Report No. (UMTA-PA 06-0099-86-1)

Rail Modernization Study

Final Report

Appendix

Development of the Cost-Effectiveness Methodology

LTI Consultants, Inc.

prepared for

U.S. Department of Transportation

Urban Mass Transportation Administration

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APPENDIX

DEVELOPMENT OF THE COST-EFFECTIVENESS METHODOLOGY

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APPENDIX A

DEVELOPMENT OF THE COST-EFFECTIVENESS METHODOLOGY

I - INTRODUCTION

The Rail Modernization Study has been conducted for the Urban Mass Transportation Administration. The Engineering Cost Estimate Phase of the study identified works costing in total, $17.8 billion (at 1983 prices) to upgrade and modernize all segments of rail transit systems.

This appendix describes the cost-effectiveness methodology used to prioritize the improvement developed in the first phase. It focuses on the economic rationale for the "weights" or "modifiers" used to calculate benefits.

The "modifiers" allowed the direct estimation of benefits achieved from the specific levels of improvement to different system elements in the study. The modifiers have been developed by quantifying the benefits of improvements for individual elements of work under two headings:

(a) Cost savings, which are dependent on:

- the type (rapid rail, light rail, commuter rail)
- change in condition
- the scale of the work (track miles improved etc.)

(b) Passenger-related benefits, which are determined by:

- the change in condition
- the scale of the work
- the number of passenger miles affected.

The modifiers allow these factors to be combined to calculate the benefit of the improvements proposed on a segment, or, where this is not possible, at the system level.

The modifiers are set out in Supplementary Section B. This appendix sets out in addition:

- the general approach by which the modifiers have been developed (see Section IV and V);
- the detailed methods used in calculating them (See Supplementary Section C);
- a general description of how they can be applied to give an overall measure of benefit (see Section VI);
- the limitations and conditions to which the modifiers are subject (See Section VII)

II - THE BENEFITS OF URBAN RAIL IMPROVEMENTS

The benefits of urban rail improvements take a wide variety of forms:

- o Improved operating efficiency:
  - Reduced operating and maintenance costs, which may be used to reduce revenue subsidies or reinvested to further the other objectives below.
- o Benefits to the passenger:
  - Reductions in travel time through increased speed and reliability;
  - Improved environment (e.g. reduced noise, smoother ride);
  - Increased safety;

- (For many projects involving replacement of essential facilities) the maintenance of a service which would otherwise have to cease.

These benefits will, in turn, tend to divert riders from road to rail travel, which will:

- o Increase transit revenues;
- o Result in external benefits
  - reduction in congestion
  - environmental improvement.

The only technique which takes full account of these diverse benefits is social cost benefit analysis. Methods of cost benefit appraisal are well established in some areas of policy formulation, but have only been applied in a limited way to transportation issues (principally new system construction).

It is this method, extended by LTI to cover other transportation improvements, which has formed the basis of much of the work described in this appendix.

III - EVALUATION REQUIREMENTS

Rigorous evaluation of a capital program involves:

(a) The quantification of the costs and benefits of the individual projects;

(b) Comparison of the continuing costs and benefits with the original capital outlay on a common basis (discounted cash flow or present value);

(c) Comparison of the results for the individual capital projects with those for the available alternatives;

(d) Allowance for the potential interaction between projects.

It should be pointed out that there is no information on alternatives in the program to be reviewed by the Cost-Effectiveness method, and that it would not be practicable to investigate closely the interaction between projects. These two factors of necessity constrained the scope of the methodology which could be developed as a comprehensive appraisal tool. Thus, the work focused on the estimation of the benefits of the different types of improvement measure proposed.

In order to carry out a full evaluation of these benefits it would be necessary to have information on the following:

- The effect of the different types and levels of improvement on:
  - operating and maintenance costs;
  - passenger traveling time and conditions;
  - the value passengers place on time savings and improvements in the traveling environment;
  - the response (in terms of traffic generation and modal transfer) of such increases in value;
  - the effect which the transfer of passengers from road travel will have on the economic costs of congestion, pollution etc.

The methodology developed and set out in this report has been based on the "Assessment of Benefits Methodology" statement prepared by LTI Consultants, Inc. on January 24, 1986, and included as Supplementary Section H.

IV - COLLECTION OF INFORMATION AND ASSESSMENT OF CHANGES IN CONDITION

One of the first tasks of LTI Consultants, Inc. was to assemble as much as possible of the information described in Section III. To this end the LTI project team undertook a search of the available literature and assembled a wide range of documentation both on the economic aspects of rail transit in the USA and on individual transit systems (See Supplementary Section G).

The team also visited the following transit operators with the objective of obtaining cost, performance, and general background data, and to assist in determining the operating benefits resulting from different improvement measures:

Boston	- MBTA
New York	- MTA, NYCTA, LIRR
Northern New Jersey	- NJT
Philadelphia	- SEPTA
Washington, DC	- WMATA
San Francisco	- BART, MUNI
Chicago	- CTA, RTA

In addition, meetings were held with the following government and research bodies in order to determine the status of current research in the USA into fares elasticities and the estimation of the direct benefits and external effects of urban rail service:

Urban Mass Transportation Administration
Transportation System Center (Boston, MA)
Institute of Transportation Studies (University of California - Berkeley)
Charles River Associates (Boston, MA)

Members of the project team were extremely well received by both operators and research bodies, who went to considerable lengths to try to provide the data.

From the discussions with the operators, however, it became apparent that:

(a) It is rare for any comprehensive cost/benefit assessment to be carried out before funding for a project is sought.

- The usual approach is for properties to define a set of (hierarchical) objectives and then to seek to judge the extent to which individual projects meet these objectives.

- Capital planners have very little hard data available on the physical effects of projects, and although a large amount of cost and performance data is available in aggregate form, it is difficult to relate this to the physical condition of the assets concerned, and still more to changes in that condition.

(b) Where changes are observed in performance or costs, they are often attributable more to changes in management or in maintenance policy than to changes in the physical condition of assets.

- In particular more systematic maintenance, while increasing costs in the short term, may increase reliability and reduce the rate of deterioration of the assets.

(c) A substantial proportion of projects included in the program are deemed essential for continued rail service operation.

- Where, as in many cities, closure is not a politically practicable option, the projects concerned are treated as unavoidable.

(d) Some of the projects included in the program were already being implemented.

In such circumstances it is understandable that relatively few resources are put into objective benefit assessments, and even more so when the incidence of benefits to funding agencies differs from the attribution of costs.

In these circumstances the prime source of information on the benefits of specific levels of improvement has been the data assembled for the Engineering Cost Estimate Phase of the Rail Modernization Study itself, which was examined in detail, referring where necessary to the original source data on individual projects. This information was complemented by the use of data derived from the London experience on the effects of improvements on passenger and on revenue costs, and by reference to the "Section 15" analyses prepared by UMTA.

From discussions with the research bodies consulted it proved possible to bring together an adequate corpus of general information on such factors as fares elasticity and values of time to provide the basis for deriving revenue generation and passenger and external benefits from specified passenger time savings. Much of this was consistent with London/UK Experience.

Taking all the sources together, the information available as a basis for assessing the effects of specific improvement measures is essentially:

- The change in condition for each sub-element of work on each segment (sometimes available at a system level only);

- The volumes (track mileage, etc.) of the different elements broken down by their condition;

- The definition of changes in condition for different elements;

- Limited performance data for different systems relating to e.g. maintenance costs, failure rates etc. This data is only available for systems as a whole at a given time, and no indication is available of how it has varied over time. In many cases comparisons are hindered by the differences in the definition of performance used;

- Experience gained in London of the likely effect of improvements on costs and passenger service.

It was a major task, starting from this data base, to derive figures relating a specific change in condition (A) of an element (B) for a given type (C) to the ultimate effect on costs and passenger benefits, taking account of:

- The volume of the element (D) improved;
- The passenger mileage affected by the improvement (E).

Given information for individual segments and systems on items A to E, the system devised must then make it possible to calculate the effect on costs and passenger benefits. The procedure developed can be summed up as follows:

Measure of benefit for a given A,B and C
= operating and maintenance cost saving plus passenger-related benefits

Where
cost savings are a function of the volume of the element improved (D)

and
passenger benefits are a function of the volume of the element improved (D) and the passenger mileage affected (E).

The general approach adopted can be summarized as follows:

(a) Assess implications for costs and for passengers of specific changes in condition by close examination of the definitions used in the RMS for determining the condition of different elements ("Bad", "Poor" etc.) and by examining the original documentation for sample projects.

(b) Study the performance data assembled during the Study to assess the likely effect of changes in condition on costs (including essential renewal costs which would otherwise have to be incurred) and their impact on passengers, supplementing this information where necessary with information drawn from London experience.

(c) Quantify expected effects on costs in relation to the volume of improvement (track miles etc.) and on passengers, in terms of time savings, in relation to passenger mileage carried and volume of the improvement.

The results of these assessments are expressed in a series of "matrices" - for each rail transit type - giving the modifiers relevant to a specific change of condition and element. The matrices are set out in Supplementary Section B and are accompanied by instructions on how they should be applied to the passenger mileage and "volume of work" data available in order to obtain figures for the expected benefits in any specific segment.

In many cases extensive assumptions were also required in regard to such factors as average load, length of journey etc. These assumptions are spelled out in Section C in the discussions on the calculation of the individual modifiers.

It must be stressed that because sweeping assumptions have had to be made (often applied to all systems of a given type) the results obtained by applying the matrices have to be interpreted with some caution. See Section VII, below, on strengths and limitations.

V - CALCULATION OF PASSENGER-RELATED BENEFITS

The passenger benefits calculated in the course of the process described in Section IV are expressed in time savings. (In certain cases the values given are "proxies" for benefits which arise in other ways, i.e. by making journeys less stressful.) From these it is necessary to calculate:

(a) the benefit to passengers in \$, by multiplying by an appropriate value of time;

(b) the effect of those benefits in generating additional transit usage, including diversion from cars, by applying appropriate elasticities;

(c) the additional transit revenue generated, by multiplying the passenger miles generated by the average fare per mile;

(d) the external benefits, by multiplying the diversion of traffic from cars by appropriate values for such factors as congestion and accident costs.

The sum of these factors represents the total passenger-related benefits from an improvement measure. This can be expressed in the formula:

$$\text{Passenger Time Savings} \times \text{VoT} \left(1 + e + \frac{e}{2\text{xfare/mile}} + N \right)$$

Where,

VoT = Value of Time
e = fares elasticity,
k = proportion of traffic transferring to/from cars x external cost per car passenger mile (See Section E)
N = external factor (See Section E)

In practice, given the fairly limited data available on elasticity and external factors, the passenger time savings are factored by a simple property - specific multiplier which also incorporates the value of time for the city concerned.

A table of these multipliers is given in Section E (Annex 1). Section E also includes the derivation of appropriate values for the factors which determine these multipliers, namely:

	Annex
o Fares elasticities	2
o External benefits	3
o Value of time	4
o Price and wage variation between cities	5

It should be noted that one of the most important passenger benefits of many projects is simply to allow services to be maintained where deterioration in critical facilities such as track or structures would otherwise make this impossible. It has, however, been made clear that is must be assumed that all segments remain in service. Within this constraint, the effective benefit of projects of this nature is simply to avoid the minimum expenditure on repair and renewal which would otherwise be required to keep the segment concerned operational, and this (an operating cost saving) is the benefit which has been attributed to such measures in calculating the modifiers given in Section B.

VI - COMPARISON OF COSTS AND BENEFITS

The next stage in the evaluation is to compare the benefits for individual improvements calculated as described above with the capital costs in order to allow the program to be prioritized. This section describes guidelines for the interpretation of the benefits calculated by the processes above. This is necessary, not only because of the general requirement to develop a methodology which gives results approximating as closely to economic benefit as possible (and the final comparison of costs and benefits is a critical part of this process), but more particularly:

(a) because the modifiers have been designed to form part of a specific process for the comparison of costs and benefits, and may not give satisfactory results if applied other than in the manner intended; and

(b) on account of the particular difficulties posed by the assessment of the benefits of those improvements considered essential to keep services in operation.

The first step in the comparison is to calculate the total annual benefits using the modifiers set out in Section B. In the case of operating cost savings this involves multiplying the appropriate modifier (which is given in terms of cost saving per track mile, per vehicle etc.) by the volume of the element improved to give the total annual cost saving of a project. In the case of passenger benefits the modifier must be multiplied by:

- the number of passenger mile s on the segment concerned;
- a scale factor, indicating the proportion of the asset improved, and of passenger mileage affected;
- the city multiplier, to convert time savings into appropriate money values for the system concerned.

In order to compare capital outlays and continuing subsequent benefits on a "like-for-like" basis it is necessary to express both in "present value" terms, discounting future revenue / benefit flow appropriately. For this purpose a discount rate of 10% has been recommended by the client. (This rate has also been used where it has been necessary to convert capital outlays into an annualized amount in the calculation of the modifiers.)

For simplicity, both the incidence of the capital expenditure and the starting point for the generation of the benefits can be taken as "now".

- o The fact that the project may not be implemented for, say, five years will not itself affect the relative balance between benefits and costs of individual projects (which is the basis of the prioritization exercise).
- o There will, however, be some distortion in the measure that the benefits do not begin to flow until the capital works are completed - sometimes as much as two or three years after the peak of the capital expenditure profile.
- o A more thorough analysis would allow for the relative phasing of the capital expenditure and the benefits.

It is then possible to calculate benefit / cost ratios for each improvement measure on a segment and to prioritize the program on this basis.

It should be borne in mind, however, that the resulting prioritization has been based on the assumption that all segments must be kept open.

- o Keeping segments open will inevitably involve major expenditure on some little used part of systems and, if there are insufficient funds for the whole program this could squeeze out improvements which are much needed or highly desirable on busier segment.

On this account it is important that the improvements concerned be identified on the prioritized list. A suggested list of the types of project concerned is given in Annex 2 to Section A: all projects affecting the elements or sub-elements indicated, where the existing condition is "poor" or "bad" would come into this category.

Because of the importance of this issue a description has been included (See Section A) of the way in which the benefits of continued operation, including external benefits, could be quantified and compared with the costs of the projects concerned.

VII - STRENGTHS AND LIMITATIONS

Other Sections of the Appendix, and several of the Suplementary Sections, mention various limitations of the approach which has been used. To put these into context, the main limitations are those envisaged before the work started. These are:

- o Standardized assumptions regarding the relationship between benefits and levels of improvement (themselves defined in a very broad manner) can never approach in accuracy a detailed project-by-project and system-by-system evaluation.

- Lack of appropriate data on the cost and passenger effects of improvements.
- Assessment was limited to the projects already identified, whereas the optimum solution in individual cases would involve the consideration of alternatives.
- It was not possible, in the time available, to consider the interaction between projects.

Other limitations became evident during the course of investigations, in particular:

- The very broad categorization, and lack of segment data, for some work (notably the element of System - wide Controls).
- The restricted range of measures of volume of work in the program (again, particularly in the case of System - wide Controls).
- Incomplete, and often uncertain nature of, performance data available from transit operators leading to a need to rely heavily on standardized figures based on average performance.

It must be stressed that, in these circumstances, it has been essential to use experience of the evaluation of rail transit projects in London to compensate partially for the lack of hard data.

The limitations therefore principally concern the <u>data</u> available. The <u>method</u> which has been used is based upon social cost benefit analysis and is the most comprehensive and reliable <u>method</u> of assessing benefits in an area of acknowledged difficulty. This basic technique, which is by now regarded as conventional in many areas, has been developed and extended on the basis of pioneering work in the field of valuing benefits to passengers. The result is a methodology, backed up by a detailed rationale (see Supplementary Sections) and explicit assumptions which will assist in reasonably confident judgments being made about:

- The total benefits and costs of the projects in the Study;

- The relative benefits of the expenditure proposed on the different types of system;
- The proportion of the total expenditure , and the expenditure on each type of system, which are likely to be worthwhile.

Because the assumptions which have been made are set out in great detail for each element of expenditure, the methodology can be used to consider specific proposals by the substitution of different specific assumption or - better still - hard data.

BENEFITS OF WORK ESSENTIAL TO AVOID SERVICE CLOSURES
SUPPLEMENTARY SECTION A

1. BACKGROUND

It is clear that the prime justification for a substantial part of the expenditure proposed is in effect to avoid having to close the line concerned.

