changes could reduce costs is associated with the general level of complexity and sophistication. There are items which, while each reasonable and involving relatively small amounts of money, collectively add up to significant dollars and increased vehicle complexity. Examples include remotely operated power driven destination signs, automatically dimmed instrument lights, an elaborate operator's cab enclosure, and automatic track sanding.

Reliability and Maintainability

In the area of reliability and maintainability, changes were identified which could reduce car procurement costs, although there were strong reservations among those interviewed concerning the impact on life cycle costs. Notwithstanding these objections, it seems clear that the stringent requirements now in the specification were not successful in preventing major equipment reliability and maintainability deficiencies. One of the changes suggested was replacement of currently specified reliability goals, analyses and plans and the two-year demonstration program with a warranty type specification. An alternative approach cited was the addition of penalty/incentive provisions for not meeting or achieving reliability goals. Need was expressed to clarify and better define the reliability goals. Careful review of the specification may be in order with the objective of substituting incentives and prequalification of bidders for the present emphasis on monitoring and testing.

Testing Requirements and Standardization

Testing requirements and standardization represent another area where it may be possible to achieve cost savings. UMTA is presently working towards rail car standardization at the subsystem and major component level. The SLRV specification, if changed to waive testing requirements for qualified components,can encourage this effort, while reducing non-recurring costs associated with testing.

Documentation Requirements

The specification presents a detailed procedure for submission and approval by the purchaser or his consultant of a broad range of technical documentation. More streamlined procedures scheduling required approvals in conjunction with critical design review meetings should be considered to reduce costs and adverse schedule impacts associated with the present method. It should be mentioned that some of the LRV experts have strong reservations concerning relaxing these requirements and considerable care will be required in devising a more efficient approach.

Passenger Comfort

Careful consideration was given to whether passenger comfort requirements were excessively stringent. It was generally agreed that noise requirements should be relaxed, as was proven necessary when Boeing Vertol built the SLRV. Most of those interviewed did not believe much money could be saved by relaxing ride quality, heating, air conditioning, or lighting requirements. It was generally accepted that for most cities today, air conditioning will be a requirement.

Dynamic Performance

In the area of dynamic performance, recommendations include elimination of the automatic speed control, less sensitive requirements on reaction time and other control tolerances, and analysis of the advantages and disadvantages of the use of conventional cam, as opposed to chopper, motor controllers.

Clarification of Requirements

Those interviewed also noted a number of areas where clearer delineation of requirements could reduce confusion and misunderstanding between the supplier and customer. Better definition of the operating environment and clearer definition of maintainability requirements were two areas cited.

Operational Factors

A final area where major cost reductions appear possible involves changes with significant impacts upon system operations. Areas identified include permitting unidirectional vehicles, allowing doors on only one side of the car, and deleting the articulation joint for applications where such changes are compatible with site constraints and operating requirements. Also suggested were deletion of the compressed air system in favor of an all electric or electric/hydraulic car, and relaxation of the friction brake duty cycle to permit a smaller and less expensive brake.

2.3 COST SAVINGS FROM SPECIFICATION CHANGES

NDL selected a number of the more promising cost reduction suggestions for a quantitative assessment of the cost savings per car, assuming a typical order of 100 cars. Tables 2.1 and 2.2 present a summary of the suggested modifications and the estimated savings per car. Savings have been divided into two categories. Table 2.1 includes those cost reductions judged to have potentially acceptable performance impacts. In this class were placed those changes where the service impact was either clearly acceptable (e.g., elimination of plug doors) or where assessment involved intangibles which precluded a precise determination of adverse impacts. Examples of the latter include changes to the procedures for reliability verification, program documentation, and testing. Table 2.2 is composed of those cost reductions with major, clearly identifiable, performance impacts. These include unidirectional cars, doors on only one side, a less stringent brake duty cycle, elimination of the articulation section and elimination of compressed air.

In many cases the savings for the various specification changes were substantial, amounting to as much as $41,400 per car. The savings for all items cannot be directly added because each modification is not completely independent. For example, only one-half the cost savings for deleting the plug doors can be added if doors are to be placed on only one side of the car. The cost savings for using wheels with damping rings is based on a 6-axle car; therefore, only two-thirds of these savings can be applied if the car is non-articulated. Because of these relationships, three representative types of composite vehicles were chosen to illustrate aggregate cost reductions.

TABLE 2.1: ESTIMATED COST REDUCTIONS WITH POTENTIALLY ACCEPTABLE PERFORMANCE IMPACTS

CHANGE	Estimated % Reduction in Cost (100 car order)
DELETE PLUG DOORS - USE FOLDING DOORS	
Contract drawing restrictions on exterior lines of vehicle replaced with a dynamic envelope and sliding/plug type doors replaced with folding doors.	4.2%
SIMPLIFY CONTROL REQUIREMENTS	
Eliminate automatic speed control, simplify control system tolerances, and encourage use of cam-type controller.	2.5%
SIMPLIFY QUALIFICATION TESTING	
Require qualification tests only for subsystems and components not thoroughly proven in rail transit revenue service. Accept data submittals in lieu of tests for proven subsystems.	2.5%
ELIMINATE DIAGNOSTIC TEST EQUIPMENT	
Eliminate special diagnostic test equipment and perform testing with general purpose equipment	2.3%
SIMPLIFY RELIABILITY REQUIREMENTS	
Delete requirement for a two year demonstration of reliability with system redesign if goals are not achieved. Also delete requirement for reliability analysis. These would be replaced by warranty provisions and provision of incentive payments for achievement of specified levels of reliability.	1.8%
SIMPLIFY DOCUMENTATION REQUIREMENTS	
Simplify documentation requirements by expediting drawing review cycle and reducing need for customer approvals. Documentation is provided customer for information only with no formal approvals required. Timely delivery of information is enforced by tieing progress payments to delivery. Customer approval of design is obtained through several formal scheduled critical design review meetings at specified project milestones. At these meetings supplier staff explain the design in detail to the customer and his consultants and questions are freely exchanged. The customer then provides all his concerns and reservations in writing within a specified period (1-2 weeks). These are negotiated at a follow-up meeting which continues until all issues are resolved.	1.0%
ALLOW WHEELS WITH DAMPING RINGS	
Permit wheels with damping rings in place of resilient wheels.	0.6%
SIMPLIFY MAINTENANCE MANUALS	
Subsystem supplier maintenance manuals permitted to be incorporated into maintenance manual without rewording by prime supplier into uniform format.	0.3%
Above change accompanied with simplification of manuals.	0.6%
RELAX CAR BODY SMOOTHNESS CRITERIA	
Relax restrictions on body finish smoothness and requirement for flush side panels.	0.4%
SIMPLIFY ARTICULATION SECTION	
Change in specification for articulation joint to permit greater design freedom.	0.4%
DELETE OPERATOR CAB ENCLOSURE	
Eliminate operator's cab enclosure and replace with simple curtain and modesty partition.	0.2%
DELETE REMOTE CONTROL OF DESTINATION SIGNS	
Permit use of manually operated destination signs without driver remote control and trainlining.	0.1%
DELETE STOP REQUEST SIGNS	
Delete illuminated stop request signs at each end of car body sections.	< 0.1%
ALLOW THREE PIECE WINDSHIELD	
Do not specify windshield thickness and permit three piece structure.	< 0.1%

Case I - High Performance Option

Figure 2.1 depicts a vehicle which combines all of the cost reductions from Table 2.1. Such a vehicle retains the original specifications for bidirectional operation, doors on both sides, friction brakes, articulation, and compressed air. Total savings are $123,300 per car for an order of 100 cars. To express this savings as a percentage it is necessary to estimate the cost of an unmodified SLRV. In order to be conservative in terms of percentage savings, a baseline SLRV price of $750,000 was assumed. This represents the unsuccessful Boeing bid on the recent order for Cleveland cars and is probably on the high side. Dividing savings by this cost to express them as a percentage, will thus produce lowside, conservative estimates. This approach was followed in computing all percentages in this report.

The $123,300 per car saved by the "High Performance Option" is equivalent to a 16.4 percent reduction in cost, assuming the $750,000 price for an SLRV.

It should also be mentioned that these savings were calculated based on engineering cost estimates of materials and labor saved by the modifications, based on equipment built to the SLRV specification. These savings would not necessarily be valid for a smaller capacity car, or for a car with different baseline performance requirements and capabilities. Some costs would tend to remain the same as vehicle size was decreased, while others would be reduced proportionately. Without a parametric car costing model, which was not the approach taken in this study, it is not possible to extrapolate these savings to other types of light rail equipment, significantly different in capacity and performance to the SLRV.

Subject to these caveats concerning misuse of the data, the 16.4 percent savings should be a reasonable estimate of the cost reduction which could be achieved by incorporating the suggested modifications into a vehicle otherwise built to the basic SLRV specification.

TABLE 2.2: COST REDUCTIONS WITH MAJOR, CLEARLY IDENTIFIABLE PERFORMANCE IMPACTS

CHANGE	% Reduction in Cost (100 car order)
ELIMINATE ARTICULATION SECTION	
Eliminate articulation section for cities where civil features such as curve radii are not limiting. Four axle car assumed to have similar passenger carrying capacity, size and performance excepting poorer manauverability.	5.5%
DOORS ON ONE SIDE ONLY	
Eliminate doors on one side of car for cities able to accept such a design.	3.0%
UNI-DIRECTIONAL CAR	
Allow a uni-directional car for cities able to accept such a design. (Savings does not include deletion of doors on one side).	2.7%
DELETE COMPRESSED AIR	
Relax specification requirements to encourage use of all electric or electric/hydraulic car with deletion of compressed air system.	2.0%
SIMPLIFY FRICTION BRAKE	
Relax requirement that friction brakes without dynamic assist must meet normal brake duty cycle and instead require them to provide only several applications. In other words, these brakes would be regarded as an emergency backup capability only. Consistent with this change, the requirement for fifteen full brake applications in the event of loss of compressor or hydraulic power would also be modified to require only several applications.	1.3%

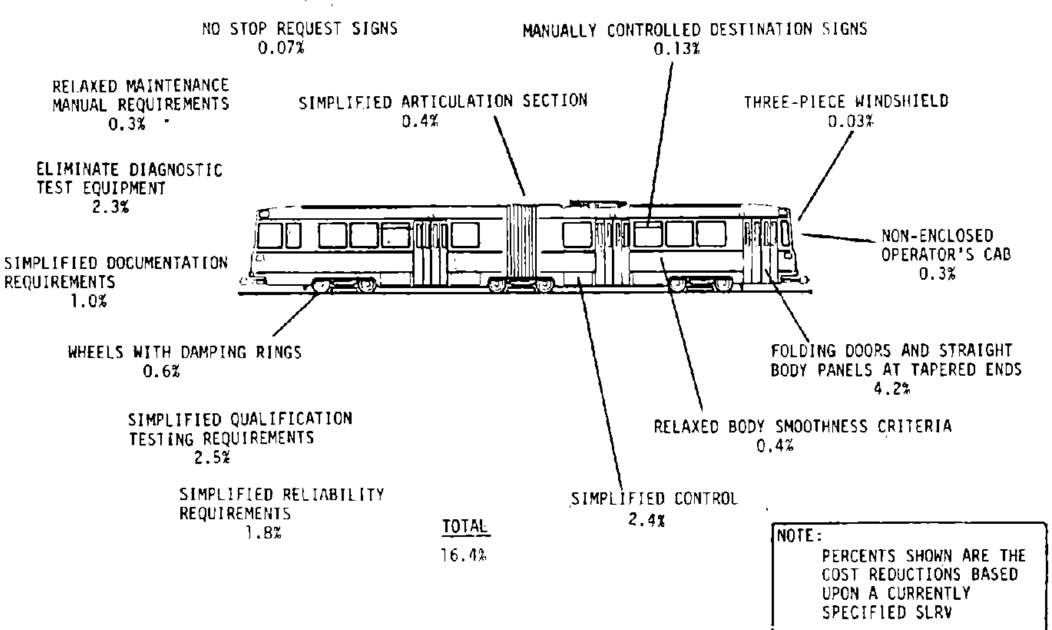


FIGURE 2.1: SPECIFICATION MODIFICATIONS AND COST SAVINGS FOR CASE I - HIGH PERFORMANCE OPTION

Case II - Alternative Low-Cost Option For Underground Operations

The Case II car (Figure 2.2) is a bidirectional car with the same passenger carrying capacity as the present SLRV but only two trucks and no articulation section. It requires a minimum curve radius of about 125 feet and would be most applicable for new light rail installations where downtown operations are underground. The Case II car includes all of the modifications with acceptable performance impact included in Case I, adjusted when necessary to account for the elimination of the articulation section. In addition, the vehicle is assumed to have smaller friction brakes and no compressed air system. This car would be similar to an enlarged version of the Chicago rapid rail car. This case shows the highest aggregated cost reduction, a savings of 24.9 percent over the present SLRV design.

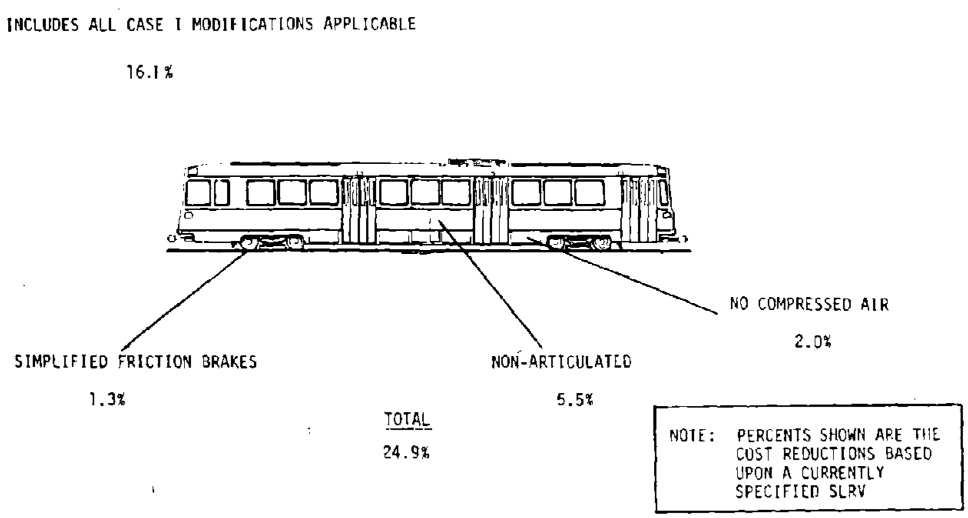


FIGURE 2.2: ADDITIONAL SPECIFICATION MODIFICATIONS AND COST SAVINGS FOR CASE II - ALTERNATIVE LOW-COST OPTION FOR UNDERGROUND OPERATIONS

Class III - Low Performance Option

Figure 2.3 shows the low performance option. In addition to the Case I modifications, this vehicle is unidirectional with doors on only one side. The articulation section is retained. Smaller friction brakes are used and compressed air is eliminated. Making necessary adjustments to savings in Tables 2.1 and 2.2 to account for single ended operation, the aggregate cost savings amount to $176,000, which represents 23.4 percent of the $750,000 per car assumed price for the SLRV as presently specified.

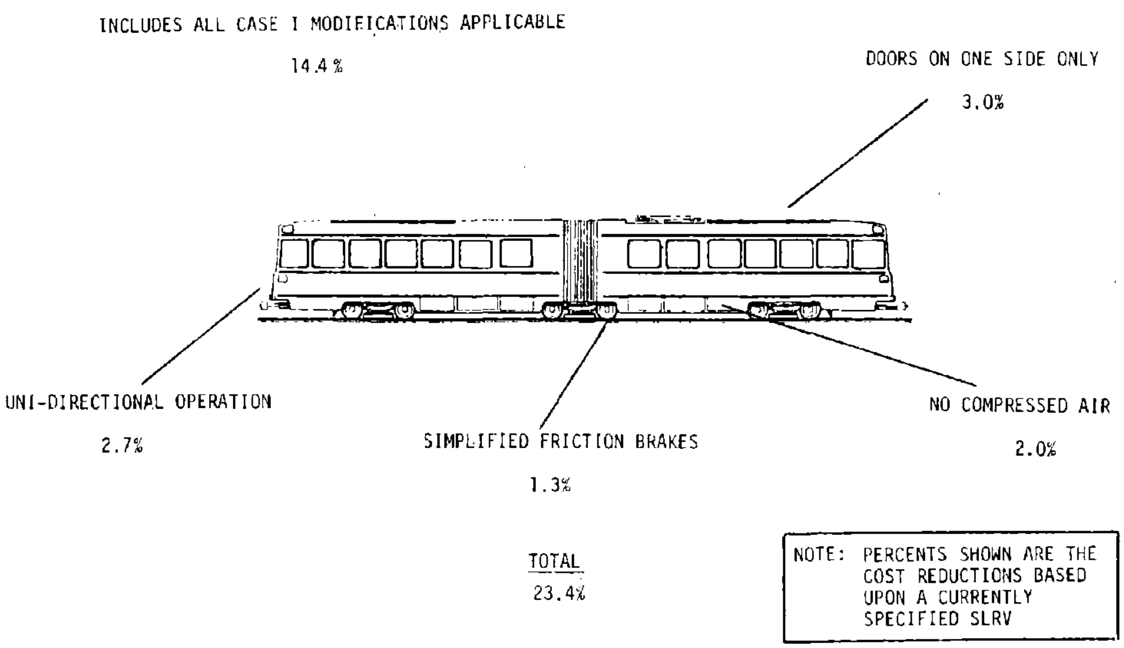


FIGURE 2.3: SPECIFICATION MODIFICATIONS AND COST SAVINGS FOR CASE III - LOW PERFORMANCE OPTION

2.4 CONCLUSIONS AND RECOMMENDATIONS

Based on this review of the light rail specification, NDL offers the following conclusions and recommendations:

- The trend towards more complex light rail vehicle designs has had a significant impact upon costs.

- Changes in the light rail specification could reduce car costs at least 16.4 percent without major impacts upon performance.

- Specification of a unidirectional all electric car with doors on only one side could increase the above cost savings to a total of 23 percent.

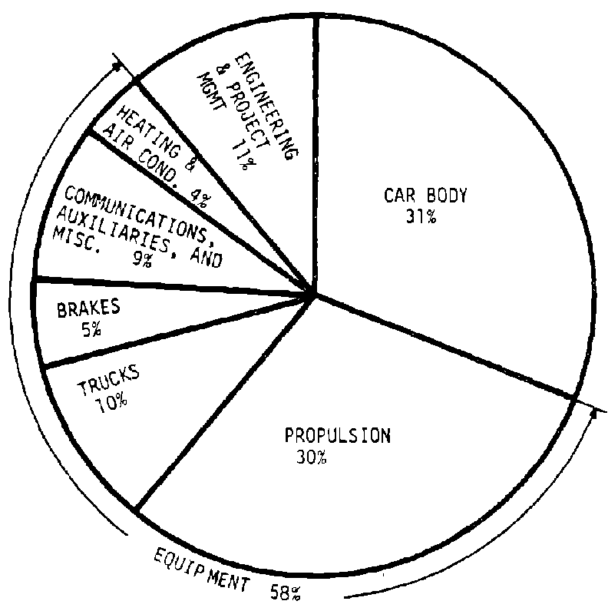
- Specification of a nonarticulated car comparable in size to the present SLRV for transit authorities able to accommodate a 125 foot minimum curve radius could increase the above cost savings to a total to 25 percent.

- The suggested changes are not unrealistic. The Canadian Light Rail Vehicle and the Frankfurt U2 car to be used in Edmonton offer concrete examples of less sophisticated light rail vehicles.

- Within the United States, the Chicago Transit Authority rapid rail cars are far less sophisticated than the present light rail car, and provide a good example of the economy which could be achieved by simplifying the light rail specification.

3.0 FACTORS AFFECTING RAIL CAR COSTS

To provide a proper perspective for any consideration of the factors affecting rail car costs, it is appropriate to first examine where the money paid per rail car is spent. To this end several independent appraisals of the cost breakdown of a typical rail car order of 200 or more cars have been examined, the results of which are summarized in Figure 3.1 which apportions costs by major vehicle subsystems.



DATA SOURCES:

1. "SOAC, State-of-the-Art Car Development Program, Volume 1: Design, Fabrication and Test," Report No. UMTA-IT-06-0026-74-1 (PB 235-703), Boeing Vertol Co., April 1974, pages 164-168.
2. Letter from David R. Phelps of the Transit Development Corp. to Joseph S. Silien of UMTA dated May 20, 1975.
3. Conference with A. T. Comeau and J. N. Brown of Kaiser Engineers on 5/15/78, at the Transportation System Center in Boston.

FIGURE 3.1: **DISTRIBUTION OF RAIL** TRANSIT CAR COSTS

A significant portion of the engineering and project management cost is of a nonrecurring nature. In other words, as the size of the order increases this category of cost would amount to progressively smaller percentages of the total.

Expenditures can also be broken down as cost centers associated with the various activities involved in producing a rail car. This approach leads to a somewhat different but generally consistent picture of costs. Table 3.1 provides such a breakdown of costs for a typical 200 car order.

TABLE 3.1: TYPICAL RAIL CAR COST DISTRIBUTION

DIRECT RECURRING COSTS		
Direct Manufacture and Assembly	11.5%	
Outside Procurement		
Car body materials	10.0%	
Equipment and Subcontracts	50.0%	
Subtotal		71.5%
NONRECURRING COSTS		
Engineering	3.0%	
Tooling	1.0%	
Testing	1.0%	
Human Factors, Reliability, etc.	0.5%	
Facilities improvements (write off)	4.0	
Subtotal		9.5%
BUSINESS RISK & PROFIT		
Field Service & Warranty	2.5%	
Interest, Cost of Money	2.5%	
Penalties for Late Delivery, Weight, Energy Consumption, etc.	1.0%	
Profit (15% of Est. Cost Items)	13.0%	
Subtotal		19.0%
TOTAL		100.0%

The foregoing estimates lead to the following general observations:

a. Well over half of the total cost of a typical rail car is for purchased materials and equipment. The propulsion system and truck assemblies account for a majority of the outside purchased equipment cost.

b. Engineering and project management cost, including tooling and nonrecurring facilities improvement costs, are about equivalent to the direct manufacturing cost for fabrication and assembly of the vehicles.

c. Due to the relatively small amount of total costs under his direct control, the prime contractor lacks flexibility to absorb overruns for redesign, production changes and modifications.

The small amount of the total car cost under the direct control of the equipment supplier is a major reason for the difficulties which have been experienced in predicting and controlling car costs.

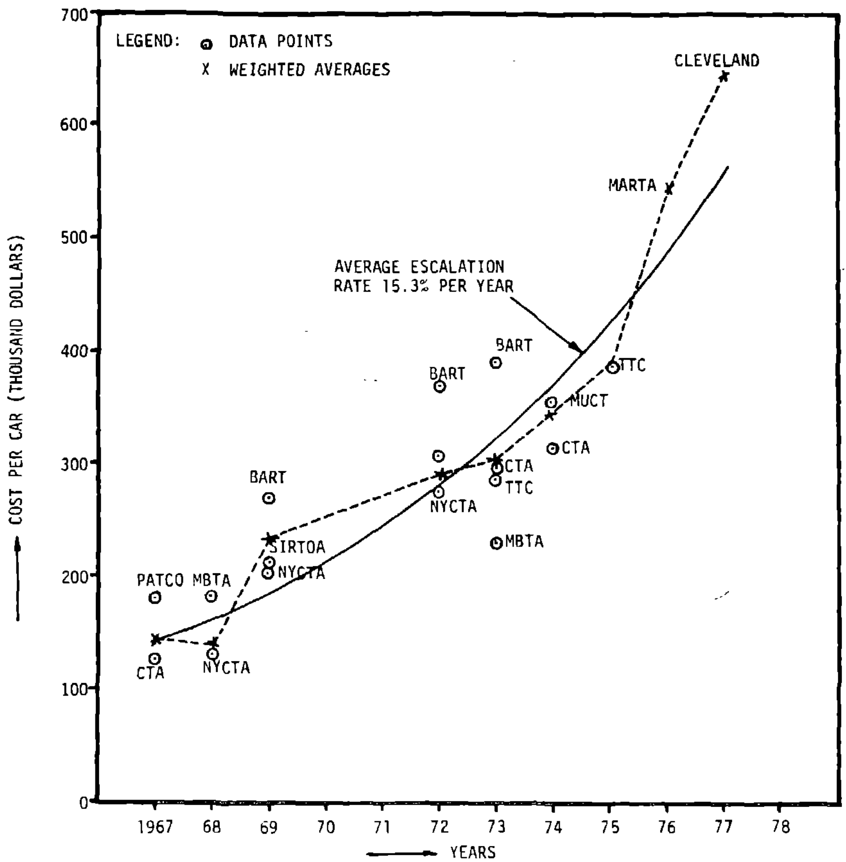
The dramatic increase in rail car costs during the past 10 years has become a matter of serious concern throughout the transit community. This concern has prompted a number of studies of this general subject and has stimulated a lot of thoughtful analysis. Whereas a thorough treatment of this complex subject is beyond the scope of this study of the impact of the light rail specification upon the cost of future procurements, it is appropriate to keep in mind the numerous influences which affect the cost within this class of transit equipment.

There are a number of independent factors which have a significant influence on rail car costs and especially on the prices which suppliers are likely to quote in response to invitations to bid. Without attempting to arrange these in any particular order, either in terms of their relative affect on cost or overall importance, they are summarized as follows:

1. Inflation - In the past ten years, there has been a dramatic increase in the cost of rail rapid transit vehicles. Figure 3.2 plots the unit cost per car for each order of fifty cars or more purchased during the period 1967 to 1977. Weighted averages for all the cars purchased each year have also been plotted and from these a best fit trend line has been drawn, indicating an average cost growth of 15.3% a year in unit car costs. Of course, this same period has been one of high general inflation. Figure 3.3 compares rail transit cost growth with both the cost index for General Railroad Equipment, as published by the Bureau of Labor Statistics, and the overall Consumer Price Index. While railroad equipment has slightly outpaced the general cost of living, the increase in rail transit car cost has been considerably greater, suggesting that factors in addition to inflation have played a role.

2. Size of the Order - As is the case for most manufacturing processes, the volume of a production run of rail cars has a marked influence on the cost per unit. This is because nonrecurring costs for tooling, shop engineering, and testing have less impact on unit costs if they can be distributed over a large number of cars. In addition, there is a tendency for the production process to become more efficient as experience with assembly operations accumulates. It is common to describe this reduction in cost per unit as order size increases in terms of a "learning curve." A 90 percent learning curve implies a ten percent reduction in the cost per unit each time the size of the order is doubled; e.g., cars costing $500,000 each for an order of 100 would only cost $450,000 each for an order of 200.

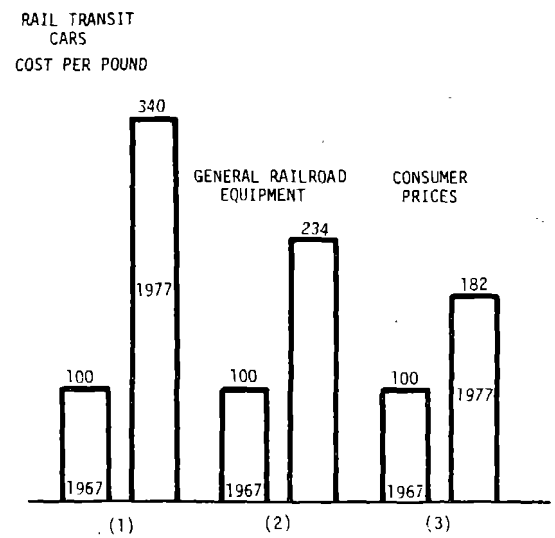
   In an effort to assess the influence of volume upon the unit costs of rail transit cars, actual cost data for the procurement of rail cars during the period 1967 through 1977 has been plotted in Figure 3.4. Car costs have been adjusted to 1978 dollars based upon the average cost growth experienced during the ten year period. To eliminate the effect of varying car sizes, the data has been plotted on a per pound basis. Rail transit costs tend to approximate an 85



DATA SOURCES:

1. LEA TRANSIT COMPENDIUM Data Base, Jan. 1977
2. SCAG Report PB-255-835
   "Rail Transit Car Costs," May 1975
3. UMTA-DC-06-0121-77-1 "Roster of North American Rapid Transit Cars 1945-1976", Jan. 1977

FIGURE 3.2: RAIL TRANSIT CAR COST TREND



SOURCES:
1. Actual Rail Transit Car Prices 1967-1977 per Figures 1 & 2
2. Overview of Labor Statistics: Wholesale Price Table for Railroad Equipment
3. Overview of Labor Statistics: Consumer Price Index, U.S. City Average, All Items

FIGURE 3.3: COMPARISON OF COST GROWTH (1967-1977)

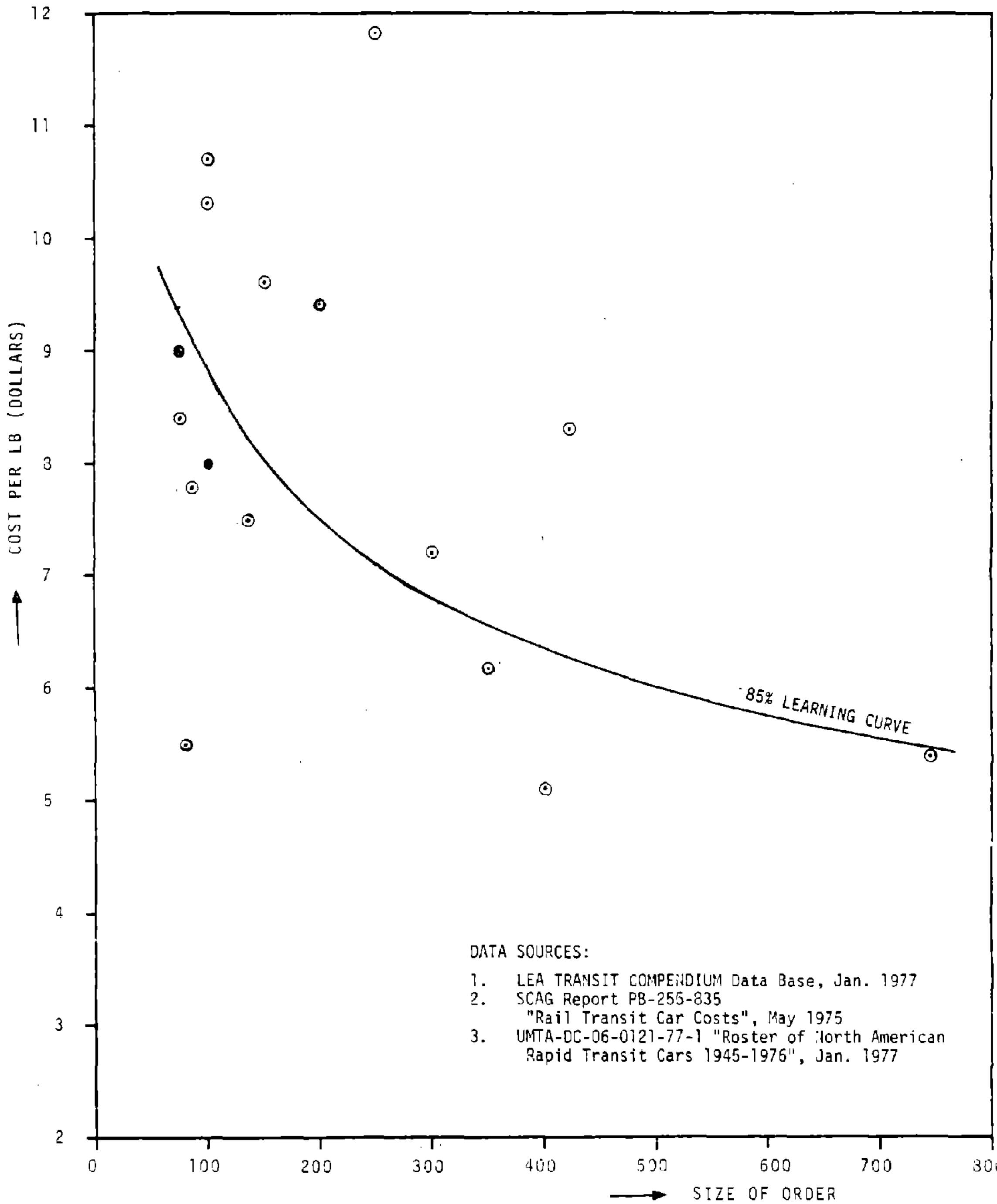


FIGURE 3.4: EFFECT OF SIZE OF CAR ORDER ON UNIT COST/POUND FOR RAIL TRANSIT

percent learning curve, or a 15 percent reduction in unit costs each time the order size is doubled. This is a relatively steep learning curve, and suggests significant sensitivity of rail costs to production volumes.