Generally the benefits of avoiding this drastic course of action will be far greater than the betterment benefits, and it is essential to consider them in an overall assessment of the modernization program.

- It is important to bear in mind, however, that to avoid closure it will of course be necessary for <u>all</u> the critical work concerned to be carried out, and that the benefits of avoiding closure can only be attributed to the whole package of works concerned, and not individually to each of those works.

2. SUGGESTED PROCEDURE

The following indicates how the assessment of the benefits of avoiding closure -- which form a major part of the overall benefits of the program -- could be undertaken.

- The suggested procedure for establishing the relative costs and benefits involved in avoiding closure (as distinct from the benefits due to betterment resulting from the works concerned) can be summarized as follows:

a) Capital Outlays

- Establish those types of work which, if not done when due, will precipitate closure.

- Assess when, on this basis, it will become essential to renew the element concerned. (This will depend not only on its current condition but also the type of element involved.)

- Calculate the present value of the program of essential works.

b) Continuing Costs and Benefits

- Assess the benefits of maintaining the service per passenger mile.

- Assess the net revenue cost, (compared to closure) of continuing operation.

- Calculate present value of continuing costs and benefits.

As an indication, these individual factors can be assessed as follows:

a) Benefits of maintaining the services are given by:

- The additional value passengers place on the service over and above what they pay in fares. It is evident that passengers place a considerable value on the advantages (speed, comfort, availability of time to read / sleep etc.) of rail travel, which is reflected in the generally low elasticity of urban rail passengers. As shown in Annex 1 to this Supplementary Section, this additional benefit (or "Consumer Surplus") is given by:

$$\frac{\text{Revenue}}{\text{Fares Elasticity}} = \frac{\text{Passenger Miles x Fare/mile}}{\text{Fares Elasticity}}$$

- The external costs (traffic congestion and accidents) avoided by those passengers not using their cars. This can be thought of as a constant (k) times the number of trips, which works out to:

$$N \times \frac{\text{fare per trip}}{\text{fares elasticity}} \times \text{No. of trips}$$

$$= N \times \frac{\text{fare/mile}}{\text{fares elasticity}} \times \text{Passenger miles}$$

where $N = \frac{\text{K x Elast.}}{\text{fare per trip}}$ as defined in Sect. E

N is the ratio of "external" benefits to passenger benefits, as for a simple change in the time costs of travel. N is 4.5% for light rail, 6% for rapid rail and 12.5% for commuter rail.

b) The costs of maintaining the service are:

operating cost - passenger revenue

= operating cost - passenger miles x average fare

c) The annual net benefit of maintaining the service is therefore:

$$\text{PMs x fare/mile} \left(1 + \frac{N + 1}{\text{Fares Elasticity}}\right) - \text{Operating Cost}$$

d) This must be compared with the total capital cost (in present value terms) of the work required to avoid closure .

3. TYPES OF WORK REQUIRED TO AVOID CLOSURE

In general, it is more likely that some elements (e.g., bridges, train protection systems, track) would deteriorate to the point where closure would be forced. One approach to identifying the projects concerned would be to include all those projects in the Rail Modernization Study for which safety has been identified as the prime goal.

A more systematic approach might be adopted in the prioritization exercise by identifying certain element codes which are considered to represent critical safety items.

- These codes could then be identified within the model and closure benefits automatically calculated.
- A suggested list of codes, based on London experience, is attached.

4. TIMING OF ESSENTIAL WORKS

In principle, "service retention" benefits flow only from the date that closure would have been forced, while the works may in fact be done earlier for other reasons. However, in the current study the simplifying assumption, that the benefits commence upon project completion, is suggested.

5. CONTINUING SAVINGS FROM CLOSURE

If a line is closed, the costs of operating staff, maintenance, energy cost, etc. will be saved. (In addition, some real estate may be released, but that is not allowed for in the present analysis.)

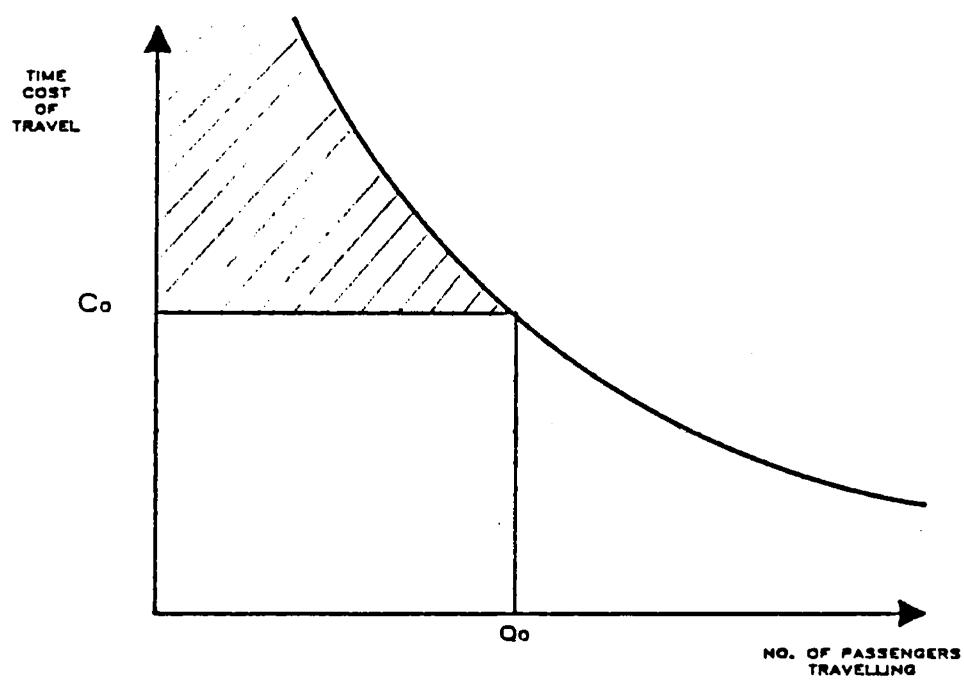
- Data on revenue costs of operation is not currently available for most segments of systems and would need to be assessed - e.g. by allocating the "vehicle" and "non-vehicle" related cost given in the UMTA Section 15 report pro rata with respectively vehicle and track mileage for the particular segment concerned.
- As a first approximation however, an estimate of revenue cost could be derived on the basis of a judgment of the operating ratio for the segment and the total revenue attributable to it (= passenger mileage x average fare).

PASSENGER BENEFITS OF AVOIDING CLOSURE

SUPPLEMENTARY SECTION A
Annex 1

In assessing the benefits to passengers of avoiding closure of a line, it is necessary to look at the "Consumer Surplus" currently enjoyed by passengers.

This is shown on the shaded area in the attached diagram, reflecting the fact that while some passengers would be willing to pay little more than they do at present, others place a very high value on having a rail service and would be willing to pay considerably more for it.



Consider an exponential demand curve

$$Q = A \exp(-\lambda C)$$

where Q = demand
A, λ = Constants
C = generalized cost/trip

This form of model has been used often in forecasting changes in demand in the UK with much success.

The consumer surplus, which is represented by the shaded areas can be calculated by integrating "under" the curve:

$$C.S. = \int_{\infty}^{C_0} A \exp(-\lambda c) \, dc$$

$$= \frac{Q_o}{-\lambda}$$

$$= \frac{\text{base revenue}}{\text{fares elasticity}}$$

Since $-\lambda f$ = fares elasticity

Thus the additional value passengers place on their travel (the Consumer Surplus) is given by the revenue divided by the fares elasticity. In cases where there are few alternatives and the mode under consideration is much preferred, the elasticity will be low and the consumer surplus therefore high.

BENEFITS OF WORK ESSENTIAL TO AVOID LINE CLOSURES:

SUPPLEMENTARY SECTION A
Annex 2

ITEMS WHOSE REPLACEMENT MAY BE ESSENTIAL TO ALLOW SERVICES TO CONTINUE ARE SIDELINED

	Code Number
Track	1000
Rail	1100 ‖
Tee Rail	1110 ‖
Continuous Welded	1111 ‖
Bolted	1112 ‖
Girder - Grooved Rail	1120 ‖
Continuous Welded	1121 ‖
Bolted	1122 ‖
Girder - Guard Rail	1130 ‖
Continuous Welded	1131 ‖
Bolted	1132 ‖
Rail Joints	1200 ‖
Ordinary Bolted Rail Joints	1210 ‖
Insulated Rail Joints	1220 ‖
Compromise Rail Joints	1230 ‖
Adhesive-Type Insulated Rail Joints	1240 ‖
Field-Welded Joints	1250 ‖
Bonded Joints	1260 ‖
Rail Fastening and Anchoring Systems	1300 ‖
Spike Fastening Systems	1310 ‖
Bolt Fastening Systems	1320 ‖
Special Fastening Assemblies	1330 ‖
Ties and/or Crossties	1400
Ballast	1500
Sub-Ballast	1510
Filter Fabrics	1520
Special Trackwork and Machinery	1600
Turnouts and Crossovers	1610
Guardrail	1620
Rail Lubricators	1630
Track Alignment, Gauge and Surface	1700 ‖
Track Alignment and Gauge	1710 ‖
Tangent	1711 ‖
Simple Curved Track	1712 ‖
Compound Curved Track	1713 ‖
Spiral-Easement Curved Track	1714 ‖
Canted Track	1715 ‖
Track Surface	1720
Uniform Profile	1721
Superelevation	1722
Rail Grinding	*1730

	Code Number
Roadway/Embankment	1800
Slope Erosion Control	1810
Vegetation Control	1820
Drainage	1830
Fencing	1840
Grade Crossings	1850
Crossing Material	1851
Crossing Protection	1852
Track Maintenance Equipment and Facilities	1900
Rail Grinding Equipment	1910
Other Maintenance Equipment	1920
Materials Yard and Warehouse	1930
<u>Vehicles</u>	2000
Self-Propelled Rail Cars	2100
Structure	2110
Traction	2120
Electrical/Electronic	2130
Miscellaneous Car Equipment	2140
Locomotives	2200
Structure	2210
Traction	2220
Electrical/Electronic	2230
Miscallaneous Car Equipment	2240
Unpowered Cars	2300
Structure	2310
Traction	2320
Electrical/Electronic	2330
Miscelleneous Car Equipment	2340
<u>Power Distribution</u>	3000
Traction Power Distribution Equipment	3100
Substation	3110
Transformer	3111
Rectifier	3112
Switchgear	3113
Overhead Wire	3120
Tramway Catenary	3121
Simple Catenary	3122
Compound Catenary	3123
Third Rail	3130
Circuit Breakers	3131
Sectionalizing Switches	3132
Cover Boards	3133
Heater Controls	3134

	Code Number
Poles and Foundations	3140
Ducting	3150
Underground Wire (Negative)	3160
Overhead Wire (Positive)	3165
Lightning Protection	3170
A.C. Power Distribution Equipment	3200
A.C. Unit Substation	3210
Transformer	3211
D.C. to A.C. Converter	3212
Switchgear	3213
Distribution	3220
Ducting	3221
Cabling (Overhead/Underground)	3222
Lightning Protection	3223
Grounding	3224
<u>System-Wide Controls</u>	4000
Train Control	4100
Train Operations	4110
Vehicle-Borne ATO	4111
Wayside ATO	4112
Central ATO--All Functions	4113
Train Protection	4120
Vehicle-Borne ATP	4121
Wayside ATP	4122
Central ATP	4123
Train Supervision	4130
Dispatching Devices	4131
Route Controls	4132
Schedule Controls	4133
Station Graphics Controls	4134
Failure Management Equipment	4135
System Status Indicators/Alarms	4136
Management Information Systems	4137
Vehicle-Borne Monitoring/Sensing Package	4138
Communications	4200
Cable Carrier	4210
Carrier Cables	4211
Carrier Terminal Units	4212
Telephone	4220
Call Boxes	4221
Central Station Equipment	4222
Public Address	4230
Vehicle-Borne Units	4231

	Code Number
Subway Stations (Repeat as above: 5210, 5220, 5230, etc.)	5200
Elevated Stations (repeat as above: 5310, 5320, 5330, etc.)	5300
At Grade Stations (Repeat as above: 5410, 5420, 5430, etc.)	5400
LRV Stop (Repeat as above: 5510, 5520, 5530, etc.)	5500
Parking Facilities (Repeat as above: 5610, 5620, 5630, etc.)	5600
Commuter Rail Stop (Repeat as above: 5710, 5720, 5730, etc.)	*5700
<u>Structures and Facilities</u>	6000
Railway Bridges	6100
Trestles	6110
Elevated Railways	6120
Girder Bridges	6130
Deck Girders	*6131
Through Girders	*6132
Multi-Girder Bridges	6133
Concrete Bridges	*6134
Truss Bridges	6140
Deck-Truss Bridges	6141
Through-Truss Bridges	6142
Pony-Truss Bridges	6143
Rigid Frame Bridges	6150
Arch Bridges	6160
Slab Bridges	6170
Moveable Bridges	6180
Culverts	6190
Box Culverts	6191
Steel Culverts	6192
Masonry Culverts	*6193
Rapid Transit Bridges (Repeat as above: 6210, 6220, 6230, etc.)	6200
Highway Bridges (Repeat as above: 6310, 6320, 6330, etc.)	6300
Buildings	6400
Substation	6410
Pump House	6420

MATRICES FOR ASSESSING BENEFITS

SUPPLEMENTARY SECTION B

1. INTRODUCTION

The modifiers set out in the tables attached are designed to enable annual operating cost savings and passenger benefits to be calculated in relation to different traffic levels applied to individual systems and their segments.

The modifiers are presented in the form of matrices which provide a specific modifier for each different type of rail transit, element of work, and change in condition. The method in which the matrices of modifiers are intended to be used is explained below.

2. MODIFIERS FOR OPERATING COST SAVINGS

The modifiers for cost savings are expressed in terms of dollars saved per unit of the element improved (e.g. track miles, square foot of bridge area, etc.), although in the case of system-wide controls, in the absence of any physical measure of the work, it has been necessary to use dollars saved/dollars spent as the modifier.

In order to derive the annual savings from a given level of improvement in a particular element, it is necessary to look up the matrix for cost savings for the type concerned (Rapid, Light, or Commuter Rail) and identify from the matrix the saving in $ for the element and change in condition concerned. The resulting figure should then be multiplied by the number of units (track miles etc.) undergoing the specified change in condition in order to derive the expected annual cost saving.

3. PASSENGER BENEFITS

The assessment of passenger benefits is undertaken in a similar manner, the relevant benefit per passenger mile being measured in seconds' traveling time equivalent for the various elements and changes in condition. The appropriate benefit per passenger mile taken from the matrices needs first to be multiplied by the number of passenger miles on the segment or system concerned. (Although in the case of station improvements a better result would be obtained by the number of passengers entering stations on the segment multiplied by average journey length.)

- In the following paragraphs this "number" is referred to as "PS" for Passenger Seconds.

This number "PS", resulting from the calculation in the paragraph above needs to be multiplied to allow for the scale of the work, to give the annual benefit in seconds.

The appropriate multipliers depend on the element concerned, as follows:

a) Track

Multiply "PS" by the track miles undergoing the change in condition, and...

Divide by the total track miles on the segment concerned.

b) Vehicles

Multiply "PS" by the number of vehicles undergoing the change in condition, and...

Divide by the total number of vehicles in regular use on the segment or system concerned.

c) Power
(Substations, Third Rail and Overhead Line)

Multiply "PS" by the number of track miles benefitting from the change in condition, and...

Divide by the total number of track miles on the segment concerned.

d) System-Wide Controls

The number "PS" does not need further adjustment for system wide controls. The number "PS" is for the whole system in each case.

e) Stations

Multiply "PS" by the square footage of station undergoing change in condition, and...

Divide by total square footage of stations on the segment or system concerned.

f) Bridges

Multiply "PS" by the area of bridgework undergoing the change in condition, and...

Divide by the total track mileage on the segment or system concerned.

g) Elevated Railways

Multiply "PS" by the length of structure undergoing the change in condition, and...

Divide by the total track mileage on the segment or system concerned.

h) Tunnels

Normally there are no passenger benefits, apart from avoiding the risk of closure.

i) Maintenance Facilities

Multiply "PS" by the area of maintenance facilities undergoing the change in condition, and...

Divide by the total area of maintenance facilities on the segment or system concerned.

NOTES:

It should be noted that "changes in condition" given in the RMS study data base relate to condition on completion of the RMS program (i.e. in ten years' time) as compared with the "starting" condition at the time that the assets concerned were surveyed.

It is for this reason that some projects come in the category "good to good" (i.e. condition change 4 to 4), the work included only serving to offset the deterioration which would otherwise have occurred in the interim.

Strictly speaking, the basis for the comparison should be the condition which the asset would have reached at the end of ten years in the absence of the proposed improvements. In the case of change in condition "4 to 4" it has thus been assumed that the condition would have lapsed to one half way between "fair" and "good", and the benefit of this change in condition has accordingly been taken as half that for a change in condition from "fair" to "good".

Consideration needs to be given to the possibility of making more systematic allowance for such deterioration in assets over the the period concerned - although this is only likely to apply to those assets, like rolling stock, for which the rate of deterioration tends to be particularly rapid.

In certain cases, in fact, the apparent effect of moving from "good" to "good" may, on the basis described above, exceed that of going from "good" to "excellent".

SAMPLE CALCULATION

Assumptions:

Project: 10 miles of track to be improved

Passenger Miles: 6,000,000 on this segment

Total Track Miles on Segment: 30 miles

Other:
- a) Rapid Rail System
- b) City = Chicago

Calculation of Passenger Benefits

(a) Time Savings

Change in Condition	Seconds Per Passenger Mile (1)	Passenger Miles on Segment (2) (Thousand Secs)	Proportion of Track Improved (Thousand Secs)
1 to 4	28	168,000	56,000
1 to 5	29	174,000	58,000
2 to 4	15	90,000	30,000
2 to 5	16	96,000	32,000
3 to 4	3	18,000	6,000
3 to 5	4	24,000	8,000
4 to 5	1	6,000	2,000

(b) Conversion From Time to $

Change in Condition	Total Time Saved (Thousand Secs)	x	City Multiplier $(3)	Annual Passenger Benefits $
1 to 4	56,000		1.21	67,760
1 to 5	58,000		1.21	70,180
2 to 4	30,000		1.21	36,300
2 to 5	32,000		1.21	38,720
3 to 4	6,000		1.21	7,260
3 to 5	8,000		1.21	9,680
4 to 5	2,000		1.21	2,420

- Note that all of the benefits shown are annual.

---

1) Annual Passenger Benefit Matrix / B - Rapid Rail Element = Track, Indicator = Miles

2) This is "PS" Number referred to above.

3) From Annex 1 to Supplemental Section E, item 23 City = Chicago, Property = CTA/Rapid Rail, Total Benefit per Second of Passenger Time Saving in $/1000 = 1.21

ANNUAL OPERATING COST SAVINGS
DESIRED MODIFIERS
COMMUTER RAIL

ELEMENT	INDICATOR	OPERATING COST BENEFIT ($/UNIT) Change in Condition: 1 to 4	1 to 5	2 to 4	2 to 5	3 to 4	3 to 5	4 to 5	4 to 4*
TRACK	Miles	48,000	62,000	34,000	48,000	9,000	23,000	14,000	4,500
VEHICLES	Number	43,000	78,000	25,000	60,000	10,000	45,000	35,000	5,000
POWER	Substations: Track Miles	20,000	20,000	16,000	16,000	7,000	7,000	0	3,500
	Third Rail: Miles	36,000	36,000	23,000	23,000	9,000	9,000	0	4,500
	Catenary: Miles	54,000	54,000	35,000	35,000	14,000	14,000	0	7,000
SWC	Cost of Improvement	0.07	0.077	0.06	0.067	0.04	0.047	0.007	0.02
STATIONS	Subway: Sq. Ft.	94	97	23	26	6	9	3	3
	Other: Sq. Ft.	65	67	21	23	5	7	2	2.5
STRUCTURES	Bridges: Sq. Ft.	16	16	12	12	3	3	0	1.5
	Elevated Railway: Lin. Ft.	272	272	217	217	54	54	0	27
	Tunnel: Lin. Ft.	13	13	8.2	8.2	2.7	2.7	0	1.3
MAINTENANCE FACILITY	Building: Sq. Ft.	26	32	19	25	7	13	6	3.5
	Yard: Sq. Ft.	0.06	0.06	0.03	0.04	0.01	0.01	0.005	0.005

10.24.86

* Note to Section B.

ANNUAL PASSENGER BENEFITS
DESIRED MODIFIERS
COMMUTER RAIL

ELEMENT	SCALE FACTOR*	PASSENGER BENEFITS (Seconds / Passenger Mile) — Change in Condition: 1 to 4	1 to 5	2 to 4	2 to 5	3 to 4	3 to 5	4 to 5	4 to 4**
TRACK	Miles Improved / Total Miles	28	29	15	16	3	4	1	1.5
VEHICLES	Number Improved / Total Number	15	21	10	16	5	11	6	2.5
POWER	Miles of Third Rail Improved / Total Miles Third Rail	0.3	0.4	0.2	0.3	0.1	0.2	0.1	0.1
	Miles of Catenary Improved / Total Miles Catenary	0.3	0.4	0.2	0.3	0.1	0.2	0.1	0.1
	Miles of Third Rail or Catenary Served by Improved Substations / Miles of Third Rail or Catenary	1.2	1.3	0.9	1.0	0.5	0.6	0.1	0.3
SYSTEM WIDE CONTROLS	Cost of Improvement	3.1	3.6	2.2	2.7	1.2	1.7	0.5	0.6
STATIONS	Subway: (Sq. Ft.) Improved / Total (Sq. Ft.)	34.4	40.8	19.0	25.4	10.8	17.2	6.4	5.4
	Other: (Sq. Ft.) Improved / Total (Sq. Ft.)	15.0	21.6	10.8	14.4	7.4	11.0	3.6	3.7
STRUCTURES	Bridges: (Sq. Ft.) Improved / Total Track Mileage	0.0062	0.0062	0.001	0.001	0	0	0	0
	Elevated Railway: (Lin. Ft) / Total Track Mileage	0.019	0.019	0.0032	0.0032	0	0	0	0
	Tunnel: (Lin Ft) Improved / Total Track Miles	0	0	0	0	0	0	0	0
MAINTENANCE FACILITY	Building: (Sq. Ft. Improved / Total Building (Sq. Ft.)	1.54	1.68	0.77	0.91	0.39	0.53	0.14	0.19
	Yard: (Sq. Ft.) Improved / Total Yard (Sq. Ft.)	0	0	0	0	0	0	0	0

10.24.86

* The Scale Factor is used to adjust the total Passenger Benefit in Seconds to allow for the scale of the works concerned, as explained in Section B.

** Note to Section B.

ANNUAL OPERATING COST SAVINGS
DESIRED MODIFIERS
LIGHT RAIL

ELEMENT	INDICATOR	OPERATING COST BENEFIT ($/UNIT) [Change in Condition] 1 to 4	1 to 5	2 to 4	2 to 5	3 to 4	3 to 5	4 to 5	4 to 4*
TRACK	Miles	36,000	50,000	28,000	42,000	9,000	23,000	14,000	4,500
VEHICLES	Number	43,000	78,000	25,000	60,000	10,000	45,000	35,000	5,000
POWER	Substations: Track Miles	48,000	48,000	33,000	33,000	14,000	14,000	0	7,000
	Third Rail: Miles	35,000	35,000	22,000	22,000	9,000	9,000	0	4,500
	Catenary: Miles	53,000	53,000	34,000	34,000	14,000	14,000	0	7,000
SWC	Cost of Improvement	0.07	0.07	0.06	0.06	0.04	0.04	0	0.02
STATIONS	Subway: Sq. Ft.	94	97	23	26	6	9	3	3
	Other: Sq. Ft.	65	67	21	23	5	7	2	2.5
STRUCTURES	Bridges: Sq. Ft.	10	10	10	10	3	3	0	1.5
	Elevated Railway: Lin. Ft.	272	272	217	217	54	54	0	27
	Tunnel: Lin. Ft.	13	13	8.2	8.2	2.7	2.7	0	1.3
MAINTENANCE FACILITY	Building: Sq. Ft.	12	15	9	12	3	6	3	1.5
	Yard: Sq. Ft.	0.10	0.11	0.05	0.06	0.01	0.02	0.01	0.005

10.24.86

* Note to Section I.

ANNUAL PASSENGER BENEFITS
DESIRED MODIFIERS
LIGHT RAIL

ELEMENT	SCALE FACTOR*	PASSENGER BENEFITS (Seconds / Passenger Mile) — Change in Condition: 1 to 4	1 to 5	2 to 4	2 to 5	3 to 4	3 to 5	4 to 5	4 to 4**
TRACK	Miles Improved / Total Miles	10	11	6	7	3	4	1	1.5
VEHICLES	Number Improved / Total Number	46	64	31	49	16	34	18	8
POWER	Miles of Third Rail Improved / Total Miles Third Rail	2.4	2.8	1.7	2.1	1.0	1.4	0.4	0.5
	Miles of Catenary Improved / Total Miles Catenary	2.4	2.8	1.7	2.1	1.0	1.4	0.4	0.5
	Miles of Third Rail or Catenary Served by Improved Substations / Miles of Third Rail or Catenary	7.2	8.0	5.1	5.9	2.9	3.7	0.8	1.5
SYSTEM WIDE CONTROLS	Cost of Improvement	21.1	24.6	15.6	19.1	6.3	9.8	3.5	3.1
STATIONS	Subway: (Sq. Ft.) Improved / Total (Sq. Ft.)	53.4	63.2	29.6	39.4	17.0	26.8	9.8	8.5
	Other: (Sq. Ft.) Improved / Total (Sq. Ft.)	25.0	33.6	16.8	22.4	11.4	17.0	5.6	5.7
STRUCTURES	Bridges: (Sq. Ft.) Improved / Total Track Mileage	0	0	0	0	0	0	0	0
	Elevated Railway: (Lin. Ft) / Total Track Mileage	0	0	0	0	0	0	0	0
	Tunnel: (Lin Ft) Improved / Total Track Miles	0	0	0	0	0	0	0	0
MAINTENANCE FACILITY	Building: (Sq. Ft. Improved / Total Building (Sq. Ft.)	1.54	1.68	0.77	0.91	0.39	0.53	0.14	0.19
	Yard: (Sq. Ft.) Improved / Total Yard (Sq. Ft.)	0	0	0	0	0	0	0	0

10.24.86

* The Scale Factor is used to adjust the total Passenger Benefit in Seconds to allow for the scale of the works concerned, as explained in Section B.

** Note to Section B.

ANNUAL OPERATING COST SAVINGS
DESIRED MODIFIERS
RAPID RAIL

ELEMENT	INDICATOR	OPERATING COST BENEFIT ($/UNIT) Change in Condition: 1 to 4	1 to 5	2 to 4	2 to 5	3 to 4	3 to 5	4 to 5	4 to 4*
TRACK	Miles	163,000	191,000	95.000	123,000	15,000	43,000	28,000	7,500
VEHICLES	Number	43,000	78,000	25,000	60,000	10,000	45,000	35,000	5,000
POWER	Substations: Track Miles	73,000	74,000	49,000	50,000	20,000	21,000	1,000	10,000
	Third Rail: Miles	37,000	37,000	24,000	24,000	10,000	10,000	0	5,000
	Catenary: Miles	55,000	55,000	36,000	36,000	15,000	15,000	0	7,500
SWC	Cost of Improvement	0.07	0.077	0.06	0.067	0.04	0.047	0.007	0.02
STATIONS	Subway: Sq. Ft.	94	97	23	26	6	9	3	3
	Other: Sq. Ft.	65	67	21	23	5	7	2	2.5
STRUCTURES	Bridges: Sq. Ft.	41	41	17	17	3	3	0	1.5
	Elevated Railway: Lin. Ft.	272	272	217	217	54	54	0	27
	Tunnel: Lin. Ft.	13	13	8.2	8.2	2.7	2.7	0	1.3
MAINTENANCE FACILITY	Building: Sq. Ft.	27	34	20	27	7	14	7	3.5
	Yard: Sq. Ft.	0.10	0.11	0.05	0.06	0.01	0.02	0.01	0.005

10.24.86

* Note to Section B.

ANNUAL PASSENGER BENEFITS
DESIRED MODIFIERS
RAPID RAIL

ELEMENT	SCALE FACTOR*	PASSENGER BENEFITS (Seconds / Passenger Mile) [---- Change in Condition ----] 1 to 4	1 to 5	2 to 4	2 to 5	3 to 4	3 to 5	4 to 5	4 to 4**
TRACK	Miles Improved / Total Miles	28	29	15	16	3	4	1	1.5
VEHICLES	Number Improved / Total Number	30	45	20	35	10	25	15	5
POWER	Miles of Third Rail Improved / Total Miles Third Rail	1.5	1.7	1.0	1.2	0.6	0.8	0.2	0.3
	Miles of Catenary Improved / Total Miles Catenary	1.5	1.7	1.0	1.2	0.6	0.8	0.2	0.3
	Miles of Third Rail or Catenary Served by Improved Substations / Miles of Third Rail or Catenary	4.5	5.0	3.2	3.7	1.8	2.3	0.5	0.9
SYSTEM WIDE CONTROLS	Cost of Improvement	11.5	13.4	8.2	10.1	3.8	5.7	1.9	1.9
STATIONS	Subway: (Sq. Ft.) Improved / Total (Sq. Ft.)	49.8	59.0	27.6	36.8	15.8	25.0	9.2	7.9
	Other: (Sq. Ft.) Improved / Total (Sq. Ft.)	26.2	31.4	15.8	21.0	10.6	15.8	5.2	5.3
STRUCTURES	Bridges: (Sq. Ft.) Improved / Total Track Mileage	0.0062	0.0062	0.001	0.001	0	0	0	0
	Elevated Railway: (Lin. Ft) / Total Track Mileage	0.019	0.019	0.0032	0.0032	0	0	0	0
	Tunnel: (Lin Ft) Improved / Total Track Miles	0	0	0	0	0	0	0	0
MAINTENANCE FACILITY	Building: (Sq. Ft. Improved / Total Building (Sq. Ft.)	1.54	1.68	0.77	0.91	0.39	0.53	0.14	0.19
	Yard: (Sq. Ft.) Improved / Total Yard (Sq. Ft.)	0	0	0	0	0	0	0	0

10.24.86

* The Scale Factor is used to adjust the total Passenger Benefit in Seconds to allow for the scale of the works concerned, as explained in Section B.

** Note to Section B.

CALCULATION OF MODIFIERS

SUPPLEMENTARY SECTION C
Annex 1

TRACK

1. SAFETY/AVOIDANCE OF CLOSURE

Track improvements will increase safety by reducing risk of derailments. If, however, track reaches the point where it presents a substantial safety risk (and there could therefore be significant safety benefits in replacing it) services would normally be abandoned.

The main benefit of much work required on the track is therefore simply to keep the track in a state adequate to allow services to continue to run. From the definition used in determining the condition codes for track it is clear that for track in "fair" condition many components will need replacement within ten years. All track replacement work rated "fair" to "bad" should therefore be included in those works essential to avoid closure.

2. EFFECT OF IMPROVEMENTS ON REVENUE COSTS

The improvement of track will affect operating and maintenance costs by:

- reducing subsequent maintenance costs;
- removing speed restrictions, and the extensions in schedule and often losses in energy which they involve;
- reducing the risk of derailment with its associated costs;
- reducing rolling stock maintenance costs.

Maintenance costs

Track maintenance costs are extremely variable, depending on the age of the track, condition of the roadbed, local drainage and soil conditions, level of traffic etc. Maintenance costs following improvement will also be substantially affected by these conditions, although improvement to "excellent", particularly with concrete sleepers, should result in maintenance work being reduced virtually to tamping and inspection for a decade or more. Considerable further investigation would be required of individual systems to obtain any reliable estimates of "before" and "after" costs. On the basis of the performance data the typical maintenance costs per track mile for different types of track :

Maintenance cost $000/year per track mile	
Rapid	Light and Commuter
50	20

From this limited basis the effect of differing condition on maintenance costs can only be notionally assessed, and further investigation will be required to establish reliable figures. Provisional figures assumed for this exercise are:

(Mtce cost - $000/year per track mi.)

Bad	100*	60*	70*
Poor	70	40	40
Fair	50	20	20
Good	40	17	17
Excellent	20	10	10

* Allows for heavy costs which should be incurred on maintenance and replacement as track nears end of life.