3. Degree of Standardization - To the extent to which standard components such as trucks, propulsion systems, brakes, etc. can be used, the supplier will be able to take advantage of lower prices due to economies of scale. Conversely, if unique equipment is required, a prime contractor's equipment suppliers will have to pass along their engineering, tooling and start-up costs. Then too, as disclosed during the course of this study, equipment such as the chopper control used on the SLRV, for which operational data is still somewhat limited, must be subject to special qualification testing, which adds to the cost. Similarly the monomotor truck used on the SLRV is a nonstandard item which must be special ordered.

   UMTA's Rail Car Standardization Program should have a beneficial affect on this aspect of car costs. The use of common subsystems such as propulsion motors, brakes, and couplers, reduces costs associated with development and testing and increases system reliability.

4. Size and Weight - There is a strong correlation between the weight of rail cars and their cost. Large cars which have ample passenger carrying capacity weigh more than smaller ones and consequently cost more. This, of course, is due to the fact that the heavier cars must have larger power plants, brakes, air conditioners, etc.

   For the 3,577 rail cars purchased during the period 1967-1977, the weighted cost per pound adjusted to 1978 price levels, was about $7.40. Although as discussed elsewhere in this section there are several other factors which influence car cost, vehicle cost per pound may be used as a fairly effective yardstick for estimating the approximate cost of a typical rail car.

5. General Business Conditions - As in most other industries, the prices bid by car suppliers are inevitably influenced by the general business climate which prevails at the time of bid preparation. Among the factors which are considered by management in establishing bid prices are the following:

- The company's workload, especially the backlog of orders for similar equipment.
- The backlog of car production work already in progress in the supply industry.
- The number of competitors interested in the same product.
- The firm's general familiarity with the production of similar equipment.
- Prior experience in dealing with the agency purchasing the cars and with their consultants.
- The cost of financing, especially interest rates.
- Status of union contracts.

6. Degree of Sophistication - Because the number of rail cars being ordered by transit authorities does not constitute a high volume business, the continuing escalation in requirements for improved performance and passenger amenities has not been offset by corresponding reductions in production costs. Unlike the telephone or electronic computer industries which have been able to provide increasingly sophisticated services and equipment without a dramatic increase in cost, most of the enhanced capabilities specified for rail cars in recent years have resulted in correspondingly higher costs.

> Of the several factors which have a strong influence on car costs, this is the principal one which can be affected by the specification changes recommended in this report. With the exception of requirements for documentation and design approval, testing, and reliability/maintainability criteria, many of these modifications involve selectively decreasing the level of vehicle sophistication.

These considerations influence the level of contingencies which car builders will build into the bid price to offset the assessment of risks. Some firms without extensive prior experience building rail cars have tended to underestimate those risk factors.

4.0 METHODOLOGY APPLIED FOR COST REDUCTION IDENTIFICATION AND ANALYSIS

As discussed in the previous chapter there are numerous factors which affect the cost of a rail transit car. This particular study has been limited to assessing the impact of requirements imposed by the light rail vehicle specification upon vehicle costs and suggesting changes to the specification with the potential for reducing these costs. In selecting a methodology for identifying cost savings, two considerations were of prime importance. First, it was essential that the approach provide an organized means for comprehensive evaluation of the specification which could filter out and identify the more promising cost reductions from a myriad of possibilities. Since such an approach inevitably requires judgment, a second consideration was that the methodology should actively solicit judgments and ideas from a multiplicity of sources, including transit operators, suppliers, consulting engineers and government officials with experience in light rail.

The approach selected uses a technique developed and refined by N. D. Lea & Associates, Inc. (NDL) in the performance of a number of similar assessment projects. In these assessments of transit systems and equipment, it was also important that many diversified views be represented. The approach may be described as a Technique of Assessment by Structured Interviewing (TASI). TASI employs a rigorous line by line review process to develop a formally structured set of interview questions. Interview comments are recorded in specially prepared booklets. Those interviewed are also asked to complete a set of numerical rating forms addressed to the same questions. The forms serve to check the validity of the interviewer's notes and assist in the analysis and filtering of results. Figure 4.1 is a flow diagram showing how the TASI techniques were specifically applied for this project.

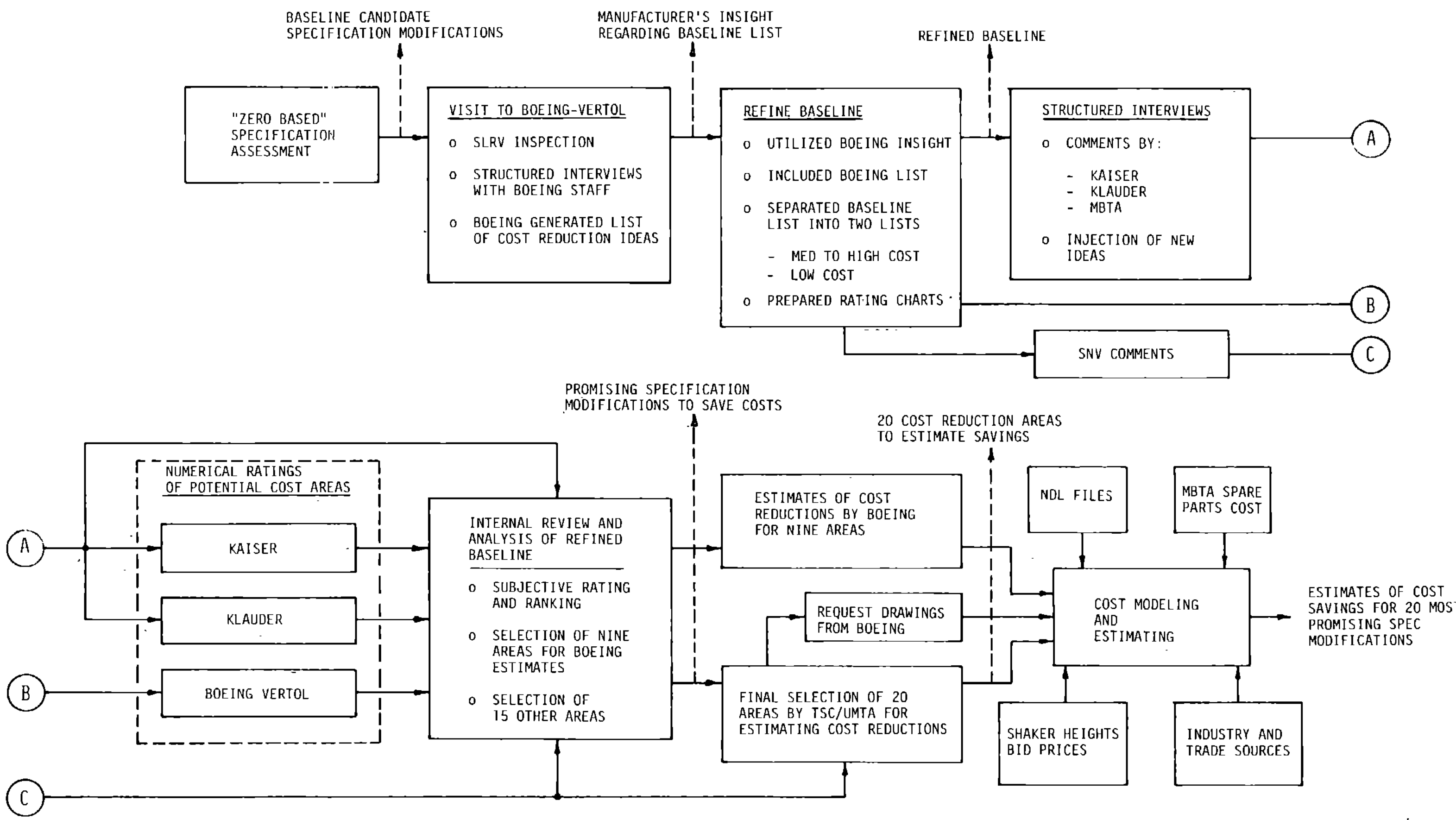


FIGURE 4.1: OVERALL STUDY APPROACH

Initially a "zero based" assessment of the SLRV specifications was performed internally to produce a baseline set of candidate specification modifications. In this "zero based" assessment all elements of the specification were reviewed line by line and screened using a set of logical criteria to determine whether further cost/performance investigation was warranted. Zero based reviews were conducted independently by several NDL investigators and combined internally into a single exhaustive list.

In preparing the list, the tendency was to include every conceivable idea, even if it was somewhat questionable, to be certain that no promising areas would be overlooked in the subsequent investigation.

This baseline set of candidate modifications was then used to provide guidance for structured interviews with Boeing Vertol, the current manufacturer of the SLRV, to obtain insight, clarifications and new ideas. As a result of these interviews, the original list was culled and a smaller refined baseline was developed. This smaller list was in turn used to provide guidance for structured interviews with the Massachusetts Bay Transportation Authority (MBTA), which operates the only SLRV's presently in service, and with Kaiser Engineers and Louis T. Klauder & Associates, the vehicle consulting engineers for MBTA and the San Francisco MUNI, respectively. Following these interviews, Kaiser, Klauder and the MBTA were asked to subjectively rate the cost and service impact of each item on forms provided by NDL. Boeing Vertol was also asked to complete the same set of forms. In addition, this list of cost saving areas was sent to the West German firm Studiengesellschaft Nahverkehr mbH (SNV) who collaborated with Mr. Meyer-Plate, director of the vehicle section of the Verband Offentlicher Verkehrsbetriebe (VöV), to provide comments concerning West German practices. SNV is a consulting organization, whose capital was contributed by 15 associates including most of the German transit equipment suppliers and some transportation authorities. In addition SNV has an 18 member Governmental Agencies Steering Committee, 9 of whose members are representatives of all levels of the German government. The VöV is an association of the transit authorities in various German cities (similar to APTA), which is actively involved in preparing recommended specifications for German light rail equipment.

The body of information (diversified viewpoints, judgments and new ideas) resulting from the interviews and the separate subjective ratings of the refined baseline was reviewed and analyzed internally. In this way a set of promising specification modifications (discussed in Chapter 5) was identified and ranked according to their potential to save costs and their impact upon performance. This ranking was then used to identify 20 of the most promising areas for which quantitative estimates of potential cost savings were developed.

The remainder of this chapter provides a more detailed explanation of the methodology used to identify changes in the SLRV specification which might reduce vehicle costs.

4.1 ZERO BASED SPECIFICATION ASSESSMENT

In the "zero based" assessment approach all elements of the specification were reviewed and evaluated by three NDL engineers in terms of their impact upon performance and cost. Logical criteria as outlined in Figure 4.2 were followed which involved asking the following questions:

a. Did the specification element have a service requirement in terms of travel time, comfort, safety, reliability, maintainability, elderly and handicapped, capacity, all weather operation, system management and control, or environmental impact? If no such requirement could be identified, the element was placed on a list of baseline candidate specification modifications.

b. If a service requirement did exist, it was considered whether elimination of the specification element might result in significant cost savings related to engineering, materials, fabrication, assembly, testing, liaison, spare parts inventory, special training, or costs for support documents and studies.

c. If the potential for significant cost savings existed, then the acceptability of any loss of performance was considered. If this appeared acceptable, the specification element was placed on the baseline list for further cost/performance assessment during structured interviews.

d. If it appeared clear that elimination of the specification requirement was impractical, possible modification or relaxation of the requirement was considered to see if it might result in a significant cost saving. If so, and if the loss of performance appeared accceptable, a modified form of the requirement was suggested for further consideration during structured interviews.

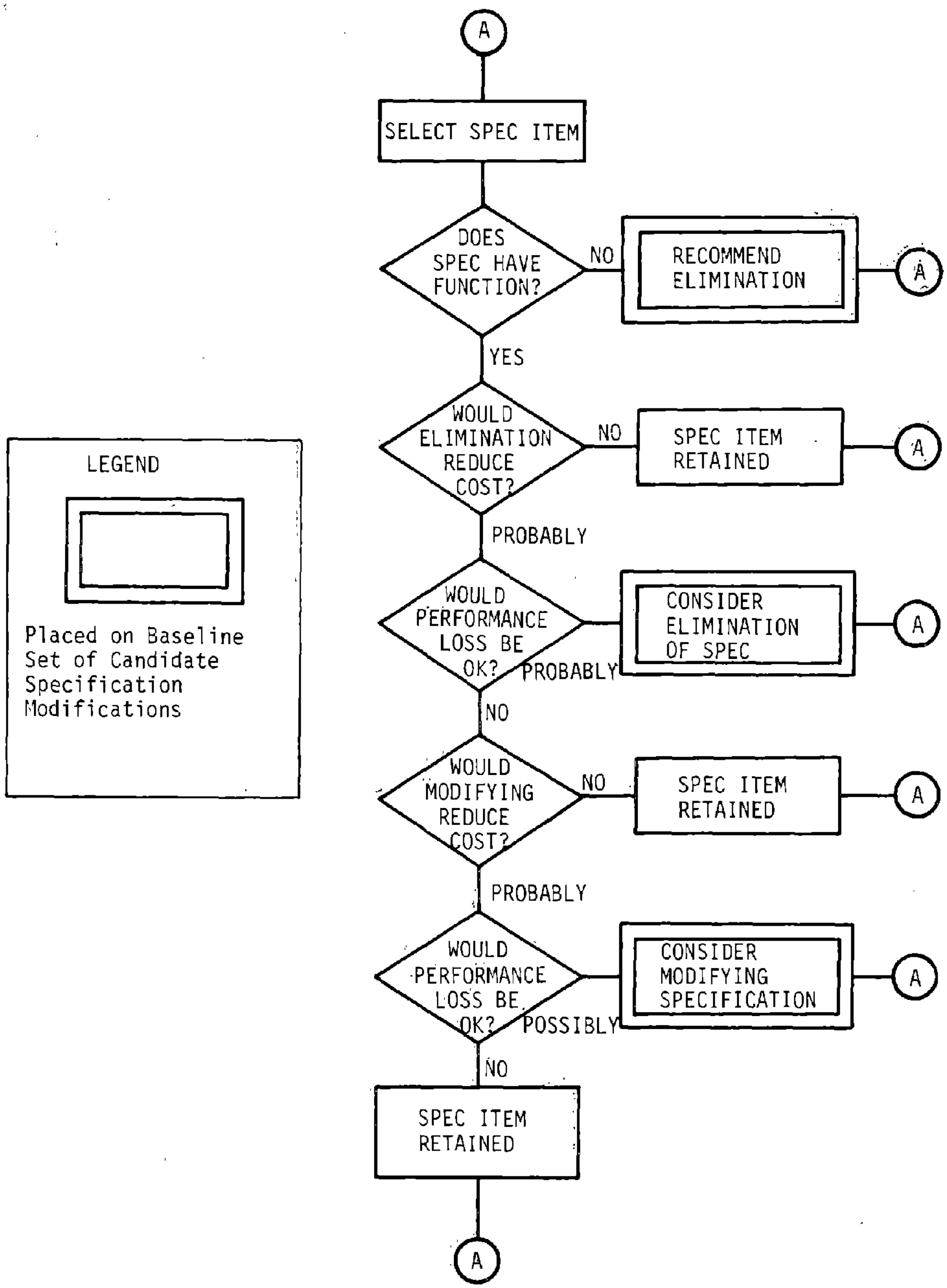


FIGURE 4.2: ZERO BASED SPECIFICATION ASSESSMENT

The approach was "zero based" in that every line item of the specification was reviewed in the above manner to see whether cost savings might be possible. In preparing the list, the policy in the event of doubt or uncertainty, was to include the element on the baseline list for further consideration, so that no promising areas would be overlooked.

This assessment process yielded approximately 640 items which formed the Baseline Set of Candidate Specification Modifications.

4.2 REFINEMENT OF THE BASELINE CANDIDATE SPECIFICATION MODIFICATIONS

The second phase of the approach was one of refining the baseline in accordance with the judgments and ideas of the current vehicle manufacturer, Boeing Vertol. This was accomplished in conjunction with a visit to the Boeing Vertol plant where the vehicle and manufacturing facility were inspected and two days of in-depth interviews were conducted with Boeing engineers. A structured interviewing technique was employed to maximize productivity and focus the interviews upon important cost issues.

Special notebooks were prepared for use by each NDL team member in carrying out these interviews. A facsimile of a sample page from one of the notebooks is shown as Exhibit 1 in Appendix A. Each candidate specification modification was presented correlated with the relevant section number and line numbers of the specification. Space was also provided for the NDL interviewer to make notes during the meeting. Five NDL personnel conducted the interviews with a team of four Boeing engineering staff members (see Table 4.1). These participants were divided into four separate groups with each group covering specific subject areas of the specifications as follows:

- Systems Performance, Propulsion, Braking and Emergency Systems
- Materials, Quality & Assurance and Management
- Mechanical Systems - car body, couplers, operators cab, door control, air comfort, and trucks
- Electrical Systems - auxiliary electrical equipment, lighting, communications, and control

TABLE 4.1: BOEING INTERVIEWS

SUBJECT AREA	BOEING STAFF	NDL STAFF
Systems Propulsion & Braking	W. Ballauer	T. McGean
Materials Q&A Management	P. Norton	F. Cooke
Mechanical System	A. Vollmecke	W. Bamberg C. Whitney
Electrical Systems	B. Toth	C. Elms

During the interviews, Boeing Vertol engineers were asked their subjective assessments of each candidate specification modification. In addition, Boeing provided NDL with their own independently generated list of potential areas for cost savings. Each candidate modification was discussed to determine its potential to reduce recurring and nonrecurring car costs.

Discussions also concerned the impacts upon performance of the proposed specification modifications. Insight was provided regarding how one candidate change affects other specifications and how such coupling increases or decreases costs or impacts performance.

The results of the interviews were then used in an internal review and refinement of the baseline candidates. Based on the results of this reassessment, a "Refined Baseline" was developed assigning the remaining areas of potential cost savings into two separate categories: items with the potential for medium to high cost savings and items with potential for only low cost savings. Those items where no cost savings were considered achievable, where the performance impact was unacceptable, or which might actually increase costs were dropped from the list. As a policy, all of the Boeing Vertol suggested cost saving items were retained. Of the original 640 items there remained 98 medium to high cost items and 82 low cost items in the two separate lists. Therefore, the interviews with Boeing Vertol eliminated approximately 70 percent of the original cost reduction suggestions.

Rating forms were prepared for these two lists of cost reductions. Exhibit 2 of Appendix A is a facsimile of one of the rating charts for specification modifications with potential for medium to high cost savings. Copies of the rating charts were sent to Boeing Vertol, Kaiser Engineers, Louis T. Klauder and Associates, and the Massachusetts Bay Transportation Authority. (Boeing Vertol, Kaiser Engineers, and Louis T. Klauder and Associates received separate DOT contracts to support this effort.) Boeing Vertol was tasked to provide ratings and comments for each item. Kaiser, Klauder and the MBTA were provided the rating forms for information purposes in preparation for subsequent structured interviews with NDL staff. After these interviews, Kaiser and Klauder also completed the forms, providing ratings and commentary. The formal ratings were structured as follows:

- Cost Impact - Ratings of the potential for reduction in vehicle procurement costs were provided on a scale of 0 to 10, with 0 being no impact and 10 being the greatest impact. If it was believed that increased costs would result then a -1 was entered.

- Performance Impact - Respondents were asked to indicate the area affected and the degree of impact (e.g., major negative, negative, none, positive or desirable, and major positive).

These rating charts were also used in preparing notebooks used by NDL personnel in conducting structured interviews separately with Kaiser, Klauder and the MBTA. A facsimile of a sample page from one of these notebooks is given in Exhibit 3 of Appendix A.

4.3 FURTHER REFINEMENT OF THE BASELINE SPECIFICATION MODIFICATIONS

In-depth structured interviews were conducted with Kaiser, Klauder and the MBTA using the specially prepared notebooks discussed above. These interviews had the following objectives:

a. To explain the procedures for rating each of the potential specification modifications and define the rating measures.

b. To discuss each potential specification modification to ensure its proper interpretation.

c. To obtain separate judgments or opinions on the value of each potential modification; i.e., the pros and cons and the potential for cost savings.

d. To obtain any suggestions for cost savings which might have been overlooked during the zero based specification assessment or in discussions with Boeing Vertol.

Interviews with these three groups were conducted separately over a period of three days by four NDL personnel. Two NDL personnel were responsible for mechanical and electrical systems and the other two were responsible for systems performance, propulsion, braking, emergency systems, materials, quality assurance, and management (see Table 4.2). There were three representatives from Kaiser, two representatives from Klauder and one representative from the MBTA. The TSC Contracting Officer's Technical Representative also participated in these interviews. By separating the NDL personnel into two groups conducting simultaneous interviews, it was possible to spend approximately a day and a half in private interviews with each of the three groups.

The prepared notebooks were used during each interview to ensure that the same material was covered for each group interviewed. The notebooks also served as a pacer to ensure that all items were covered within the allotted time.

TABLE 4.2: KAISER, KLAUDER, MBTA INTERVIEWS

SUBJECT AREA	KAISER	KLAUDER	MBTA	NDL
Systems Propulsion/ Braking Management Q&A Materials	A. Comeau N. Brown T. Gibson	J. Gustafson J. Edgar	J. Sisson	T. McGean F. Cooke
Mechanical Systems Electrical Systems	A. Comeau N. Brown T. Gibson	J. Gustafson J. Edgar	J. Sisson	C. Elms W. Bamberg

Formal numerical ratings of the potential specification modifications (i.e., the Refined Baseline) were prepared by Kaiser and Klauder separately after the interviews, at their own leisure and within their own organizations. Therefore, both Kaiser and Klauder provided two separate reviews of the potential specification modifications; once during interviews and again by completing the rating charts. This yielded the following advantages:

- Provided a check on the notes taken by the NDL interviewer to ensure that what was said during an interview was correctly recorded.
- Provided the interviewee time to give additional thought to a subject and/or to collaborate with associates within his organization and develop a more substantial response.
- Provided a period of time after the interview for the interviewee to digest the discussions and generate new ideas.

An internal review and analysis was performed by NDL using the results of both the interviews and rating charts. The following criteria was used in evaluating the rating chart responses from Boeing Vertol, Kaiser and Klauder.

- An item was assumed to have negligible cost impact if the average cost rating score was less than 0.5. These items were then deleted from further consideration.

- An item was assumed to have unacceptable cost/performance tradeoff if:

  a. The average cost rating score was less than 1.0 and any respondent cited a negative performance impact.

     or

  b. The average score was less than 3.0 and any respondent cited a major negative performance impact.

- All remaining items were retained for internal assessment.

Figure 4.3 summarizes the results of the NDL internal analysis of the rating forms. The chart divides the cost reduction items into four columns, depending on the degree of performance impact. Items judged to have the most negative performance impacts appear in the left hand column, while those changes which might improve performance are in the far right hand column. Within columns, items are arranged from top to bottom in order of descending cost savings. The numbers on the left hand side of the chart correspond to the average of the cost savings scores estimated by Boeing Vertol, Kaiser and Klauder. (A 10 represents maximum potential for cost savings.) The heavy solid line in the figure represents the cut-off criteria used by NDL. Items below the solid line were deleted from further consideration. As can be seen, a total of 51 items remained after evaluation of the rating forms.

In addition, NDL also performed a separate internal evaluation based on notes taken during the interviews with Kaiser, Klauder and the MBTA by assigning ratings as follows:

9	MAJOR NEGATIVE	NEGATIVE	NEUTRAL TO POSITIVE	SIGNIFICANT POSITIVE
6	Eliminate coupling	*Doors on only one side*	*Bidirectional cars optional*	*Delete plug doors*
5	*No redesign if reliability goals unmet*		*Simpler reliability program* *Reduce design approvals* *Simplify drawing review*	
4	*Relax friction brake duty cycle*	Relax interior noise level	*Delete DTE* Define operating environment	
3		*Relax restrictions on exterior lines* No envir. chamber tests	*Test only unproven equipment* *Simplify MTBF requirements* *Wheels with damping ring OK.*	
2		Simplify door operation No full size mockups *Modify operator cab encl.* Allow one row of fluor. lts. Clarify fail-safe definition *Simpler test documents* *Relax 15 brake applications without compressor*	*No reliability analysis* *Allow elect. connectors* *Relax body finish rules* Delete digital encoder No dual ground brushes *Simplify articulation joint cosmetic design* *No sign control at cab*	
1		Allow 12/24 volt LVDC Delete stepwell lights	Fewer destination signs *No power driven signs* No subsystem noise specs Relax HVAC temp. limits Eliminate safety plan No. comm. betw. operators No automatic sanding Permit pedestal seats *Eliminate psgr. stop req. lts.* No sound powered phones Shielded C&C wiring run with other wiring Specify power supply toler.	*Three-piece wind-shield.*
0.5	NOTE: Italics indicates items selected by TSC and UMTA for quantitative analysis.		No storage for jack Shop power plug optional Only audible track brake ind. Fewer master control detents	

FIGURE 4.3: RESULTS OF INTERNAL ANALYSIS OF RATINGS BY BOEING-VERTOL, KAISER AND KLAUDER

1.0 - If the comments indicated the idea was worthwhile

0.5 - If the comments were ambiguous

0 - If the comments indicated the idea was not worthwhile

The ratings for each item from the three interviews were summed to produce total ratings on a scale from 0 to 3 in increments of 0.5. Table 4.3 summarizes the results of this analysis of the interviews. Items are organized in three columns. The left hand column includes those judged to have relatively low cost reduction potential with cost savings increasing to the right. Items with a total score of less than 1.0 were eliminated from further consideration and are not shown.

The cost reduction items retained for further consideration on either Figure 4.3 or Table 4.3 were next combined into a single list and arranged in descending order. Most of the items had been identified in both the interviews and the rating forms. Where the potential specification modifications had similarities or complimented one another, they were combined to form a synthesis of ideas which reduced the total set to a manageable number. A comparison was then made with comments to the rating charts provided by SNV to reflect the West German practice in light rail vehicle design. Further internal review based heavily upon specific comments in the interview notes and considerable judgment resulted in selection from this list of 24 items as the most promising. These 24 items were then discussed in a meeting with experts from TSC and UMTA and 20 selected for quantitative analysis of their potential cost savings. (See Chapter 6.) Those items which formed the 20 selected items are indicated in italics in Figure 4.3 and Table 4.3.

Figure 4.4 depicts the screening which was achieved through the overall process of applying the Technique of Assessment by Structured Interviewing.

TABLE 4.3: RESULTS OF INTERVIEWS OF KAISER, KLAUDER AND THE MBTA

1-1.5	2-2.5	3
Allow 12/24 volt LVDC	*Establish specific maint. goals*	Relax interior noise level
No redesign if reliability goals unmet	*Reduce design approvals*	No subsystem noise specs
Eliminate load weighing	*Simplify drawing review*	Define operating environment
Relax friction brake cycle	*Bidirectional cars optional*	*Relax restrictions on ext. lines*
Simpler reliability program	*Simpler test documents*	*No reliability analysis*
Explicitly specify manuals required	Eliminate safety plan	*Test only unproven equipment*
Explicitly call out spare parts	No track brake cutout	Eliminate jerk rate adjustment
Only require specialized support equipment	No owner approval of speed sensor	No dual ground brushes
Automatic coupling optional	Fewer master control detents	Only audible track brake indicator
Simplify MTBF requirements	*Eliminate ASC*	Delete roof shroud
No full size mockups	Simplify communications specs.	Eliminate auto. dimmed instru. lts.
Specify minimum traction capability	*Modify operator cab enclosure*	*Performance spec. for windshield*
Relax 15 brake applications without compressor	*Allow electrical connectors*	*Delete plug doors*
Allow modulation of dynamic braking to correct wheel slip	Delete digital encoder	*No power driven destination signs*
No automatic sanding	Delete energy simulation	*Doors on only one side*
Shop power plug optional	Delete sub-audible tones for PA	Reduce interior lighting intensity
Specify power supply tolerance	Delete PA tone annunciator	Illuminate only certain critical switches
No adjustment of rates for wheel wear		Eliminate pantograph & use trolley pole
Delete in-car diagnostic taps		*Delete DTE*
Eliminate light fixture noise limit		
Eliminate truck safety bars		
Eliminate coupler control at console		
Allow wheels with damping ring		
Eliminate compressed air		
Reduce speaker requirements		
Reduce time emergency power required		
Allow pedestal seats		
Simplify car body structural criteria		
Simplify operator's seat		
Simplify specs on fuse & breaker boxes		
Eliminate passenger stop req. lights		
Eliminate 2-way comm. betw. drivers		
Delete key lock of amplifier		

NOTE: Italics indicate items selected by TSC and UMTA quantitative analysis.

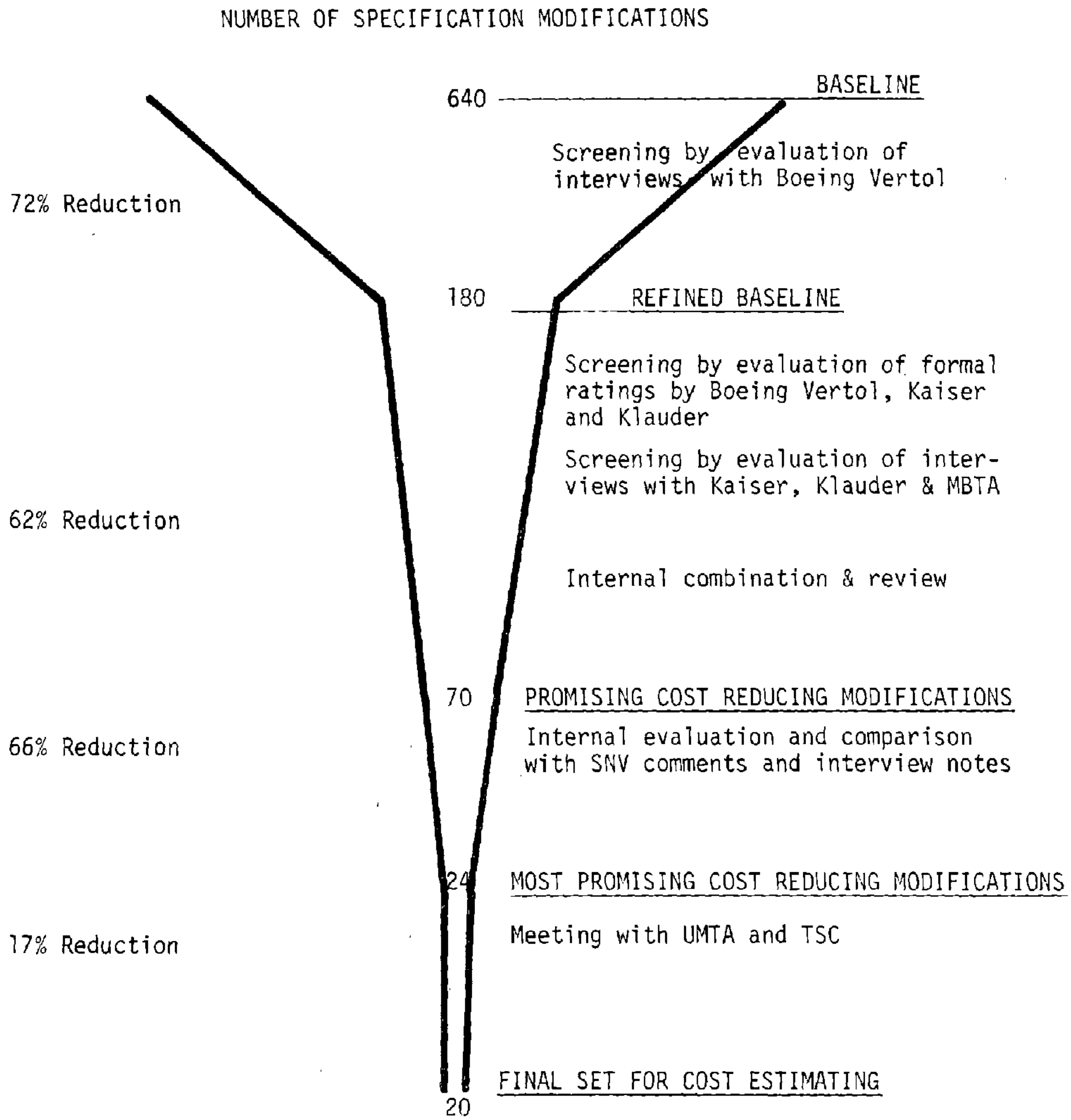


FIGURE 4.4: PROGRESSIVE REDUCTION PROCESS APPLIED IN DETERMINING COST REDUCING MODIFICATIONS OF THE SLRV SPECIFICATION

4.4 QUANTITATIVE ANALYSIS OF COST REDUCTION FOR SELECTED AREAS

Twenty promising modifications to the SLRV specification were identified through the screening process outlined above. Boeing Vertol prepared detailed estimates of the potential cost savings for nine of these modifications. NDL concentrated its analysis on the remaining 11 and a review of the Boeing Vertol estimates. Independent checks upon those estimates included the following:

- An independent gross estimate for each of the 20 items by engineers from the Chicago Transit Authority.
- Comparison of total savings generated by combinations of compatible items from recent rail car bids and purchases.
- Comparisons of cost savings with other car cost models.