Reducing Speed Restrictions

According to the performance indicators the proportion of speed restricted track ranges from 0% to 20% of any system - although part of these restrictions may be due to the configuration rather than the condition of the track, the average figures being:

Typical proportion of speed-limited track (%)

Rapid	Light	Commuter
3.3	-	1.6

No information is available on the extent of the speed limits imposed, but they are here assumed of the order of, say, 40 mph line speed reduced to 20mph.

The effect of such a speed limit would be to increase travel time per mile from 90 secs to 3 minutes - i.e. an increase of 90 secs per mile affected.

Now the average saving to be achieved in the long run by reducing train running times is estimated at $1.5 (rapid rail) or $1.3 (commuter rail) per car minute (see Section D).

The saving per mile of speed restriction removed (where normal running speed is 40 mph) is therefore:

	Rapid	Commuter
($ per car mile)	2.25	1.95
Typical traffic intensity: (No. of cars per day)	900	100
Total saving p.a. Assuming annual flow = 300 x week day flow ($000 p.a. per mile of speed restriction)	607	59

It is assumed for this purpose that the proportion of speed-restricted track will vary as follows for different track conditions:

	Rapid %	Commuter %
Bad	20	20
Poor	10	10
Fair	-	-
Good	-	-
Excellent	-	-

Then the overall cost of speed restrictions per track mile will be as follows:

	Rapid	Commuter
	(Cost per track mi. - $000 p.a.)	
Bad	121	12
Poor	61	6
Fair	-	-
Good	-	-
Excellent	-	-

Reduction in derailments

This has been considered but found to amount at most to about $150 per track mile per year, and is therefore ignored for the purpose of this report.

Reduced rolling stock maintenance

This is very problematic, and is not quantified in the present exercise.

Summary

The overall effect on operating and maintenance costs of different conditions of track can be summarized as follows

Additional Maintenance and Operating Cost
(Compared with track in excellent condition)
($ / year per track mile)

	Rapid	Light	Commuter
Bad	201	50	72
Poor	111	30	36
Fair	30	10	10
Good	20	7	7
Excellent	-	-	

3. PASSENGER BENEFITS

The passenger benefits of track improvements are primarily:

Elimination of speed restrictions.

These were discussed above in relation to operating costs. On the basis discussed above, the passenger benefit per mile of speed-restricted track amounts to 90 seconds per passenger mile traversing that section. The normal disbenefit per passenger mile over a section of track will need to be adjusted in the same proportion. Thus, using the figures given for different conditions of track indicated above, and allowing for the fact that some speed restrictions may be attributable to causes other than track condition, the disbenefit per passenger mile of speed restrictions are of the following order:

Disbenefit of speed restrictions
(seconds per mile)

	Rapid	Light	Commuter
Bad	18	-	18
Poor	9	-	0
Fair, Good, Excellent	-	-	-

Improved ride

The quality of ride depends both on the track and the rolling stock, the relative contributions varying very widely. For the present analysis it is assumed that each contributes to the extent of 50%.

Passenger preference evaluation on LRT has shown that passengers put a value of about 1p per mile on a smooth ride (equivalent to about 22 seconds in London conditions). Assuming that the full improvement which track can contribute (11 secs. per mile) is achieved in the transition from "Poor" to "Good", then the relative disbenefit to passengers from a poor ride for different conditions, as compared with the ride achieved for excellent track might be:

Value of improved ride (secs. per passenger mile)

	Rapid	Light	Commuter
Bad	11	11	11
Poor	7	7	7
Fair	4	4	4
Good	1	1	1
Excellent	-	-	-

Summary of Passenger Effects

Disbenefit to Passengers as Compared With Track in Excellent Condition (secs. per passenger mile)

	Rapid	Light	Commuter
Bad	29	11	29
Poor	16	7	16
Fair	4	4	4
Good	1	1	1
Excellent	-	-	-

4. OTHER BENEFITS

In some cases track improvements (notably the use of welded in place of jointed rail) can bring significant benefits to residents living near the railroad. This is not quantified in the present analysis.

5. MODIFIERS

On the basis of the discussion above, the modifiers for different changes in condition are estimated to be as follows:

Change in Condition	Modifier Rapid	Modifier Light	Modifier Commuter
Maintenance and Operating Costs ($ 000 annual saving per track mile improved)			
1>4	181	43	65
1>5	201	50	72
2>4	91	23	29
2>5	111	30	36
3>4	10	3	3
3>5	30	10	10
4*>4	10	3	3
4>5	20	7	7
Passenger Benefits (Seconds per Passenger mile per track mile improved)			
1>4	28	10	28
1>5	29	11	29
2>4	15	6	15
2>5	16	7	16
3>4	3	3	3
3>5	4	4	4
4*>4	0.5	0.5	0.5
4>5	1	1	1

CALCULATION OF MODIFIERS

SUPPLEMENTARY SECTION C
Annex 2

VEHICLES

1. SAFETY/AVOIDANCE OF CLOSURE

In contrast with, for example, the condition of track or bridges, it is unusual for vehicles to reach such a state that it becomes unsafe or physically impossible to run a service: normally some sort of service can continue to be maintained even with "poor" or "bad" vehicles by resorting to cannibalization and / or incurring exceptionally heavy maintenance expenditure. Vehicles are not therefore included as one of the areas of expenditure essential for continuation of the service.

2. MAINTENANCE AND RENEWAL SAVINGS

In considering the benefits of rolling stock improvement unpowered cars and motives are regarded together, in the same manner as self-propelled vehicles, which make up the great majority of the vehicles on the systems concerned. Thus one unpowered vehicle is considered equivalent to a self-propelled vehicle, its cost being adjusted for the cost of providing/improving the motive power associated with it.

All the performance data provided as part of the RMS for vehicles have been reviewed to assess any possible correlation with condition. In practice there was no evidence of such a correlation for any of the three types of data collected: operating and maintenance costs, mean time/distance between failures, or number of in-vehicle injuries per million car miles. In many instances individual performance indicators were in fact worse for modern stocks, while at least for interval between failures some of the figures appear to be the result of misinterpretation or error (e.g. an MTBF quoted of 5.8 hours for commuter vehicles on one system).

It is implausible, however, that there should be no overall improvement in performance and/or revenue costs for modern vehicles once teething problems have been overcome, and the difficulty in interpreting the performance data may result in part from the existence of possible trade-offs between costs and performance. Thus higher maintenance costs may lead to greater reliability and a reduced spares requirement, while by increasing train speed (and forgoing potential energy savings) it may be possible not only to reduce passenger journey time but also to reduce the number of trains and staff required.

Evaluation of new rolling stock purchases for London has shown that the gains be achieved by optimizing the "mix" of energy, capital and maintenance costs may be very large - although with the stocks being considered for future replacement (currently in "fair" condition) they are not sufficiently great to justify advancing the purchase of new vehicles - and are unlikely to reach this level until the stock reaches poor or bad condition.

When they reach this point the overall benefits of replacement (leaving out of account improvements in passenger environment - see below) are likely to be just adequate to amortize the replacement cost. This would imply - translated to American conditions and vehicle costs (capital cost about $800,000 per car)- that the benefits of moving from "bad" to "excellent" would be of the order of $85,000 p.a. per vehicle.

Of this benefit, part is accounted for by savings in passenger time due to a shortening of about 5% in journey time, and typically worth about $8,000 p.a. (This is discussed further in section 3). The remaining $78,000 is attributable to avoidance of subsequent renewal and additional maintenance costs.

Assuming that in favorable conditions a saving of the same order can be achieved in the US (although this must depend on such factors as the ability to exploit higher performance trains) then the corresponding savings for different conditions might be as follows:

Differences in maintenance and operating costs

($000 per vehicle p.a., compared with new vehicles in "excellent" condition)
(All modes)

Bad	78
Poor	60
Fair	45
Good	35
Excellent	--

It should be noted that the condition rating is assumed in part to reflect the age and performance characteristics of the existing stock. The improvement obtained in practice in purchasing new vehicles must depend critically on the precise features of the design adopted.

3. PASSENGER BENEFITS

Investment in new or better vehicles will improve traveling conditions as current standards of decor, amenity etc are incorporated. The principal benefits are likely to arise from better heating/ ventilation / air conditioning, a smoother ride, and less noise inside the car. London Transport has surveyed passengers' priorities regarding vehicle attributes and estimates can be made of the implied time saving (i.e. reduction in the disutility of travel) achieved by improvements. The time savings for each attribute are:

	Seconds per Passenger Mile
Improved Ride	10.0*
Quieter Ride	9.1*
Better Heating	21.2
Better Ventilation	24.1

* Further value attributable to track improvements

(Heating and ventilation are probably different aspects of the same attribute rather than completely separate, and thus a value of 22.8 secs/ passenger mile is taken.)

Improvements to all these aspects might be estimated to confer an implied time savings of 42 secs./passenger mile; however, interdependence is highly likely and such a value appears implausibly high. It has been assumed for the present purpose that the base position is one in which train environment imposes an implied time penalty of 20 secs/ passenger mile compared to "perfection". This base is treated as condition "Fair" (in that London Underground trains offer an environment about half-way between the best and the worst to be found in the U.S.). However, even at "Excellent", residual dissatisfaction will persist and 2 secs/ passenger mile has been assumed; at "Bad" conditions, the full 40 second penalty implied by the London survey data is assumed. "Poor" and "Good" points are interpolated.

	Seconds per Passenger Mile
Bad	40
Poor	30
Fair	20
Good	10
Excellent	2

Conversely, the implied time savings compared with "Bad" are as follows:

	Seconds per Passenger Mile
Bad	-
Poor	10
Fair	20
Good	30
Excellent	38

The above has been computed in London conditions in relation to car miles traveled. Benefits to the passenger will depend however not on the distance traveled but on the time spent in the vehicle.

The implied time saving (as compared with "bad") for each condition on a "passenger minute" basis (assuming 20 mph average speed) are:

Time Savings
(Seconds per Passenger Minute)

	Rapid Rail
Bad	0
Poor	3.3
Fair	6.7
Good	10
Excellent	12.7

The implied time savings per passenger mile for each system type will be determined by the respective speeds:

Average speed (mph)

Rapid	Light	Commuter
20	13	40

In calculating the implied time savings appropriate to different modes in the U.S., allowance should also be made for a potential increase in performance with modern vehicles, giving perhaps the following time savings for improvements from any condition to "excellent" only (assuming track configuration etc. allows):

Time savings

Rapid	Light	Commuter
(% existing travel time)		
5%	2.5%	2.5%

Rapid	Light	Commuter
(secs. / passenger mile)		
9	7	2.2

(Light Rail may be constrained by factors such as road congestion, and commuter rail by the fact that a smaller proportion of the time is spent accelerating than on Rapid rail.)

These time savings will in turn reduce the benefits per passenger mile to be expected from the improvements in passenger environment mentioned above.

Allowing for all these factors, the implied time savings for travel by each of the three modes will be:

Implied time savings compared with "bad" (seconds per passenger mile)

	Rapid	Light	Commuter
Bad	0	0	0
Poor	10	15	5
Fair	20	30	10
Good	30	46	15
Excellent	45*	64*	21*

* Net figure allowing for reductions in journey time, and resulting reductions in effect of environmental benefits.

In order to calculate the total benefit from a specific improvement measure the figures given above must be:

Multiplied by:

Total number of cars undergoing improvement
System passenger miles

And divided by:

Total number of cars

The figures for numbers of cars should if possible be assessed on a segment basis or, failing this, on a systemwide basis.

4. CONCLUSIONS

Cost savings:

COST SAVINGS

($000 per year per car improved/replaced)

	All Modes
1>4	43
1>5	78
2>4	25
2>5	60
3>4	10
3>5	45
4>5	35
4>4	5

The passenger benefits resulting from different levels of improvement will be:

Passenger Benefit
(seconds per passenger mile benefiting from improvement)

	Rapid	Light	Commuter
1>4	30	46	15
1>5	45	64	21
2>4	20	31	10
2>5	35	49	16
3>4	10	16	5
3>5	25	34	11
4>5	15	18	6
4*>4	5	8	2.5

In order to assess the total benefit for a segment or system this must be multiplied by:

$$\frac{\text{Total Passenger mileage x no. of vehicles in given improvement category}}{\text{Total no. of vehicles in regular service on segment / system}}$$

CALCULATION OF MODIFIERS

SUPPLEMENTARY SECTION C
Annex 3

POWER SUPPLY

1. INTRODUCTION

Assessing the benefits of improvements in power supply presents some difficulty at first sight in that changes in performance may be due to improvements in wayside installations or in sub-station equipment, or in both. The problem, given the difficulty of disentangling the contribution of the two types of asset, is to find if possible a common unit for measuring the "scale" of the improvement.

In practice the capital and maintenance costs of substation plant are largely determined by its capacity (in kW) - although the choice between h.v. a.c, l.v. a.c, and l.v.d.c. will also have a considerable impact which it has not been practicable to take into account in the present analysis. The capacity required is in turn a function of:

(a) the maximum number of vehicles likely to be on the section served at any time;

(b) the energy demands of the vehicles;

(c) the degree of reserve capacity considered necessary and the level of security to be provided through "cross-feeding" of adjacent sections.

The first factor is the most important, and is determined by the track mileage served, the consist of trains, and the minimum headway between them. On the basis of the RMS operating statistics for different types of line it appears that the typical substation capacity required per track mile (including reserve) is:

Capacity per track mile (kW)

Rapid	Light	Commuter
1500	1000	1000

o This is subject, however, to large variations from system to system.

It is proposed therefore to use track miles as the base measure of power plant requirements for each mode. There are, however, marked differences in the cost of wayside installations for distribution between overhead wire and third rail, and these are therefore assessed separately.

The benefits from improvements to the power supply system take the following form:

Safety / avoidance of closure

Renewal and maintenance savings

Operation cost savings, due to
  Energy savings
  Centralization of control

Passenger benefits, due to
  Improved reliability
  Greater supply capacity and improved train performance / frequency

2. SAFETY / AVOIDANCE OF CLOSURE

The physical condition of power distribution equipment will rarely reach the point where the safety hazards will force closure of a line - although this is conceivable, for example, if serious deterioration has occurred in the overhead structures. There may also be the risk of fire from failures in d.c. cables, particularly in underground sections if low-smoke cables are not already used.

3. RENEWAL AND MAINTENANCE SAVINGS

Because of the wide variety of types of system used, it is possible to derive only very approximate figures for typical costs of renewing existing installations. These are summarized as follows:

	Rapid	Light	Commuter
Substations			
		($000, each)	
Capital Cost	2,500	2,500	2,500
	(miles of catenary/third rail)		
Typical electrified track mileage served	4.0	6.0	20.0
	($000/electrified track mile)		
Unit Cost	625	416	125

Overhead wire/ Catenary (incl. support)

Total costs quoted from $35 to $ 185 per track foot. Take standardized cost average $100/foot.

		($000/mile)	
Capital Cost	528	528	528

Third Rail

Cost typically $65 per track foot.

		($000/mile)	
Capital Cost	343	343	343

The definitions used in assessing the condition of the equipment imply the following remaining lives:

	Remaining life in existing condition (years)
Bad	< 5
Poor	10
Fair	25
Good/Excellent	>25

No data was available on the costs of maintaining electrical plant. In its absence and given the lack of time to seek data from individual systems, the only practicable course has been to base the maintenance costs on the typical replacement costs of the assets concerned. In the UK maintenance costs of electrical equipment are typically about 2% of asset replacement values, although it is likely that they could rise to 6% on assets in "bad" condition as compared with perhaps 1% for good or excellent condition.

On this basis annual maintenance costs per track mile for equipment as compared with that for equipment in good/excellent condition are assumed to vary as follows:

	Maintenance Cost ($000/year)		
	Rapid	Light	Commuter
Substations			
Bad (5% of renewal cost)	31	21	6
Poor (4%)	25	17	5
Fair (2%)	13	8	3
Good/Excellent	-	-	-
Overhead Systems	------ All Types -------		
Bad		26	
Poor		21	
Fair		11	
Good/Excellent		-	
Third Rail Systems	------ All Types -------		
Bad		17	
Poor		14	
Fair		7	
Good/Excellent		-	

The total maintenance and renewal savings expressed in present value terms, from renewing assets now rather than waiting until they are life-expired can be summarized as follows:

	Cost Avoided - Present Values		
	Rapid	Light	Commuter
Substations	($000 per track mile served)		
Bad			
Renewal in near future	625	416	125
Poor			
Renewal in 10 years	241	160	48
Additional Maintenance Cost Over that Period	153	103	31
	394	263	79
Fair			
Renewal in 25 years	57	38	11
Additional Maintenance Cost over that Period	113	76	23
	170	114	34

	All Types ($000 per mile)
Overhead Systems	
Bad	
Renewal	528

	Cost Avoided - Present Values
	All Types [Cont.] ($000 per mile)
Poor	
Renewal in ten years	204
Additional maintenance Cost over that period	130
	334
Fair	
Renewal required in 25 years	49
Additional maintenance cost over that period	95
	144

Third Rail Systems

	All Types ($000 per mile)
Bad	
Renewal essential in near future	343
Poor	
Renewal essential in 10 years	132
Additional maintenance cost over that period	81
	213
Fair	
Renewal required in 25 years	32
Additional maintenance cost over that period	59
	91

o Expressed in annual terms over the 50-year life of the renewal assets, the savings are:

	$ 000 per mile/year		
	Rapid	**Light**	**Commuter**
Substations			
Bad	62	41	12
Poor	39	26	8
Fair	17	12	4
Good/Excellent	-	-	-

	All Types
Overhead Systems	
Bad	53
Poor	34
Fair	14
Good/Excellent	-
Third Rail Systems	
Bad	35
Poor	22
Fair	9
Good/Excellent	-

4. OPERATING SAVINGS

Energy savings

Old fashioned plant - e.g. motor generators, mercury arc rectifiers, earlier generations of transformers - is substantially less energy efficient than modern equipment. Energy losses in this plant may be compounded by, for example, the use of old distribution cables of poor conductivity, or the growth in load and / or attrition of material which has made overhead wires and conductor rails inadequate to meet demand. The overall losses could reach 8 per cent or more in extreme cases compared with those for equipment in excellent condition. The variation between "bad" and "excellent" conditions is likely to be on the following lines:

Loss in energy due to condition of equipment between h.v. supply and train (compared) with "excellent" equipment

	(All Types)
Bad	8%
Poor	6%
Fair	3%
Good	1%
Excellent	nil

(Note: figures related to improvements in both substations and third rail/catenary)

The total energy consumed per track mile per annum varies with local conditions, service headway, rolling stock design etc., but on the basis of system-wide values for headways and train lengths is likely to vary as follows:

(million kWh per electrified mile/year.)

	Rapid	Light	Commuter
Total Energy used p.a.	1.8	0.4	0.7

- o On this basis, assuming average energy costs of 6c. per kWhr, the costs of the energy losses will be :

Costs of energy losses (\$000/yr. per track mile)

	Rapid	**Light**	**Commuter**
Bad	8.64	1.92	3.36
Poor	6.48	1.44	2.52
Fair	3.24	0.72	1.26
Good	1.08	0.24	0.42
Excellent	-	-	-

- o The energy savings are allocated 75% to substations and 25% to overhead/third rail.

Control Costs

Some installations still do not use full centralized remote control, and modernization of this aspect of the system should result in substantial staff savings - to judge by London savings, perhaps of the order of one attendant per 10 track miles (allowing for shift cover etc.) for a rapid rail system.

Whether these savings will be achieved will depend very much on local conditions, but the potential saving on substation costs per track mile, assuming average staff costs of \$60,000 p.a., and that savings on all types are similar, may be:

Operating costs compared with system in excellent condition

($000/year per electrified mile)

	All Types
Bad	+6
Poor	+6
Fair	+2
Good	-
Excellent	-

(The total maintenance and operating savings are summarized in paragraph 7.)

5. PASSENGER BENEFITS

Passengers benefit in two ways from improvements to power distribution system:

- o A more reliable service, thanks to the reduction in the number of failures due to distribution problems;
- o A faster service on those stretches where train performance is currently constrained by lack of distribution capacity.

Increased Reliability

Two performance indicators were gathered in the Rail Modernization Study for power systems reliability:

- the mean time between failures for the system concerned;
- the proportion of trips suffering delays due to power system deficiencies.

Examination of the performance data concerned, however, reveals only limited correlation between the two: e.g. some systems have a significant number of failures, without any recorded effect on passengers, while in general, where recorded, the number of passenger trips affected appears far greater than the number of failures would lead one to expect. Given that the latter measure provided a more direct indicator of passenger effects, however, it has been chosen in preference for this analysis. Although the relationship between delays and condition of the power system is not very consistent, it appears that a change in average condition from "fair" to "excellent" can be expected to be accompanied by a reduction in the proportion of vehicle trips delayed from about 0.5% to 0.05%. There is no apparent significant difference between rail, light, and commuter rail.

Extrapolating from these figures, the overall effect of changes in condition on failure is estimated as follows:

Percentage of Trips Delayed Due to Power System Deficiencies

	(All Types) (%)
Bad	1.0
Poor	0.75
Fair	0.5
Good	0.15
Excellent	0.05

The total passenger disbenefit resulting from such delays will be approximately:

Passengers on trains (p) x maximum delay (m) + passenger arriving at stations (s) x ½ maximum delay (m).

Now passengers on trains (p)

= passenger mileage on train/average train trip length (l)

And passenger arriving at stations (s).

$$= \text{passengers on trains } (p) \ \frac{= \text{ maximum delay } (d)}{\text{average journey time } (t)}$$

The total disbenefit per passenger mile per delay

$$m/l + \tfrac{1}{2}\, m/l \times m/t$$

o Now, assuming that normal maximum delay is 30 minutes and:

	Rapid	Light	Commuter
		(minutes)	
Average journey time (t)	15.6	11.1	30
Average journey length (l)	10	7.5	30

Then the disbenefit for different conditions (doubling to convert waiting time to travel time) will be:

	(Seconds per Passenger Mile)		
Bad	7.1	11.3	1.8
Poor	5.3	8.5	1.4
Fair	3.5	5.6	0.9
Good	1.1	1.7	0.3
Excellent	0.4	0.6	0.1

o These are allocated 75% to substations and 25% to overhead/third rail.

Benefits of Faster Running

Only on three systems was lack of supply capacity quoted as a constraint on travel time - two in fair, one in excellent condition. Given the extent to which this problem depends on local condition and development of traffic, it is not considered appropriate to include faster running as a benefit for incorporation in the standard benefit matrix.

6. OTHER BENEFITS

There may in some cases be benefits to residents adjacent to substations because of reductions in sub-station noise. This is unlikely, however, to be significant factor.

7. SUMMARY

The total operating and maintenance savings can be expressed in the following matrix:

Operating and Maintenance Savings

	Rapid	Light	Commuter
Substations	**($000 per mile of catenary/third rail served by sub-station)**		
Bad	74	48	20
Poor	50	33	16
Fair	21	14	7
Good	1	-	-
Excellent	-	-	-
Overhead	**($000 per mile of catenary)**		
Bad	55	53	54
Poor	36	34	35
Fair	15	14	14
Good	-	-	-
Excellent	-	-	-

Operating and Maintenance Savings

	Rapid	Light	Commuter
	($000/year per mile of third rail)		
Third Rail			
Bad	37	35	36
Poor	24	22	23
Fair	10	9	9
Good	-	-	-
Excellent	-	-	-

The passenger benefits are summarized as follows:

	(Seconds per Passenger Mile) Rapid	Light	Commuter
Substations			
Bad	5.3	8.5	1.4
Poor	4.0	6.4	1.1
Fair	2.6	4.2	0.7
Good	0.8	1.3	0.2
Excellent	0.3	0.5	0.1

Scale factor: Miles of third rail/catenary served by improved substations divided by total length of third rail/catenary.

	Rapid	Light	Commuter
Overhead/Third Rail			
Bad	1.8	2.8	0.4
Poor	1.3	2.1	0.3
Fair	0.9	1.4	0.2
Good	0.3	0.4	0.1
Excellent	0.1	0.1	-

Scale factor: Miles of third rail/catenary improved divided by total length of third rail/catenary.

CALCULATION OF MODIFIERS

SUPPLEMENTARY SECTION C
Annex 4

SYSTEM WIDE CONTROLS

1. INTRODUCTION

The proposed investment in this area mainly occurs in large projects embracing many sub-elements without any detailed breakdown. Thus impacts occur in many areas, the principal ones being:

1. Safety (train protection etc.)

2. Maintenance costs

3. Operating costs

4. Passenger Benefits

   (a) Journey time reliability (dispatch systems etc)
   (b) Journey stress (arrival information etc.)
   (c) Security

Without detailed project content information, it is only possible to estimate average benefits from investment in this area, having made assumptions about the impact of benefits on different journey attributes. The analysis is also constrained by the lack of any physical base (like track miles for track work) against which to measure volume of work. Fortunately, the proposed investment in this areas is similar to that in the London Underground Investment Program, both as a proportion of the whole and (broadly) in content. The estimates are therefore presented as overall benefits from system-wide control investment, weighted by the likely impacts in each area.

By definition, investment in this area does not lend itself to segmentization, and very few of the projects appear to be allocated to segments. Benefits should therefore be allocated to all passenger journeys on the system concerned, unless more specific data is available, in which case the benefits are to be attached to all passengers on the segment(s) affected.

The various sub-systems falling into this general element contribute in differing ways to the impacts. There are:

- "First Order" impacts, where the sub-element directly delivers the benefit (e.g. public address systems). In these cases it is assumed that 100% of the applicable benefits are obtainable. About 80% of the London Underground Investment Program for system-wide controls falls into this category, and it is assumed that a similar proportion of Rail Modernization Study expenditure will do so.

- "Second Order" impacts, where there is no direct impact but the element is a key link in the information chain (e.g. radio, CCTV systems). Here it is assumed that "transmission losses" of about 25% occur, i.e. only 75% of the potential benefits are obtainable. About 10% of expenditure is likely to lie in this area.

- "Third Order" impacts, where an element is a general part of the control system but cannot be directly related to the benefit (e.g. command center buildings). A further "transmission loss" of 25% is assumed, i.e. 56% of the potential benefits are obtainable, and the remaining 10% of system-wide control investment has been treated this way.

The weighted average benefit will therefore be 87.6% of the maximum potential benefit. The following figures for each passenger benefit area show the "100%" level, and the final weighting is provided in the summary.

2. SAFETY

This is unlikely to vary significantly by element condition - transit systems do not typically accept degrees of safety and an unsatisfactory safety level may precipitate closure. Safety effects are therefore taken into account in the assessment of closure avoidance undertaken for appropriate projects.

3. MAINTENANCE AND OPERATING COSTS

Maintenance and Renewal

Any analysis of the effects of the condition of signaling on failure rates is hampered by the lack of a suitable physical measure of the scale of the facilities into which it can be applied. In practice, system-wide controls tends to be area where replacement of equipment may not result in maintenance savings, and the greater complexity of new equipment may reduce the scope for reductions in failure rates too.

To a large extent the levels of renewal and maintenance on control equipment is determined by the need to maintain standards of safety (which accounts for 63% of the expenditure included on SWC in the RMS program) and of operational effectiveness. In total perhaps 90% of all expenditure is attributable to these two purposes, only 10% representing betterment giving operating or passenger improvements. It should be noted in this context that although the nominal life of such equipment is given as 35 years in the RMS, in many cases equipment remains in use for much longer than this.

On the basis of the definitions of the different condition level,s the expenditure required on maintenance and renewal for conditions bad to good, as compared with the preventive maintenance required for assets in "excellent" condition, may be of the order indicated:

Bad	Replace within 3 years
Poor	Replace within 10 years. In the interim, as compared with a system in "excellent" condition, annual maintenance costs = 4% of essential replacement costs to take asset from Bad > Good.
Fair	Replace within 20 years. In the interim additional maintenance costs = 2% of essential replacement costs.
Good	No additional maintenance costs or significant reduction in life compared with "Excellent".

The level of maintenance costs will then be:

$ saved on essential maintenance / renewal per $ of improvement costs

	Present Value	Annualized Over 35-year Life
	ALL TYPES	
Bad	0.67	0.07
Poor	0.567	0.06
Fair	0.387	0.04

Apart from the savings in specific additional repairs indicated above, improvement and replacement of SWC's will probably not result in any maintenance savings - the greater reliability of the new equipment being offset by its greater technical complexity, with high cost preventive maintenance tending to offset heavy expenditure on frequent call-out maintenance.

Operating Cost

The proposed investment will probably not result in major operating cost savings. London Transport's experience of signaling systems renewal is that only a relatively small part, entailing closure of local signal boxes (towers) adjacent to interlockings, and transfer to central control rooms, generates significant cost savings. The project descriptions suggest that most of the proposed expenditure in Code 4100 (Train Control) will be a renewal character. Some projects are, however, described from which cost savings may accrue and it is assumed that these may account for about 10% of the total proposed investment (i.e. the proportion applicable in London). Evaluation in London has shown that this expenditure is self-financing over the project's life, i.e. at the discount rate of 7% there will be a saving of $0.075 p.a. (assuming the investment has a 40-year life)/ $ initial cost. For simplicity, the benefit can be expressed as $0.00705 / $ capital cost for all Code 4100 and 4300 investment. If a 10% discount rate is used, the expenditure will not then be self-financing.

These estimates are recommended for rapid and commuter rail systems only. It is unlikely that cost saving investment on this kind will occur on light rail systems which if new already incorporate command centers, or if old use little or no controlled signaling.

Only more detailed appraisal can reveal whether the betterment element of such works will in practice be worthwhile.

The operating benefits can therefore be summarized as follows:

Benefit ($/year) per $ of cost of improvement

	Rapid	Light	Commuter
Bad, Poor, Fair, Good	-	-	-
Excellent	0.007	-	0.007

Summary of Operating and Maintenance Cost Savings

The total operating and maintenance savings for differing levels of improvement can therefore be summarized as follows:

$ Saved / year per $ of Spending on Improvement

	Rapid	Light	Commuter
Bad > Excellent	0.077	0.07	0.077
Bad > Good	0.07	0.07	0.07
Poor > Excellent	0.067	0.06	0.067
Poor > Good	0.06	0.06	0.06
Fair > Excellent	0.047	0.04	0.047
Fair > Good	0.04	0.04	0.04
Good > Good	0.02	0.02	0.02
Good > Excellent	0.007	-	0.007

4. PASSENGER BENEFITS

Journey Time Reliability

These benefits attach to projects having operating efficiency as a primary goal impact, and / or having any impact on reliability / availability.

Passengers tend to allow safety margins on most journeys, especially those with a fixed-time objective (catching a plane, arriving for work), and the greater the degree of variability , the greater will be the margin allowed, hence the time allowed for the journey will be increased. Control system in bad / poor physical condition will not only be unreliable in their physical performance, but will also be older on average and will probably incorporate less sophisticated information and control systems. Hence the ability to manage the service to the best advantage will be less, and operation will be more irregular that with a good system.

Performance indicators suggest that, with a control system rated as "Fair", about 5% of train trips encounter system-related delays (MBTA); this falls to 1 - 2% where condition is "Good" (NYCTA, PATH, etc.). This has to factored by average passenger journey length divided by average train trip length.

Assumed values are:

	Rapid	Light	Commuter
		(Miles)	
Average journey length	5.2	2.4	20
Average train trip length	10	7.5	30

"Delays" is not defined, and it is assumed that the average delay in these cases in one headway, i.e. about 5 minutes on rapid and light rail systems offering a "walk-on" service. For different reasons, a similar benefit can be attached to commuter rail systems because delays will tend to show as late arrival of scheduled trains rather than a temporary interruption to the flow of trains.

Certain system projects will achieve capacity increases, reducing journey and / or waiting time. The benefits tend to be very specific to the project and it is considered that the average benefits below can reasonably represent the effects of such projects (bearing in mind that the values are expressed as waiting time reductions and thus a project reducing journey time must generate twice the time benefit to achieve the same value as a waiting time reducing project).

The table below gives the implied time savings for various condition changes (A) per passenger and (B), allowing for the differences in journey length between modes, per passenger mile.

	Passenger Benefits (seconds' waiting time)					
	A			B		
	Seconds/Passenger			Seconds/Passenger Mile		
	RR	LR	CR	RR	LR	CR
Bad > Excellent	15.6	9.6	20	3.0	4.0	1.0
Bad > Good	14.0	8.6	18	2.7	3.6	0.9
Poor > Excellent	10.9	6.7	14	2.1	2.8	0.7
Poor > Good	9.4	5.8	12	1.8	2.4	0.6
Fair > Excellent	7.8	4.8	10	1.5	2.0	0.5
Fair > Good	6.2	3.8	8	1.2	1.6	0.4
Good > Excellent	1.6	1.0	2	0.3	0.4	0.1
Good > Good	3.2	1.9	4	0.6	0.8	0.2

Journey Stress

The benefits estimated here are for any projects impacting upon operating efficiency and including work in Project Code area 4200 (Communications systems) and subsidiary codes.