In estimating the cost savings for each of the 20 items the following areas of costs were generally considered:

- Non recurring costs - e.g., engineering design and production management, special tooling, special testing.
- Recurring material costs - separately for materials saved and materials added.
- Manufacturing labor costs - generally as a percent of materials costs per Boeing Vertol estimates or cost per labor hour, whichever was more applicable.

The results of these estimates and their analysis are included in Chapter 6 of this report.

5.0 PROMISING AREAS FOR COST REDUCTION

This chapter reviews the major areas for cost reduction identified through the interview and survey process. In addition, areas which originally appeared promising, but were discarded after further investigation, are also included to pinpoint the reasons for this action.

Basically the SLRV specification dictates a sophisticated, high performance vehicle. Table 5.1 compares some of the Boeing LRV characteristics with those of PCC cars. Two points should be stressed. First, many of these features provide important improvements in operational capability and should not necessarily be discarded. Second, in some cases the feature is not explicitly required by the SLRV specification but rather emerges as the practical solution to a variety of specific performance requirements. For example, compressed air is not directly specified, but is implicitly necessary to economically meet requirements imposed for brake duty cycle, noise, ride quality, load weighing, and load leveling. In view of the complexity, weight and cost associated with addition of a compressed air system, it may be wise to reassess these performance requirements to see whether they can be made compatible with an all electric or electric-hydraulic car.

Potential changes to the SLRV specification tend to fall into well defined categories. A number involve design and manufacturing constraints upon the supplier. Restrictions on body contours and the requirement for plug doors are examples where it might be advantageous to allow greater latitude to the vehicle designer.

Another area where specification changes could reduce costs is associated with the general level of complexity and sophistication. Numerous "wish list" types of gingerbread, while in each case seeming reasonable and involving relatively small amounts of money, collectively add up to significant dollars

TABLE 5.1: BOEING LRV VS. PCC CAR CAPABILITY

PCC	Boeing LRV	STUDY ASSESSMENT
Unidirectional (usually)	Bidirectional*	Unidirectional car should be considered when local conditions permit
Nonarticulated	Articulated*	Nonarticulated car should be considered when local conditions permit
Compressed air or all electric	Compressed air and hydraulic power supplied	Compressed air could be deleted. Hydraulic may be needed for large sized LRV
Folding Doors	Plug doors*	Plug doors should be deleted
Manual destination signs	Remote operated ** destination signs	Manual destination signs would be adequate
Cam controller	Chopper controller	Cam control option should not be discouraged
Open cab	Enclosed cab area*	Allow open cab area. Not needed now that exact fare is in common use
Two piece windshield	One piece windshield*	Allow two or three piece windshield
Low level steps	High andlow level loading**	Do not change
No air conditioning	Air conditioning***	Air conditioning needed - do not change
Trolley pole	Pantograph*	Pantograph desirable - do not change
Manual sand box	Automatic sanding and slip slide control*	Might delete automatic sanding
Metal springs	Airbag suspension	Air suspension not essential. May require compromises in noise and ride quality if metal springs are used
No PA system	Full communications provided*	Make local option
No automatic diagnostics	DTE provided*	Delete DTE
No load weighing	Load weighing provided*	Delete if compressed air is eliminated

*These capabilities are explicitly required by SLRV spec.
**Required for MUNI but not for MBTA.
***Required for MBTA but not MUNI.

and increase complexity and maintenance costs. Examples cited by those interviewed include remotely operated power driven destination signs, automatically dimmed instrument lights, an elaborate operator's cab enclosure and automatic track sanding.

Testing requirements and standardization represent another area where it may be possible to achieve cost savings. UMTA is presently working towards rail car standardization at the subsystem and major component level. (ref. 1) The LRV specification, if changed to waive testing requirements for qualified components, can encourage this effort, while reducing non recurring costs associated with testing.

In the area of reliability and maintainability, changes were identified which could reduce car procurement costs although there were strong reservations among those interviewed concerning the impact on life cycle costs. Notwithstanding these objections, it seems clear that the stringent requirements now in the specification, while adding significantly to program costs, were not successful in preventing major equipment reliability and maintainability deficiencies. Careful review of the specification may be in order with the objective of substituting incentives and prequalification of bidders, for the present emphasis on monitoring and testing. In a related area, the requirements for documentation and design approvals could also be streamlined to reduce adverse schedule impacts associated with delays in obtaining customer approvals.

Careful consideration was also given to whether passenger comfort requirements were excessively stringent. It was generally agreed that noise requirements should be relaxed. This proved a practical necessity when Boeing Vertol built the LRV. (ref. 2) Those interviewed in general did not believe much money could be saved by relaxing ride quality, heating, air conditioning or lighting requirements.

In the area of dynamic performance, recommendations included elimination of the automatic speed control, less sensitive requirements on reaction time and other control tolerances, and more encouragement of the use of conventional as opposed to chopper motor controllers. (ref. 3)

Those interviewed also noted a number of areas where clearer delineation of requirements could reduce confusion and misunderstanding between the supplier and customer. Better definition of the operating environment and clearer definition of maintainability requirements were two areas cited.

A final area where major cost reductions appear possible involves changes with significant impacts upon system operations. Areas identified include permitting unidirectional vehicles, allowing doors on only one side, and deleting the articulation joint for applications where such changes are compatible with site constraints and operating requirements. Cost savings can be significant and appear to justify offering such features as an option in the SLRV specification.

The following sections discuss these areas for potential cost savings in further detail.

5.1 DESIGN AND MANUFACTURING CONSTRAINTS

Some parts of the present SLRV specification are written so that the designer and manufacturer are restricted with respect to economical design solutions and manufacturing methods. The need for setting limits at the beginning of the design process is recognized. However, economical vehicle system solutions necessitate a certain amount of design freedom to choose between and combine technical options in order to produce an economical and serviceable product.

An example of this type problem is the approach taken to specifying the exterior vehicle lines in the specification, which led Boeing Vertol to build the car with complex curved vehicle ends. The overriding reason for specifying exterior vehicle geometry is to ensure that the dynamic vehicle envelope is compatible with the geometric constraints of the prospective transit systems which will operate the vehicle. Therefore, it is sufficient to specify a maximum dynamic vehicle envelope. By illustrating detailed front end configurations, the specification appears to have perhaps inadvertently constrained the design options available to the vehicle suppliers.

Restrictions on Exterior Lines

A number of vehicle layout drawings provided as part of the SLRV specification are quite detailed concerning seat and door locations, exterior lines, and contours of the car. Contract Drawing Number 2 of the SLRV specification, shows vehicle longitudinal and cross sections and requires the vehicle side walls to bend slightly inward towards the roof. Contract Drawing Number 3 of the SLRV specification, while not dimensional, provides detailed guidance on the cab layout and console and appears to require the vehicle ends to taper off in the form of a complex curve. Contract Drawing Number 4 provides a static and dynamic cross section of the car to be used for clearance purposes. The specification is somewhat ambiguous as to whether these drawings are intended to indicate the actual vehicle layout and appearance or are purely illustrative. For example, section 2 of the specification states "The Contract Drawings indicate only a general industrial design of the vehicle." Yet the introduction to Chapter 3 of the specification states that "The car body shall be constructed and assembled in conformity with the general arrangement and dimensions shown on the contract drawings and with this specification."

It seems clear that for the MBTA/MUNI procurement, the drawings were followed quite closely. The Boeing Vertol vehicle very accurately reflects the SLRV contract drawings in both layout and appearance. The price of this conformity has been completely curved vehicle front ends, requiring a special door design and, according to Boeing staff, adding significantly to the cost of the car.

To assure the vehicle supplier the design and manufacturing freedom he needs to minimize his fabrication costs, the SLRV specification and contract drawings could be modified to clearly indicate only the required dynamic envelope and necessary dimensions with respect to under body clearance, platform location, and so forth.

Such a specification modification would permit simple straight front sections as are found on the Helsinki Valmet Oy Articulated Tramcar, the DÜWAG M-6/M-8 Tramcars, or the Schindler Articulated Cars Type Be 4/6. Observation will show that most European light rail vehicles have straight side walls for the tapered ends. This is particularly significant because older European systems have narrow curves and very limited clearance.

The cost savings resulting from specifying the dynamic envelope rather than utilizing detailed drawings are high, particularly because it carries over to other system components. An important consequence would be elimination of the need for a special front door design caused by the three dimensional complex curve shape. In addition, plug doors would no longer be required at the vehicle ends to provide a curved profile. Performance of the vehicle would not be adversely affected by this modification.

Doors

The specification requires sliding/plug type doors. This is a type of sliding door which, when closed, moves inward so that the door is flush with the vehicle exterior.

Deletion of the requirement for sliding/plug doors would provide significant gains in terms of design freedom and manufacturing freedom. If in addition, as was discussed earlier, the tapered vehicle ends were straightened, it would permit the same door to be used throughout the vehicle.

These two changes, straightening the tapered ends of the car and deleting the requirement to use plug type doors, would permit the use of simple folding doors. There are several advantages:

- Simpler modular design, permitting pre-installation checking
- Utilization of standard off-the-shelf components
- Simpler tooling design
- Elimination of the need for a separate locking actuator; a simple over center lock can be utilized
- Reduction of number of parts needed

Sliding doors could also be used, and will also be less expensive than the plug type doors. There may be clearance problems with sliding doors at the ends of the car depending on the specific design and location of the door. Folding doors were assumed in the cost analysis for this study.

The main advantage of plug doors is that a car body exterior can be achieved which appears smoother and has less obstructions and gaps. The value of this intangible is difficult to assess, and needs to be weighed against the more tangible advantages that other designs can offer.

All those interviewed concurred that the requirement for plug doors should be deleted so that other design options would not be foreclosed.

Vehicle performance should not be adversely affected by allowing folding or sliding door designs. Since the number of parts would be reduced, maintainability should improve with consequent reductions in operating and maintenance costs. The capital cost savings have been found to be high, $31,300 per car if all folding doors are acceptable.

Outer Surface Smoothness Criteria

The specification is quite stringent with regard to surface finish. It requires that "spot welds or rivets where visible must be ground smooth and filled as necessary so as to be practically invisible to the naked eye upon close inspection after the final coatings of paint have been applied." The subjective nature of this requirement can lead to disagreement over its interpretation.

In the case of the Boeing SLRV, steel side panels were fastened using a combination of rivets and resistance welding. According to Boeing Vertol representatives, considerable effort was spent in concealing rivets and providing an acceptable finish in areas around access doors. It is possible that the subjective interpretation of "practically invisible" may have led to misunderstandings which added to the cost of the vehicle.

In reading the specification it was difficult to determine whether it would have permitted more cost effective manufacturing approaches, such as the use of corrugated panels, or the covering of rivet and weld areas with chrome beauty stripes. Certainly grinding of welds and rivets would seem to be an inefficient process for attaining an attractive vehicle finish.

The concerns voiced during the interviews in defense of the specification requirement were related to the need to assure an aesthetic vehicle appearance. However, this can also be achieved by using interlocking panels or beauty stripes, and in addition, there is no real evidence of how important vehicle exterior aesthetics are to the transit riding public. Normal wear and tear may quickly produce scratches and surface flaws, especially with the vandalism and graffiti problems present in many cities. Such damage could tend to make an over zealous concern with initial vehicle appearance somewhat irrelevant.

Clarifying the requirements concerned with surface finish would not have any adverse affects on vehicle performance or maintainability, and could save not only the cost of grinding rivets and welds, but some $1,300 per car presently spent on touching up cars rejected for surface blemishes or imperfections.

Articulation Joint

The design of the articulation section was to a large degree ruled by specification requirements that this vehicle section present an appearance, with respect to the rest of the car, of being a single, smooth structure. Deletion of this appearance requirement would allow for more traditional articulation designs.

European design practice for articulation sections usually allows exposed structures as long as safety is not impaired. Frequently bellows are employed for cover and protection. Klauder representatives were of the opinion that some articulation designs do not need cosmetic panels, but that the Boeing Vertol SLRV does since the mechanical elements were designed with the assumption that such covers would be provided.

Deletion of the requirement for overlapping articulation side panels would result in a simplification of the articulation design with accompanying reduction of manufacturing constraints. The value of smooth appearance at the articulation section is debatable. Deletion of the requirement would not affect performance and is estimated to save approximately $2,700 per car on a 100 car order.

Windshield

The specification presently stipulates a single piece windshield with a thickness of at least nine-sixteenths (9/16) inches. An alternative would be to replace this requirement with a functional specification. The Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways, ANSI Z26.1-166, specifies requirements for glazing materials for use in passenger cars, multi-purpose passenger vehicles, motorcycles, trucks and buses. Federal Motor Vehicle Safety Standard No. 205 requires adherance to this ANSI standard. For development of requirements for the SLRV windshield these standards,which are used for buses,would provide a good basis. This approach was recommended by the car manufacturer, Boeing Vertol. The as-built SLRV specification does, in fact, make reference to ANSI Z26.1-1966 even though the nine-sixteenth (9/16) inch minimum thickness requirement is still included.

All those interviewed concurred in changing the specification to permit installation of a three piece windshield. This would also reduce reflections of interior lighting on the windshield in the operator's field of vision. If a three piece windshield were used its dimensions would be comparable to those for bus windshields. Bus specifications require 1/4 inch safety glass, less than half the thickness presently required for the SLRV.

This modification would not impair vehicle performance or safety. However, first cost savings are small, on the order of only $200 per car. The real savings can be expected in reduced repair and replacement costs for broken glass over the lifetime of the vehicle.

Electrical Systems

Several requirements concerned with the electrical systems were identified where modification appeared to have potential for reducing design and manufacturing constraints. These requirements involved shielded control and communication wiring, low voltage dc levels, and electrical connectors.

It was suggested that the specification permit cab signal and Automatic Speed Control wiring to be run with other wiring providing it is shielded. However, further investigation revealed a general consensus that this is not desirable for reasons of safety. Physical separation, as presently specified, reduces the possibility of unsafe conditions caused by electromagnetic coupling. In addition, even though combining wires would simplify the manufacturing process the cost savings would be minimal.

Presently, the specification calls for a low voltage system based on 37.5 VDC. Change of this requirement to allow 12 or 24 volt supply was considered. However, the 12 VDC system would require excessive wire cross section. Boeing Vertol proposed the use of 28 VDC which would meet MIL-STD-704 and allow utilization of more standard equipment. Klauder and Kaiser representatives pointed out that the specified 37.5 VDC is a well established voltage for the electric transit industry. The standard for European transit control systems is 30 VDC. Kaiser representatives suggested that the specification could be rewritten so that the 30 VDC European standard could be employed.

According to the present specification, multipin positive lock connectors with metal or molded housing may be provided as approved. This is an open ended specification and could be changed, permitting the use of electrical connectors to enhance modularization so long as MIL-C 5015 environmentally protected or equal connectors are used. While the use of high quality connectors is expensive, we considered whether cost savings might be realized through simplification of wiring harnesses and modularization. These cost impacts are difficult to quantify since they would require a complete re-evaluation of all electrical systems and their wiring. Maintainability could be enhanced by using breakout boxes for trouble shooting and simplifying the replacement of defective modules. NDL performed a preliminary quantitative analysis which indicates that in terms of first cost, the added cost of the connectors will be greater than any savings in vehicle assembly.

German light rail vehicle technology specialists believe the use of electrical connectors is very important. Klauder representatives suggested that greater use of connectors should be phased in gradually so that reliability can be assessed.

5.2 LEVEL OF COMPLEXITY AND SOPHISTICATION

There are a number of areas where the specification increases the complexity of the vehicle. Many of these do not seem essential to providing basic transportation services or are site-specific and may not be necessary in all cars. Perhaps the "Standard" LRV specification should permit each transit authority to specify these options according to local needs and practices. For example, the current specification is quite detailed with respect to the on-board communications equipment. It might be preferable for each authority to write its own communications specifications to meet local requirements and assure compatibility with existing equipment.

Communications

It may be desirable to specify the on-board communication equipment in terms of functional and performance requirements. Presently, hardware specifications are provided which may be biased towards particular suppliers. The consensus of those interviewed was that the amount and type of communication equipment should be a local option so that an authority can specify equipment compatible with existing equipment. Some operators may not wish to include two-way radios in the vehicle specifications. For example, the Chicago Transit Authority (CTA) is experimenting with hand-held radios, rather than vehicle mounted radios. These hand-held radios permit the operator to remain in continuous communication with the central monitor in the event he must leave the operator's cab to inspect a problem. They also reduce the number of units needed since only one is required per train rather than one in each car.

Other equipment required by the communications specifications which tends to increase system complexity includes the digital data encoder, train line communications between operators in all cars in a train, and provision of circuits for sound powered phones for use by maintenance crews. The digital data encoder was specified to automatically transmit vehicle status to a central monitor. Many transit authorities are now beginning to put this type of automatic vehicle monitoring on bus fleets.

However, present bus specifications, while making provision for installation of communications, leave the details of the equipment as a local option. In general those interviewed considered that specification of the digital data encoder in light rail should also be a local option. In cases where the digital encoder is specified, it becomes economical to also provide other features including public address from wayside through the vehicle's PA system, sub-audible tones to actuate the PA system, silent alarm systems for operator/passenger security, and automatic radio malfunction alert systems. (As a practical matter, CTA engineers are questioning the value of real time failure reporting since their experience has shown that critical malfunction items can be detected by the operator and handled over normal two-way radio communication.)

The need for communication between operators in each vehicle depends upon local conditions and probably should be offered as an option. For example, procedures in Boston require an operator in each vehicle of the light rail train to collect the fares and to open and close doors, and serve a crime prevention purpose. Communications between operators at this site are necessary to coordinate door operations.

The SLRV specification requires lines and receptacles to permit maintenance crews to connect sound powered phones. While deletion of this requirement would not represent a large cost savings, it is another example of increased sophistication. Apparently this capability was added for use with the Diagnostic Test Equipment (DTE), the elimination of which has also been cited as a potentially significant cost savings. Even if DTE equipment is purchased, sound powered phones with their own lines could be used instead of incorporating the lines in each car.

Operator's Cab and Instrument Panel

The present specifications call for the operator's position to be completely enclosed with a door which can be locked. This requirement appears to be site-specific to provide security for the operator and protect the fare box. Since the specification was written, the MBTA has implemented an exact fare system and as a result would probably no longer require this protection. Most of the experts interviewed agreed that a fully locked enclosure should be offered as a local option. In cases where a full enclosure is not provided, a simple partition behind the operator with a curtain could be sufficient. All interviewees considered it essential to provide a locked cover for the instrument panel. The capital cost savings from deleting the enclosure is estimated to be about $2000 per car.

The destination signs are specified to be motor driven and controlled from the operator's console. In Boston manually operated signs were installed. In San Francisco, operating policy has vehicles changing their designated destinations at strategic points; therefore, the motor driven signs were specified to save the operator's time. Another reason for using motor driven signs in San Francisco is that sometimes there is only one operator for a train of two or more vehicles. Those interviewed were of the opinion that motor driven signs were unnecessary on a standard vehicle and should be optional.

Both visual and audible track brake indicators were specified. The consensus was that provision for two indications is unnecessary and that only audible indication would be sufficient.

Automatically dimmed instrument panel lights were specified, controlled by outside lighting conditions to become brighter as the ambient illumination level increases. The as-built specification eliminates this feature because of continued problems with the equipment. Klauder mentioned that in daylight the lights were not visible anyway. The consensus was that adjustment of the instrument lights could be provided by a simple rheostat as is done on a bus or automobile.

The specification also requires individual illumination for door switches, track switches, the headlight controls, the cab light switch, and the horn and gong actuators. All experts agreed that this is not an important requirement and could be deleted. It was pointed out that only critical functions need be separately illuminated.

The present specification calls for eight detents for positioning the master controller. The Boeing As-Built specifications eliminated three of the detents (full field, minimum power, and minimum brake). Also maximum power and emergency braking are not provided as detents but are the maximum excursions of the handle. All experts agreed that future specifications should not provide any more identified positions (detents) than the following:

- Maximum power
- Coast
- Minimum Brake
- Full Service Brake
- Full Service Brake plus Track Brake
- Emergency Brake

Door Operation

The present specification requires that switches be provided so that the operator can open and close each of the six car doors separately. In addition an unlocking button is provided to permit passengers to open the door by touching "touch bars" on any given side door. Lighted indicators on the operator's console indicate if a given door is open. Consideration might be given to simplification of door control in two cases:

1. Eliminate the touch bars and utilize only operator control. A disadvantage of this concept is that use of the touch bar reduces the number of door actuations which could reduce maintenance and increase actuator lifetime.

2. Delete operator "open" control, provide passenger actuated touch bars or push buttons both inside and outside each door and provide

one button on the operator's console to unlock the doors and one button that closes all opened doors. Basically this is the West German practice. While this concept deletes "open" switches on the console, it adds passenger operated touch bars or push buttons on the outside of the vehicle at each door.

Movable steps for high or low platform loading were required for San Francisco at each of the doors except the end doors. This further complicates the door control.

Dual Ground Brushes

Dual ground brushes were specified to ensure grounding around the anti-friction bearings of the axles. Separate ground brushes were specified for the 600 VDC and low voltage DC. The as-built specification deleted this requirement. All experts agreed that both the 600 VDC and low voltage DC could be terminated at a single ground point and that only one ground brush should be required.

Fewer Destination Signs

Presently the specification calls for two destination signs on each side of the vehicle and one at each end. The possibility of deleting some of these signs was explored. All agreed that side signs were more important than end signs for the types of operations in Boston and San Francisco. In fact some believed that the number of side signs should be increased or existing ones made larger. It should be pointed out that two of the present side destination signs are so located that they are obscured when the adjacent doors are open. This greatly reduces their value to the passenger. The consensus was that the SLRV specification should continue to require end signs and two sets of side signs. While providing two signs per side increases costs, these extra costs were judged to be small in comparison with the benefits to the riding public.

Shop Power Plug

The specification required provision of a shop power plug to permit movement of vehicles in and out of the repair shop with the pantograph in the locked down position. Because shops are generally equipped with overheads, most experts agreed that this provision might be made optional. It was also pointed out that the power plug is not usually used for traction but for checking other 600 VDC equipment.

Automatic Sanders

The current specification requires that sand be fed to the track automatically by the slip/slide control. Boston has disconnected this automatic feature because sand in the tunnels interferes with the train signalling system. In general it was agreed that most properties where single vehicles are operated do not need automatic sand feed. In train operation, automatic sanding may be desirable because the train operator cannot detect wheel slip or slide in one of the following cars.

5.3 OPERATIONAL FACTORS

This section summarizes several areas where important cost savings were identified, but which involve significant compromises in operational performance. There are no simple answers to some of the trade-offs discussed in this section, since each city will have different site constraints and operational requirements. What we have attempted to do is to illuminate the critical issues and where possible quantify the cost savings, to help prevent the temptation to overspecify vehicle capabilities.

In general, it is recommended that bidirectional vehicles with doors on both sides be offered as one option, or a unidirectional car with doors on only one side as another option. Similarly, it is suggested that non-articulated full size cars be offered for cities which can tolerate a 125 foot minimum curve radius.

The savings associated with deletion of the compressed air system are also significant. While the specification does not now require compressed air, we recommend a detailed review to determine what performance modifications would be necessary to permit an all electric or electric hydraulic car to be offered as a practical matter. In particular, relaxation of requirements for the friction brake duty cycle and for load leveling will be necessary.

Compressed Air

The SLRV specification does not explicitly require a compressed air system and air suspension. Nonetheless, performance requirements tend to lead suppliers to bid this type of equipment, though it is by no means clear that it offers significant performance advantages. "All-electric" light rail vehicles without compressed air are in common use in Europe. Examples include the Frankfurt U2 and P8 cars and the Düsseldorf Model 300. (ref. 4) It is not universally agreed that air operation is superior. For example, in an assessment of LRV's, De Leuw, Cather notes that "The vulnerability of pneumatic systems to interference due to cold is widely known... . In recent times, the increasing complexity of modern light rail vehicles has resulted in a preference for all electric or electric hydraulic designs. This design change would improve the cold weather operational reliability of LRT, and probably had some bearing on the selection of the U2 car (an all electric design) for Edmonton." (ref. 5) In the United States the Chicago Transit Authority uses all electric or electric hydraulic design exclusively for all its rapid rail cars. In a paper given at the National Conference on Light Rail Transit, Joachim von Rohr, a German vehicle engineer stated that "Compressed air equipment is sometimes used on LRV's, although most modern streetcars built in Europe after 1945 have been all electric cars... . The decision to use air for LRV's is rather arbitrary, but because of space problems and the increased friction brake performance requirements on larger, faster cars, sometimes compressed air is indispensable." (ref. 6)

As these quotations make clear, there is no unanimity concerning the desirability of using compressed air. The Studiengesellschaft Nahverkehr-mbH (SNV) in its review of our suggested cost reductions, stated that deletion of compressed air would be acceptable. (ref. 7) Boeing Vertol also found this change acceptable. Louis T. Klauder and Associates showed some concern about the ability to design a fail-safe electric brake and commented that although many PCC cars and European cars have been built as all electric, "Successful emergency stops were not one of their attributes." (ref. 8)

Sources disagree on the savings from deletion of compressed air. The Chicago Transit Authority commented "we would expect savings in weight but probably not in dollars." (ref. 9) On the other hand, Boeing engineers informally guessed the savings could run as high as $50,000 per car. (ref. 10) NDL's own detailed cost analysis based upon Boeing costs and trade data, estimates the savings at about $15,000 per car (see chapter 6 of this report). The savings are almost entirely from elimination of the compressor and associated control equipment, accumulators, and air/hydraulic boosters for the brake system.

The presence of these savings, coupled with a lack of any overwhelming advantage to use of compressed air, suggests that serious consideration be given to modifying the specification to encourage the use of "all electric" or "electric hydraulic" cars.

<u>Relax Friction Brake Duty Cycle</u>

At present, the SLRV specification requires that the friction brake be designed to bring a fully loaded car to rest within 1000 feet from a speed of 55 mph. This must be possible at any time during a complete round trip in which the dynamic brakes are inoperative and the vehicle continues to make all scheduled passenger stops. (ref. 11) In short, the friction brake must be able to assume the service braking duties of the dynamic brake in the event of a motor failure. Furthermore, if a pneumatic or hydraulic system is used, the system must have sufficient storage capacity after loss of the compressor or hydraulic power unit for 15 full brake applications and releases. (ref. 12)

The philosophy is not to provide a <u>safety</u> backup capability, in event of brake failure, but rather an <u>operational</u> backup capability able to maintain normal vehicle operation without dynamic braking. The Chicago Transit Authority does not require this capability, being satisfied with a friction brake able to provide a single safe stop in the event of dynamic braking failure. European practice similarly is usually not so conservative. The potential savings from relaxing these requirements has been estimated by Boeing Vertol staff at nearly $10,000 per car. (ref. 13)

Beyond this savings, relaxation of the friction brake duty cycle is probably essential if an "all electric" or "electric hydraulic" car is to be practical, since it is most unlikely that a non air-brake could meet the stringent duty cycle presently imposed by the SLRV specification. However, it should be mentioned that relaxation of the friction brake duty cycle can present a safety hazard should the vehicle continue to be operated after failure of its dynamic braking system. This is a trade off which requires further investigation.

Bidirectional Operation

Many of the pre-PCC streetcars were double ended to permit operation on simple track layouts with switchbacks. As streetcar systems evolved, single direction operation became popular. Greater car reliability reduced the requirement for turnbacks and maximizing seating became an important goal. However, where subway construction was involved, the bidirectional car remained preferable since it could turn back at a simple crossover track.

Today the advantages and disadvantages of bidirectional operation remain much the same. The bidirectional car can turn back with a simple crossover, which requires less land than the loop or "wye" required by a single ended car. In addition, the bidirectional car permits passenger loading from either island or side platforms.

Disadvantages of bidirectional operation include the requirement for doors on both sides of the vehicle, which reduces the seating capacity and increases the cost for doors. In addition, vehicle reliability is decreased since there are twice as many door mechanisms, which experience shows are particularly failure prone. Another disadvantage is that two operator's consoles are required, which reduces passenger capacity and increases the cost and technical complexity of the car. (ref. 14)

Because of these disadvantages, it is important to carefully examine the operational need for bidirectional vehicles. The new Canadian LRV's being built for Toronto are single direction cars. Many PCC cars, including those used in Boston, are single ended. Similarly, LRV's now operate single ended in Amsterdam (the LHB-8 axle tram), Antwerp (BN 4-axle tram), Basel (Schindler Be 4/4 and Be 4/6), Bern, Braunschweig, Bremen, Goteburg (ASEA type M-28), Helsinki, Nürnberg and the Hague. (ref. 15)

SNV states that the tendency toward tunnel construction for light rail in German cities has caused a recent preference for bidirectional vehicles, because of the high cost of underground turnarounds. (ref. 16)

Where construction is above ground, the preference would appear to favor the unidirectional vehicle. NDL cost estimates indicate that the use of unidirectional cars with doors on only one side could save $30,000 per car, even when allowance is made for provision of turnback loops and costs of the added ROW required*(see Chapter 6). This savings is probably understated because it does not include savings from reduced maintenance of door equipment and cab controls.

The consensus of all those interviewed under this study was that the SLRV specification should offer unidirectional cars as an option for those transit systems whose operational conditions make their use practical.

Elimination of Articulation Section

Articulated cars evolved in Europe as a means of obtaining larger vehicles, and hence higher driver productivity, while maintaining the ability to negotiate the tight turns intrinsic to ancient German street networks. Large cars would be practical without an articulation joint if curve radii could be kept greater than approximately 125 feet. Therefore, the use of articulated vehicles in this country requires careful assessment, especially in midwestern and western states where street layouts are much less restrictive than in Europe.

Klauder Engineers have stated that "The most significant reduction of both capital and life cycle costs to the present designs can be accomplished by eliminating the articulation section in cities where civil features are not limiting." (ref. 17) This study indicates that savings of $35,000 per car are possible if the articulation section is deleted, even accounting for ROW costs associated with larger turn radii*(see Chapter 6). Two points should be stressed. First of all, ROW availability is not just a matter of dollars -- frequently right-of-way is simply not available. The area in question may contain a historical building, citizen opposition may preclude acquisition and/or political constraints may exist. Any of these or a myriad other reasons may make it impossible to obtain right-of-way and may require

Assumes ROW at $20/ft^2$

operation with tight radius curves. However, the system builder should be aware that he can save 5 percent of the vehicle costs, even making reasonable allowance for added right-of-way, if 125 foot radius curves and nonarticulated equipment are acceptable.

The second point to be stressed is that unidirectional operation is incompatible with the nonarticulated car if the LRV crush capacity of 219 persons is to be maintained. Since a large, nonarticulated car will be relatively unmaneuverable, reversible operation is essential to permit rerouting of vehicles by switchbacks and track crossovers. (ref. 18) Therefore, operators should examine their particular site requirements and select either a highly maneuverable articulated car, in which case bidirectional operation may be unnecessary, or alternatively a large turn radius nonarticulated car with a bidirectional capability. Either way, savings of 5 percent in car costs will be available. Requiring both articulation and bidirectional operation may be over specification for many applications.

Automatic Coupling

Since automatic couplers add 1309 pounds in weight (ref. 19) and cost between 10 and 20 thousand dollars per car, consideration was given to the possibility of operating with single cars, married pairs, or towbar couplings. The prospects did not seem encouraging. Both MBTA and Klauder staff remarked that the PCC car has a form of automatic coupling and eliminating that feature would be "reducing SLRV to an operational status less than that of the thirty year old PCC cars which they are to replace." (ref. 20) (Actually, the PCC is not a completely automatic coupling because the electrical connections have to be energized manually, while on the SLRV this is done automatically.) Training was cited as a way of increasing productivity by SNV. (ref. 21) This is true in Europe, where the honor fare system eliminates the need for an attendant in trailing cars. In this country, present practice requires an attendant in each vehicle so coupling adds no productivity. What it does add is line capacity, which can be needed in rush hour, and reliability, since a dead car can be pulled by another car in an emergency. The need for automatic coupling is not universal; for example, SEPTA in Philadelphia does not operate its PCC cars in trains. In addition coupling was not part of the baseline PCC specification, but was offered only as an option for those cities desiring it. Nonetheless, the reactions of those interviewed would seem to indicate that the cost savings would not be worth the loss in operating flexibility of abandoning the automatic coupling feature.

Reduction of Cruise Speed

Consideration was also given to possible savings from reducing the speed capability of the SLRV. The consensus of those interviewed was that cost savings from such a reduction would be modest. Opinions concerning the impact on operational capability were mixed. Klauder stated that "for most applications 50 mph should be retained or increased." (ref. 22) Kaiser, on the other hand thought that 30-40 mph would be acceptable. (ref. 23) Clearly, the performance impact of the speed specification is heavily dependent upon its application and is therefore difficult to assess. The range of maximum speeds of eight recent German LRV's mentioned in a report by Joachim von Rohr was 70-100 km/hr (44-62 mph), bracketing that of the SLRV specification. (ref. 24)

In view of the modest cost savings involved, further consideration of a reduced speed capability is not recommended.

5.4 RELIABILITY AND MAINTAINABILITY

The requirements dealing with reliability and maintainability are among the more important aspects of a specification for sophisticated equipment such as a modern light rail vehicle. Naturally, the purchaser desires the best reliability and maintainability obtainable since these are factors which affect operating and maintenance costs. However, excessively sensitive requirements can cause the bid price to be significantly higher by increasing the risk to the manufacturer, especially if the vehicle design is to be totally new and there is any expansion of the state-of-the-art. For self protection, the builder will try to anticipate the costs involved with redesign and retrofit activities required to assure the vehicle meets the specifications. This added cost penalty is aggravated if the number of cars in the order is small, or there is no assurance that there will be follow-on orders for the same design.

Throughout the structured interviews and rating processes conducted by NDL, special attention was given to investigating the reliability and maintainability specifications and their affect upon vehicle cost and performance. The following are highlights of those areas where costs appeared to be most sensitive.

Reliability Requirements

The current SLRV specification has four reliability elements. First, there are reliability goals (MTBF) established for critical subsystems of the car (i.e., propulsion, friction brakes, auxiliary electrical and controls, and door/step operation and control). Second, a reliability analysis of the final design is required to demonstrate that these reliability goals have been met. This analysis must be approved by the owner before release of the design for manufacture. Third, a reliability plan is required, also to be approved by the owner, with monthly progress reports submitted on the implementation of the plan. Fourth, a two-year demonstration period is specified during which failures and failure rates are to be closely monitored on 50 vehicles. If the demonstration indicates failure to meet the reliability goals, then the supplier is required to review and if necessary, redesign the affected subsystem and modify the entire fleet. This process continues until the goals are met. In addition to these reliability requirements, warranty provisions are also provided.

The results of the SLRV program to date fail to substantiate that these provisions are necessarily successful in preventing reliability problems associated with the introduction of a new vehicle design. Boeing Vertol cited the present reliability requirements as having high cost impact because of the risks which are placed upon the manufacturer. Opinions concerning each of the four elements of the reliability requirements were expressed by individuals during the interviews. Comments were also provided on the rating charts. While these opinions do not represent a consensus, they do indicate that modification of the reliability requirements might save costs and increase resultant reliability.

Responses to the "Refined Baseline" set of Candidate Specifications suggested a need to clarify and simplify the reliability goals. Respondees expressed a variety of opinions. Kaiser suggested there was need for better definition of the subsystems. Presently it is not clear what is included or not included in each subsystem. For example, no distinction is made between a diode failure in the propulsion system and a traction motor burnout in determining compliance with the MTBF goal. Kaiser also pointed to confusion in distinguishing between goals and requirements. The MBTA representative believed the manufacturer should be asked to define reliability goals in his proposal or early in the project which would then become a binding part of the contract. This would eliminate the need to require reliability analyses and reliability program plans by demonstrating reliability through service performance. The West Germans stressed the importance of choosing "realistic" reliability goals. Klauder did not believe the reliability goals should be relaxed, because in their opinion the MTBF's were "loose in comparison with other equipment." They agreed that clarification and more rigorous definition are needed. One problem pointed out by Klauder was that the present definitions allow problems to occur which are not classified as a failure. Failure is limited to an event which requires the vehicle to be removed from service for corrective maintenance, excluding numerous less serious equipment malfunctions which nonetheless require maintenance actions.

The possibility of eliminating the reliability analysis was also suggested. Klauder stated that reliability analysis was needed only on new design vehicles, but agreed that in the case of the SLRV it did not prevent problems from occurring after the vehicles were delivered. The specification required approval of the analyses by the owner. Kaiser suggested submitting the results of the analyses to the owner for "information" only. SNV commented that the reliability analyses should be performed on a prototype vehicle. NDL concurs with the value of the analyses in these cases, but believes it can be deleted as a specification requirement. The analyses have their greatest value when used by the manufacturer as an internal control to rationally apportion the budgeted vehicle failure rates among its subsystems.

Suggestions to delete the requirement for a reliability program plan from the specification were often made in conjunction with the above concept for deleting the analysis. Klauder took strong exception stating that the "reliability requirements were the last line of defense," and that deleting the program and its monthly reports would be unacceptable. Kaiser stated that the monthly reports were not essential and could be deleted. The representative from the MBTA stated that the monthly reports were seldom used.

The two-year reliability demonstration program required by the specification was cited by Boeing Vertol as especially punitive. Boeing stated that fleet modifications should be subject to negotiation. It was Klauder's opinion that for this type reliability specification, the two-year demonstration was necessary. However, the addition of penalty/incentive provisions might be desirable for not meeting or achieving the reliability goals. Kaiser suggested that a warranty on design deficiencies might be better and could possibly eliminate the need for the two-year demonstration.

Obviously there is need for an assurance specification. The question is, can assurance be provided only by a Reliability Requirements Program or can it be achieved by other methods, particularly if costs can also be reduced?

From the interviews there was a consensus that this area of the specification definitely needs improvement.

A warranty type of specification might be more successful. For example, the Advanced Design Bus specification provides assurance through warranty. It includes a Fleet Defect provision for items covered by warranty. If over 20 percent of a delivery on 50 or more coaches (25 percent if 10 to 49 coaches or waived if order is less than 10 coaches) experience the same defect during the warranty period, then the manufacturer is required to correct the problem and institute a work program to prevent the occurrence of the same defect in all coaches purchased under the contract. In addition, the warranty period on that component is to be reinitiated to extend from the date of correction of the defect for the original full warranty period.

Use of a warranty specification could provide the following benefits:

- Does not require definition of reliability requirements, especially where there are problems of specifying realistic reliability goals.
- Reduces the risks to the manufacturer and extra costs assigned, especially for a new vehicle design.
- Allows some negotiation concerning who bears the cost for modifications necessary to correct problems where design deficiencies are not involved.
- Does not require elaborate reliability analyses and monitoring efforts which may be inappropriate for a small car order.

<u>Diagnostic Test Equipment (DTE)</u>

The current specifications require that a single automatic diagnostic tester be supplied with the car order. The idea was that the DTE would allow use of lower skilled technical personnel to troubleshoot problems on a very sophisticated vehicle, particularly in the case of chopper controlled propulsion. The DTE was also envisioned as saving manpower and thus reducing maintenance costs.

It was suggested as a result of the TASI interview process that the DTE might be eliminated and that either portable (suitcase) testers could be provided or standard test equipment used. However, if the DTE were eliminated, some other form of automated tester might be required if chopper control were supplied. The owner did not express satisfaction with the DTE and would prefer the portable testers. In fact the DTE which was developed in response to the LRV specification cannot be operated by low grade personnel and requires knowledge of computer software. Elimination of the DTE could save over $17,000 per car on a 100 car order.

Some of the other suggestions for modification of the specifications to reduce costs are based upon the concept of providing a less sophisticated vehicle. Such changes also will tend to reduce the need for a DTE, particularly if cam/resistor propulsion control is specified. For these reasons it is probable that the DTE, if offered, should be an optional item. Consideration should also be given to not including any DTE in the vehicle specification but rather specifying it separately. This would allow the owner to specify the DTE functionally in accordance with his particular local requirements. Actual design of the DTE should not commence until the first few vehicles (or prototype vehicles) are completed and general maintenance and repair problem areas have been identified. This will assure that the DTE capabilities are properly matched to actual vehicle maintenance activities.

Maintenance Manuals

Maintenance manuals are specified to conform with a common format and style. Therefore, neither subsystem supplier manuals, nor pages from such manuals, could be directly inserted but had to be reworked to conform with the required format. Kaiser suggested changing these specifications to permit directly incorporating subsystem supplier manuals. This would decrease nonrecurring costs associated with manual preparation. Both Klauder and the MBTA suggested that manuals be organized according to the format that is used in Manufacturers Technical Data, ATA specifications 100 and 101 as published by the Air Transport Association. These guidelines were developed for aircraft and airport ground equipment.

It is interesting to observe that the current SLRV maintenance manuals have 2 1/2 times the number of pages as those prepared for the new CTA rapid rail cars, also built by Boeing Vertol. The CTA car is much less sophisticated than the SLRV, so this difference graphically illustrates the impact of vehicle complexity upon maintenance activities.

Ease of Maintenance

The current specifications concerning maintenance are somewhat general, prescribing various features which are intended to provide for easier maintenance. These features cover fault-isolation procedures in manuals, built-in test points, failure indicators, nameplates and coding, cabinets and enclosures, door panels and openings, interchangeable components, commercially available hardware, access for inspection, ease of removal of major components, and means to verify operability of redundant hardware during maintenance and testing.

A number of those interviewed suggested specifying maintainability goals in terms of time limits to accomplish certain tasks. All experts interviewed expected that such a modification would increase vehicle costs. It was still considered as a desirable modifcation to help circumvent subsequent design problems resulting from individual interpretations of the requirements. Such more detailed maintainability goals would have to be carefully developed and reviewed by the transit authorities prior to insertion into the specification.

5.5 TESTING REQUIREMENTS AND STANDARDIZATION

The light rail vehicle specification calls for proof and verification of vehicle design through the testing of components, systems, combinations of systems and completed vehicles; the submittal of drawings, photographs, calculations, and design data; and the production of models, mockups and samples. (ref. 25) The procedure involves, in the words of the specification, a "comprehensive test program" (ref. 26) including both qualification and acceptance testing of components and complete vehicles.

Component and subsystem acceptance and qualification tests are summarized in Table 5.2, tests on complete vehicles are summarized in Table 5.3. The test program will be seen to be comprehensive and extensive, requiring elaborate test equipment and facilities. Examples include an environmental chamber able to contain a complete vehicle, strain gauges, structural testing gear to apply a 75,000 pound load, a spray chamber to test for water leakage, a dynamometer, fatigue and endurance test rigs, and considerable electrical equipment. A completely different approach may be seen in specifications prepared by UMTA for the Advanced Design Bus. (ref. 27) This test program relies heavily on visual inspection. Complete test equipment is limited to a tape measure, portable light meter, standard voltmeter, stop watch, tachometer, decelerometer, tire gauge, thermometer, 100 pound pull scale, and a standard truck scale for measuring vehicle curb weight. (ref. 28) In addition to this much simpler test program, the Advanced Design Bus specification requires no submission of drawings or circuit diagrams for customer approvals. The resident inspector is given access to such material but no approvals are required, other than the mutual development of a satisfactory in-plant quality assurance program. (ref. 28b)

Since there should not inherently be a vast technological difference between a modern bus or an LRV, and since both represent new vehicles, the question arises as to why the difference in approaches to documentation and testing? A major difference is, of course, historical and is related to the traditional customized approach to rail car procurement. However, since a goal of the SLRV program has been vehicle standardization, this factor can be somewhat discounted.

TABLE 5.2: COMPONENT/SUBSYSTEM ACCEPTANCE/QUALIFICATION TESTS

COMPONENT OR SUBSYSTEM	QUALIFICATION TESTS		ACCEPTANCE TESTS	
	DESCRIPTION	NUMBER OF UNITS	DESCRIPTION	NUMBER OF UNITS
Traction motor	Performance test Vibration test Noise test	5 1 Not specified		
Traction gear	Endurance under load Noise test	1 Not specified	Performance under load	5% of units
Motor generator/alternator	Performance/duty cycle	Not specified	Performance/duty cycle	Not specified
Battery	Performance test	1		
Friction brake	Response & linearity Dynamometer test Proof pressure test Fatigue Endurance Environmental	1 1 1 1 1 1	Proof pressure test In-service reliability	All units 50 units
Parking brake	Force to move car	1		
Brake controller	Voltage extremes	1	Proper operation	All units
Propulsion controller	Voltage extremes	1	Proper operation	All units
Complete propulsion system	Performance test	1	In-service reliability	50 units
Tracks	Static load test with strain gauges Fatigue test Pressure test Shock & vibration test	1 - 2 1 - 2 1 - 2 1		

TABLE 5.2 : COMPONENT/SUBSYSTEM ACCEPTANCE/QUALIFICATION TESTS (Continued)

	QUALIFICATION TESTS		ACCEPTANCE TESTS	
COMPONENT OR SUBSYSTEM	DESCRIPTION	NUMBER OF UNITS	DESCRIPTION	NUMBER OF UNITS
Coupler and draft gear	Buff loading Deflection & emergency release Casting static load Gathering range/mechanical coupling Electrical coupling Coupler assembly wear & life	Not specified Not specified Not specified Not specified Not specified Not specified		
Auxiliary electrical and control			In-service reliability	50 units
Under car equipment	Noise test	Not specified		
Doors	Noise test Endurance test	Not specified 1 of each type	In-service reliability	50 units
Air conditioning	Environmental chamber test	1		
Heating system	Environmental chamber test	1		
Windshield	Impact test	1		
Car body	Load test - compression	1		
Pantograph	Load test - vertical	1		
Diagnostic test set			High potential	All units
Packaged components	Tested as part of QA program		Performance checkout	All units

TABLE 5.3: COMPLETE CAR ACCEPTANCE/QUALIFICATION TESTS

QUALIFICATION TESTS		ACCEPTANCE TESTS	
DESCRIPTION	NUMBER OF UNITS	DESCRIPTION	NUMBER OF UNITS
Clearance test	1	Weighing	All units
Weight distribution	2	Water tightness	All units
Light intensity	1	Wiring continuity	All units
Radio interference	2	Insulation resistance	All units
Ride quality	2	High potential	All units
Vibration test	1	Vehicle dynamic performance	All units
Maintainability test	1	In-service reliability	50 units
Vehicle dynamic performance	2		
Energy consumption	1		
Wayside noise	Not specified		
Interior noise	Not specified		
Noise transmission loss	Not specified		

OTHER MANAGEMENT RELATED REQUIREMENTS

Carbody stress analysis
Front end mockup - fullscale
Door & steps mockup - full scale
Under floor arrangement - full scale
Pueblo testing

Some consultants and authorities view the elaborate testing and review prerogatives as necessary, and cite the problems with the Boeing Vertol SLRV as justification. An alternative perspective questions why the expenditure of all this additional money and time failed to head off the many problems which have occurred.

From discussions with all parties, the major SLRV problem appears to have been the development of a completely new piece of equipment without benefit of the prototype stage, in which developmental problems can be detected and corrected. This problem was aggravated since the supplier had no prior experience in the building of any rail equipment. Consultants and authorities have viewed the testing and documentation requirements as means to enforce performance from the supplier. The evidence is that their attempt to do this has not been completely successful. In any litigation, the heavy involvement of the authority and its consultants in review and monitoring activities can only complicate their efforts to recover damages.

The conclusion would seem to be that if the procurement involves a proven supplier building a traditional design of rail car, then such controls are unnecessary. If the procurement, on the other hand, involves an inexperienced supplier developing new equipment, the controls will not be sufficient to prevent serious problems from developing, and insertion of a prototype stage into the project will be necessary. In short, testing and approval requirements in the SLRV specification seem to be enough to harrass and add cost to the supplier, but not enough to assure the desired product to the purchaser.

In discussions with consultants and authorities a modified approach to testing has emerged which is consistent with the present UMTA movement to rail car standardization at the subsystem level. (ref. 29) The approach would involve certification of major components and subsystems for transit use, after qualification testing at Pueblo or the supplier's facility, or by a documented record of satisfactory revenue service in rail applications. Certified components could then be used in a light rail procurement without added qualification testing. Actual program testing would be limited to acceptance testing of completed vehicles. If a manufacturer wished to use unproven equipment, it would be necessary to conduct the required qualification tests to obtain certification. Boeing Vertol has estimated the savings in testing at $2,152,000 or, for a 100 car order, $21,520 per car. (ref. 30) This approach appeared acceptable to all concerned parties interviewed including staff from Boeing, SNV, Klauder, Kaiser and the MBTA, providing equipment has been proven in hard revenue service. (ref. 31, 32, 33, 34) In the words of Klauder staff "Successful experience would be defined as documented proof that the subsystems provided meet the reliability requirements spelled out in the spec and this does not mean qualification by similarity to some remote, obscure, and/or unrelated equipment." (ref. 35)

There was also general agreement that data submittals should be adequate for materials, flammability and other routine tests. Klauder stated that while the specification calls for tests, such submittals were in fact accepted in some cases for the Boeing Vertol SLRV. (ref. 36)

With regard to specific requirements, those interviewed favored retention of the vehicle stress analysis, at least on the first order of a particular type vehicle. There was no unanimity on testing of the air conditioning and heating system using a climatic chamber. Staff from the MBTA and the equipment supplier thought an in-service test might be acceptable. Klauder felt the chamber test should be retained, citing the poor performance of the MBTA SLRV air conditioner as proof of need for the test, although the same evidence could alternatively be taken as indicating the test was ineffective. The Advanced Design Bus specification does not require an environmental test chamber. Air conditioning in the Advanced Design Bus is tested by placing heaters on board the vehicle to raise the temperature to a point where the air conditioning becomes fully operable. (ref. 37) Such an approach is certainly hundreds of thousands of dollars less expensive, unless a cold chamber of the necessary size is available at the manufacturer's facility.

With regard to the requirement for full size mockups, there was general agreement that mockups were useful, especially the undercar mockup which is used to locate equipment. Boeing Vertol felt the mockup could be deleted if a prototype development stage were inserted into the program. (ref. 38)

5.6 DOCUMENTATION REQUIREMENTS

The specification prescribes a detailed procedure for submission and approval by the purchaser or his consultant of a broad range of technical documentation. According to Boeing Vertol these requirements have resulted in a cumbersome and time consuming administrative burden which has contributed to the high cost of the SLRV. Boeing estimates that approximately $7200 per vehicle could be saved on a 100 car order if these documentation requirements were streamlined and simplified. Essentially Boeing Vertol recommends that, in lieu of the existing piece-meal detailed review and approval process, a series of critical design review meetings be scheduled, at which time the purchaser and his consultants can review the significant design features and authorize the manufacturer to proceed with production or direct that modifications be made, as circumstances dictate.

The MBTA and SLRV consultants Louis T. Klauder & Associates and Kaiser Engineers consider that review and approval of the supplier's designs are essential to ensure that the end product meets the contract requirements. In varying degrees they acknowledged that some relaxation of the approval process would be acceptable, but cited that despite the detailed review, serious problems have developed. Because of these differences of opinion among those involved with the LRV Program, considerable care will be necessary in devising improved documentation and review procedures.

At issue appears to be the basic procurement approach adopted for this major car order for two separate operating transit systems. The specification requires the supplier to design the equipment to satisfy very detailed performance requirements. Design and other technical drawings must be approved by the purchaser before any production can be initiated, and the Purchaser's technical consultants are charged with the responsibility of conducting a meticulous review before approvals are granted. This automatically results in a time consuming procedure with inevitable disputes over differences of opinion and judgment calls. The manufacturer believes that in certain cases the purchaser's consultants have imposed unrealistic demands and have been slow in acting on requests for approval. The purchaser and his consultants on the other hand sincerely believe that only as a result of their vigilance has acceptable equipment been produced.

It is the judgment of NDL that the procurement philosophy employed for the current SLRV program for Boston and San Francisco should be re-examined critically to determine how best to relieve the manufacturer of the burden of detailed design reviews, while at the same time insuring that the purchaser's legitimate right to approve significant design features are preserved. The critical design reviews suggested by Boeing are worthy of consideration but other techniques employed on procurements of comparable scope and complexity should also be investigated to determine whether significant benefits could be achieved. Among the several procedures which could be employed are two alternative approaches which appear worthy of consideration:

a. Performance Specification with Detailed Design by Manufacturer

Under this arrangement, manufacturers would be invited to submit a two or three stage bid involving separate prices for (1) preparing and submitting detailed design drawings and specifications, (2) fabricating 2-5 prototype vehicles for demonstration and acceptance testing, and (3) manufacturing the required number of final production vehicles. The vehicle design would be owned by the transit operating authority or the Federal Government and could be used later for subsequent procurements. The operator would have the option of terminating the contract at the completion of either the design or the prototype testing stage, should circumstances dictate.

b. Detailed Plans and Specification by the Operating Transit Authority

This procedure involves issuing very detailed design drawings to prospective manufacturers in much the same manner as State and Municipal Highway or Public Works Departments do for major construction projects. Under such an arrangement, the role of the Architect/Engineer on construction projects could be assumed by one or more operating authorities or by consulting firms or a combination of both, utilizing pooled experience with a variety of transit vehicles. The initial development of the PCC car is an example of how such a procedure could be successfully implemented. Alternatively, a non-proprietary design developed by a manufacturer as outlined above, could be used as the basis for a bid solicitation.

It is NDL's view that a more straightforward procurement process would result in significant savings in cost. Boeing's estimate of $7200 per car is considered to be quite realistic. In NDL's opinion, other manufacturers less geared to documentation requirements than Boeing might place a significantly higher value on the potential savings to be achieved from streamlining the design documentation and review process.

5.7 PASSENGER COMFORT

A number of possible modifications to the specification were concerned with passenger comfort. The present specification is explicit when describing the relevant comfort criteria. The areas of the specification which consider passenger comfort include the following:

- Noise
- Light system
- Passenger environment
- Ride comfort

Noise

The overall interior noise level was specified not to exceed 65 dBA at all locations at least one foot from any car body surface. This was to be measured under normal conditions with all auxiliary equipment operating. In addition, specific maximum noise levels are described for different subsystems and equipment.

The present SLRV is not in compliance with the overall maximum 65 dBA interior noise level, and this requirement has been relaxed in the "As Built" specification. It was recommended that this noise criteria be changed to 72 dBA $\pm$ 2 dBA. There was agreement between all interviewed transportation specialists that this change is acceptable and would have only negligible impact on passenger comfort.

There was disagreement on the suggestion to eliminate all requirements for equipment and subsystem noise levels and to retain only overall vehicle requirements for noise levels. Klauder representatives maintain that the specification should remain as written. Other transportation specialists found the change acceptable and anticipated no negative performance impact. The Klauder representatives were concerned that once a device is designed, built and installed on a vehicle it would be virtually impossible to change it to meet overall vehicle noise criteria. Boeing Vertol engineers reported significant cost impact caused by an effort to meet specific noise requirements for equipment and subsystems, which were not necessary to achieving the overall vehicle noise limit.

Because noise output is not simply additive, there is no assurance that individual specification of maximum noise levels for equipment and subsystems will provide for meeting an overall specified noise level. As the vehicles which are being built now show, the intended goal of the present specification to achieve a low overall noise level by specifying equipment and subsystem noise levels was not achieved. The "as-built specification" limit had to be raised by 7 dBA. Specifying only the overall vehicle requirements for noise would allow the developer/manufacturer more latitude to trade off noise impacts at the equipment and subsystem level in a way which is the most practical and economical.

A key deficiency of the present specification is that no criteria are imposed concerning noise levels when negotiating curves, despite the fact that wheel squeal on curves is the most serious noise source for light rail vehicles. Use of a performance specification for noise on curves, in place of the current requirement for use of resilient wheels might allow the use of wheels with damping rings or even steel wheels with aluminum rims as on the BART vehicles. Tests performed at SEPTA showed that ring-damped wheels effectively reduce wheel squeal. (ref. 39) (However, with age the damping rings become frozen in the grooves and the damping effect is lost. Additional research is being undertaken where the rings are being made from other materials and mounted so that they do not become frozen to the groove with age.)

Interior Lights

The specification requires that the passenger section, except in the articulation unit, shall be illuminated by continuous fluorescent fixtures mounted in the ceiling above the seats. It is further required that the lighting intensity be 35 foot candles at the reading plane and 20 foot candles at the floor. Additional incandescent step-well lights were required in the side walls of the step-wells on the basis of one per door panel.

Several changes were proposed to the technical specifications covering the lighting systems. Boeing Vertol proposed elimination of the step-well lights. Their basis for this suggestion was that the design requirement for illumination of step areas and at the ground level outside of the door areas, according to the requirements in the Federal Register, (Vol. 41, No. 85, Part 609-Transportation for Elderly and Handicapped Persons) could be met by the overhead interior lighting only. This change, however, would result in only small savings. Additionally, there is some question whether the requirements for outside illumination would in fact be met without step-well lighting.

Some savings could be achieved by reducing the required lighting intensity and allowing the use of only one line of fluorescent light fixtures along the center of the ceiling instead of the two rows of lighting presently required by the specification. This change could be combined with the elimination of the requirements on maximum brightness ratios such as 40/1 between fixtures and ceiling and 10/1 between fixtures and walls. Other specifications on types of interior materials, finish, and color do not appear to be coordinated with such brightness ratios. Only one of the interviewed parties (Klauder) opposed a reduction of lighting intensity, quoting the recommended "normal reading" light intensity from the IES Lighting Handbook of 30 foot candles. It should be noted here that the 35 foot candle requirement was not met.

There was agreement among light rail transportation specialists commenting that a single row of lights down the middle of the vehicle would interfere with even light distribution because lighting for seated passengers would be blocked by standees. In addition, use of a single row of lights would require design modifications to the normal configuration for air conditioning diffusers.

Environment

Air conditioning is optional in the present specification. For cases where the option is exercised a detailed air conditioning specification is provided. The consensus was that the present specification is generally reasonable and does not require major changes.

It may be practical to reduce the required fresh air intake by accounting for fresh air which naturally passes through open doors. This would reduce the cost for air conditioning equipment. Presently, fresh air is specified to be 30-40 percent of the total, while Chicago rapid transit cars now being built use only 15 percent fresh air, even though they also must operate in tunnels. The high light rail fresh air intake requirement, more than twice that of the Chicago vehicles, was defended by the interviewed transportation specialists as being necessary to provide adequate fresh air in the event of vehicle malfunction and resulting delay inside tunnels.

Ride Comfort

The light rail vehicle ride quality requirements are quite stringent and result in what is generally acknowledged to be an excellent ride. There was some concern that these requirements may have added to truck and suspension costs. Discussions with Boeing Vertol, Kaiser, Klauder and the MBTA, did not indicate that this had been the case. Two reservations should be cited. First, to obtain a smooth ride, Boeing Vertol has used what is known as a "stiff truck." This implies heavy yaw damping. By comparison the PCC truck is quite free to swivel. There is some concern that the trend to stiff trucks, which are desirable for high speed ride quality, may contribute to truck derailments in switches and tight radius turns. The second reservation concerns the deletion of air suspension which would be necessary if an all-electric or electrical hydraulic vehicle were built. It is quite possible that a coil spring suspension could not meet the stringent LRV ride quality specifications, so that relaxation might be necessary to achieve the savings from deletion of the compressed air system. (See section 5.3.)

5.8 DYNAMIC PERFORMANCE

Specifications for dynamic performance affect some very significant vehicle subsystems, namely, propulsion and brakes and their control. These subsystems alone account for approximately 35 percent of the vehicle's total cost. The review of the specifications, structured interviews, and evaluation of rating forms indicated some areas where requirements for close control of performance may have influenced the choice of propulsion and brake equipment and required the addition of other sophisticated sensing and control hardware.

Compared with conventional rapid rail equipment, LRV's operate under a much wider range of conditions. This means that an LRV should not be designed for a narrow high performance range. The LRV driver must react to a wide variety of situations. As a result the driver must have considerable operating flexibility so that highly automated features, such as precise control of speed and acceleration and braking profiles, are of much less value than they would be for conventional rail equipment.

This section highlights those areas of the specification dealing with performance where cost savings might be achieved.

Performance Control Tolerances

The present specification requires high performance and tight control of acceleration and braking. The higher acceleration performance allows the SLRV to attain a speed of 50 mph in about the same time as the PCC car could reach 36 mph. (ref. 40) Tight control of performance allows the vehicle to achieve a more constant performance over the speed range and for varying load conditions. Examples of the tight tolerances specified are as follows:

- Deviation from nominal full acceleration rate of 2.8 mph shall not exceed 10 percent.

- Jerk adjustable between 2.0 to 3.0 mphpsps and set at 2.5 mphpsps ± 5%.

- Modulation within a power or brake mode not to exceed 0.2 sec in response to a step input.

- Response time for mode change not to exceed 0.5 sec.

- Slip/spin control not to exceed 0.1 sec in response to a step input.

These tolerances basically dictate inclusion of other more sophisticated equipment as follows:

- Load weigh feedback to control acceleration and braking rates in response to changes in vehicle loads.

- Hydraulically actuated brakes to decrease brake response time.

- Adjustments of speed sensors for wheel wear to provide accurate speed sensing.

Load weigh is probably the most essential of these requirements influenced by the tight control tolerances. By adjusting for load variations, more uniform performance is achieved. It also provides greater control of jerk and stopping distance, particularly where Automatic Speed Control is used. Load weigh is also important to the control of multiple units, where the loads on each car may be different. Unless some form of propulsion thrust equalization is provided, buffing could cause jerky performance. Also wheel slip/spin in a lightly loaded following car might go undetected by the operator and cause excessive wheel and rail wear. The basic idea is to relieve the operator of this fine tune control. On PCC cars the series wound motors have a torque speed characteristic which tends to inherently compensate for propulsion differences due to load variations between cars. Separately excited motors, as used on the Boeing SLRV, can be designed to have characteristics that will also provide this type compensation. However, in either case, compensation is derived inherently as a function of the motor current and RPM and not based upon actual acceleration levels. This places a limit on such a form of implicit acceleration control. When tighter control is required, it becomes necessary to provide it through additional active control, sensing the variations in vehicle load.

Air actuated brakes cannot meet the tight response time specified. While electric brakes can meet the response time, they usually cannot provide the necessary capacity to meet other specifications for duty cycle. Therefore, air controlled hydraulic brakes are implicitly specified by a combination of the required response time and duty cycle. This increases costs by requiring additional hardware such as a pneumatic/hydraulic booster for each truck and the associated hydraulic lines and valving.

Adjustments must also be provided in the speed sensing equipment to compensate for wheel wear. Such adjustment is necessary to meet the performance specified for the Automatic Speed Control. All respondents interviewed considered that compensation was necessary to meet specific control tolerances (i.e., propulsion control and compatibility of performance in trains).

Not only are the car costs increased by the necessity to provide more sophisticated equipment, but provision of the extra equipment increases maintenance requirements. Moreover, the greater the complexity, the more it taxes the skills of maintenance personnel, increases the burden for training programs, necessitates preparation of expensive maintenance manuals, and increases the need for diagnostic test equipment.

Propulsion Control

There appears to be no bias in the current specification for either chopper or cam/resistor propulsion control. Both types are allowed. Current pricing shows that the cost of the entire propulsion system can be as high as $30,000 more when chopper control is used. Hard data is not yet available on the energy which might be conserved when regenerative braking is employed through application of the chopper.

Besides being more expensive, chopper control increases the weight. For example, comparisons of weight differences for cam versus chopper control for the State-of-the-Art Car (SOAC) showed that the chopper could increase car weight by almost 1000 pounds. (ref. 41) Use of the chopper may also increase other costs such as the need for automated diagnostic test equipment.

Consideration should be given to specifying cam control for a standard LRV because of the large potential savings that can be achieved. Substitution of the chopper should be left as an option for the owner.

Automatic Speed Control (ASC)

The form of ASC specified for the SLRV is not provided to regulate speed per sé but rather to enforce compliance with speed limits. For Boston the ASC imposes a simple speed limit. If the operator exceeds this 50 mph limit by 2 mph brakes are automatically applied. Between 50 and 52 mph the operator is given a fixed time interval to reduce his speed. If he fails to do so within this time, brakes are also automatically applied. For San Francisco the ASC is coupled with the cab signalling equipment so that the speed limits can vary from control block to control block.

Klauder considered that ASC was essential when cab signals are employed to ensure safety. All respondents agreed that Automatic Train Protection (ATP) was necessary for exclusive rights-of-way and in tunnels. For other installations such as semi-exclusive rights-of-way or street running, ATP and ASC are unnecessary. Kaiser pointed out that ATP can be implemented where necessary through the use of wayside aspect signals, eliminating the need for cab signalling and ASC. For these reasons NDL recommends that ASC not be included in the "standard" specification but be left as an option to fit the needs of the owner.

Overhead Power Collector

Overhead current collection is specified by use of a pantograph or trolley poles. However, the special provisions for both MBTA and MUNI cars specified that production vehicles be equipped with pantographs. Only the first three (pilot) vehicles for the MBTA were to be equipped with trolley poles.