Transit travel entails uncertainty about final arrival time, aggravated by lack of information about train arrivals. Such information is particularly valuable when the service is not operating to schedule. London Transport's surveys of passengers' information requirements have shown that good information about approaching trains reduces the disutility of time spend waiting by 10 - 15% (compared to very little information), and is therefore equivalent in economic terms to reducing the wait itself by about 20 seconds. The range quoted reflects the different types of service pattern encountered on the London Underground system, which generate differential information requirements, and the lower end is taken as the starting point for these estimates. The other points on the scale are also derived from LT experience and reflect the situations which can be obtained by providing selected elements of the information system such as platform train indicators.

		Seconds' Waiting Time Per Passenger Mile		
	Seconds/ Passenger	Rapid	Light	Commuter
Bad > Excellent	18	3.5	7.5	0.9
Bad > Good	14	2.7	5.8	0.7
Poor > Excellent	12	2.3	5.0	0.6
Poor > Good	9	1.7	3.8	0.5
Fair > Excellent	9	1.7	3.8	0.5
Fair > Good	5	1.0	2.1	0.3
Good > Excellent	5	1.0	2.1	0.3
Good > Good	2.5	0.5	1.0	0.1

Security

Security systems will also generate passenger benefits through reducing anxiety, but only if passengers regard them as effective, which is probably not strictly a function of physical condition. However, "Bad" / "Poor" systems are likely to be ineffective and seen to be so by reason of obviously poor physical condition, old technology etc., and it is assumed that any measure affecting security which improves condition from "Bad " / "Poor" to "Fair", "Good" or "Excellent" will generate some passenger benefit. SWC projects will affect most types of station and it is therefore possible to make only an average estimate. The value taken is the mid-point of the station modernization benefits, on the basis that London experience of modernized stations has shown that the perception of security is significantly better than that of passengers at unmodernized stations.

	Seconds' Waiting Time Per Passenger Mile		
	Rapid	Light	Commuter
Bad > Excellent	2	4.5	0.3
Bad > Good	2	4.5	0.3
Poor > Excellent	2	4.5	0.3
Poor > Good	2	4.5	0.3
Fair > Excellent	0	0	0
Fair > Good	0	0	0
Good > Excellent	0	0	0
Good > Good	0	0	0

Summary of Passenger Benefits

The proposed projects will affect most of the areas outlined above but data limitations do not permit detailed attribution of benefits. As most appear as single entities at substantial cost, it has been assumed that the benefits will in general be additive rather than alternatives. The estimate of average benefit has therefore been made by weighting the different benefit categories by the quantity of expenditure addressing the relevant goals;

- All expenditure impacts on reliability
- 96.4% impacts on journey stress (communication improvements
- 63% impacts on security

The individual benefits are therefore factored appropriately and summed, the whole then being factored by 0.876 to take account of the different degrees of impact expected.

Seconds / Passenger Mile

	Rapid	Light	Commuter
Bad > Good	11.5	21.1	3.1
Bad > Excellent	13.4	24.6	3.6
Poor > Good	8.2	15.6	2.2
Poor > Excellent	9.8	18.3	2.6
Fair > Good	3.8	6.3	1.2
Fair > Excellent	5.5	9.9	1.7
Good > Excellent	2.2	4.2	0.7
Good > Good	1.9	3.1	0.6

CALCULATION OF MODIFIERS

SUPPLEMENTARY SECTION C
Annex 5

STATIONS

1. INTRODUCTION

Although relatively little work at stations is essential on safety grounds to allow the stations concerned to remain open, a large proportion of the work included in the RMS program is required in order to keep station buildings in a reasonable state of repair and to allow the existing level of passenger amenities to be maintained. In addition, the program includes measures which will lead to some betterment in the station environment with consequent passenger benefits.

2. MAINTENANCE AND OPERATING SAVINGS

Maintenance savings will arise from avoidance of piecemeal replacement on revenue account and from more efficient painting, cleaning etc., through use of low maintenance surfaces.

Replacements Avoided

All surfaces at a station will eventually need replacement: in the absence of a capital investment this will be done as and when deemed necessary through the routine maintenance system. This will fall on revenue account and will also be more costly overall by being done as several (or many) individual tasks, but there is the advantage that expenditure may be deferred.

- It is therefore assumed that all or most of the works would be required in the foreseeable future and estimates of "maintenance costs avoided" can be made on the following basis"
- Projects addressing "Bad" or "Poor" conditions have a 90% "minimal renewal" element - the remaining 10% affects aesthetics or future maintenance costs. Projects on "Fair" or "Good" condition stations are 100% minimum renewals.
- Works carried out piecemeal would cost on average 15% more through site set-up, overhead costs etc. being incurred more often.

- The works would on average be carried out over a 10 year period where conditions are "Bad"/"Poor" and 20 years where condition is "Fair"/"Good".

Thus the renewals avoided can be estimated as:

"Bad"/"Poor": (0.9 X 1.15 / 10) X
(PV factor for 10 years at 10% /
annualizing factor for 40 years at 10%)
= \$0.0650 (p.a.) /\$initial cost.

"Fair"/"Good": (1.15 / 20) X
(PV factor for 20 years at 10%
annualizing factor for 40 years at 10%)
= \$0.0501 (p.a.) /\$initial cost.

Reduced Future Maintenance

London Transport's Station Maintenance Program has demonstrated the future cost savings achievable through installing new finishes that require no painting or are easier to clean and maintain. These savings continue through the life of the new finishes (up to 40 years) and are additional to the benefits estimated above. The detailed appraisal required for approval purposes has shown that, using the 7% discount rate required for LRT appraisals, major station schemes taking the physical condition from "Bad" to "Excellent" yield savings with a present value of 25% of the initial cost. These savings occur mainly where "Bad", "Poor" or "Fair" conditions are being tackled, as the materials will usually be old and costly to maintain. It is thus assumed that savings of 7% can be obtained for each condition change from "Bad" through "Good", with a final 4% obtainable by moving thence to "Excellent". On an annual basis, the savings are 0.53% and 0.3% respectively of the capital cost of the works. Where no condition change is expected, half of the benefits of moving up from the existing condition grade are assumed, reflecting the avoidance of the deterioration which could otherwise occur in the interim.

The annual operating cost savings per $ initial cost are therefore estimated as:

	Renewals Avoided $ p.a.	Future Savings $ p.a.	Total $ p.a.
Bad > Good	0.0650	0.0158	0.0808
Bad > Excellent	0.0650	0.0188	0.0838
Poor > Good	0.0650	0.0106	0.0755
Poor > Excellent	0.0650	0.0135	0.0785
Fair > Good	0.0501	0.0053	0.0554
Fair > Excellent	0.0501	0.0083	0.0584
Good > Excellent	0.0501	0.0030	0.0531
Good > Good	0.0250	0.0026	0.0277

Note: Avoided renewals savings are based on a 10% discount rate.

The cost/ sq foot for improvements can be derived from project data, and for each improvement level is:

	Subway Stns	Other
Bad > Good	$1159	$800
Bad > Excellent	$1159*	$800*
Poor > Good	$ 299	$266
Poor > Excellent	$ 299*	$ 95
Fair > Good	$ 132	$106
Fair > Excellent	$ 156*	$125
Good > Excellent	$ 23	$ 54
Good > Good	$ 21	$ 34

* assumption: specific data not available

Operating Cost Savings

Station improvements may in some cases bring savings in operating cost, e.g., through automation of fare collection, changes in layout which reduce station starting requirements, etc. In the absence of more specific information in these areas, no provision has been made for such savings in the present analysis.

Summary of Maintenance Cost Savings

These estimates are for application to the square footage of all "Code 5000" projects.

	Operating Cost Savings ($ p.a./sq ft)	
	Subway Stns	Other
Bad > Good	94	65
Bad > Excellent	97	67
Poor > Good	23	20
Poor > Excellent	26	23
Fair > Good	7	6
Fair > Excellent	9	7
Good > Excellent	1	3
Good > Good	3.5	3

3. PASSENGER BENEFITS

Improved station environment can be expected to generate additional ridership by reducing the stress associated with travel. Experience of completed modernization projects in London indicates that benefits are also obtained through improved perceptions of personal security in a modernized environment.

London Transport uses the following estimates in planning the Station Modernization Program (a $120m program currently under way):

% generation ridership for modernization to "excellent" condition

STATION TYPE	PRESENT CONDITION				
	Excellent	Good	Fair	Poor	Bad
"Surface"- at grade or elevated	0.0	0.2	0.6	0.8	1.2
"Sub-surface"- below ground but with some natural light to platforms	0.0	0.3	0.8	1.1	1.9
"Tube"- up to 150' below ground, platforms fully enclosed,elevator/ escalator access	0.0	0.4	1.1	1.7	2.6

These estimates can be converted back to "implied time savings" - i.e., the reduction in waiting time that would be expected to generate the increases shown. For example, the highest generation (2.6% in the bottom right cell is equivalent to that which would occur from a fares reduction of 16.6%, assuming a fares elasticity of -0.16 (the typical London Underground value). With an average trip fare of £0.50, the implied monetary value is £0.083; with waiting time valued at £3.19/hour, the implied time saving is about 90 seconds per journey, or 18 seconds/ passenger mile.

The factors taken into account are:

o Physical characteristics - subway stations' condition has more effect on an assessment of traveling conditions as the waiting area is completely enclosed. The security aspect is also much more important. Therefore, separate estimates are given for subway (Code 5200) stations, the implied time saving being mid-way between the London "sub-surface" and the "tube" types. While being fully enclosed (like London "tube" stations), subway stations do not usually have lengthy elevator/escalator access. For all other stations, (codes 5100,5300 - 5700) the implied time savings are based on the London definition. Projects affecting LRV/Commuter Rail stops may provide improved facilities (e.g. weather protection) which will generate similar benefits).

- Journey length - this varies by system type and thus introduces differences in the values attributable to station projects. (This is additional to those differences inherent in system type, which are taken into account in the elasticities set out in Appendix F.) Both elasticity of demand and the priority attached to station improvements can be expected to vary with journey length (the latter because train / service features assume greater relative importance in longer journeys). Specific data to calibrate this relationship to U.S. conditions is not available and the relationship used is that derived from detailed analysis of the London survey data:

  - Rapid Rail systems - the average journey length (5.2 miles) is similar to that in London and no adjustment is required.

  - Light Rail - the average journey length is 2.4 miles and the values are 10% of the Rapid Rail value.

  - Commuter Rail - the average journey length is 20 miles and the values are 69% of the Rapid Rail value.

  The figures in the following matrix have been doubled for application to segment passenger miles data, as the London figures are calculated for application to "originating and ending" usage of individual stations.

Estimates for improvement levels:

Condition Change	Passenger Benefit (Seconds per passenger mile)					
	Subway (code 5200)			Other		
	RR	LR	CR	RR	LR	CR
Bad > Good	49.8	53.4	34.4	26.2	28.0	18.0
Bad > Excellent	59.0	63.2	40.8	31.4	33.6	21.6
Poor > Good	27.6	29.6	19.0	15.8	16.8	10.8
Poor > Excellent	36.8	39.4	25.4	21.0	22.4	14.4
Fair > Good	15.8	17.0	10.8	10.6	11.4	7.4
Fair > Excellent	25.0	26.8	17.2	15.8	17.0	11.0
Good > Excellent	9.2	9.8	6.4	5.2	5.6	3.6
Good > Good	7.5	8.4	5.4	5.2	5.6	3.6

Note: Both originating and ending trips at the station(s) are deemed to obtain benefits.

The passenger mileage benefiting should ideally be calculated by multiplying the number of passengers entering stations on the segment x average journey length, which should give better result that multiplying by total passenger mileage on segment (which may e.g. include "through" passengers).

CALCULATION OF MODIFIERS

SUPPLEMENTARY SECTION C
Annex 6

STRUCTURES AND FACILITIES

1. INTRODUCTION

The vast majority of the expenditure proposed on structures and facilities relates to bridges and tunnels, and only these assets are therefore analyzed here. The characteristics of each in regard to e.g. maintenance requirements differ markedly, and the two are therefore treated separately in the analysis below. In addition the units of measurement used for elevated track (linear feet) and bridges (square feet) are different, and these two forms of bridge structure are also therefore treated separately.

There are no hard data from the modernization study on the performance of this type of asset and in these circumstances the betterment benefits to be achieved through improvement or replacement must be largely conjectural.

2. SAFETY/AVOIDANCE OF CLOSURE

As with certain other elements, it is highly unlikely that bridges or tunnels would be allowed to deteriorate to the point where they would represent a significant safety hazard. All bridges and tunnels in a "poor" or "bad" condition would need at least major repairs within ten years if services are to continue on the lines concerned.

3. BRIDGES AND ELEVATED RAILWAYS

MAINTENANCE AND RENEWAL SAVINGS

With bridges there are limits to the extent to which the structures can be kept serviceable by continuing maintenance and, beyond a certain point of deterioration, major renewal becomes essential. Maintenance costs will nevertheless tend to rise considerably with advancing age to meet the cost of e.g. rust treatment, repointing of brickwork, etc. In the absence of data from the RMS on the costs of maintaining bridges, the effect of age on maintenance costs must be a matter of judgment, and is here assessed in relation to the costs of replacement.

In practice the cost of capital works - and the corresponding maintenance costs will vary greatly with the material, type (e.g. trestle, through girder, moveable, etc), span and length of bridge concerned. It is impracticable to allow for all the variations in the present analysis, which is based on two main types:

Elevated railway	Cost ($ per linear foot)
Typical reconstruction cost:	2000(1)
Maintenance cost in "Poor" /"Bad"condition as compared with "excellent":	80 / year
Maintenance cost in "Fair" Condition:	40 / year

Other bridge structures	Cost ($ per sq. ft)
Typical replacement cost	100
Additional Maintenance cost compared with that for "excellent" condition	
Poor:	4 / year
Fair:	2 / year

1 Obtained from RMS Data.

On the basis of the condition definitions used in the RMS, it is assumed that the expenditure required to keep the assets in serviceable condition (as compared with that for a bridge rated "excellent" will be broadly as follows:

Renewal and maintenance costs

Condition		Bridges (Present $/sq.ft.	Elev. Rlys. Values) $/ln.ft
Bad	Modernization needed without delay....................	100	2000
Poor	Major repairs/replacement needed within 10 years....	77	1540
	Additional maintenance cost in interim................	24	480
		101	2020
Fair	Major repairs in 25 years at $100 per sq. ft............	9	180
	Maintenance cost in interim	18	360
		27	540

On this basis matrices can be developed as follows:

Additional Maintenance and Renewal Cost

	Bridge structures ($ per sq. ft. / year)	Elevated railways ($ per linear ft. year)
Bad	10	202 (2)
Poor	10	202
Fair	3	54
Good	-	-
Excellent	-	-

OPERATING SAVINGS - BRIDGES

Where rail bridges have deteriorated to "bad" or "poor" condition, speed limits are likely to be introduced, leading to slower running and additional operating costs and passenger disbenefits.

On highway bridges it is possible that weight limits will have to be imposed, with a substantial social disbenefit. For the purpose of this approximate analysis this cost disbenefit is assumed comparable with the rail disbenefits, and no distinction is therefore drawn between highway and railroad bridges.

No performance data is available on the extent or level of running speed limits imposed for structural reasons. The impact of such speed restrictions will vary greatly depending on the maximum line speed and length of the bridge. Much of the loss in time will result from the need to decelerate and reaccelerate afterwards.

2 Capital works unavoidable. Figures allow for further benefits which arise use of construction to "good" or "excellent" condition.

If typically such restrictions result in a reduction in speed from 40 mph to 20 mph on both rapid and commuter rail (they will have little effect on light rail), and typical performance ratings allow the necessary deceleration and acceleration to take place over a total distance of 330 yards, then loss in time =

(in decelerating and accelerating)

Average speed of 30 mph instead of 40 mph over 330 yards: 5.6 seconds per speed restricted site.

(during passage over bridge, for distance equivalent to length of train and length of bridge): 0.017 secs. per foot.