The relative merits of pantographs versus trolley poles were discussed during the interviews in regard to potential cost savings. Boeing stated that trolley poles would be less expensive but that their electrical current capacity (450 amperes continuous) could not meet the duty cycle needed for the SLRV (650 amperes rms). They also considered the trolley pole configuration to be a simpler design. Providing that the duty cycle could be reduced to the current capacity of a trolley pole, Kaiser agreed to specifying trolley poles over a pantograph. Klauder said they would prefer a trolley pole particularly if the car were to be unidirectional. The MBTA believed the selection should be an option of the authority. Klauder also cited potentially higher costs of maintenance of the overhead where trolley poles are used. It should also be pointed out that the overhead for trolley poles is different from that for pantographs and more expensive (i.e., "special work" requirements at intersections, merges and turnouts). However, where an existing system's overhead has been designed for trolley poles, as was the case in Boston, conversion to use of pantographs involves considerable expense for overhead modification.

5.9 CLARIFICATION OF REQUIREMENTS

In reviewing the specification with the parties who had to work directly with it, comments were voiced concerning ambiguities or lack of clarification in certain areas. Not all of these changes would reduce vehicle costs. In some cases, such as better specification of maintainability requirements, the result could be an increase in costs. However, the consensus was that clarification in the following three areas would reduce misunderstandings, improve the climate of relationships between the various parties, and possibly reduce life cycle costs by producing a better vehicle.

One area mentioned was more specific definition of maintainability requirements. At present, the specification is quite general, asking that "maximum consideration to maintenance, troubleshooting, component removal, repair and inspection shall be given in the design of the vehicle" and providing some general design guidelines. Subsequently a maintainability test is required on one of the completed vehicles including a demonstration of troubleshooting procedures, component replacement, system calibration and adjustments, removal of a truck, and separation of the vehicle at the articulation section. Apparently there was considerable disagreement concerning what constituted adequate maintainability, and a number of those interviewed suggested the specification provide target numbers for time to perform some of these activities.

Another area where clarification may be desirable is in definition of the vehicle operating environment. The specification requires that "The Light Rail Vehicle shall be designed and manufactured to operate successfully within the intended environment of city streets, private right of way, and subway operation." Nowhere is this environment specified in terms of track alignment, profile and general condition, or the presence of severe environmental problems such as dust particles in subway areas which contain high iron content. While some parties interviewed believed a knowledgeable supplier should have expected iron dust in the tunnels, it would certainly have been desirable had the specification warned of this hazard. In general, more specific delineation of the operating environment, along the lines of the recent Miami/Baltimore railcar specification, is highly recommended.

A third area requiring clarification is the definition of "fail-safe" in Section 2 of the SLRV specification. Considerable confusion resulted from the statement "All operating equipment affecting personal safety and forming a part of the vehicle shall be designed to operate in a fail-safe manner as approved." Subsequently, the as-built SLRV specification provided a page of definitions indentifying the state known to be safe for a variety of vehicle functions. To reduce confusion, it is recommended that these modifications concerning failsafe design be incorporated into the SLRV specification for future procurements.

6.0 ESTIMATED COST SAVINGS FOR SELECTED SPECIFICATION MODIFICATIONS

The previous chapter has reviewed the many potential cost reduction areas identified during this study. As was explained in Chapter 4 of this report, twenty of the promising proposed changes to the SLRV specification were selected for a quantitative assessment of the expected cost savings. This chapter summarizes the cost analysis and its results. The purpose for this task was not only to obtain estimates for each of the particular cost areas, but to get a general idea of the overall vehicle cost savings which might be achievable by making changes to the specification.

Method of Analysis and Sources for Cost Information

Eleven of the twenty cost reduction areas were directly assessed by NDL. The other nine were estimated by Boeing Vertol engineering staff. These Boeing estimates were reviewed by NDL. In addition, independent order of magnitude estimates for most of the twenty areas were contributed by engineers from the Chicago Transit Authority.

Cost data was obtained from a variety of sources. Spare parts costs for the Boeing Vertol SLRV were obtained from that company's bid submissions to the Greater Cleveland Regional Transit Authority (GCRTA) for light rail equipment, and from a capital grants application submitted by the MBTA requesting funding for additional SLRV spare parts. Since costs for spare parts are generally marked up significantly, these costs could not be used directly. Original equipment costs were obtained from suppliers, and from review of the detailed cost estimates prepared by Boeing Vertol for this study. By this means, it was possible to establish a spare parts markup factor which was used to convert spare parts costs into new car costs. Further cost information was obtained from discussions with Chicago Transit Authority engineers. Boeing Vertol staff, beyond preparing nine of the estimates directly, were also continually helpful in response to specific questions.

Another approach to cost estimates made use of a variety of both published and unpublished (sometimes proprietary) reports concerned with vehicle costs. Published reports included a subsystem level vehicle cost estimate prepared for the State-of-the-Art Car, a rapid rail vehicle developed by UMTA. (ref. 41) Data from these sources was used to develop cost per pound estimates for typical categories of rapid rail equipment. These estimates were used in conjunction with the light rail vehicle weight budget to estimate subsystem and major component costs as a check on figures derived from spare parts or vendors. Final sources of information were the light rail vehicle engineering drawings. Drawings were requested from Boeing Vertol related to all equipment to be costed. The drawings and associated bills of materials were used to estimate costs for standard elements, such as window glass and paneling, based on square footage or related dimensional parameters scaled from the blueprints. In addition, the number and complexity of drawings served as a guide in estimating non-recurring engineering and manufacturing cost estimates.

In this manner, using a variety of sources, estimates of savings were obtained for all twenty potential cost reduction areas.

Operational Impacts of Cost Reductions

The major emphasis of this study was upon reductions in light rail vehicle first cost; although, as has been outlined in Chapters 4 and 5, careful attention was paid to identifying adverse impacts on performance and operating costs. In evaluating the twenty potential cost reduction areas, it was useful to divide them into two categories. The first category includes those cost reductions judged to have potentially acceptable performance impacts. In this class were placed those changes where the service requirement impacts were either clearly acceptable (for example, elimination of plug doors), or where the assessment involved intangibles which precluded a precise determination of adverse impacts. Examples of the latter include changes to the procedures for reliability verification, program documentation, and testing.

The second category of cost reduction areas was composed of those with major, clearly indentifiable performance impacts. These changes include uni-directional cars, doors on only one side, a less stringent brake duty cycle, elimination of the articulation section, and elimination of compressed air. To provide some feel for the operational impacts involved, cost estimates accounting for factors other than vehicle savings were prepared for two situations; a unidirectional vehicle with doors on only one side, and a four-axle car with no articulation section. These analyses include impacts of the change on required fleet size, maintenance costs, track switching and interlocks, and right of way requirements. While not exhaustive, the analyses indicate the types of operational trade-offs involved, and suggest that even considering the adverse mission impacts, some of these areas may well be worthy of serious consideration.

General Assumptions

In performing the cost analyses, certain assumptions were commonly used including the following:

a. labor costs for assembly and installation was taken at 12% of the cost of the elements involved;

b. the wage rate for labor used in manufacturing was estimated at $14-$18 per hour;

c. engineering costs were estimated at $33 per hour or $3200 per assembly drawing;

d. based upon considerable analysis, 44% of the cost of spare parts was generally deducted to arrive at original equipment costs (this ratio was adjusted somewhat for particular types of equipment);

e. a vehicle order of 100 units was assumed in assigning nonrecurring costs on a per vehicle basis.

In assessing operational impacts the following operating scenario was assumed:

a. fleet size of 70 cars
b. interest rate 10% - constant dollars
c. route length of 40 track miles
d. twenty curves less than 125 feet in radius
e. six switchbacks or turnbacks including two at the ends of the route and four enroute
f. cost of right of way - 0-$50 per square foot

6.1 MODIFICATIONS WITH POTENTIALLY ACCEPTABLE PERFORMANCE IMPACT

Of the 20 specification modifications selected for quantitative cost analysis 15 were identified which would have potentially acceptable performance impacts. The following are the cost savings estimated for each of these modifications.

Curved Tapered Car Body Ends and Plug Doors

Presently the contract drawings show curved car body sides and require plug doors. It is suggested that restrictions on the exterior car body lines which complicate the end door and forming of body side panels be relaxed and that only clearance envelopes be specified. This would allow a car with tapered ends to be designed with straight side panels as is done for many European designs. In addition, folding doors would be specified rather than plug doors. Sliding doors would also offer an acceptable and less expensive alternative to plug doors. This cost estimate, however, assumes the specification of folding doors throughout.

Use of folding doors and straight car body sides have the following advantages:

- Utilizes straight door tracks
- Utilizes common design and hardware--all door panels are the same
- Utilizes simpler modular design--permits pre-installation checking
- Utilizes standard off-the-shelf components
- Simplifies tooling design
- Replaces the articulated mirror with a fixed mounting
- Eliminates need for separate locking actuator--utilizes over center lock
- Utilizes 80 percent fewer parts
- Simplifies body structure design

Table 6.1 summarizes the cost savings which might be realized. Savings are approximately $31,300. Nonrecurring cost savings are significant. This is an example where costs are decreased by specifying standard hardware. In this case qualification testing alone makes up 55 percent of the nonrecurring cost savings. The greatest cost savings are derived from use of a common blinker door system module throughout the car, which reduces the parts count by 80 percent and reflects as 81 percent of the potential cost savings. The folding doors are much easier to install, representing 14 percent of the estimated cost savings.

TABLE 6.1: COST SAVINGS BY USING FOLDING DOORS AND STRAIGHT SURFACES AT TAPERED BODY ENDS

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Design, 5 drawings @ $3,200 each	$16,000	
Tooling design & fixtures	10,000	
Qualification testing of front door	49,200	
Mockup planning, fabrication, assembly, and installation	15,000	
TOTAL	$90,200	$ 902
RECURRING COST SAVINGS		
Materials Saved		
Car body (flat panels) fabrication		$ 400
Common blinker door system used front and sides saves 80% in parts		25,275
Replace articulated mirrors with fixed rear view mirrors		350
TOTAL		$26,025
Labor Saved		
Door module installation cost reduction 6 doors @ $720 each		$ 4,320
Mirror installation		5
TOTAL		$ 4,325
NET COST SAVINGS		$31,252

Separate gross cost estimates were provided by Chicago Transit Authority (CTA) engineers who suggested that $10,000 to $20,000 could be saved by eliminating the plug doors and $5,000 to $10,000 could be saved for simple sheet metal shapes. These estimates total to a range of $15,000 to $30,000 per car and are comparable to the detailed estimate of Table 6.1.

Simplified Propulsion Controls

The present specification allows use of either chopper or cam/resistor propulsion control. Potential cost savings are anticipated if cam/resistor control is specified. The specification also include an Automatic Speed Control for the San Francisco cars which works in conjunction with the cab signals. The ASC is considered to be important only where cab signals are used; therefore, they should be optional and not included with a standard specification. In addition, the specification requires high performance acceleration and braking with tight control tolerances. These stringent performance specifications dictate the use of hydraulically actuated brakes which might be eliminated were control tolerances relaxed. Due to the nature of LRV operations, performance specifications could be relaxed for many applications, affecting braking and propulsion requirements.

Table 6.2 indicates a total of approximately $18,000 in cost savings which might be realized if cam/resistor control were specified, ASC eliminated, and the hydraulic brakes deleted. CTA engineers estimated these savings at $20,000 per car.

Elimination of chopper controls in favor of cam/resistor control represents 67 per cent (approximately $12,000) of the total cost savings. Discussions with a representative of the General Electric company indicated that the potential savings might be as high as $25,000 to $35,000, but estimates from other sources were considerably lower. A representative from Westinghouse indicated that the savings would be approximately 10 percent of the cost of the chopper controlled propulsion system. In a

TABLE 6.2: COST SAVINGS BY SIMPLIFYING CONTROLS

A. DELETE OPTION FOR CHOPPER CONTROL - REQUIRE CAM/RESISTOR CONTROL

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Primary vehicle engineering, planning, mockups, etc., are expected to be the same		None

RECURRING COST SAVINGS

Telephone conversation with GE - cam $25,000 less than chopper

Telephone conversation with Westinghouse - Save 10% of total propulsion system, including motors, gear boxes and controller.

DÜWAG quoted $12,150 saving for cam control on their LRV bid to Cleveland

MBTA spare parts costs reduced by ratio of 1.8

Chopper controller and resistor assembly	$ 48,333
2 propulsion motors	33,333
Gear boxes	22,222
TOTAL	$103,888
Brown Boveri supplied propulsion sets to Breda for Cleveland LRV's	$140,000
1. Savings of 10% of $103,888 (MBTA)	$ 10,389
2. Savings of 10% of $140,000 (Brown Boveri)	$ 14,000
3. DÜWAG quoted savings	$ 12,150

NET COST SAVINGS

Average of 1., 2., and 3., above (Materials - $10,875, Labor - $1,305)	$12,180

NOTE: The above estimated average cost saving is considered to be conservative with respect to GE quoted cost savings.

B. DELETE AUTOMATIC SPEED CONTROL (ASC)

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Engineering, 4 drawings @ $3,200 each	$12,800	$ 128
RECURRING COST SAVINGS		
Materials Saved		
ASC Electronics		$1,750
Indicator Lights Panel, 2 @ $50 each		100
Alarms, 2 @ $50 each		100
Associated wiring to cab signals and cab console		200
TOTAL		$2,150
Labor Saved		
Assembly @ 12% of $2,150		$ 258
NET COST SAVINGS		$2,536

C. DELETE HYDRAULIC BRAKES

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Engineering, 2 drawings @ $3,200 each	$6,400	$ 64
RECURRING COST SAVINGS		
Material Saved		
Hydraulic Boosters, 3 @ $981 each		$2,943
Labor Saved		
Assembly @ 12% of $2,943		353
TOTAL		$3,296
NET COST SAVINGS		$3,360

D. TOTALS (A + B + C)

NON-RECURRING COST SAVINGS	$ 192
RECURRING COST SAVINGS	
Materials	15,968
Labor	1,916
TOTAL	$18,076

recent bid to provide new LRV's for GCRTA (Shaker Heights), DUWAG quoted a savings of $12,500 for substitution of cam/resistor control for the specified chopper control. Brown Boveri is supplying the entire propulsion system to Breda, who was the successful bidder for the GCRTA order, at $140,000 each. Ten percent of this amount would be $14,000. A review of spare parts costs for the MBTA indicates that the Boston SLRV propulsion sets would cost approximately $104,000 each in a multiple car order; a ten percent cost savings would represent $10,400. The average of $12,180 for these three separate cost estimates is only about one-half the savings indicated by the GE representative, and therefore, should be considered conservative.

ASC is provided through additional electronic circuitry in the propulsion and braking Electronic Control Unit (ECU). The ASC receives inputs from the car borne cab signals which are supplied separately by the owner. In addition, the operators console is equipped with speed limit indicator lights and an audible alarm. Costs for the indicator lights and audible alarm were taken from the MBTA spare parts cost list and discounted. Boeing Vertol provided the difference in spare parts costs for ECU's with and without ASC, which was also discounted.

The most significant savings from elimination of hydraulically actuated brakes is attributed to the pneumatic/hydraulic boosters. Costs for hydraulic brake actuators and associated plumbing were considered to be the same as for pneumatic actuated brakes.

Qualification Testing

The current specification requires qualification testing for all critical components and/or subsystems. It was suggested that the specification be modified to require qualification testing only for those components and/or subsystems which have not been thoroughly proven in rail transit revenue service.

Table 6.3 estimates a total nonrecurring cost savings of approximately $1.9 million or $19,000 per car for a 100 car order. These estimates were provided by Boeing Vertol based upon their experience on the current SLRV's. In the event that vehicles were to be purchased whose design was essentially the same as a previous car order, then an additional cost savings of $274,000 could be realized from deleting the combined Systems Lab Test and Tests of Car Body Compression and Vertical Load. In this case the total costs saved per car would increase to $21,520 for a 100 car order.

TABLE 6.3: COST SAVINGS BY SIMPLIFYING QUALIFICATIONS TEST REQUIREMENTS

NON-RECURRING COST SAVINGS	
Qualification Tests Deleted	
DC Traction Motor	$ 270,000
Propulsion Control	220,000
Gear Box	110,000
Static Converter	44,000
Battery	27,000
Friction Brake System	305,000
Truck	222,000
Coupler and Draft Gear	70,000
Windshield	30,000
Doors	215,000
Equipment Noise	76,000
Air Conditioning/Heating Test in Climatic Chamber	289,000
TOTAL	$1,878,000
NET COST SAVINGS (100 cars)	$ 18,780/Car

Diagnostic Test Equipment

Special provisions specified that automated Diagnostic Test Equipment was to be supplied with purchase of the cars. This included a single computer controlled console for use in the maintenance facilities, associated cables for connection to a vehicle and special test points to be incorporated in the vehicles. The chief purpose for the automated equipment was for test and trouble-shooting chopper propulsion controls and other "nonstandard" sophisticated car equipment. Therefore, if the specifications were to be modified to allow a less complicated car, particularly one with cam/resistor control, then the need for a DTE would be greatly reduced. Table 6.4 estimates the cost savings from deleting the requirements for DTE from the specification.

Table 6.4 summarizes the elements saved which total approximately $17,600 per car. Nearly 90 percent of the cost savings are attributed to nonrecurring costs for design, engineering and fabrication of the DTE itself; approximately $1.55 million total or $15,500 per car for a 100 car order.

TABLE 6.4: COST SAVINGS BY ELIMINATION OF THE AUTOMATED DIAGNOSTIC TEST EQUIPMENT (DTE)

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Materials Saved		
2 DTE test carts @ $700,000 each	$1,400,000	
6 pressure transducers @ $500 each	3,000	
TOTAL	$1,403,000	$14,030
Labor Saved		
Less engineering and design of individual vehicle installation, 3 drawings plus 7 revisions	$ 21,600	
Less engineering and design of DTE	120,000	
Mockup planning, fabrication, assembly and installation	10,000	
TOTAL	$ 151,600	$ 1,516
		$15,546
RECURRING COST SAVINGS		
Materials Saved		
Wiring & connectors		$ 157
Pressure fittings & plumbing		443
Revised electronic units & panels 11 receptacles & assorted wiring		1,000
Revised low-voltage power supply 1 terminal board & associated wiring		100
TOTAL		$ 1,700
Labor Saved		
Component installation, 12% of $600		$ 72
Wiring fabrication and installation		314
TOTAL		$ 386
NET COST SAVINGS		$17,632

These cost estimates were provided by Boeing Vertol based upon their recent experience with producing the SLRV's. The recurring costs were mainly derived from deleting plumbing, wiring and receptacles required to provide signal output to the DTE. The recurring costs were only 12 percent of the total savings per car.

CTA engineers estimated that $800,000 in nonrecurring costs could be saved plus $1,000 to $2,000 per car in recurring costs. For a 100 car order this represents a savings of $9,000 to $10,000 per car. These amounts are approximately one-half the estimate given in Table 6.3. The largest difference is the estimate for the nonrecurring costs.

Reliability Requirements

Section 5.4 of Chapter 5 discussed the need for specifying assurance by methods other than the current method of reliability goals, reliability analysis, reliability program plans, and a two-year demonstration. Cost savings were estimated assuming that assurance would be specified through warranty provisions and by providing incentive payments in the contract for achievement of specified levels of reliability. An example would be specifying a maximum failure of 12 percent of a given component in a given year with the penalty that all such components, including the remaining 88 percent must be changed out and replaced with redesigned, more reliable components if the failure rate is not achieved. This is the philosophy of the Chicago Transit Authority for the 200 new cars which Boeing Vertol is presently manufacturing.

Table 6.5 shows the derivation of the cost savings estimated by Boeing Vertol. All costs are of a nonrecurring nature and total $1.33 million or $13,300 per car for a 100 car order. These cost savings are for eliminating the requirements for the reliability analysis and the two-year demonstration program, 62 percent and 18 percent of the cost savings, respectively.

TABLE 6.5: COST SAVINGS BY SIMPLIFYING MEANS FOR ESTABLISHING RELIABILITY

NON-RECURRING COST SAVINGS	
Delete requirement for reliability analysis	$ 820,000
Delete two-year demonstration program	510,000
TOTAL	$1,330,000
NET COST SAVINGS (100 cars)	$ 13,300 car

Documentation Requirements

Cost savings were estimated for specification modifications that would simplify documentation requirements by expediting the drawing review cycle and reducing the need for customer approvals. It was assumed that all documentation is provided to the customer for his information only, without the requirement for formal approvals. Timely delivery of information submittals would be enforced by tying progress payments to delivery. Customer approval of the design would be obtained through several formal, critical design review meetings scheduled to coincide with specified project milestones. At these meetings, supplier staff would explain the design in detail to the customer and his consultants and questions would be freely exchanged. The customer would then provide all his concerns and reservations in writing within a specified period (e.g., one to two weeks). Follow-up meetings would be held to negotiate all issues and design changes.

Table 6.6 outlines the cost savings based upon the experience of Boeing Vertol in designing the SLRV. Savings total approximately $724,000. These are all nonrecurring costs and represent a savings of $7,240 per car for a 100 car order. The two largest cost savings involved changes to documentation and drawings after the mock-up review and changes to test procedures and reports. These two changes accounted for over 80 percent of the total savings.

TABLE 6.6: COST SAVINGS BY SIMPLIFYING DOCUMENTATION REQUIREMENTS

NON-RECURRING COST SAVINGS		
LESS ENGINEERING DESIGN & ADMINISTRATIVE TIME		
Obtain customer agreement on 128 drawings . . .		$ 3,200
Resolve customer comments on submitted drawings		
• Prepare responses on 128 drawings . . .	10,240	
• Customer review meetings	7,680	
• Incorporate agreed-to changes to 64 dwgs	30,720	
• Resubmit drawings for approval, 64 dwgs	2,560	
• Resolve further comments and incorporate changes	15,360	
• Re-release drawings to manufacturing	2,560	
• Replace changed drawings	11,520	
SUBTOTAL		$ 80,640
Obtain customer approval of contractor requested producibility type changes (85 drawings)		$ 54,200
Incorporate changes per customer after mockup review and re-submit for approval		
149 changes	$238,400	
Negotiations	5,120	
SUBTOTAL		$243,520
Obtain customer approval and incorporate changes for qualification test procedures & test reports, acceptance test procedures and other miscellaneous documentation		
120 reports	$288,000	
Vendor coordination, 50 2-day review meetings	54,200	
SUBTOTAL		$342,200
TOTAL		$723,760
NET COST SAVINGS (100 car order)		$ 7,238/car

Resilient Wheels

It was suggested that wheels with damping rings might be substituted for presently specified resilient wheels. Table 6.7 shows an estimated cost savings of $4,800 per 6-axle vehicle. All of this cost savings is of a recurring nature and is the difference between supplier prices for the two different types of wheels. CTA engineers estimated these cost savings at $6,500 per car.

TABLE 6.7: COST SAVINGS IF WHEELS WITH DAMPING RINGS ARE SUBSTITUTED FOR RESILIENT WHEELS

NON-RECURRING COST SAVINGS	PER CAR (100 cars)
No difference in engineering or other costs	None
RECURRING COSTS	
Materials Saved	
Accoustaflex wheels, 12 @ $900 each	$10,800
Materials Added	
Damping ring wheels, 12 @ $500 each	(6,000)
Labor Saved	None
NET COST SAVINGS.	$ 4,800

The damping ring wheel is essentially a standard steel wheel with a groove provided during casting. The damping ring is pressed into this groove at a nominal cost of five to ten dollars. This type wheel is not presently in revenue service in the U. S. Tests were performed at the Southeastern Pennsylvania Transit Authority comparing damping ring wheels with standard steel wheels and resilient wheels. The results showed that ring damped wheels dramatically reduced the wheel squeal noise in short radius curves. However, with age the rings became frozen in the grooves and the noise reduction characteristic is lost. Investigations are presently underway to prevent the rings from becoming frozen by use of different materials for the ring.

Maintenance Manuals

The current specification requires that maintenance manuals be written and assembled to one common format. Estimated in Table 6.8(A) are the cost savings that might be realized if vendor manuals were incorporated directly into the car builders manual. The MBTA SLRV maintenance manuals have 3135 pages of which 2460 pages are concerned with vendor equipment. Approximately 1100 of these vendor related pages were reworked. Drawings constitute approximately 20 percent of the manuals, so that an estimated 880 pages of text and 220 drawings were reworked. Unit prices were developed for reworking text pages and drawings as follows:

Rework Text Page:

4 hrs. engineering & editor time @ $33.32/hr.	$135
Typesetting and layout of 8 1/2 x 11 inch page	25
Total	$160

Rework Drawing:

24 hrs. drafting @ $20.00/hr. (per drawing)	$480

TABLE 6.8: COST SAVINGS ON MAINTENANCE MANUALS

A.	WHERE VENDOR MANUALS AND/OR PAGES ARE DIRECTLY INSERTED		
	NON-RECURRING COST SAVINGS		PER CAR (100 cars)
	Text not reworked, 880 pages @ $160 each	$140,800	
	Drawings not reworked, 220 swgs. @ $480 each	105,600	
	TOTAL	$246,400	$2,464
	RECURRING COST SAVINGS		None
	NET COST SAVINGS		$2,464
B.	WHERE MAINTENANCE MANUALS ARE SIMPLIFIED, USING BOEING VERTOL CTA CAR AS A MODEL		
	NON-RECURRING COST SAVINGS		PER CAR (100 cars)
	Text deleted, 1491 pages @ $160 each	$238,560	
	Drawings deleted, 372 dwgs @ $480 each	178,560	
	Printing (100 copies)		
	1863 pages @ $7/page	13,041	
	TOTAL	$430,161	$4,302
	RECURRING COST SAVINGS		None
	NET COST SAVINGS		$4,302

On this basis the total estimated savings were approximately $246,000 of nonrecurring costs or $2460 per car for a 100 car order.

Table 6.8(B) gives an estimate of the cost savings if a less complicated car were specified, using as an example the new cars built by Boeing Vertol for the CTA. For this example a total of 1863 pages would be eliminated at a total non-recurring cost savings of $430,000 or $4,300 per car for a 100 car order.

Car Body Smoothness Criteria

Presently the specification requires that the car body be constructed of either steel or an aluminum alloy. In the case of aluminum an integrated structure was required. In the case of steel, a totally welded structure was required except that rivets were allowed where welding was impractical. Of particular consequence was the requirement that "no protrusions shall be visible on the side sheets" and that spot welds and rivets where visible "must be ground smooth and filled as necessary so as to be practically invisible to the naked eye upon close inspection after the final coatings of paint have been applied."

It was suggested that the smoothness criteria be relaxed so that all rivets need not be finished to be "invisible" and some protrusions would be allowed. For this cost estimate it was assumed that at least two rows of welds and rivets along each car side would be covered by attached beauty moldings or chrome strips. All other rivets and welds would be ground and filled as currently specified. Table 6.9 shows a net savings of approximately $3,300 per car. The majority of these savings are with respect to the original fabrication and finish -- $1980 or 60 percent of the total. The 40 percent remaining savings were estimated for correction of defects. Approximately 70 man-hours of labor per car has been the experience for correcting surface defects on the current SLRV's.

TABLE 6.9: COST SAVINGS BY RELAXING CAR BODY SMOOTHNESS REQUIREMENTS

NON-RECURRING COST SAVINGS	PER CAR (100 cars)
Little or no difference in engineering costs	None
RECURRING COST SAVINGS	
Materials Saved	
Body filler & primers to cover rivets & welds during body fabrication & finish	$ 300
Body filler, primers and paints to correct defects identified by inspectors	100
Materials Added	
240 ft. of beauty molding to cover two rows of rivets & welds per car side @ $2/ft.	(480)
TOTAL	($ 80)
Labor Saved	
Surface preparation during initial manufacture 120 hrs. @ $18/hr.	$2,160
Correction of defects 70 hrs. @ $18/hr.	1,260
TOTAL	$3,420
NET COST SAVINGS	$3,340

Articulation Section Design

The current specification requires the articulation section to be designed to "present an appearance with respect to the rest of the car of being a single, smooth structure." It was suggested that the specification allow use of an articulation diaphram (bellows) as the outside cover, which eliminates the need for a complicated assembly of overlapping panels.

Table 6.10 shows the elements of this cost savings which total approximately $2700 per car. The majority of the savings are derived from deleting material associated with the overlapping panels and shrouds, which are almost three times as expensive as a bellows. The costs of the materials saved were taken from the MBTA spare parts cost list and discounted. The cost of the diaphram was taken from spare parts costs quoted by bidders for the new GCRTA light rail cars and also discounted.

TABLE 6.10: COST SAVINGS BY SIMPLIFICATION OF ARTICULATION DESIGN REQUIREMENTS TO PERMIT WIDE RANGE OF DESIGN

NON-RECURRING COST SAVINGS	PER CAR (100 cars)
Less engineering, 2 drawings @ $3,200 each . . . $6,400. . . .	$ 64
RECURRING COST SAVINGS	
Materials Saved	
Dome	$ 500
4 panels	1,000
2 top shrouds	500
4 side shrouds	1,000
2 rain gutters	200
Auxiliary hardware	200
TOTAL	$3,400
Materials Added	
Articulation diaphram (exterior bellows)	($ 700)
Diaphram mounting hardware, 56 ft. @ $5.70 ft.	(320)
TOTAL	($1,020)
Labor Saved	
12% of $3,400 - $1,020	$ 286
NET COST SAVINGS	$2,730

Enclosed Operator's Cab

It was suggested that the requirement for complete and locked enclosures of the operator's cab be deleted and that only a modesty panel and curtain be placed behind the operator. In addition, locking covers would be provided for the instrument panel of bidirectional cars.

Table 6.11 gives the breakdown of the estimated cost savings which total approximately $2000 per car. This estimate assumed two cab enclosures, one at each car end. Unit values for the current assembly materials were taken from the MBTA spare parts cost list and discounted. Nonrecurring cost savings were estimated on the basis of data provided by Boeing Vertol. Where vehicles are designed to be unidirectional, the cost savings per car would reduce to approximately $1260.

TABLE 6.11: COST SAVINGS BY NOT REQUIRING ENCLOSURE OF OPERATOR'S CAB

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Less engineering, 5 drawings @ $3,200 each	$16,000	
Tooling design & fixtures	6,000	
Mockup planning & installation	9,000	
TOTAL	$31,000	$ 310
RECURRING COST SAVINGS		
Materials Saved (two cab enclosures)		
2 left hand panels		$ 600
2 door assemblies		800
2 right hand panels		400
2 door tracks and misc. hardware		200
TOTAL		$2,000
Material Added		
2 modesty panels		($ 200)
2 curtains		(100)
2 locking covers for instrument panels*		(200)
TOTAL		($ 500)
Labor Saved		
12% of ($2000 - $500)		$ 180
NET COST SAVED		$1,990

*Applicable only to bidirectional cars

Remote Controlled Destination Signs

The specification requires that all destination signs for vehicles built for San Francisco be equipped with motors and that they be remotely controlled from the operator's console. This includes trainlining to permit the signs in each car of a train to be changed from one operator's console. Costs have been estimated assuming this feature is eliminated and destination signs are changed manually.

The difference in the cost of a manual versus motorized sign was estimated on the basis of weight differences using the MBTA spare parts cost list (discounted) to establish the cost per unit of weight. The cost of the control unit was taken from spare part costs given in bids for new GCRTA light rail cars, also discounted.

Table 6.12 shows that the total estimated savings per car are approximately $1,000. Approximately one-half of these savings are for the remote control unit.

TABLE 6.12: COST SAVINGS FROM DELETING REMOTE CONTROLLED MOTORIZED DESTINATION SIGNS

NON-RECURRING COST SAVINGS	PER CAR (100 cars)
Less engineering & design, 1 drawing @ $3,200	$ 32
RECURRING COST SAVINGS	
Materials Saved	
Difference in cost for signs - motorized versus manual 6 units at $45 each	$270
Destination sign control unit	482
Wiring and other miscellaneous	100
TOTAL	$852
Labor Saved	
12% of $852	$102
NET COST SAVINGS	$986

Stop Request Signs

Four lighted "Stop Request" signs, two per car section, are required to indicate to passengers when a stop has already been requested. This was specified to reduce the annoyance to the operator caused by repeated requests for the same stop. It was suggested that the basic feature could be provided without the stop request signs by inhibiting the chime from sounding after the first one or two requests.

Table 6.13 shows a modest cost savings of $500 per car from this modification. The cost for each sign was taken from the MBTA spare parts cost list for consumable items.

TABLE 6.13: COST SAVINGS BY DELETING STOP REQUEST LIGHTS

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Less engineering & design, 3 drawings @ $3,200 each	$9,600	$ 96
RECURRING COST SAVINGS		
Materials Saved		
Stop request light signs, 4 @ $65 each		$260
Associated wiring and hardware		100
TOTAL		$360
Labor Saved		
12% of $360		$ 44
NET COST SAVED		$500

Windshield

Cost savings were estimated for replacing the currently specified 9/16 inch thick single piece windshield with three pieces of glass, two for the windshield and one to separately cover the destination sign. The cost of the single piece windshield assembly was taken from the MBTA consumable spare parts cost list. Comparisons were made with bus windshields that are specified to be 1/4 inch thick and are larger in size than a two-piece SLRV windshield. The cost of the 1/4 inch thick glass and associated mounting hardware was taken from the MBTA consumable spare parts cost list for current SLRV side windows. These costs were comparable with other data sources for transit car glazing unit costs.

TABLE 6.14: COST SAVINGS BY ALLOWING A THREE-PIECE WINDSHIELD

NON-RECURRING COSTS	PER CAR (100 cars)
Little or no difference in engineering & design costs	None
RECURRING COST SAVINGS	
Materials Saved	
2 single-piece windshields (front & rear) @ \$200 each . .	\$400
2 windshield mountings (sash) @ \$225 each	450
TOTAL	\$850
Materials Added	
2 sets three-piece windhsield (1/4" thick safety plate)	
2 x 21.1 ft.^{2} @ \$5/ft.^{2}	(\$212)
Windshield mounting, 70.4 ft. @ \$5.70/ft.	(401)
TOTAL	(\$613)
Labor Saved	
Assumed to be same as for single-piece windshield	None
NET COST SAVINGS	\$237

Table 6.14 shows a potential cost savings of only about $240 per car, much less than was anticipated by NDL and others during the structured interviews. While the manufacturing cost savings proved to be low, there should be additional savings in materials and labor for replacement of broken glass over the lifetime of the car.

Connectors for Low-Voltage DC Circuits

It was anticipated that there would be cost savings if acceptable multi-pin connectors were used for connecting low-voltage DC cables, rather than the current practice of ring-tongue connections at terminal strips. Table 6.15 shows that instead of a cost savings, specification of connectors could cause a cost increase as much as about $3500.

To estimate the difference in costs where connectors are used it was determined that the SLRV has approximately 2300 low-voltage electrical connections that could be made through multi-pin connectors. It was assumed that no significant cost differences would exist between cable fabrication where the wire ends are terminated with ring-tongues or at the pins of a connector. Therefore, the cost savings would occur during assembly of the car through time saved by simply "plugging in" the connectors. Boeing Vertol estimated that the time required for each single point ring-tongue terminal connection is one minute. For acceptable connectors, a MIL-C-5015 environmentally protected connector and receptacle, averaging 17 pins each, were assumed.

Use of connectors provides the advantage that test points do not have to be specifically provided. Instead electrical connection for these signals can be accomplished by using breakout cables or breakout boxes which are inserted during maintenance between a cable connector and its receptacle. This would save an estimated $2000; however,an increased cost of approximately $1500 per car would still remain.

Boeing Vertol engineers have advised NDL that their cost estimates concur that use of multi-pin connectors will not produce any savings. CTA engineers independently estimated that permitting connectors might save a negligible $200 per car. The advantages of using connectors, therefore, are not in car costs but would have to be based upon the potential for maintenance cost savings.

TABLE 6.15: COST SAVINGS ESTIMATE IF CONNECTORS ARE ALLOWED FOR LOW VOLTAGE DC CIRCUITS

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Cable design engineering	None	
Engineering for special test points	$21,600	
Deletion of special test points from mockup	5,000	
TOTAL	$26,600	$ 266
RECURRING COST SAVINGS (Increase)		
Materials Saved from Removing Test Points		
Wiring & connectors		$ 157
Revised NYAB panel		100
Revised chopper unit		200
Revised electronic control unit		100
Revised propulsion control unit		600
Revised low-voltage power supply		100
TOTAL		$1,257
Materials Added		
Connectors, 135 @ $15 each		($2,025)
Receptacles, 135 @ $15 each		(2,025)
TOTAL		($4,050)
Labor Saved		
Cable manufacturing		None
Installation of cables in vehicle 2300 connection ÷ 60 connections/hr. x $14/hr.		$ 540
Manufacturing associated with test points		314
Assembly associated with test points 12% of $1,257		151
TOTAL		$1,005
NET COST SAVINGS (Increase)		
Where test points are also deleted		($1,522)
Where test points are not deleted		($3,510)

6.2 MODIFICATIONS WITH MAJOR PERFORMANCE IMPACTS

This section includes a summary of the cost reductions for those areas with major, clearly identifiable performance impacts. The nature of these adverse impacts is thoroughly discussed in Chapter 5 of this report. In most cases, this section only provides estimates of the savings in vehicle first cost. However, in two cases an attempt has been made to account for the costs associated with the adverse performance. The two cases were selected because they involve changes which combine exceptional cost savings with severe operational impacts. The first case consists of operation of unidirectional cars with doors on only one side. The second case consists of operation of a vehicle with the same passenger carrying capacity as the present LRV, but no articulation section. This large, four-axle car is assumed limited to a minimum turn radius of 125 feet.

This section is organized to begin by presenting separate estimates for the first cost savings for each of the proposed modifications. The two analyses accounting for the costs of operational impacts follow, drawing upon the other cost estimates as appropriate.

Permit a Unidirectional Car

This modification would permit an authority which did not require bidirectional operation to specify a unidirectional vehicle. Such a vehicle only requires an operator's cab at one end, with savings from elimination of the other operator's enclosure along with all driver equipment, controls, and amenities. The rear destination sign is also eliminated. Additional seating is provided in the space formerly occupied by the cab. Doors are retained on both sides of the car permitting use of both side and center island platforms. Savings from placing doors on only one side of the car, a common feature with unidirectional operation, have been separately costed in the section which follows.

The savings in vehicle first cost, as estimated by Boeing Vertol engineers, have been summarized in Table 6.16. For a 100 car order, these savings amount to nearly $20,000 per car. An independent estimate from the Chicago Transit Authority based on their experience dating back to 1948 is that single ending will reduce vehicle cost by 6 percent. Based on current CTA costs of $300,000 per car, this would be a savings of $18,000, comparable to the Boeing figure.

TABLE 6.16: COST SAVINGS ESTIMATE IF CAR IS MADE UNIDIRECTIONAL

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Engineering design time	$30,000	
Manufacturing & tooling	30,000	
TOTAL	$60,000	$ 600
RECURRING COST SAVINGS (Increase)		
Material Saved from Deleting One Cab		
Instrument panels & cab lighting		$ 565
Cab heating, air conditioning, defroster wipers and washers		$1,210
Replace cab glass, visors & mirrors with standard vehicle glass		1,090
Communications panel		600
Master controller		3,750
1 set head & tail lights		100
Destination & run signs		575
Motorman's seat & console furniture		1,460
Cab enclosure & support structure		4,950
Horn & gong		225
Glare curtains		175
Sand box & sander control		740
Associated wiring relays circuit breakers & misc.		2,400
TOTAL		$17,840
Materials Added		
Additional seating		($ 500)
Lighting fixtures & wiring		(640)
Interior paneling & trim		(750)
TOTAL		($ 1,890)
Labor Saved		
Labor for component installation		$ 1,800
Wiring installation		1,630
TOTAL		$ 3,430
NET COST SAVINGS (Increase)		$19,980

Permit Doors on Only One Side of Vehicle

This modification would permit a city to specify a car with doors on only one side. Such an option would also require unidirectional cars, a modification which was separately costed in the previous section.

TABLE 6.17: COST SAVINGS ESTIMATE FOR DOORS ON ONLY ONE SIDE OF CAR

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Engineering design time	($4,400)	
Manufacturing & tooling	6,000	
TOTAL	$1,600	$ 16
RECURRING COST SAVINGS (Increase)		
Material Saved from Deleting Half of Doors		
Switches, valves and tubing		$ 300
Door panels - (6)		3,600
Actuators - (6)		720
Locking actuators and cams (6)		4,320
Tracks, waist rails and trolleys		5,400
Door relay panels		800
Stepwells and windscreen assemblies		900
Lighting fixtures		390
Articulated mirror		400
Side destination signs (2)		1,000
Hardware, trim panels and wiring		4,500
TOTAL		$22,330
Materials Added		
Baseboard heaters		($ 50)
Car body side skin and structure		(600)
Windows and glazing		(450)
Added seating		(450)
Interior panels and flooring		(3,200)
Stanchion bars and fittings		(150)
TOTAL		($ 4,900)
Labor Saved		
Door installation and testing		$ 3,600
Wire bundle fabrication & installation		2,000
TOTAL		$ 5,600
Labor Added		
Cost of installing window, interiors & seats		(850)
NET COST SAVINGS (Increase)		$22,196

Specifying doors on one side of the SLRV eliminates 6 door panels, actuators and associated equipment, along with the door tracks and guides, stepwells, and electrical relays. Indirectly associated equipment which can be deleted includes special entry lighting, windscreens, destination signs on one side, and a special articulated mirror which operates in coordination with the rear door. Materials added include additional seating, windows, baseboard heaters and additional car body materials and paneling. In preparing these estimates, doors were assumed to be the more expensive plug type as presently used on the light rail vehicle.

The savings in vehicle first cost, as estimated by Boeing Vertol engineers, are summarized in Table 6.17. For a 100 car order, these savings amount to over $22,000 per car. The Chicago Transit Authority independently estimated a savings between $10,000 and $20,000 per car for elimination of doors on one side. In view of the complex plug type doors used on the SLRV, the Boeing Vertol figures agree quite well with the CTA estimate.

Operation of unidirectional cars with doors on only one side would save a total of $42,000 per car. The costs associated with the adverse operational impacts of this type car are discussed later in this section.

<u>Less Strenuous Brake Duty Cycle</u>

The present SLRV friction brakes are required to meet the normal vehicle service brake cycle, even if motor dynamic braking is unavailable. In addition, fifteen full brake applications are required in event of loss of compressor or hydraulic power. A proposed modification was to only require the friction brake to provide several repeat applications in the event of loss of motor dynamic braking, or compressor or hydraulic power. The friction brake would thus serve as an emergency brake, instead of a fully redundant backup service brake.

The primary savings from this change are from the lesser heat transfer demands on the brake, which permit use of a much smaller disc and caliper. In addition, some small savings accrue from the smaller reservoirs required.

Boeing Vertol engineers estimated the savings from these changes at about $10,000 per car on an order of 100 cars.

Table 6.18 summarizes the basis for this estimate. Chicago Transit Authority engineers independently estimated the savings at about $5000 per car.

TABLE 6.18: COST SAVINGS ESTIMATE FOR LESS STRENUOUS BRAKE DUTY CYCLE

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Engineering design time	$ 9,000	
Manufacturing & tooling	9,000	
TOTAL	$18,000	$ 180
RECURRING COST SAVINGS (Increase)		
Material Saved from Smaller Brake		
Smaller disc & caliper (6)		$6,000
Smaller reservoirs		200
Simplified plumbing		$1,500
TOTAL		$7,700
Labor Saved		
Simplified fabrication, assembly, testing & installation		$2,000
NET COST SAVINGS (Increase)		$9,880

Deletion of Articulation Section

This modification would permit elimination of the articulation section for cities where civil features such as curve radii are not limiting. Vehicle capacity would be kept the same, but the body reconfigured to a four-axle design requiring a larger turn radius of about 125 feet. Savings would accrue from eliminating the center truck, its brake system, and the articulation assembly and associated shrouding.

Table 6.19 summarizes the savings as estimated by Boeing Vertol engineers, which amount to $41,000 per car on a 100 car order. Chicago Transit Authority engineers estimated the savings at $100,000 per car. NDL prepared a third estimate which was quite close to the Boeing Vertol figure.

TABLE 6.19: COST SAVINGS ESTIMATE IF ARTICULATION SECTION IS DELETED

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Engineering design time	$103,840	
Wiring design layout	16,800	
Qualification testing	134,000	
Manufacturing & tooling	100,000	
TOTAL	$354,640	$ 3,546
RECURRING COST SAVINGS (Increase)		
Materials Saved by Deleting Articulation Section		
Brakes		$ 7,250
Center truck		6,346
Wheels and axles		6,000
Articulation assembly		7,304
Lighting		529
Side shrouds, wire & misc.		3,000
TOTAL		$30,429
Labor Saved		
Assembly and installation		$ 3,411
Wiring labor		4,000
TOTAL		$ 7,411
NET COST SAVINGS (Increase)		$41,386

Deletion of Compressed Air System

While the present SLRV specification does not explicitly require compressed air, numerous requirements drive the equipment supplier to select that option. Relaxation of the specification in these areas could permit deletion of compressed air and operation with an all-electric or electric hydraulic car.

In costing this option, deletion of the compressed air system and substitution of electric hydraulic brakes was assumed. These brakes are operated by a solenoid controlled pump which controls the hydraulic brake pressure. Such a system is presently used on cars operated by the Chicago Transit Authority.

The air actuated doors on the SLRV were assumed replaced with electrically actuated doors. Since electric actuation is not practical with sliding plug doors, these doors were assumed replaced by folding air actuated doors in the baseline system. Costing was then based on the difference between the cost of air actuated folding doors and electrically actuated folding doors. Since the electrically actuated doors are more expensive, this substitution resulted in an increase in the cost for vehicle door systems.

Deletion of the compressed air system also makes it necessary to eliminate the air suspension along with its load leveling and load weighing features, and substitute a simple coil spring suspension. Trucks of this type are presently used on all Chicago Transit Authority cars. Small additional savings are associated with these changes.

NDL performed a detailed analysis of the savings from deleting the compressed air system. A complete breakdown is provided in Table 6.20. The analysis did not consider any increase in cost associated with the increased load on the low voltage power supply which might somewhat reduce these savings. The net cost savings for a 100 car order is estimated at almost $15,000 per car. This compares with an estimate of some $50,000 per car informally provided by Boeing, and a CTA estimate that there would probably be no savings.

TABLE 6.20: COST SAVINGS ESTIMATE IF COMPRESSED AIR SYSTEM IS DELETED

NON-RECURRING COST SAVINGS		PER CAR (100 cars)
Compressed air system design	$30,000	
Manufacturing tooling	10,000	
TOTAL	$40,000	$ 400
RECURRING COST SAVINGS (Increase)		
Materials Saved from Removing Compressed Air		
Air compressor package with motor		$ 7,350
Main & supply reservoirs		500
Compressor control unit		2,500
Hydraulic boosters (3)		3,000
Compressor electrical control panel		1,200
Miscellaneous components		450
Associated piping and valves		500
Air operated door actuators* (12)		1,500
Door valves, locking devices & regulators*		4,500
Air springs		2,200
Load weigh, leveling, valves & piping		500
Pantograph valves & piping		500
TOTAL		$ 24,800
Materials Added		
Electric/hydraulic brake solenoid valve and hydraulic pump		($ 1,600)
Associated piping & valves		(400)
Electric door actuator system		(8,000)
Coil springs for trucks		(1,200)
Electric/hydraulic pantograph control system		(700)
TOTAL		($11,900)
Labor Saved		
Labor for component installation		$ 1,548
NET COST SAVINGS (Increase)		$14,848

*Assumes use of air operated folding doors since all electric sliding/plug doors are not practical

Impact of Operational Factors on Savings from Permitting a Unidirectional Car with Doors on One Side

Previous analyses have demonstrated that operation of unidirectional cars with doors on only one side can reduce purchase costs by over $40,000 per car. However, the inability of these cars to reverse direction limits their operational flexibility. The major limitation is the inability to terminate routes at switchbacks, which requires all vehicles to continue to the more lightly patronized end of the line in order to turn around. This limitation can be overcome by installing turnaround loops with switches at intermediate locations along the route, providing that right-of-way is available. In this analysis, double turnaround loops were installed every four miles along the route. The loops are interconnected by a double slip switch so that vehicles can not only use the loops to turn around, but can also switch to the parallel track to bypass failed equipment or permit track repairs. These double loops are assumed to replace double crossover switches installed for the same purposes on a system with bidirectional vehicles.

The cost analysis performed considers the savings in per car costs for unidirectional cars with doors on one side, compared against the increased trackwork and right-of-way costs associated with provision of these turnbacks. In addition, the analysis considers the reduction in fleet size made possible by the larger capacity of the unidirectional car, which is assumed to hold 12 additional passengers.

The analysis is conservative in estimating savings for the unidirectional car because it ignores the following areas, both of which would be favorable to single ended operation:

a. It does not consider the operating cost savings that the larger vehicle capacity reflects in increased driver productivity;

b. It does not consider the reduced maintenance costs which should result from elimination of one set of vehicle controls and displays, along with associated wiring and relays.

On the other hand, the analysis assumes the relative maintenance costs for the double loops and switchbacks are comparable. In fact, the tight curve radii for turnbacks should increase wheel and track wear, thus favoring the bidirectional option.

Despite these factors, the cost of right-of-way should be the dominant factor, and it is believed the present analysis gives a conservative estimate of potential savings from unidirectional operation. Table 6.21 summarizes the savings from a 70-vehicle fleet operating over a 40-track-mile system. Total savings exclusive of right-of-way costs are over 4 million dollars or nearly $60,000 per car. Figure 6.1 shows the net savings per car as a function of the cost of right-of-way. Even with the right-of-way at $30 per square foot, savings of over one million dollars or $15,000 per car appear possible.

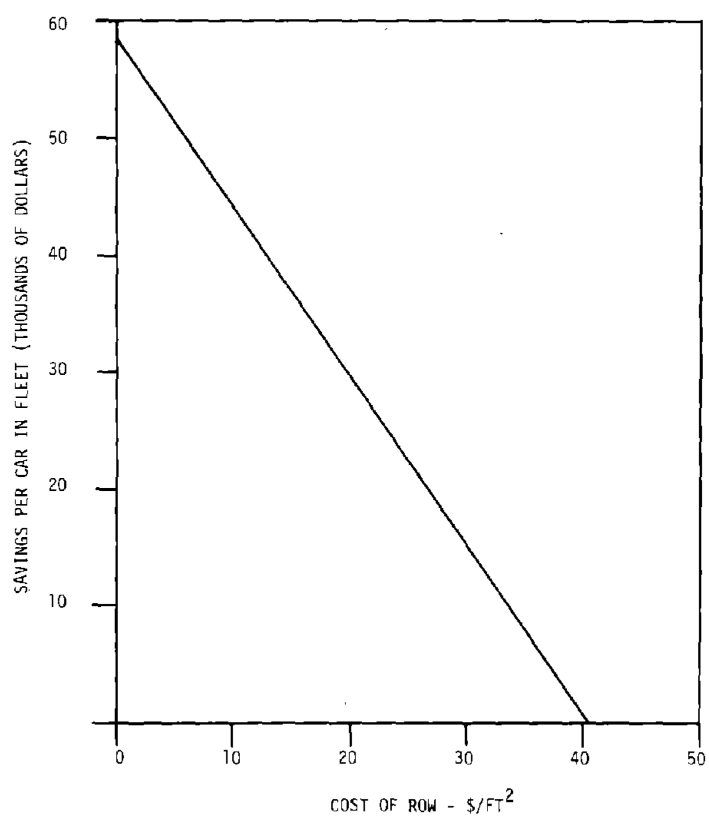


FIGURE 6.1: NET SAVINGS FROM UNIDIRECTION OPERATION WITH DOORS ON ONE SIDE CONSIDERING COST OF ADDED ROW

TABLE 6.21: IMPACT OF OPERATIONAL FACTORS ON SAVINGS FROM UNIDIRECTIONAL CAR WITH DOORS ON ONE SIDE

AFFECT OF INCREASED VEHICLE CAPACITY ON FLEET SIZE

Crush capacity is increased by 12 passengers due to removal of one cab. This increases crush capacity by 5.5%. For a 70-vehicle fleet, 3 fewer cars are needed.

Savings at $700,000 per car are . . . . $2,100,000.

SAVINGS ON PER CAR COST FOR UNIDIRECTIONAL CAR

From Table 6.16 savings are (17,840 - 1,890 + 3,430) 67 + 60,000
or . . . . $1,358,460.

SAVINGS ON PER CAR COST FOR DOORS ON ONLY ONE SIDE

From Table 6.17 savings are (22,330 - 4,900 + 5,600-850) 67 + 1,600
or . . . . $1,487,660.

ADDITION OF DOUBLE LOOPS WITH SWITCHES

Assume 4 double loops are added. Each has one double slip switch and 4 simple split switches. Cost for switches and interlockings is estimated at $558,000. Cost for extra track assuming 422 feet per double loop at $65.53/foot is $27,654.

Total added cost . . . . $(2,342,616)

ADDITION OF SIMPLE LOOPS AT ENDS OF LINE

Two simple loops added, one at each end of line. Total of 80.8 feet of extra track per loop at $65.53 per linear foot.

Total for 2 loops . . . . $(10,590)

ELIMINATION OF DOUBLE CROSSOVER SWITCHES

Eliminate four double crossovers, each costing $372,800.

Total savings $1,491,200

RIGHT-OF-WAY COSTS

Added land for double loops . . . . 20,493 ft^2 each

Added land for end loops . . . . 9211.5 ft^2 each

Total extra land for two end loops and 4 double loops . . . . 100,395 ft^2

SUMMARY OF SAVINGS

Reduced fleet size	$2,100,000
Reduced cost - unidirectional car	1,358,460
Reduced cost - doors on one side	1,487,660
Cost of 4 double loops	(2,342,616)
Cost of 2 simple loops	(10,590)
Elimination of 4 double crossovers	1,491,200
TOTAL SAVINGS EXCLUDING RIGHT-OF-WAY	$4,084,114

SAVINGS VERSUS RIGHT-OF-WAY COST	TOTAL	PER CAR (70 cars)
Net savings - no ROW cost	$4,084,114	$58,344
Net savings - ROW $10/ft^2$	3,080,164	44,002
Net savings - ROW $20/ft^2$	2,076,214	29,660
Net savings - ROW $30/ft^2$	1,072,264	15,318
Net savings - ROW $40/ft^2$	68,314	976
Net savings - ROW $50/ft^2$	(935,636)	(13,366)

In conclusion, localities should give serious consideration to trade-offs such as these before committing to bidirectional operation.

Impact of Operational Factors on Elimination of the Articulation Section

Previous analysis has demonstrated that operation of a four-axle vehicle with equivalent passenger carrying capacity as the present six-axle car can result in savings of between $40,000 and $100,000 per car in the LRV purchase price. It is estimated that such a vehicle would require a minimum turn radius of 125 feet, as opposed to 42 feet for the present articulated design.

It is clear that such an option may not be viable in many cases where right-of-way constraints make 125-foot turn radii impractical. Nonetheless, an analysis was performed to get some idea of the trade-offs between land cost and vehicle savings. The analysis uses the cost savings cited by Boeing Vertol for elimination of the articulation joint. Vehicle capacity is assumed to be unaffected by the change. Savings from reduced maintenance associated with brakes, wheels, and articulation elements were estimated at 1.7¢ per vehicle-mile with average vehicle mileage at 35,000 miles per year.

Added right-of-way was assumed required for 20 turns, formerly using 42 foot radii and now requiring 125 foot radii. Figure 6.2 shows the additional land required. The analysis assumes all additional land required by the more gradual curve radius must be purchased, while assuming no credit for the land required by the 42 foot turn radius curve but no longer required by the wider turn.

A present worth analysis was used to convert annual savings from reduced vehicle maintenance costs to an equivalent first cost. A 60-year period was used for the analysis with the fleet renewed after 30 years. The total present worth of savings from vehicle costs and maintenance, but excluding costs for added right-of-way were over three and a half million dollars or more than $50,000 per car. (Table 6.22) Figure 6.3 shows the affect of

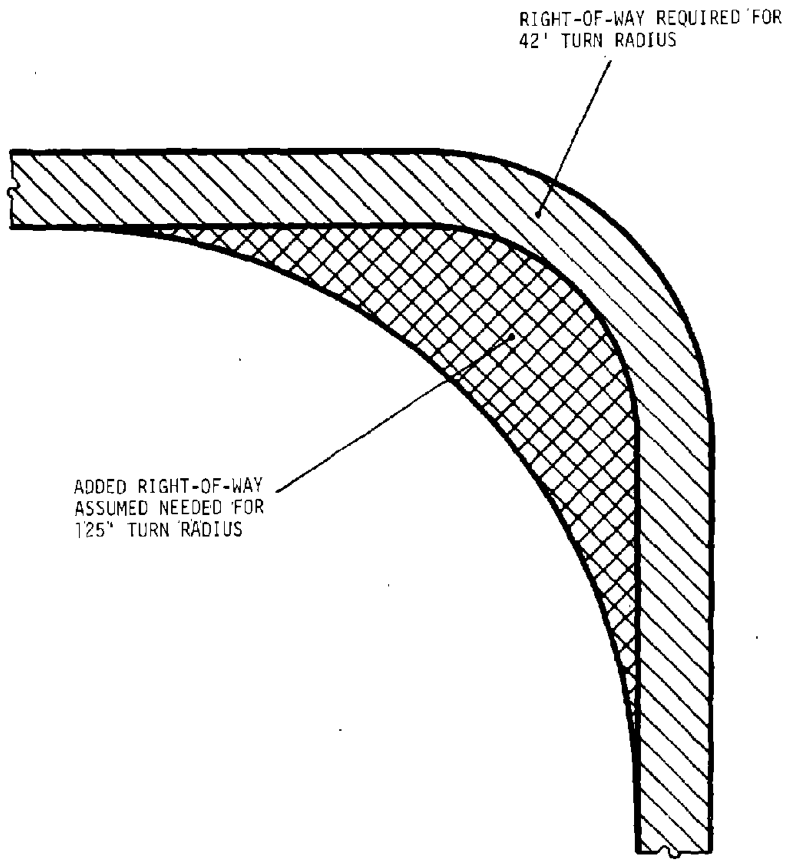


FIGURE 6.2: TURN RADIUS AND RIGHT-OF-WAY REQUIREMENT

right-of-way cost on the present worth of savings per vehicle in the fleet. With right-of-way at $30 per square foot, savings of over $25,000 per car are possible. Even with right-of-way at $50 per square foot, savings are over $8,500 per car.

In conclusion, it appears that serious consideration should be given, especially for new light rail installations, to designing the right-of-way to accept large, nonarticulated cars.

TABLE 6.22: IMPACT OF OPERATIONAL FACTORS ON ELIMINATION OF ARTICULATION SECTION

SAVINGS PER CAR FROM ELIMINATING ARTICULATION UNIT

From Table 6.6 savings are (30,429 + 7,411) 70 + 354,640
or $3,003,440

SAVINGS FROM REDUCED VEHICLE MAINTENANCE

Assume savings of 1.7¢ per vehicle mile for 35,000 miles per year per vehicle in the fleet.

For 70 cars savings are . . . . $ 41,650/yr.

ADDED COST OF RIGHT-OF-WAY

Additional ROW for a 125 ft radius curve versus 42 ft radius curve is estimated at 2,975 ft^2. For 20 turns the ROW required is increased by . . . . 59,500 ft^2.

PRESENT WORTH OF SAVINGS

(Land at 60 years, vehicles at 30 years)

Present worth of land . . . . 59,500 x (cost/ft^2)

Present worth of maintenance (60 years at 10%) . . . . $ 415,134

Present worth of car savings

First car order 3,003,440

Second car order 172,127

TOTAL PRESENT WORTH LESS LAND $3,590,701

PRESENT WORTH OF SAVINGS VERSUS ROW COST

	PRESENT WORTH OF SAVINGS	
	TOTAL	PER CAR (70 Cars)
No ROW cost	$3,590,701	51,296
ROW $10/ft^2	2,995,701	42,796
ROW $20/ft^2	2,400,701	34,296
ROW $30/ft^2	1,805,701	25,796
ROW $40/ft^2	1,210,701	17,296
ROW $50/ft^2	615,701	8,796

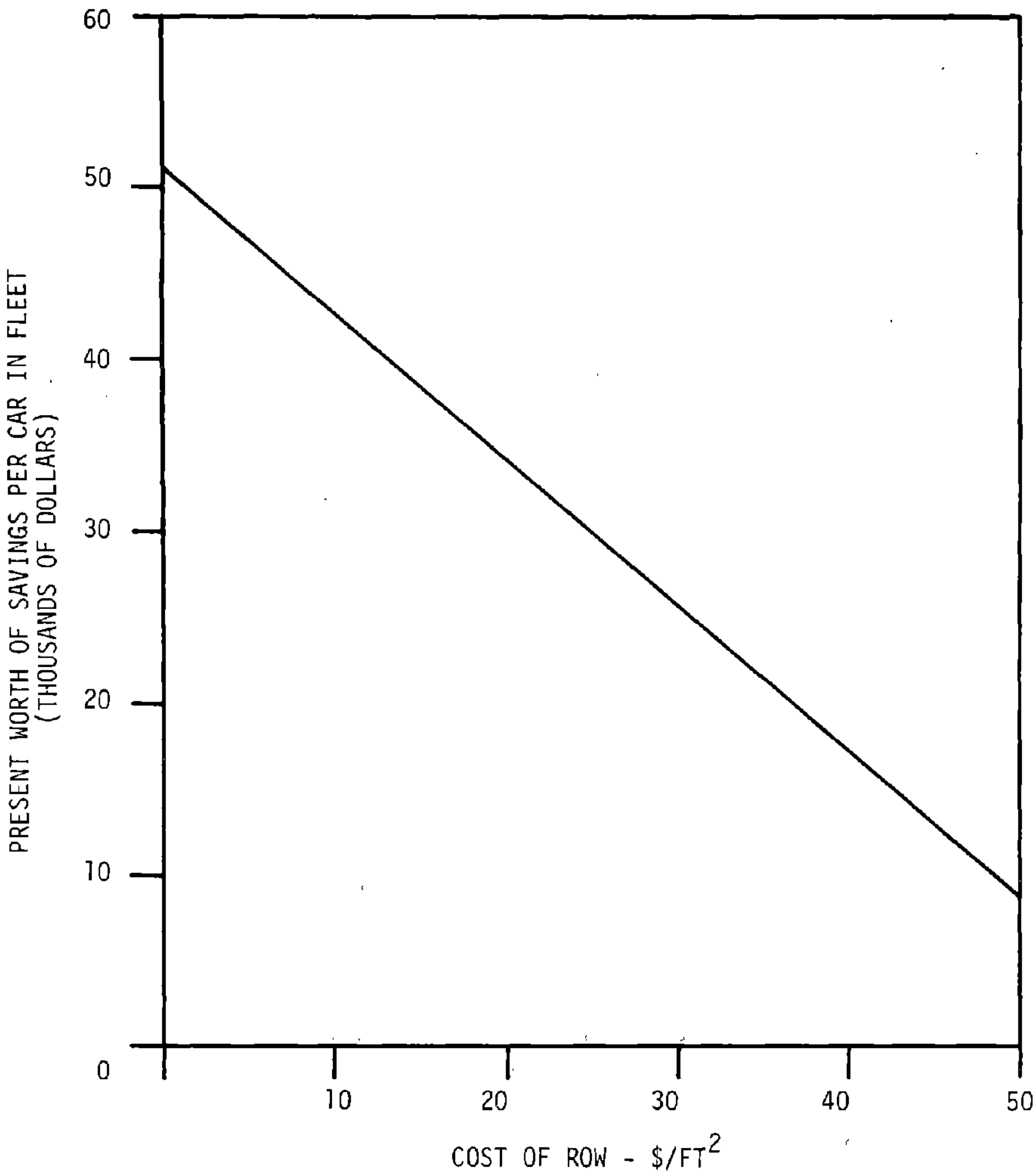


FIGURE 6.3: NET SAVINGS FROM ELIMINATING ARTICULATION JOINT CONSIDERING COST OF ADDED ROW

6.3 AGGREGATED COST SAVINGS ESTIMATES

Table 6.23 summarizes the cost savings estimated separately for each of the 20 selected specification modifications. Item numbers 1 through 15 are the modifications which would have "acceptable" performance impact. Item numbers 16 through 20 would have major impact upon performance. The cost savings for all 20 items cannot be directly added because each modification is not completely independent. For example, only one-half the cost savings for deleting plug doors can be added if doors are to be placed on only one side of the car. The cost savings estimate for using wheels with damping rings is based upon a 6-axle car; therefore, only two-thirds of these savings can be applied if the car is nonarticulated. Because of these relationships, three representative types of vehicles were chosen to demonstrate aggregate cost reductions.

Case I - High Performance Option

Figure 6.4 depicts a vehicle which is classed as the High Performance Option. For this case, all of the "acceptable" performance impact modifications have been included and are added in Table 6.23 to produce a cost savings of $123,300. This represents a 16.4 percent reduction in cost, assuming $750,000 is the price for a currently specified SLRV. The high performance car retains the original specifications for bidirectional operation, doors on both sides, friction brakes, articulation and compressed air. Figure 6.4 also shows the percent reduction in cost that might be realized from each of the specification modifications.