Given a typical train length of 250 ft and average length of speed restricted bridge of 70 ft., then the loss in time during passage across the bridge will be 320 x 0.017 secs. = 5.4 secs.

On these assumptions, the typical total loss per restriction will therefore be 11 secs.

The equivalent figures for a bridge in "Poor" condition might be:

- Speed restriction 30 mph.
- Distance to decelerate and accelerate to and from 30 mph = 240 yards.
- Time lost per restriction = 1.7 secs (acceleration and deceleration) + 1.8 secs (passage of bridge) = 3.5 secs.

Given the marginal cost per car minute{3} in service of (rapid rail) and $1.3 (commuter rail), then the overall increase in train costs will be:

Additional train running cost
(excl. energy) per speed restriction

	($) Rapid rail	($) Commuter rail
Bad	0.28	0.24
Poor	0.09	0.08

There will also be additional energy costs.

If it requires typically 2kWh to accelerate a car from 20mph to 40mph, at 6c. per kWh, then the cost per car crossing speed restriction will typically be $0.12. For acceleration from 30mph to 40mph the figures would be about 1.5kw and $0.09.

The total cost per car crossing a speed restricted bridge will therefore be:

	($) Rapid rail	($) Commuter rail
Bad	0.40	0.36
Poor	0.18	0.17

Bearing in mind that the train frequency on surface sections tends to be lower than on subway sections of rapid rail (say 450 cars per track per day, as compared with 900 average assumed elsewhere), the total no. of cars crossing such bridges each day both ways may typically be:

Rapid rail	Commuter rail
900	200

3 See Supplemental Section E, Annex 3.

And the total cost given that annual flow = 300 x week day flow, will be:

Total operating costs resulting from speed restrictions ($ p.a. per speed restriction)

	($) Rapid rail	($) Commuter rail
Bad	108,000	21,600
Poor	48,600	10,200

No data is available on the incidence of such speed restrictions in relation to the bridge condition, and it must be borne in mind that bridges in poor/bad condition will only affect services if speed at the location concerned is not restricted for other reasons (e.g. track curvature, proximity to station), and of course if they are rail, not road bridges.

Assuming that all "bad" bridges result in a speed restriction to 20 mph, but that this only "bites" in 50% of cases, while "poor" bridges have speed restrictions which "bite" in only one quarter of all instances, then the total disbenefit will be as follows:

Cost of Speed Restriction [$ per sq.ft. of Bridge(4)]

	($) Rapid rail	($) Commuter rail
Bad	30.8	6.2
Poor	7.0	1.5
Fair/Good/ Excellent	nil	nil

4 Derived from linear feet on assumption that bridges are on average 25 ft. carrying double tracks.

PASSENGER BENEFITS - BRIDGES

The passenger will incur time losses of:
(seconds per restriction)

	Rapid rail	Commuter rail
Bad	11	11
Poor	3.5	3.5

Bearing in mind that only one half of bad and one quarter of poor bridges will eventually cause restrictions, the total time loss will be:

	Seconds Lost per Bridge (average)
Bad	5.5
Poor	0.9

Now, assuming average bridge is 70 ft long and 25 ft wide, time lost per sq. ft. of bridge is:

	Rapid Rail & Commuter (Seconds per Sq. ft)
Bad	0.0031
Poor	0.0005

Now total passenger time lost p.a.

= no. of passengers traversing bridges concerned p.a. x time lost (T) per sq. ft x total sq. ft. (A) of bridge.

= A x T x average passenger flow over bridges concerned.

= A X T x passenger miles p.a. divided by (track miles X 0.5)

Now time lost per passenger mile per track mile per sq. ft.
= T / 0.5 = 2T

where d = average distance traveled, i.e. 5.2 miles for rapid and 20 miles for commuter rail.

On this basis:

Time lost (secs) per passenger mile/
per track mile per sq. ft. of bridge deck

	All Modes
Bad	0.0062
Poor	0.0010

OPERATING SAVINGS AND PASSENGER BENEFITS:
ELEVATED RAILWAYS

In the case of elevated railways (a) the volume of work is measured in linear feet, and (b) normally long stretches will need to be repaired, and the time losses will be determined more by the total length than by the number of separate speed limits required.

Normally elevated railways are rapid rail, and only this mode's characteristics are considered.

For a speed restriction of 40 mph reduced to 20 mph the loss in time will be 0.017 secs. per linear ft. to which must be added 5.6 secs for each speed-limited stretch.

Assuming these are on average 1/2 mile in length (= 2640 ft), then the average loss per linear foot will be 0.019 seconds (0.017 + 5.6/2640).

Allowing for the likelihood that, because of the presence of stations etc., half of such delays will "bite" the net loss in time per linear foot will be 0.0095 seconds for structures in "bad" condition. By analogy with the discussion above on bridges, the net loss per linear foot for elevated lines in "poor" condition will be 0.0016 seconds per linear foot.

The effect on overall operating costs will be:

(a) Energy costs of reaccelerating once for every 1/2 mile stretch of speed limited track - i.e. $0.12 (0.09)(5)per car passing over each section of speed-limited track.

Assuming these are on average 1/2 mile in length, and speed restrictions only "bite" for 50% and (25%) of length, then the cost per linear foot will be $2.27 x 10-5 (8.5 x 10-6)

(b) The "time cost" of providing a train (at $1.5 per car minute). Using the time losses quoted above, this amounts to about $0.00024 ($0.00004) per linear foot

Given a typical two-way daily traffic on such lines of 900 cars, the total time and energy costs p.a. will be:

	$ per year per linear foot
Bad	0.00026 x 270,000 = 70.2
Poor	0.000049 x 270,000 = 13.2

The effect on Passengers will be:

	Seconds per Linear Foot - Rapid Rail Only
Bad	0.0095
Poor	0.0016

Now, on the same basis as for bridges, given the average journey length for rapid rail = 5.2 miles:

	Time lost as compared with structures in Fair to Excellent Condition (Seconds per Passenger mile/Track linear foot)
Bad	0.019
Poor	0.0032

5 Figures in brackets relate to "poor" condition.

4. TUNNELS

RENEWAL AND MAINTENANCE COSTS

In the case of tunnels, extensive deterioration can normally only be corrected by major capital works, which can only be deferred to a limited extent by more intensive maintenance beyond e.g. repointing brickwork, patching of steel roofs of cut-and-cover sections etc.

The cost of maintaining tunnels in serviceable condition are taken to be as follows:

Costs of Maintaining Tunnels in Serviceable Condition ($ / Linear Foot)

Condition	Expenditure Required	Present Value	Annual Cost Eq.
Bad			
	For Tunnels in "Bad" condition it will be necessary to proceed with major repairs without delay. The annual cost of these over a 100 year life will be 0.1 x major repair cost of, typically, $130 per linear foot.(6)...................	130	13/yr
Poor			
	In the case of tunnels in "poor" condition, the overall costs (compared with tunnels rated "good" or "excellent") of maintaining structure in serviceable condition was assumed to be:		
	- Additional short term maintenance @ $5.2 per foot for 10 years.....................	32	
	- Major repairs 10 years, hence (@ $130/linear foot)..	50	
		82	8.2/yr

6 Source: RMS cost estimating data.

Fair		
In this case major renewals might be deferred at least 25 years.......	12.0	
- Annual maintenance might be one third of those for "poor" structures - i.e. $1.56/ln.ft.	15.4	

	27.6	2.7/yr
Good/Excellent		
The cost of maintaining tunnels in "good" and "excellent" condition are taken to be identical	nil	nil

On this basis the variation in maintenance costs with change of condition might be broadly as follows:

Maintenance Costs All Modes
($ p.a. per linear foot)

Bad	13
Poor	8.2
Fair	2.7
Good/ Excellent	-

PASSENGER BENEFITS

Tunnel deterioration does not normally necessitate the introduction of speed limits, and therefore causes no net disbenefit to passengers (although there may be serious disbenefit while major repairs are in progress).

5. CONCLUSION

BRIDGES

The cost saving for different changes in condition per square foot can be derived from the following table:

Cost saving
($ per square foot)

	Rapid	Light	Commuter
Bad	41	10	16
Poor	17	10	11.5
Fair	3	3	3
Good	-	-	-
Excellent	-	-	-

Significant passenger benefits from improvement measures will only be achieved where speed restrictions can impinge heavily - i.e on rapid and commuter rail. These can be summarized as follows:

	Passenger disbenefits (Seconds per passenger mile per track mile /sq. ft. of bridge in condition X)
	ALL TYPES
Bad	0.0062
Poor	0.0010
Fair	-
Good	-
Excellent	-

In order to derive the total benefits for the segment these figures must be applied by:

$$\frac{\text{area of bridgework improved}}{\text{total track mileage in segment}}$$

ELEVATED RAILWAY

The matrices applicable are generally similar to those for bridges, except that the unit used is linear foot and only rapid rail is covered.

The cost saving for different changes in condition per linear foot can be derived from the following table:

	Cost ($ per linear foot) based on Rapid Rail only
Bad	272
Poor	217
Fair	54
Good	-
Excellent	-

	Passenger disbenefits ($ per passenger mile per track mile/sq. ft. of bridge
Bad	0.019
Poor	0.0032
Fair	-
Good	-
Excellent	-

It is suggested that because of the limited amount of elevated railway carrying commuter rail services, mainly in New York, the rapid rail figures be used.

In order to derive the total benefits for the segment these figures must be multiplied by:

$$\frac{\text{area of bridgework improved}}{\text{total track mileage in segment}}$$

TUNNELS

In this case the only benefit is in terms of reduced maintenance costs, at:

	Maintenance costs ($ per linear foot)
Bad	13
Poor	8.2
Fair	2.7
Good	-
Excellent	-

CALCULATION OF MODIFIERS

SUPPLEMENTARY SECTION C
Annex 7

MAINTENANCE FACILITIES

This area is divided in two categories - maintenance facility investment (principally buildings and equipment) and yard investment (mainly track).

1. MAINTENANCE FACILITIES

Maintenance and Renewal Cost Savings

A maintenance facility's continued operation depends upon the structural safety of the buildings and operation of the equipment. It is apparent from the descriptions of existing conditions and from the principles applied in assessing condition gradings that many facilities are approaching the end of their useful life, and, if not replaced, will require heavy and continuing maintenance expenditure.

On the basis of the condition code gradings it is estimated that costs of the following order would have to be incurred in order to keep the facilities (or at least the buildings) in a serviceable condition for a period equal to the nominal life (50 years) of a new facility.

Additional costs incurred (as compared with facilities in "excellent" condition):

Condition	Definition
Bad	"Materials have reached their life expectancy ... systems non-operational ... non-repairable: All expenditure up to "fair" condition assumed essential in short term, with subsequent maintenance expenditure as for "fair"
Poor	"Requires frequent major repairs" Assume that continuing maintenance expenditure of 8% per year of capital outlay required to improve asset from "bad" to "good" is needed.

Fair	"Requires frequent minor repairs" Assume that 4% per year of expenditure for "bad">"good" is required	
Good	"Infrequent minor repairs" Assume that 2% of all expenditure for "bad">"good" is needed.	
Excellent	(Preventive expenditure only required)	

Now, from examination of the RMS data the expenditure required per square foot to bring maintenance facilities up from bad to excellent condition is:

Average cost of improvement
Bad to Excellent
($ per sq. ft.)

Rapid	Light	Commuter
404	171	369

From this, assuming that to achieve poor, fair etc. condition requires the proportion of the full "bad" to "excellent" expenditure shown, then the costs to achieve intermediate conditions may be broadly as indicated:

	% of full "Bad to Excellent" Cost	Average cost of improvement from "bad" to condition indicated ($ per sq. ft.) Rapid	Light	Commuter
Bad	-	0	0	0
Poor	25%	(101)*	(43)	(92)
Fair	50%	(202)	(86)	(185)
Good	85%	343	145	314
Excellent	100%	404	171	369

* Figures in brackets designate cost for condition from which improvements are made: there are virtually no improvement projects in program which bring assets only to "poor" or "fair" condition.

On the basis of the matrix of maintenance costs avoided, given above, the costs would be as follows:

Maintenance costs
(Compared with excellent condition
$/sq.ft. per year)

	Rapid	Light	Commuter
Bad*	34	15	32
Poor	27	12	25
Fair	14	6	13
Good	7	3	6
Excellent	-	-	-

* Maintenance saving includes annuitized cost of urgent renewals expenditure over life of improved assets.

The effect of specified changes in condition can be summarized as follows:

Maintenance Savings
($ per year per sq.ft. of maintenance facilities improved)

	Rapid	Light	Commuter
1>4	27	12	26
1>5	34	15	32
2>4	20	9	19
2>5	27	12	25
3>4	7	3	7
3>5	14	6	13
4>5	7	3	6
4>4	7	1.5	3.5

2. PASSENGER BENEFITS

Train Service Performance

The quality of the maintenance facilities is likely to influence the time to repair trains and hence the number available for service. London Transport has estimated that the benefits of getting an extra train into service (by improved availability rather than new purchase) is equivalent to a time saving of 85,000 passenger hours per annum or 77 seconds per passenger per vehicle mile at the load factor for the system. The value arises from reduced waiting time, less overcrowding etc; benefits which are of universal application. It is therefore assumed that, on average, this benefit will be achieved in U.S. conditions, with the overcrowding benefits generated on the busier systems being matched by the greater waiting time reductions achieved on the less intensively used systems.

No performance data is available for the effect of the condition of facilities on car availability. In its absence, the present (weighted) average maintenance facility condition (approximately "Fair") is taken as the base for assessing the effect of condition changes. It has been assumed that:

- "Bad" conditions cause train availability to be about 1.5% lower than base.

- "Poor" conditions lead to a loss of 0.5%

- "Good" OR "Excellent" conditions permit an additional 0.5% service to be operated compared to base

(Note that investment in maintenance facilities will not cure all train availability problems; the above estimates attempt to reflect the fact that transit authorities tend to regard maintenance facility shortcomings as obstacles to be overcome in getting the service out.)

The passenger benefit per passenger mile arising from say a 1% improvement is 77/200, assuming that the average mileage per additional train is half that of the average train in service.

On this basis, the benefits of various maintenance facility condition changes affecting train availability are estimated as:

	Seconds per year / system
Bad > Good	0.77
Bad > Excellent	0.77
Poor > Good	0.39
Poor > Excellent	0.39
Fair > Good	0.19
Fair > Excellent	0.19
Good > Excellent	-
Good > Good	0.10

Train Cleanliness

This is a further source of benefits; it is likely that facilities in "Fair" condition will be able to give less attention to this aspect than those in better condition. London Transport priority evaluation surveys indicated that ridership would be increased by 0.1% by "Cleaner trains, inside and out" (Survey question phrasing). In London conditions, this implies a value equivalent to 8.7 seconds per journey or 1.7 seconds per passenger mile. It has been assumed that investment in code areas 7120, 7130, 7140 (and subsidiary codes) may result in cleaner trains. However, only 25% of the "London benefit" is suggested to take account of:

- the demand for cleanliness in part being due to litter inside trains which cannot be addressed by maintenance facility improvements, and

- the probability that much of the investment will not be directed at cleaning activities (specific project details are not available).

Thus taking the present situation as the base "Fair", the following assumptions are made about the effects of different conditions:

- Even at "Excellent" conditions, residual dissatisfaction remains such that only 90% of the potential benefits can be achieved;

- "Good" conditions permit 45% of the benefits to be achieved;

- "Poor" conditions are likely to generate a further 50% dissatisfaction, due e.g. to difficulty in seeing station names through the windows;

- "Bad" conditions will cause an additional 50% dissatisfaction, (i.e. in total 125% worse than "fair") as it is probable that the cars will not only be dirty but badly affected by graffiti, making for a threatening traveling environment;

	Implied Time Saving/ Seconds per Passenger Mile
	ALL TYPES
Bad > Good	0.765
Bad > Excellent	0.913
Poor > Good	0.447
Poor > Excellent	0.595
Fair > Good	0.234
Fair > Excellent	0.382
Good > Excellent	0.148
Good > Good	0.117

Summary of passenger benefits

The two sources of benefit can be combined into a single matrix on the basis that all investment may confer train availability benefits (or benefits of a similar order of magnitude), and that 85% also confer train cleaning benefits. The estimates apply to all system types.