Case II - Alternative Low-Cost Option for Underground Operations

This class vehicle is a bidirectional car with the same passenger carrying capacity as the present SLRV but only two trucks and no articulation section. The Case II car (Figure 6.5) includes all of the modifications with acceptable performance impact which were included in Case I with minor exceptions. Only 2/3 of the savings for wheels with damping rings were included. The higher

TABLE 6.23: SUMMARY OF ESTIMATED COST SAVINGS FOR 20 SELECTED SPECIFICATION MODIFICATIONS

	SPECIFICATION MODIFICATION	NON RECURRING	RECURRING MATERIALS	RECURRING LABOR	TOTAL (a)	CAR TYPE I (a)	CAR TYPE II (a)	CAR TYPE III (a)
1	Delete plug doors, use folding doors	902	26,025	4,325	31,300	31,300	31,300	15,700
2	Simplify control requirements	192	15,968	1,916	18,100	18,100	18,100	18,100
3	Simplify qualification testing	18,780	-	-	18,800	18,800	18,800	18,800
4	Eliminate Diagnostic Test Equipment	15,546	1,700	386	17,600	17,600	17,600	17,600
5	Simplify reliability requirements	13,300	-	-	13,300	13,300	13,300	13,300
6	Simplify documentation requirements	7,238	-	-	7,200	7,200	7,200	7,200
7	Allow wheels with damping rings	-	4,800	-	4,800	4,800	3,200	4,800
8	Relax maint. manual requirements (b)	2,464	-	-	2,500	2,500	-	-
	(c)	4,302	-	-	4,300	-	4,300	4,300
9	Relax car body smoothness criteria	-	(80)	3,420	3,300	3,300	3,300	3,300
10	Simplify articulation design	64	2,380	286	2,700	2,700	-	2,700
11	Delete operator cab enclosure	310	1,500	180	2,000	2,000	2,000	1,300
12	Delete remote controlled dest. signs	32	852	102	1,000	1,000	1,000	1,000
13	Delete stop request signs	96	360	44	500	500	500	500
14	Allow three-piece windshield	-	237	-	200	200	200	200
15	Allow connectors for LVDC circuits	266	(2,793)	1,005	(1,500)	-	-	-
16	Eliminate articulation section	3,546	30,429	7,411	41,400	-	41,400	-
17	Doors on one side only	16	17,430	4,750	22,200	-	-	22,200
18	Unidirectional car	600	15,950	3,430	20,000	-	-	20,000
19	Delete compressed air	400	12,900	1,548	14,800	-	14,800	14,800
20	Simplify friction brakes	180	7,700	2,000	9,900	-	9,900	9,900
	TOTALS					123,300	186,900	175,700

(a) Total amounts have been rounded to the nearest $100
(b) Allow direct use of vendor pages
(c) Results of simplifying car to greatest extent possible

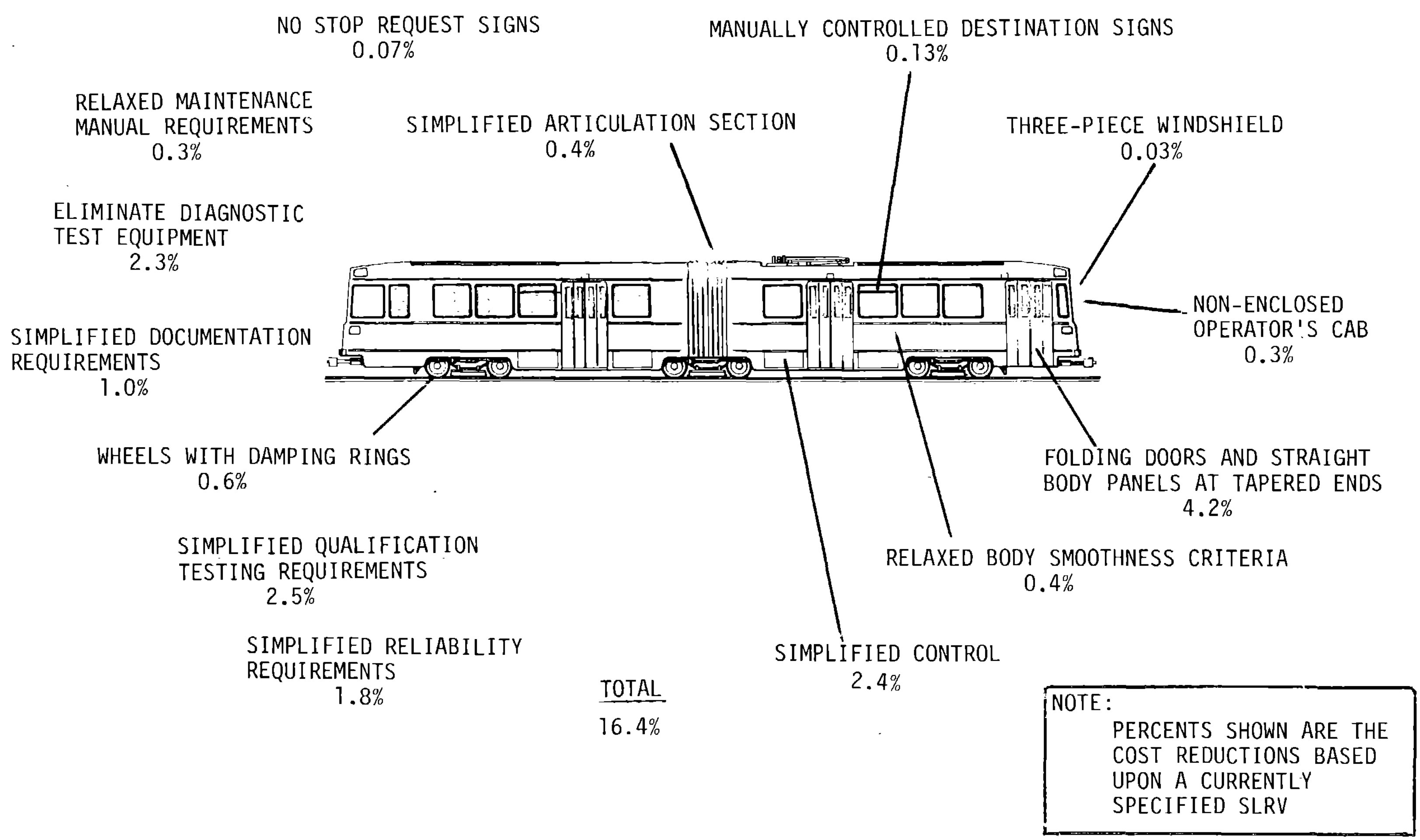
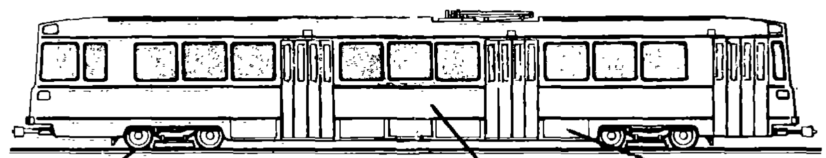


FIGURE 6.4: SPECIFICATION MODIFICATIONS AND COST SAVINGS FOR CASE I - HIGH PERFORMANCE OPTION

INCLUDES ALL CASE I MODIFICATIONS APPLICABLE

16.1%



NOTE: PERCENTS SHOWN ARE THE COST REDUCTIONS BASED UPON A CURRENTLY SPECIFIED SLRV

FIGURE 6.5: ADDITIONAL SPECIFICATION MODIFICATIONS AND COST SAVINGS FOR CASE II - ALTERNATIVE LOW-COST OPTION FOR UNDERGROUND OPERATIONS

estimate for simplified maintenance manuals was assumed. Cost savings for simplifying the articulation are of course deleted since the vehicle is nonarticulated. In addition, the vehicle is assumed to have simplified friction brakes and no compressed air.

The vehicle is assumed to have the same capacity as the currently specified SLRV. Bidirectional operation and doors on both sides were retained for underground operation where turnarounds may be prohibitive. A car of this class is similar to a larger version of the new CTA rapid rail cars. This case shows the highest aggregated cost reduction, a savings of 24.9 percent over the present SLRV design.

Case III - Low Performance Option

Figure 6.6 shows the Low Performance Option. In addition to the Case I modifications it is a unidirectionally operated, articulated vehicle with doors on only one side. The friction brake system is simplified and there is no compressed air.

The contributions to cost reduction for the Case I modifications must be slightly reduced. Only one-half the savings for deleting plug doors apply because the vehicle has doors only on one side. The cost savings for deleting the operator's cab enclosure is reduced because there is only one operator's cab. Some added savings are obtained since a locking instrument panel cover is not necessary. The higher estimate for savings from simplified maintenance manuals was applied.

Case III has aggregated cost savings of approximately $175,700 which represents a reduction of 23.4 percent from the present SLRV cost of $750,000.

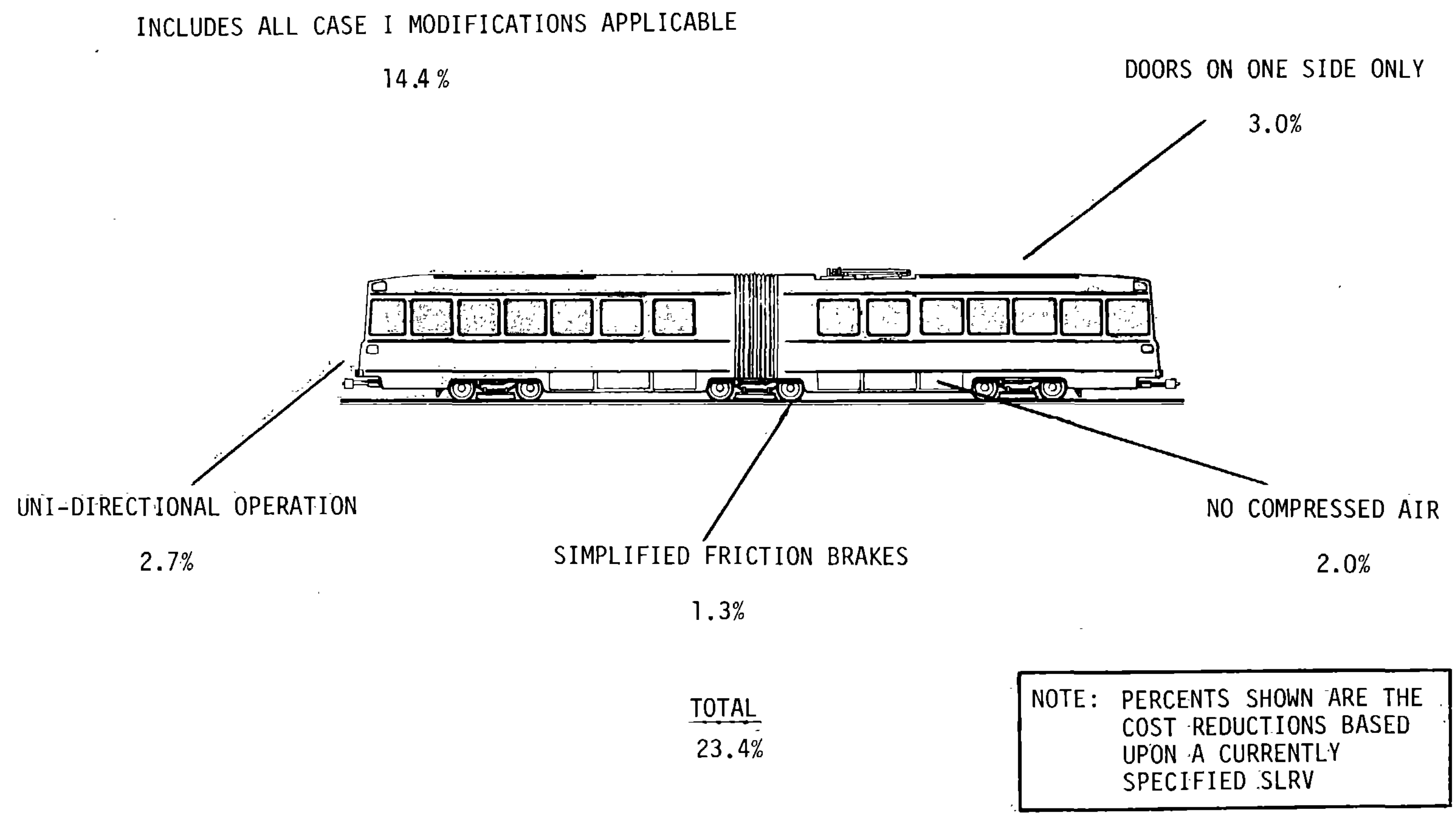


FIGURE 6.6: SPECIFICATION MODIFICATIONS AND COST SAVINGS FOR CASE III - LOW PERFORMANCE OPTION

7.0 REFERENCES

(1) "A Determination of the Optimal Approach to Rail Rapid Transit Car Standardization" UMTA report No. IT-06-0131-76-1, R. Morris, N. McGinnis, M. deRegt and W. Reinhardt, International Research and Technology Corp., Arlington, Va., August 1976. PB 259-363.

(2) "Standard Light Rail Vehicle Specification, Technical Section" (defining the SLRV as built for the Massachusetts Bay Transportation Authority as updated through June 14, 1977.) Pages 2-13 through 2-15.

(3) "Potential Specification Modification," Kaiser Engineers, received under letter of May 25, 1978, from A. T. Comeau of Kaiser.

(4) "Foreign Light Rail Vehicle Development," Joachim von Rohr, Light Rail Transit, Transportation Research Board Special Report 161, Washington, D. C., 1975, page 105, Table 1.

(5) "Light Rail Transit, A Study of the Art Review" DOT UT 50009, E. S. Diamant et al, De Leuw, Cather and Co., Chicago, Illinois, Spring, 1976, page 135. PB 256-821.

(6) Reference 4, page 104.

(7) Review of "List of Candidate SLRV Specification Modifications Expected to Have Medium to High Cost Reduction Potentials," internal project document received from Studiengesellschaft, Nuhverhehr mbH (SNV).

(8) "N. D. Lea & Associates, Inc. Potential LRV Specification Modifications Review and Evaluation," Louis T. Klauder and Associates, Philadelphia, Pa., May 22, 1978, item 69, page 22.

(9) "List of Specification Areas for Estimating Cost Savings to the SLRV," internal project document received from Chicago Transit Authority under cover of letter from Thomas L. Wolgemuth, Manager, Engineering, September 21, 1978.

(10) "Notes on Visit to Boeing Vertol SLRV Inspection and Orientation," Wolfgang Bamberg, NDL-20, April 18, 1978, page of notes facing comments section 3, line 192-195.

(11) "Standard Light Rail Vehicle Specification, Technical Section," section 12.5.6, lines 177-186.

(12) Ibid, section 12.5.7, lines 187-195.

(13) "Boeing Vertol Quantitative Case Studies of Nine Potential SLRV Cost Reduction Items," under cover of letter of June 28, 1978, from N. D. Pritchett, Sr., Contract Administrator Boeing Vertol Company, Philadelphia, Pa., Item 4.

(14) See Reference 5, pages 123-124.

(15) Lea Transit Compendium, Light Rail Transit. Vol. II, No. 5, N. D. Lea Transportation Research Corporation, Huntsville, Alabama, 1975.

(16) See reference 7, note B.

(17) "LRV Value Engineering Study," letter from J. S. Gustafson of Louis T. Klauder and Associates, Philadelphia, Pa., May 25, 1978, page 3.

(18) See for example reference 8, item 5, page 3.

(19) "N. D. Lea & Associates, Inc. - LRV Value Engineering Study - Task IIIB - Weight Breakdown and Related data," Attachment (1), page 1 of 2, 8-2700-01-1-1929, Boeing Vertol.

(20) See reference 8, item 4, page 2.

(21) Reference 7, page 1, note A.

(22) See reference 8, item 1, page 31.

(23) Reference 3, "List of Candidate SLRV Specification Modifications Expected to Have only Low Cost Reduction Potentials," page 1.

(24) See reference 4.

(25) See reference 11, section 2.3, pages 2-20.

(26) Ibid.

(27) "Baseline Advanced Design Transit Coach Specifications," Urban Mass Transportation Administration, Washington, D. C., April 4, 1977 (Acceptance tests, pages III-9 et seq.).

(28) Ibid.

(28b) See reference 27 (Quality Assurance Provisions, page 111-7).

(29) See reference 1.

(30) See reference 13, item 8.

(31) See reference 7, item 19.

(32) See reference 8, item 18, page 8.

(33) See reference 3, page 2.

(34) "Notes From Interviews with Kaiser, Klauder, MBTA and TSC" Tom McGean, NDL-20, May 15-17, 1978, Comments facing Section 2, line 1488-1579.

(35) See reference 8, item 18, page 8.

(36) Ibid.

(37) See reference 27, Predelivery - Road Test, page 3 of 3.

(38) "Boeing Vertol Subjective Assessments of List of Candidate SLRV Specification Modifications Expected to Have Medium to High Cost Reduction Potentials," item 25, page 3.

(39) Kurzweil and Shipley, "Eliminating Wheel Squeal," Passenger Transport, October 13, 1978.

(40) See reference 5.

(41) State-of-the-Art Car Development Program, Volume I, Design, Fabrication and Test, Boeing Vertol Company, UMTA Report No. UMTA-19-06-0026-74-1, April 1974. PB 235-703.

APPENDIX A

SAMPLE PAGES FROM INTERVIEW NOTEBOOKS AND RATING FORMS

EXHIBIT 1: FACSIMILE OF A SAMPLE PAGE FROM THE NOTEBOOKS USED DURING INTERVIEWS WITH BOEING VERTOL

Section	Line Number		Candidate Specification Modification	Comments
9			Auxiliary Electrical Equipment & Wiring	
9	148-155	(L)	Reduce emergency load on battery or requirement for continuous one hour emergency operation	Needed if vehicle is far out on line and has to limp back to barn. This really drives the size of battery.
9	148-175	?	~~Replace nickel~~ cadmium storage battery with ~~lead-acid battery(s)/on~~ as conventional rail cars	
9	156-173		Eliminate battery design specification	} Can't answer. Don't recall any gripes
9	175-176		Eliminate battery over temperature protection	
9	184-185		Permit use of simple switches instead of relays for ac auxiliary circuits (as are commonly used in homes, boats, trailers, etc.).	No AC on car
9	188-189	(L	Permit 600 volt circuit breakers instead of fuses	
9	189-195	(L	Eliminate 32 volt interlock on fuse box cabinet	
9	196-199	L	Eliminate requirements concerning material of fuse panel base and other design specifications	— No problem
9	200-201	L	Eliminate green light on fuse box door	
9	214-217		~~Permit use of fuses for LVDC system~~	
9	217-218	(L)	Eliminate lock on LVDC breaker panel door	Presently is behind a locked panel and then a locked box also.
9	220-228	L	Eliminate design details on circuit breakers	Could leave out, particularly in this case. They use single pole breaker.
9	239-272	M-L	Potential to reduce no. of circuit breakers pending elimination of certain functions in other areas (e.g., cab signals, slip-slide, etc.)	
9	275-276		Place operator console only at one end of car (non-bi directional vehicle)	} could be done because MBTA only uses one end.
9	275-276		Eliminate one operators cab and panel	
9	278		Adjust destination signs manually instead of from operators console	MBTA is manual only, SF is automatic.
9	279	(H-M	Eliminate coupler control from operator's console	They have only the console and mechanical manual control of coupler — High saving if automatic coupling feature is eliminated
9	295-298	(L)	Eliminate automatic dimmer device to regulate intensity of illumination of switches and indicators. Use single rheostat control.	They had real problems with this and it was changed.
9	~~296-297~~		Eliminate ~~automatic dimmer on console~~ lights controlled by ~~light sensor~~. Replace with rheostat	
9	298-305	(M)	Do not require individual illumination of door switches, track switches, headlight control, cab light switch and horn and gong actuators	Boeing "as-built" deletes these

EXHIBIT 2: FACSIMILE OF A PAGE FROM THE COMPLETED RATING FORMS BY KAISER ENGINEERS

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	COST* IMPACT	PERFORMANCE IMPACT		COMMENTS
			MISSION AREA	DEGREE	
2: 686-738 & 748-764 10: 115-121 12: 171-175	Eliminate all requirements for equipment and subsystem noise levels, retain only overall vehicle requirements for noise level	2	------	Minor Positive	
2: 168-180	Provide explicit specification of operation environment rather than stating "in the ... environment intended".	3	Eliminate Confusion	Minor Positive	An expanded list of typical problem areas would help bidders new to the industry.
2: 57-62	Relax contract drawing restrictions on exterior lines of vehicle, vehicle interior layout and seating arrangement.	2	Esthetics Pass. Comfort	Minor Negative	Specify an envelope
2: 414-416	Consider allowing 12 or 24 volts DC low voltage power instead of 37.5 volts.	0	------	Minor Negative	This would impact experienced transit manufacturers with proven equipment at 37.5V
2: 740-746	Relax 65 dBA interior noise level to 70-75 dBA	6	Pass Comfort	Minor Negative	65 dBA is not being met presently (6?-7?) may be optimum.
2: 877-925	Establish specific maintainability goals in terms of time to accomplish maintenance tasks	-1	Maintainability	Minor Positive	
2: 952-968	Clarify and simplify MTBF requirements	0	Reliability	Minor Positive	Better definition of what is "in" each system is needed
2: 970-980	Eliminate need for reliability analysis	0	"	"	Eliminate need to submit
2: 982-992	Eliminate need for reliability program and progress reports on a monthly basis.	3	"	Major Positive	Preliminary reliability data could be part of the other monthly report
2: 1012-2261	Simplify test plans and procedures and limit qualification tests to unproven equipment. Explicitly define scope of test program and design verification requirements. Accept data submittals for windshield, materials flamability and other routine tests.	1	Reduce Qualification Testing	Minor Positive	This should be acceptable if equipment was "proven" in "identical" application. Explicit definition depends on vendor and his design.
2: 1488-1579	Eliminate need to test airconditioning and heating system in an environmental chamber	4	-------	Minor Negative	Lower cost alternative tests may be desirable
2: 1071-1079	Simplify test report documentation	0	-------	-------	The specification wording is very liberal

*Give rating on a scale of 0 to 10 with 10 being the highest impact on costs.

EXHIBIT 3: FACSIMILE OF A SAMPLE PAGE FROM THE NOTEBOOKS USED IN INTERVIEWING KAISER, KLAUDER AND THE MBTA

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	
3: 803-903	Reduce required number of side destination signs from two to one per side of vehicle.	Current SLRV is a long car and requires more side identification. Could eliminate the end signs but must retain the side signs.
3: 813-817	Delete requirement for power driven destination signs operated from operator control panel.	These were for MUNI only. Agree to eliminate power driven and remote control
5:	OPERATOR'S CAB	
5: 19-48	Modify operator's cab eliminating full enclosure and provide a locking cover for the operator's console. Install a modesty panel with a curtain behind the operator.	Was specified to protect fare box and operator. Could be an option. Fare box could be secured by other means.
6:	DOOR CONTROL	Should specify what is to be more prevalent.
6: 7-14	Provide doors on only one side of vehicle	Design vehicle such that doors on both sides is optional.
6: 16-34	Simplify door operation such as using folding doors actuated by touch plates or similar devices.	Don't see that touch plates will reduce costs. Really they may increase costs but could save wear and tear on the door operating mechanism.
6: 179-180	Eliminate red pilot light on vehicle exterior above each door location to indicate when doors are not locked.	Never see operators using them / What makes the door expensive is all the limit switches and other mechanisms
7:	AIR COMFORT SYSTEM	
7: 17-94	Do not specify air conditioning in detail. Only specify what environment is to be provided. Reduce the amount of fresh air intake by accounting for fresh air which naturally comes through opened doors.	Considers the spec is about as wide open as any Air-cond. spec. If air-cond. is to remain then they would not change existing spec.
8:	LIGHTING SYSTEMS	
8: 34-43	Reduce requirements for lighting intensity: 35 foot candles at reading plane and 20 foot candles at floor.	Yes - could go to 25 footcandles. Thinks the spec is in APTA guidelines.
8: 45-49	Eliminate specifications on maximum brightness ratios: 40/1 between fixture and ceiling and 10/1 between fixture and walls. Other specifications on types of interior materials, finish and color appear not coordinated with such brightness ratios.	Eliminate these ratios altogether
8: 71-74	Allow use of only one line of flourescent light fixtures along center of ceiling.	Would cause some problems in getting light to the sides

APPENDIX B

RESULTS OF INTERVIEWS WITH THE MBTA, KAISER AND KLAUDER

The following lists give potential specification modifications which could reduce SLRV costs. They are presented in rank order according to the desirability to change the specification and not according to cost reduction potential. Potential modifications with the same rating have not been placed in rank order of desirability. The following rating definitions were used:

1 - If the idea were considered worthwhile

1/2 - If the comments were ambiguous

0 - If the comments indicated the idea was not worthwhile

Because there were three separate parties interviewed, the maximum rating is 3. Potential modifications receiving a total rating of zero are not listed.

POTENTIAL SPECIFICATION MODIFICATIONS WITH
MEDIUM TO HIGH COST SAVINGS POSSIBILITIES

SECTION: LINE NUMBER	MODIFICATION	RATING
2: 686-738 & 748-764 2: 740-746	Eliminate all requirements for equipment and subsystem noise levels, retain only overall vehicle requirements for noise level. Relax 65 dBA interior noise level to 72 dBA.	3.0
2: 168-180	Provide explicit specification of operating environment rather than stating "in the... environment intended".	3.0
2: 57-62	Relax contract drawing restrictions on exterior lines of vehicle, vehicle interior layout and seating arrangement.	3.0
2: 970-980	Eliminate need for reliability analysis	3.0
2: 1012-2261	Simplify test plans and procedures and limit qualification tests to unproven equipment. Accept data submittals for proven equipment and supplies.	3.0
3: 471-503	Specify windshield by quality, such as impact resistance and not by requiring it to be 9/16 inch thick. Use a three piece windshield.	3.0
3: 571-626 6: 16-34	Delete specification for sliding/plug type doors. Permit outside sliding or folding doors. Do not curve the sides at the vehicle ends. The car can be tapered but with straight panels. This will allow use of the same door throughout.	3.0
3: 813-817 9: 419-420	Delete requirement for power driven destination signs operated from the control panel.	3.0
6: 7-14	Provide doors on only one side of vehicle.	3.0
8: 34-43 8: 45-49	Reduce requirements for lighting intensity, presently set at 35 foot candles at reading plane and 20 foot candles at floor. Also either eliminate fixture/ceiling and fixture/walls brightness ratios or make them compatible with other specifications for interior color and finish.	3.0

SECTION: LINE NUMBER	MODIFICATION	RATING
9: 298-305	Do not require illumination of door switches, track switches, headlight control, cab light switch and horn and gong actuators. Only illuminate certain critical switches.	3.0
9: 554-621 9: 625	Eliminate pantograph and use trolley pole. This could be an option. It may require reducing car power since trolley pole is rated to 450 amp continuous. If vehicle is to be single direction operated only one trolley pole is required.	3.0
19: General	Delete automatic diagnostic tester. If diagnostic test equipment is to be included, then provide a number of smaller "suit case" type testers.	3.0
2: 877-925	Establish specific maintainability goals in terms of time to accomplish maintenance tasks.	2.5
2: 1934-2258 2: 2056-2212	Reduce amount of customer approvals of vehicle design. Reduce requirements for submission and especially approval of drawings and photographs, and subsystem documentation. Replace with a cleaner more organized approach using critical design review meetings.	2.5
2: 1071-1079	Simplify test report documentation	2.5
9: 464-474	Specification presently calls for eight master controller detents. Detents are required only for coast and maximum service brake. Maximum power and emergency brake are positions only.	2.5
9: 687-870	Eliminate the Automatic Speed Control System (ASC). Simple wayside aspect signals will suffice for tunnels and exclusive right-of-ways.	2.5
13: General	Do not specify the vehicle communications in detail. Address only functional and performance requirements and leave the detailed design up to the contractor.	2.5

SECTION: LINE NUMBER	MODIFICATION	RATING
1: 434-475	Expedite process for drawing review cycle to reduce schedule interference.	2.0
2: 23-25 5:9 9: 275-276	Make bidirectional capability and operators cab at both ends of car an option.	2.0
5: 19-48	Do not require full enclosure of the operator's cab. Provide a locking cover for the console and install a modesty panel and curtain behind the operator.	2.0
9: 899-903 9: 1258-1260	Permit use of electrical connectors to enhance modularization.	2.0
13: 668-701 13: 33-38	Delete train to wayside data transmission capability. Also delete wayside to train public address which this equipment provides.	2.0
2: 414-416	Consider allowing 12 or 24 volts DC low voltage power instead of 37.5 volts.	1.5
12: 35-36	Do not require friction brake without dynamic assist to meet stringent brake duty cycle (regard friction brake only as an emergency capability).	1.5
15: 85-285	When manuals are specified they should be explicitly to insure that all bidders will interpret the requirements in the same way. (Use ATA 100 guidelines).	1.5
15: 290-525	Explicitly call out quantity and type of spare parts required.	1.5
2: 25-27 4:9 9: 500-612 9: 670-677	Make automatic coupling of vehicles in trains an option. Allow purchase of single car units without coupling.	1.5
9: 279	Eliminate controlling the coupler from the operator's console.	1.5
19: 99-102	Many test points would not be required to be specifically brought out if connectors were used. Provide breakout boxes and cables as part of specialized test equipment.	1.5

SECTION: LINE NUMBER	MODIFICATION	RATING
2: 1007-1010	Eliminate need to redesign fleet if reliability goals are not met. Shorten two year demonstration period.	1.0
2: 588-599 10: 126-133 10: 139-143 12: 18 12: 112-114 12: 222-228	Eliminate load weigh requirement for acceleration and braking control.	1.0
2: 982-992	Eliminate need for reliability program and progress reports on a monthly basis.	1.0
15: 499-525	The specification is very general in regard to support equipment to be furnished. It is suggested that only very specialized equipment be required.	1.0
2: 952-968	Clarify and simplify MTBF requirements.	1.0
2: 2214-2257	Eliminate need for full-size mockups of vehicle	1.0
12: 364-416	Specify minimum traction or grade capability which must be achieved by sanding equipment.	1.0
11: 368-377	Allow use of wheels with dampening ring instead of resilient wheels.	1.0
11:9	Eliminate need for a compressed air system	1.0
13: 151-178	Do not require eight speakers per car. Also relax specification on speaker enclosures and frequency response.	1.0
2: 1488-1579	Eliminate need to test air conditioning and heating system in an environmental chamber.	0.5
3: 418-443	Allow more freedom in selecting interior body materials. Possibly provide an approved list of materials or specify toxicity, flamability, strength, cleanability, etc.	0.5
3: 40-61 3: 170-177	Relax smoothness criteria on vehicle outer surface, for example, let rivits show if they are spaced evenly and arranged aesthetically. Also, allow use of a bellows at articulation section and do not require doors to fit flush with body surface.	0.5

SECTION: LINE NUMBER	MODIFICATION	RATING
8: 150-156	Delete requirements for step well lights as long as the overhead light fixture will illuminate the step well and ground area outside the door area under both normal and emergency lighting conditions.	0.5
9: 459-642	Eliminate requirement for customer approval of master control handle and other design features.	0.5
9: 897	Allow some wires to be spliced using a controlled process.	0.5
2: 185-186	Make curve radius requirement buyer's option and make articulated cars optional if not required.	0.5
	KAISER SUGGESTIONS	
A6: 153	Eliminate preference for chopper	
A9: 238-266	Eliminate Pueblo testing	
15: 187	Allow flexible format so contractor can submit subcontractors manuals.	
	MBTA SUGGESTIONS	
12: 241-254	Delete requirement for air compressor after-cooler and use chemical air dryer.	

POTENTIAL SPECIFICATION MODIFICATIONS WITH
MEDIUM TO LOW COST SAVINGS POSSIBILITIES

SECTION: LINE NUMBER	MODIFICATION	RATING
2: 569 10: 226-230 10: 299-300	Eliminate adjustment of jerk rate.	3.0
10: 448-460	Delete separate ground brushes around antifriction bearings for 600V and LVDC ground paths. (Use only one ground path for both voltages).	3.0
12: 357-358 12: 430	Use only audible indication that track brakes are applied (delete visual indicator).	3.0
3: 335-340	Delete roof shroud	3.0
3: 742-775	Provide simple cord activated chime for passenger stop signaling. Delete acknowledgement light.	3.0
9: 295-298 13: 86-89	Eliminate automatic dimmer device to regulate intensity of illumination of switches and indicators. Use a rheostat.	3.0
15: 62-69	Delete safety plan.	2.5
12: 352-354	Eliminate track brake cutout in electric locker.	2.5
10: 478-479	Delete owner design review and approval of speed sensor.	2.0
2: 1875-1932 10: 219-224	Do not require submission of energy simulation.	2.0
13: 58-67	Use simple switch instead of sub-audible tone codes to actuate PA system.	2.0
13: 68-70 13: 127-134	Delete local tone annunciator preceeding public announcement over PA system.	2.0
12: 187-194	Reduce requirement for 15 full brake applications in event of loss of compressor or hydraulic prime power.	1.5
10: 201-202	Allow modulation of dynamic braking to correct wheel slip if chopper is used.	1.5

SECTION: LINE NUMBER	MODIFICATION	RATING
2: 510-514 12: 237-238 12: 400-402	Eliminate automatic sanding and place under operator control.	1.5
2: 125-126 2: 336-344	Provide clearer definition of worst case power supply requirements including fault capacity, source impedance, ripple content, etc.	1.5
8: 54-55	Eliminate noise requirements on light fixtures since it replicates already stiff 65 dBA requirement.	1.5
11: 519-528	Eliminate wooden bar and brackets (safety bars) in front of trucks	1.5
2: 355-360	Make requirement for shop power plug an option.	1.0
2: 614-617	Eliminate adjustment of rates for wheel wear	1.0
10: 482-489 12: 440-445	Delete in-car diagnostic taps for propulsion and braking current measurement.	1.0
14: 45-48	Reduce time emergency power is provided.	1.0
3: 506-568	Do not require cantilevered seats only. Allow use of pedestal seats.	1.0
3: 577	By specifying stiffness of car body it has limited structure and materials that can be used. A bumping load of specified pounds or impact with a 1/4 pound ball may give more latitude to manufacturer.	1.0
5: 68-73 5: 72-73	Specify a simpler operators seat	1.0
9: 189-195 9: 200-201 9: 217-218	Eliminate detailed specification of interlocks, and green light on fuse box. Provide only a warning. Eliminate lock on LVDC braker panel.	1.0
9: 220-228	Allow use of single-pole circuit breakers	1.0
9: 325-326	Eliminate passenger stop request switches on console.	1.0
13: 30-31	Eliminate two-way communications between on-board operating personnel.	1.0
13: 272-290	Delete keylock of PA amplifier and fasten with vandal proof screws or conceal in electric cabinet.	1.0

SECTION: LINE NUMBER	MODIFICATION	RATING
2: 275-409	Reduce 50 mph cruise speed	0.5
3: 381-386	Sub-floor should be an option left to the manufacturer if desired impacts, penetrations and other requirements are specified.	0.5

KAISER SUGGESTIONS

2: 1220	Reduce 300% to 150% proof pressure test.	
2: 1230	Reduce 2 million to ½ million.	
	Eliminate high-lo step	
2: 1601	Specify water pressure and nozzle configurations	
12: 238	Eliminate slip slide cutout switch.	

APPENDIX C

RESULTS OF SUBJECTIVE RATINGS OF POTENTIAL SPECIFICATION MODIFICATIONS BY BOEING, KAISER AND KLAUDER

The following are tabulated scores from the completed rating forms by Boeing Vertol, Kaiser and Klauder. Boeing Vertol rated only those areas which had been categorized as having "medium-to-high cost reduction potential." Kaiser and Klauder reviewed all cost areas.

The number under the column for each reviewer is his rating of that item on a scale of 1-10, where 10 is the maximum potential for cost reduction. To the right of the number occasionally appears pluses or minuses. These relate to the impact of making the particular change upon mission performance. Two minus signs indicate the reviewer noted a major adverse impact. An adverse impact is indicated by a single minus sign. If the change might actually improve mission performance, this is indicated by a plus, while a major improvement is indicated by two pluses.

In a few cases, the reviewer thought the change would increase rather than decrease costs. This is indicated by a minus sign preceding the cost number.

In the far right column are the totals of the individual numerical ratings of all reviewers and also totals of the pluses or minuses relating to mission performance impacts (in summing, one plus was assumed to cancel one minus). The average rating is obtained by dividing this total by three for those items reviewed by Kaiser, Klauder and Boeing, and by two for those items Boeing did not review.

In addition, these ratings are marked in the far right column using the following code: a single "x" preceding the rating indicates the average score for the particular item is either equal to or less than 0.5, or it is equal to or less than 1.0 and respondent cited a negative impact; the symbol "xx" indicates an average score of less than 3.0 and any respondent citing a major negative impact on mission performance; all items marked "x" or "xx" were deleted from consideration for quantitative cost analysis.

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
1:	GENERAL REQUIREMENTS				
1: 75-77 2: 98-106 12: 51-56	Clarify failsafe requirements	0	6-	1	7-
1: 434-475	A very detailed drawing review cycle is specified where the manufacturer must submit numerous drawings "down to and including the module and circuit board level" for review and approval by the pruchaser. It is suggested that these requirements be relaxed.	5++	7--	3	15
2:	SYSTEMS REQUIREMENTS				
2: 23-25 5: 9 9: 275-276	Eliminate bidirectional capability. Eliminate operator's cab at one end of vehicle.	10++	7	10	27++
2: 25-27 4: 9 9: 500-612, 670-677	Eliminate requirement to operate in trains. Eliminate coupler/draft gear and provide tow bar stored aboard each vehicle for emergency towing. Also, eliminate all trainlined circuits.	6--	9--	10	25----
2: 185-186	Relax 42 foot curve radius requirement	2--	3--	1	xx6----
2: 198	Reduce 9% grade requirement	1--	2-3 -	1	xx4.5---
2: 1007-1010	Eliminate need to redesign fleet if reliability goals are not met	?-	10--	5	15---
2: 405-406 10: 93-95	Limit towing of dead car with one other car to grades less than 3%	0	1-2 -	0	x1.5-
2: 588-599 10: 126-133 10: 139-143 12: 18 12: 112-114 12: 222-228	Eliminate load weigh requirement for acceleration and braking control	2--	1-2 -	1	xx4.5---

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
2: 686-738 & 748-764 10: 115-121 12: 171-175	Eliminate all requirements for equipment and subsystem noise levels, retain only overall vehicle requirements for noise level	2+	1-2 -	2	5.5
2: 168-180	Provide explicit specification of operation environment rather than stating "in the ... environment intended".	3+	0-10	4	12+
2: 57-62	Relax contract drawing restrictions on exterior lines of vehicle, vehicle interior layout and seating arrangement.	2-	2-3	6	10.5
2: 414-416	Consider allowing 12 or 24 volts DC low voltage power instead of 37.5 volts	0-	0-	4	4--
2: 740-746	Relax 65 dBA interior noise level to 70-75 dBA	6-	0-	7	13--
2: 877-925	Establish specific maintainability goals in terms of time to accomplish maintenance tasks	-1+	-1++	-1	x-2+++
2: 952-968	Clarify and simplify MTBF requirements	0+	0-10	6 (for these three rows, bracketed)	11+
2: 970-980	Eliminate need for reliability analysis	0+	2-3		8.5++
2: 982-992	Eliminate need for reliability program and progress reports on a monthly basis.	3++	7--		16
2: 1012-2261	Simplify test plans and procedures and limit qualification tests to unproven equipment. Explicitly define scope of test program and design verification requirements. Accept data submittals for windshield, materials flamability and other routine tests.	1+	9-10 -	1	11.5
2: 1488-1579	Eliminate need to test air conditioning and heating system in an environmental chamber	4-	2-8 -	1	10--
2: 1071-1079	Simplify test report documentation	0	6-	1	7-

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
2: 1934-2258	Reduce amount of customer approvals of vehicle design. Reduce requirements for submission and approval of drawings and photographs.	5++	7--	3	15
2: 2007-2018	Eliminate need to submit car body stress analysis	0-	2--	1	x3---
2: 2056-2212	Submit subsystem documentation for information only without requiring owner approval	1++	3--	3	xx7
2: 2214-2257	Eliminate need for fullsize mockups of vehicle	1-	5-	2	8---
3:	CAR BODY				
3: 40-61	Relax smoothness criteria for vehicle outer surface. Presently the specification does not allow any portrusions in the outer surface and requires that doors fit flush with the vehicle surface.	3+	1-	4	8
3: 170-177	Delete cosmetic side panels to cover up the articulation section.	1+	1-	4	6
3: 418-443	Do not require use of specific materials for car interior, but provide an approved list of alternative materials including thermo-formed materials.	0--	0-1	2	x2.5--
3: 449-463	Allow more lattitude for selection of thermal and sound insulation material. For example, urethane foam is not presently permitted.	1--	0-	0	x1---
3: 471-503	Specify windshield by quality (e.g., impact resistance) and not by requiring it to be 9/16 inch thick. Also, allow the windshield area to be smaller and that it not be required to also cover the destination sign.	2+	2-3++	1	5.5+++
3: 571-626	Delete specification for sliding/plug type doors. Permit outside sliding or folding doors. If the curved side panels at the front and rear door areas were straightened, the same door could be used throughout the vehicle. If high-low steps are to be required, such as for San Francisco, then specify outside sliding doors.	3++	7-8+	10	20.5+++

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
3: 803-903	Reduce required number of side destination signs from two to one per side of vehicle.	2+	1-2 -	2	5.5
3: 813-817	Delete requirement for power driven destination signs operated from operator control panel.	1+	1-2 -	3	5.5
5:	OPERATOR'S CAB				
5: 19-48	Modify operator's cab eliminating full enclosure and provide a locking cover for the operator's console. Install a modesty panel with a curtain behind the operator.	2-	3-4 -	2	7.5--
6:	DOOR CONTROL				
6: 7-14	Provide doors on only one side of vehicle	7-	6-7 -	9	22.5--
6: 16-34	Simplify door operation such as using folding doors actuated by touch plates or similar devices.	0-	7-8+	-1	8.5
6: 179-180	Eliminate red pilot light on vehicle exterior above each door location to indicate when doors are not locked.	1-	1-	1	x3--
7:	AIR COMFORT SYSTEM				
7: 17-94	Do not specify air conditioning in detail. Only specify what environment is to be provided. Reduce the amount of fresh air intake by accounting for fresh air which naturally comes through opened doors.	0--	2-3 --	1	xx3.5----
8:	LIGHTING SYSTEMS				
8: 34-43	Reduce requirements for lighting intensity: 35 foot candles at reading plane and 20 foot candles at floor.	1+	0.1-	1	x2.5
8: 45-49	Eliminate specifications on maximum brightness ratios: 40/1 between fixture and ceiling and 10/1 between fixture and walls. Other specifications on types of interior materials, finish and color appear not coordinated with such brightness ratios.	1+	0	0	x1
8: 71-74	Allow use of only one line of flourescent light fixtures along center of ceiling.	2-	2-3 -	3	7.5--

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
8: 86-93	Eliminate specifying details on lighting fixture design and lens material.	0-	1-2 -	0	x1.5--
8: 117-118	Eliminate the requirement for shielded cable to be used between the inverter and the load. Using shielded cable imposes additional capacitive loads. Suggest that shielded cable be used only if electrical interference conditions warrant its use.	1-	0-1 -	1	x2.5--
8: 150-165	Delete requirements for step well lights as long as other specifications require an overhead light fixture. The design requirement should be to meet the illumination requirements specified in the Federal Register for step areas and at the ground level outside of the door areas.	1-	1-	1	x3--
9:	AUXILIARY ELECTRICAL EQUIPMENT, CONTROLS & WIRING				
9: 71-77	Eliminate automatic timing and switching circuits for switching to emergency power. Those loads to be powered under emergency power could be connected directly to the battery, through a switch, and those not to be powered could be tied directly to the auxiliary power supply.	0-	1-	1	x2--
9: 239-272	Potential exists to reduce the number of circuit breakers if other electrically powered features of the car are eliminated.	1-	?	?	x1-
9: 279	Eliminate controlling the coupler from the operator's console	1-	0-	1	x2--
9: 298-305	Do not require individual illumination of door switches, track switches, headlight control, cab light switch and horn and gong actuators. The Boeing SLRV as built specification deletes these.	1	1-	1	x3-
9: 320	Place pantograph control at only one of the operator's cabs, but not both. Allow pantograph to be positioned only by rope.	2--	1-	?	x3---
9: 419-420	Eliminate provision for installation of destination sign control at operator's cab.	2+	1	3	6+

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
9: 464-474	The specification presently calls for eight master controller detents. The number of detents might be reduced. For example, the Boeing SLRV as built specs detected detents for Minimum Power and Minimum Brake.	0+	1	1	2+
9: 554-621	Eliminate pantograph and use trolley pole. This can be done only if the total car power is reduced since the trolley pole is limited to 450 amp continuous.	3+	5	0--	xx8-
9: 679-685	Delete requirements for convenience outlets.	1+	0-1 -	1	x2.5
9: 897	Allow some wires to be spliced using a controlled process	0-	?	2	x2-
9: 899-903 & 1258-1260	Permit usage of electrical connectors to enhance modularization of components and at areas such as the console switch panel, electrical lockers, air comfort control boxes, door control, relay panels, operator's cab, vehicle interior, etc.	2+	3-4 -	3	8.5
9: 913-925	Permit that wires with potential difference greater than 50 volts to be run in the same conduit or raceway.	1--	2-3 -	5	xx8.5----
9: 918-921	Eliminate need to physically separate and tape wires at different voltages.	1--	2-3	5	xx8.5--
9: 926-928	Permit cab signal and Automatic Speed Control wiring to be run with other wiring if it is shielded.	1	2-3 -	0	3.5-
9: 940-943 10: 514-515	Specifications required "Hypalon or equivalent insulated wire of adequate physical strength (No. 6 or larger) may be cleated in place using cleats made of approved synthetic material". The customer would only approve molded rubber. The specification should list clamps design requirements, such as, the clamp design must guarantee 1/16 inch minimum insulation thickness between	1--	0-	1	x2 ---

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
	the cable and supporting metal clamp. The specification should also specify the maximum allowable spacing between supporting devices. Boeing found that 30 inches-horizontal and 24 inches-vertical was sufficient. The specification should not allow owner approval of cable routing and support.				
	The specification requires that all undercar wiring, where possible, shall be run in plastic coated metal raceways and wire ducts in an approved manner, and securely fastened, with necessary sound insulation to prevent wear and rattles. It should be revised to allow undercar wiring to be simply laid in raceways without securely fastening.	0--	?-	5	xx5---
9: 976-987	The specification should be more definitive in the type of wire terminals permitted for use. The spec presently requires that terminals used on conductors of No. 10 AWG size or smaller, shall be of the insulating type and shall be so designed as to securely grip and hold the insulation on the conductor.	1--	2-3 -	1	xx4.5---
	This criteria can be met by several types of wire terminals, such as ring tongue, fork and faston terminals. The use of faston type terminals reduces the assembly and installation costs and hence the vehicle costs and are suitable for the application as demonstrated on many transit vehicles including CTA 2200 and 2400 Series Cars. Although the specification did not prohibit the use of faston type terminals, the customer's consultants did prohibit their use.	0--			
9: 1037-1062	The Specification requires that wire marking be continuous along the length of each wire.	1++	0-	1	x2+
9: 1227-1233 17: 461-499 17: 520-533	The specification requires that wires for control and auxiliary circuits shall not be smaller than No. 12 AWG, No. 16 if insulated with ethylene tetrafluoroethylene (ETFE), except within equipment enclosures and for special apparatus where special types of wire are recommended for use by the manufacturers and approved by the Owner.	3--	0-	1	xx4---
	Suggest that the specification be revised to allow the use of No. 20 AWG size wire for general interconnecting	2--			

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
	purposes where circuit conditions permit. Aircraft wiring for comparable service is 24 AWG.				
9: 1239-1244	The specification requires that equipment enclosures shall be weatherproof.				
	Equipment access doors and cable penetration points are sealed to maintain the weatherproof integrity of the enclosures. Drain holes are provided in the bottom of the compartment to allow any liquid which may accumulate in the bottom to drain out. The customer's consultants have forced the addition of a cotter pin in each drain hole to act as a wiggler in the hole as the car travels along the rails and keep the drain hole open.	1-	0-	1	x2--
	The addition of these cotter pins was unnecessary as the smoothness of the LRV ride will not cause these cotter pins to wiggle.				
	Suggest that the specification define if drain holes are required and to call out wigglers if desired.				
9: 625	Eliminate one trolley pole if vehicle is to be single direction operated only.	3++	?	related to bi-directional car	
9: 687-870	Eliminate Automatic Speed Control System (ASC). Note: The ASC does not modulate the propulsion and brake systems. Control is provided by the operator via the control handle. The ASC simply requires the operator to obey the speed limits. If he does not respond within a specified time limit then the ASC will command either normal service braking or emergency braking as necessary.	2++	4-5 -	2--	xx8.5-
10:	PROPULSION SYSTEM & CONTROL				
10: 84-92	Relax duty cycle requirement for propulsion system	1--	?	0	x1--
10: 93-95	Delete performance verification of brakes by dynomometer.	1--	0-	1	x2---

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
11:	TRUCK ASSEMBLIES				
11:	Allow use of wheels with dampening ring instead of resilient wheels	5+	0-	5	10
11:9	Eliminate the need for compressed air system	-1--	3-	2	xx4---
12:	FRICTION BRAKE SYSTEM				
12: 35-36	Do not require friction brake without dynamic assist to meet strigent brake duty cycle (regard friction brake only as an emergency capability)	4--	5-	5	14---
12: 364-416	Specify minimum traction or grade capability which must be achieved by sanding equipment	0+	0	1	x1+
12: 473-476	Do not require quick disconnect hydraulic fittings.	1--	1-	1	x3---
13:	VEHICLE COMMUNICATIONS				
13: General	The majority of the words in this section appear to describe in detail an off the shelf communication system by a specific vendor. The specification should address itself to only the functional and performance requirements and specific design requirements such as transmitting and receiving frequencies. The detail design is the responsibility of the contractor.	0+	0-	1	x1
13: 27-28	Allow use of the simple "Transit Phone" in lieu of radio communications.	4--	2-3-	0	xx6.5---
13: 33-38	It is specified that the public address system on board the vehicle be addressed from the wayside over the communications system. This feature is expected to be of low cost if the communications system includes a digital encoding unit. It is suggested that wayside public address be made optional or required only if a digital encoding unit is to be required.	2++	1-2	5	8.5++

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
13: 72-134	Simplify requirements for the Communications System Control Head and delete words "as approved by the Engineer".	?+	0	1	x1+
13: 137-317	Delete detailed design guidance for the public address system. It presently appears to specify a particular vendor's product. The specification should address only functional and performance requirements.	?-	1-2 -	1	x2.5--
13: 151-178 290-296	The specification requires eight (8) speakers per car, four (4) in each body section.				
	Suggest that the quantity of speakers be reduced to three in each body section. The speaker enclosures are more elaborate than they need to be and the frequency response bandwidth greater than necessary.	1	0-1 -	1	x2.5-
13: 352-701	Delete detailed specifications for the FM transmitter and receiver. Specify only functional and performance requirements.	?--	1-2 -	1	x2,5---
13: 412-415	Delete adjustment and alignment of radio system on board the vehicle. Use plug-in units and allow these adjustments to be made in shop.	required by FCC	0-	1	x1-
13: 499-505	Delete automatic radio malfunction detector and alert system. This suggestion is particularly relevant if the digital encoding unit is deleted because there will be less chance for malfunctions.	1--	0-1 -	5	xx6.5---
13: 668-701	Delete train to wayside data transmission capability (i.e., the digital encoding unit).	1++	1-2	5	7.5++
13: 706-716	The requirement for sound powered phone lines should be deleted. They add unnecessary cost and complexity to each car. The maintenance requirement can be fully satisfied with a portable sound power phone and cable.	1++	1-2 -	1	3.5+
13: 742-743	Allow communications system components to be plug-in units for easy removal and installation and for maintenance in shop.	0	0-	1	x1-

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
13: 748-752	Do not require that <u>all</u> communications wiring be twisted pair and shielded.	0	0-1 -	1	x1.5-
14:	<u>EMERGENCY SYSTEMS</u>				
14: 68-85	Delete passenger emergency switches which automatically emergency brake the vehicle.	1++	0-1 --	1	x2.5
15:	<u>SYSTEM SUPPORT</u>				
15: 85-285	Delete education and training of operating and maintenance personnel and preparation of manuals from the vehicle specifications. These requirements should be specified separately and are dependent upon specifically what the purchasing property desires. When manuals are specified they should be done so explicitly to insure that all bidders will interpret the requirements in the same way.	2++	6--	?	xx8
15: 290-525	The listing of repair components is subject to varying interpretations. Spare parts and their quantity should be explicitly called out. The owner is given the right "... to increase the required number of any item.. not to exceed 100%...". It would appear that a bidder would have to include a substantial contingency in his price for this flexibility.	0+	0-	1	x1
	Consideration should be given to negotiating a separate contract for spare parts and not including them in the car costs.	3--			
15: 499-525	The specification is very general in regard to support equipment to be furnished. It is suggested that only very specialized equipment be required.	0	0	1	x1

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
19:	DIAGNOSTIC TEST EQUIPMENT				
19: General	Do not include manufacture of any diagnostic test equipment with the purchase of the vehicle. Employ conventional trouble shooting and testing techniques.	3++	7-	4	14+
	Consider deleting the use of one all emcompassing diagnostic tester and provide a number of smaller portable single-function testers.		-1++		
19: 99-102	Test points would not need to be provided if cable connectors are allowed in wiring (reference Section 9 line nos. 899-903). The tester hook-up cables could include breakout cables that could be easily connected via these connectors without interrupting circuits.		-1-	-1	x-2--
19: 302-304	Delete open ended approval of test programs by owner.		?-	3	x3-
	PROCUREMENT PROCESS				
	The following general observations are submitted with reference to the general procurement process and the possible cost implications of some of the program management philosophies which are implicit in the SLRV Specification and those who are administering it.				
	1. Differences in program management philosophies between individual operating properties can have a profound effect on the cost to the supplier. Some properties know exactly what they need (CTA for example in Boeing's experience) and follow a consistent pattern in administration of their procurement contracts. Others are somewhat vague and don't pin down exactly what they want and later demand as much as they can. Potential suppliers thus are placed in the position of trying to "calibrate" the "confusion factor" in terms of what it may cost them in processing disputes and losing arguments. In short, projects for mature properties with well established and seasonal procurements and project management personnel can be expected to receive more				

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
	advantageous bids than those without a well established track record.				
	2. Foreign bidders, and those who have not had first hand experience with the idiosyncrasies of individual properties are likely to miscalculate what it will cost them to actually do the work to the satisfaction of their customers.	0			
	3. There are potential conflicts between the practice of having the purchaser approve in meticulous detail the technical features of the design - including the right to direct unilateral changes, and at the same time holding the manufacturer responsible for reliability and overall performance.	0		1	

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
2:	SYSTEMS REQUIREMENTS				
2: 27 & 409	Reduce 50 mph cruise speed	2++	?-		x2+
2: 132-167	Relax crashworthiness goals and requirements	2+	0--		x2-
2: 125-126 2: 336-344	Provide clearer definition of worse case power supply requirements including fault capacity, source impedance, ripple content etc.	2+	0		2+
2: 302-313	Modify vibration and shock criteria	0--	0		x0--
2: 355-360	Make requirement for shop power plug an option	1++	0-1		1.5++
2: 510-514 12: 237-238 12: 400-402	Eliminate automatic sanding and place under operator control	2+	1-2 -		3.5
2: 569 10: 226-230 10: 299-300	Eliminate adjustment of tractive effort output and jerk rate	1+ jerk only	0- jerk only		1
2: 614-617	Eliminate adjustment of rates for wheel wear	1--	0-1 -		x1.5--
2: 1875-1932 10: 219-224	Eliminate energy simulation and simply check power consumption at site. Place performance requirement for energy consumption in spec if desired.	0	0		x0

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
3:	CARBODY				
3: 112-154	Strengthen the specification to provide dynamic loads and forces. This will help reduce the risk of structural failure in final test.	0--	-1 +		x0-
3: 286-322	Straight vehicle sides would provide some savings, however, once tooled, sloping sides pose no problems except for increased number of rejected pieces.	-2--	1-2		x0.5--
3: 335-340	Roof shroud could be eliminated.	1-	0		x1-
3: 381-386	Sub floor should be an option left to manufacturer if desired impacts, penetrations and other requirements are specified. Permits use of sandwich panels.	1-	?		x1-
3: 415-416	Floor materials used in transit vehicles should be specified as to finish and color but not as to details of fabricating the individual joints and mating with walls and other surfaces.	2--	1-2 --		xx3.2----
3: 506-568	Cantilevered seats provide little latitude to the manufacturer for using standard seats. Pedestal seats would have a broader application. Small savings can be achieved if pads are eliminated from fiberglass formed seats.	2+	1-2 -		3.5
3: 577	By specifying stiffness it has limited structure and materials that can be used. A bumping load of specified pounds or impact with ¼ pound ball would give manufacturer more latitude.	1--	?		x1--
3: 614-625	Overly specified doors. Size could be reduced for front and rear doors.	2--	0-1 --		xx2.5----
3: 742-775	Providing simple cord activated chime for passenger signaling will provide savings. Acknowledgement lights and other luxury signalling not necessary.	2++	1		3++

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
4:	<u>COUPLERS AND DRAFT GEAR</u>				
4: 72-79	Providing lock arrangement to one side may provide savings if sepecified for all vehicles.	0--	0-		x0---
5:	<u>OPERATOR'S CAB</u>				
5: 68-73	Savings might be achieved by eliminating the capability to swivel the seat 90 degrees toward the door of the vehicle.	1++	0-		x1+
5: 72-73	Use black iron tubular material primed and painted for the operator chair support.	1-	0-		x1--
5: 117-125	Special folding mirror can be eliminated. A concept for a particular authority.	1-	0-1 -		x1.5--
5: 156-159	Provide only one warning system either a gong or a horn on each vehicle.	1++	1-2 --		xx2.5
6:	<u>DOOR CONTROL</u>				
6: 30-34	Eliminate timing circuit for doors.	1+	1-		x2
6: 214-220	Eliminate the by-pass switch. This function can be handled by switches located at each door.	1-	0-1 -		x1.5--
7:	<u>AIR COMFORT SYSTEM</u>				
7: 87-91	There are devices available that can be purchased that will handle the diffuser adjustment problems. Specify the end requirement but not how to accomplish.	?-	0-1 -		x.5--
7: 100	Specifying electric heaters that are separate from air conditioning creates difficulties in control. Specify end requirement desired in the A/C Systems.				

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
7: 120-127	Bracketing the manufacturer by specifying the inside vehicle height, floor height and overall height provides little opportunity for the provision of overhead room to package A/C System and other required components. Target dimensions would provide builder with more latitude.	2--	0		x2--
7: 170	Condenser ambient temperatures should not be specified. Both ambient and location should be left to supplier.	0-	?-		x0--
7: 186-227	Each piece of evaporator should not be specified.	0-	0-		x0--
7: 212-213	Belt drives could be used effectively.	1--	0-		x1---
7: 216-218	Too restrictive. Should not be specified.	1--	3-4 -		xx4.5---
7: 269-277	Too restrictive and should be opened up.	2+	1-2 -		3.5
8:	LIGHTING SYSTEMS				
8: 51-52	Eliminate beam width requirements for light fixtures.	1--	0-1 -		x1.5---
8: 54-55	Eliminate noise requirement since it replicates already stiff 65 dbA requirement.	1++	?		x1++
8: 57-60	Specify headlights in terms of conventional bus sealed beam lights.	1--	0		x1--
8: 78-80	Do not specify finish for light fixutres.	1-	0-1 -		x1.5---
8: 84-85	Reduce life requirement for lamp fixtures.	1--	0-1 -		x1.5---
8: 150-156 & 164-165	Eliminate step-well lights so long as required illumination is provided in door area.	2-	0-1 -		2.5--
8: 210-213	Eliminate interlock to prevent operation of front end of car with stoplights but no headlights.				
8: 212-213, 223-224, 237-238	Permit fuses instead of circuit breakers for stop lights, markers and destination signs.	2--	0-1 -		xx2.5---

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
8: 244-249	Eliminate line breaker overload lights.	1+	0-1 -		x1.5-
9:	AUXILIARY ELECTRICAL EQUIPMENT & WIRING				
9: 68	Eliminate battery "overcharge" indicator on operator's console.	1-	0-1 -		x1.5--
9: 189-195	Eliminate 32 volt interlock on fuse box cabinet.	1+	0-1 -		x1.5
9: 200-201	Eliminate green light on fuse box door.	1+	0-1 -		x1.5
9: 217-218	Eliminate lock on LVDC breaker panel door.	1--	0-1 -		x1.5---
9: 220-228	Eliminate design details on circuit breakers.	?	0-1 -		x0.5-
9: 295-298 13: 86-89	Eliminate automatic dimmer device to regulate intensity of illumination of switches and indicators. Use rheostat.	1+	0 -		x1
9: 325-326	Eliminate passenger stop request switches	2+	0 -		x2
9: 529-533 971-974	Reduce number of spare trainline wires.	2--	1-2 -		xx3.5---
9: 989-1025	Replace design guidelines for ground connections with a voltage drop requirement.	1+	0 -		x1
9: 1030-1033	Permit breaks in shielded wires provided they are properly spliced or connected.	1--	0-1		x1.5--
9: 1239-1244	Permit mounting of Auxiliary Electrical System components within car body and relax requirements for vibration, etc accordingly.	?-	0		x0-
9: 1258-1262	Specify connectors according to MIL C	-2-	-1 +		x-3

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
10:	PROPULSION SYSTEM AND CONTROL				
10: 201-202	Allow modulation of dynamic braking to correct wheel slip.	0+	0		x0+
10: 282-289	Define impact and debris environment for motor blower explicitly.	1-	0		x1-
10: 448-460	Delete separate ground brushes around antifriction bearings for 600 V and LVDC ground paths.	2-	2-3		4.5-
10: 478-479	Delete owner design review and approval of speed sensor.	0	0-		x0-
10: 482-489 12: 440-445	Delete in car diagnostic taps for propulsion and braking current measurement.	1-	1-		x2--
10: 509-515	Replace clamshell quick disconnect for motor lead cables from truck body with simple lugs.	1-	1-		x2-

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
11:	TRUCK ASSEMBLIES				
11: 519-528	Eliminate wooden bar and brackets (safety bars) in front of trucks.	1+	0-1 -		x1.5
12:	FRICTION BRAKE SYSTEM				
12: 187-194	Reduce requirement for 15 full brake applications in event of loss of compressor or hydraulic prime power.	2-	2-3 -		4.5--
12: 352-354	Eliminate track brake cutout in electric locker.	1+	1-		x2
12: 357-358 12: 430	Use visible or audible indication that track brakes are applied, not both.	1++	0-1		1.5++
13:	VEHICLE COMMUNICATIONS				
13: 30-31	Eliminate two-way communications between on-board operating personnel.	1+	2-3 -		3.5
13: 58-67	Use simple switch instead of sub-audible tone codes to actuate PA system.	1+	0		x1+
13: 68-70 127-134	Delete local tone annunicator preceeding public announcement.	1+	0-1 -		x1.5
13: 90-134	Simplify mode selector using a simple selector switch.	0-	0		x0-
13: 272-290	Delete key lock of amplifier - fasten with vandal proof screws or conceal in electric cabinet.	?	0-		x0-
13: 376-389	Delete radio mounting and enclosing restrictions, except for louvers.	1--	0-1 -		x1.5---
13: 392-398	Delete radio packaging design guidance particularly to protect from dust.	1--	0-1 -		x1.5---

SECTION: LINE NO.	POTENTIAL SPECIFICATION MODIFICATION	KAISER	KLAUDER	BOEING	TOTAL
14:	EMERGENCY SYSTEMS				
14: 45-48	Reduce percent of lighting supplied by emergency system.	1-	0-		x1--
14: 68-85	Delete passenger emergency switch: provide only pull chime for passenger stop request.	2+	0-1 --		xx2.5-
14: 86-89	Provide either operator master control actuated emergency braking or emergency switch, but not both.	1+	1--		x1-
14: 91-99	Delete storage for emergency jack.	1+	0-1		1.5+
15:	SYSTEM SUPPORT				
15: 62-69	This safety plan provision generates much paper work. Modest savings might be achieved by deleting this requirement.	2+	1-2		3.5+
16:	MANAGEMENT SYSTEMS AND QUALITY ASSURANCE				
16: 72-74	Requirements for technical documentation can be subject to various interpretations. Recommend a broad statement of objectives only.	2--	0 --		x2----
17:	MATERIALS AND WORKMANSHIP				
17: 900-1047	The specification calls out certain brand names of paint or "equal". Instead it should allow selection of grades of paint subject to meeting recognized ASTM standards and procurement by a competitive process.	1-	0		x1-

APPENDIX D

NEW TECHNOLOGY

The research carried out for
this report developed no new technology.