	Passenger Benefits (seconds / pass. mile)
Bad > Good	1.535
Bad > Excellent	1.683
Poor > Good	0.770
Poor > Excellent	0.896
Fair > Good	0.389
Fair > Excellent	0.515
Good > Excellent	0.126
Good > Good	0.194

3. YARD FACILITIES

Storage yards comprise mainly track and thus benefits will accrue through reduced track maintenance costs. It is considered that there will be no significant passenger benefits from improvements here, as availability and cleanliness have been assessed above.

Section C - Annex 1 has estimated maintenance costs for track in various conditions; however yard trackage receives very little maintenance because of the slow speed and non-passenger use. The maintenance cost for different conditions for all system types has therefore been taken as 25% of the light rail costs given in the track paper:

	$000 p.a./ track mile
Bad	15
Poor	10
Fair	5
Good	4
Excellent	3

Like maintenance facilities investment, yard investment is measured in square feet of yard area and it is thus necessary to estimate the track mileage associated with area. Inspection of the system data indicates that on average there is 0.000009 track miles/ sq foot of yard area for rapid/light rail systems and 0.000005 miles for commuter rail systems. It is thus possible to estimate the following effects on maintenance costs/ square foot of yard area for the various condition changes resulting from Code 7200 investment:

	($ saved per sq. ft.)	
	Rapid/ Light	Commuter
Bad > Good	0.10	0.06
Bad > Excellent	0.11	0.06
Poor > Good	0.05	0.03
Poor > Excellent	0.06	0.04
Fair > Good	0.01	0.01
Fair > Excellent	0.02	0.01
Good > Excellent	0.01	0.005
Good > Good	0.005	0.005

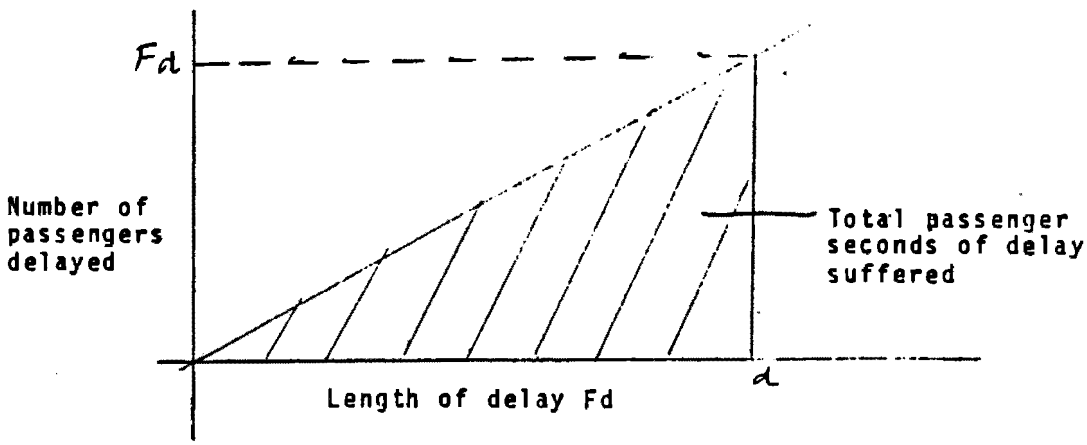
ASSESSMENT OF BENEFITS

SUPPLEMENTARY SECTION D
Annex 1

EFFECT OF FAILURES AND DELAYS TO TRAFFIC

Particularly on a line with a frequent service, the effect of any delay will be compounded by the fact that the longer the delay, the more passengers will be affected.

In general, on a line with a flow of F passengers per seconds, a delay of d seconds will be felt by Fd passengers, the delay perceived ranging from d down to virtually nil at the margin. The total passenger seconds delay experienced will then be given by the area under the following curve:



The total passenger seconds delay will therefore be $\frac{Fd^2}{2}$ and will be very sensitive to the exact length of the delay. Now the rate of flow is related to the passenger mileage on the segment as follows:

Total annual passenger mileage = P on segment

Daily usage = P/300, say, assuming approximately half normal service at weekends. Assuming 16 hours a day operation, then average usage will be $\frac{P}{4800}$ passenger miles per hour, or, if the total track mileage = m, the average flow will be $\frac{P}{4800 \times 3600\ m}$ passengers per second throughout the system. Evidently this will vary widely both with time of day and location on the system although the latter factor may not be very significant, bearing in mind the perturbations in the central area service which can be caused on the outlying parts of the system. If for this purpose the "average" flow is used (i.e. $F = \frac{P}{4800 \times 3600m}$

then the total passenger delay will be:

$$\frac{P}{3600 \times 4800m} \times \frac{d^2}{2} = \frac{Pd^2 \times 580}{m \times 10^6} \text{ seconds}$$

ASSESSMENT OF BENEFITS

SUPPLEMENTARY SECTION D
Annex 2

COST OF PROVIDING AND OPERATING TRAINS

	Rapid	Light	Commuter
		($/car mile)	
Train operating and maintenance costs:	3	5.1	7.1
(source: typical values based on RMS performance data)			
Of this energy costs represent 6.6kWh/car mile x $0.06 =	0.4	0.4	0.4
Other revenue costs therefore =	2.6	4.7	6.7

Now capital costs of rapid transit vehicles are typically $0.8m per car (source: typical values in UMTA Study of transportation systems data, October 1985), which is equivalent in revenue terms to $94,000p.a. Now annual mileage/car for each type of system is: ....

	Rapid	Light	Commuter
		miles/car	
	14,000	10,000	7,000

	Rapid	Light	Commuter
		($/car mile)	
Whence average amortized capital cost per car mile is:......	6.7	9.4	13.4
Whence total cost/car mi. is ..	9.7	14.5	20.5

In practice, however, it may be difficult to achieve effective reductions in costs through reductions in car mileage since: (a) scheduling and staffing arrangements may make it difficult to achieve the potential savings in operating and maintenance staff costs or in vehicle requirements and (b) if vehicles can be saved, they may still have a substantial remaining life and it may be a considerable time before the savings will be reflected in reduced purchases of new rolling stock. In these circumstances it is assumed that reductions in car mileage will achieve only the theoretical energy savings plus one half of the theoretical savings in other revenue costs and in capital costs in the case of rapid and light rail, and, because of its more rigid cost structure, only 25% in the case of commuter rail.

The savings in train costs with changes in car mileage can therefore be summarized as follows:

	Marginal saving ($/car mile)		
	Rapid	Light	Commuter
Energy savings	0.4	0.4	0.4
Other Savings	4.6	7.0	5.0
	5.0	7.4	5.4

In some cases (e.g. the elimination of speed restrictions) "car minutes" will be saved without any corresponding reduction in car mileage. Again subject to the same constraints as mentioned above, it should then in principle be possible to achieve some saving in operating costs excluding energy, and in train requirements.

In this case the scope for non-energy savings on rapid rail lines should be comparable to that achieved with reductions in car mileage except in the case of commuter lines, however, where typically most of the stock (and train crews) make only one return trip morning and evening. In these circumstances there may often be little impact on operating costs, and it is proposed therefore to assume only 10 per cent of the non-energy savings can be achieved.

Taking into account the average speeds for different modes:

	Rapid	Light	Commuter
	($/car mile)		
Average non-energy cost per car mile	9.3	14.1	20.1
	(average speed, mph)		
	20	13	40
	($/car minute)		
Then the average cost per car minute is:	3.1	3.0	13.4
and the marginal cost saving per car minute saved will be:...	1.5	1.5	1.3

DERIVATION OF CITY MULTIPLIERS

SUPPLEMENTARY SECTION E

Once having obtained the passenger benefits (expressed in seconds saved) from the matrices as described in Section B, it is necessary to convert these to social benefit - which depends on circumstances in individual cities. A set of city multipliers has been developed for this purpose, which incorporate a number of factors which are discussed in detail in the Annexes indicated below.

E1 The City Multipliers

E2 Fares Elasticities

E3 Externalities

E4 Value of Time

E5 Price and Wage Variation Between Cities

1. CALCULATION OF PASSENGER RELATED BENEFITS

The passenger related benefits consist of:

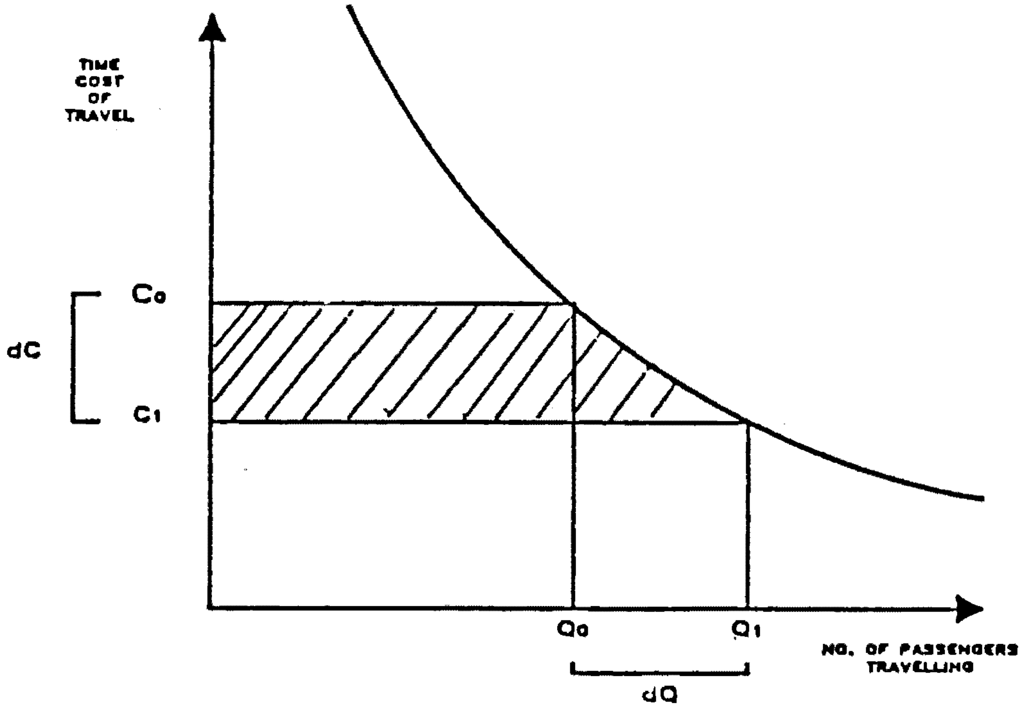
Direct benefits (consumer surplus)

Resulting revenue generation

External benefits resulting from transfer of traffic from car to transit

The benefits in these individual areas are calculated in the following manner:

Consider a change in time cost of travel (valued in $) from $C_0 > C_1$, giving rise to a change in passengers $Q_0 > Q_1$.



It can be shown that, at the margin:

$$dQ = \frac{Q' \cdot dc \cdot e}{f}$$

where e = fare elasticity
f = fare per trip

The resulting benefits are:

(1) Passenger benefits (Consumer Surplus)

The passenger benefits comprise those to existing passengers (who gain the full cost saving) and to new passengers (who, on average gain 1/2 the cost saving). This is shown by the shaded area on the diagram.

Then Consumer Surplus = Qdc + 1/2 dQ dc =

$$= Q'dc \left(1 + \frac{e.dc}{2f}\right)$$

(2) Revenue Generation

The change in revenue is the average fare times the increased number of journeys $f.dQ = Q'dc.e$

(3) Externalities

The external costs are a constant (k) times the increased number of journeys:

$$k.dQ = \frac{kQ'dc \, . \, e}{f}$$

where k reflects the proportion of traffic transferring to/from car and the external costs of increased car traffic (see Annex 4).

Overall, the passenger related benefits add together to:

$$Q'dc \times \left(1+e \; \frac{+e}{2f} + \frac{k.e.}{f} \right)$$

Thus, the overall benefits vary in direct proportion to the total passenger time savings.

If the time cost is assessed per passenger mile, then "Q'dc" can equally be expressed as:

> Passenger mileage x change in time cost per passenger mile.

And the passenger related benefits can be expressed as:

$$\text{PMs x Time savings (Secs./ Pass. Mile)} \times \frac{\text{VOT}}{60 \times 60} \times \left(1 + \text{elast} + \frac{\text{elast}}{2\text{xfare}} + \text{external factor} \right)$$

$$\text{PMs} \times \underset{(\text{secs/PM})}{\text{Time savings}} \times \frac{\text{VoT}}{60 \times 60} \times \left(1 + e + \frac{e}{2f} + N\right)$$

Where VoT = value of time

e = fares elasticity

f = fare per journey

N = The calculation of the multiplier M is given below, where

$$M = \frac{\text{VoT}}{60 \times 60} \times \left(1 + e + \frac{e}{2f} + N\right)$$

k.e. =

2. VALUE OF PASSENGER RELATED BENEFITS

Now the relevant values of the different factors, and the corresponding city multipliers, using a standardized value of time of $3 per hour traveling time (see Annex 4) are:

	Rapid	Light	Commuter
Elasticity[1]			
Large Cities	-0.15	-0.15	-0.3
Small Cities	-0.2	-0.2	-0.4
Fare Per Journey[2]	\$0.80	\$0.50	\$3.00
External Factor (N)[3]	0.06	0.045	0.125
Multipliers (assuming a standard value of time)			
Large Cities	0.00109	0.00112	0.00123
Small Cities	0.00115	0.00120	0.00133

1 See Annex 2.

2 Figures based on a synthesis of data from RMS and UMTA Section 15 reports.

3 See Annex 3.

These figures need then to be adjusted for relative income in the different cities concerned (a value of time of $3 per hour corresponds to the incomes in New York and New Jersey), as shown in Annex 5. The resulting multipliers for each property are shown in Annex 1.

CITY MULTIPLIERS

SUPPLEMENTARY SECTION E
Annex 1

To convert time savings given in seconds per passenger mile into social benefit in $

#	TRANSIT PROPERTY	TYPE	STANDARD BENEFIT per second of Passenger Time Saving ($/1000)	RELATIVE INCOME	TOTAL BENEFIT Per Second of Passenger Time Saving ($/1000)
1	PATCO	RR	1.09	1	1.09
2	NJTC	LR	1.12	1	1.12
3	NJTC	CR	1.23	1	1.23
4	MBTA	RR	1.15	0.95	1.09
5	MBTA	LR	1.2	0.95	1.14
6	MBTA	CR	1.33	0.95	1.26
7	NYCTA	RR	1.09	1	1.09
8	SIRTOA	RR	1.09	1	1.09
9	PATH	RR	1.09	1	1.09
10	LIRR	CR	1.23	1	1.23
11	METRO-N	CR	1.23	1	1.23
12	-				
13	SEPTA	RR	1.09	0.97	1.06
14	SEPTA	LR	1.12	0.97	1.09
15	SEPTA	CR	1.23	0.97	1.19
16	PAAC	LR	1.2	1.04	1.25
22	PAAC	CR	1.33	1.04	1.38
17	WMATA	RR	1.15	1.13	1.3
18	M+DOT	CR	1.33	1	1.33
19	-				
20	GCRTA	CR	1.15	0.95	1.09
21	GCRTA	CR	1.33	0.95	1.26
23	CTA	RR	1.09	1.11	1.21
24	RTA BN	CR	1.23	1.11	1.36
25	RTA C+NW	CR	1.23	1.11	1.36
26	RTA ICG	CR	1.23	1.11	1.36
27	RTA RI	CR	1.23	1.11	1.36
28	RTA MIL	CR	1.23	1.11	1.36
29	RTA N+W	CR	1.23	1.11	1.36
30	RTA SS	CR	1.23	1.11	1.36
31	MARTA	RR	1.15	0.81	0.93
32	BART	RR	1.15	1.24	1.43
33	MUNI	LR	1.2	1.24	1.49
34	MTDB	LR	1.2	1.19	1.43
35	CALTRANS	CR	1.33	1.24	1.65
36	NEWO	LR	1.2	0.89	1.07

FARES ELASTICITIES

SUPPLEMENTARY SECTION E
Annex 2

1. In many cases, U.S.research work in this area is based heavily on experience in London. While estimates of bus fare elasticities are available for a wide range of U.S. cities, very few studies have been done on rail systems. Table #1 summarizes the results which are available. Such evidence as there is supports the view expressed by Ecosometrics (1980) and Bly (1976) that the fares elasticities are not appreciably different between the U.S.and London.

2. The elasticities assumed in the evaluations are:

	New York, Chicago Philadelphia	Other
Rapid Transit/ Light Rail	-0.15	-0.2
Commuter Rail	-0.3	-0.4

The justification for these values is given below

Table #1

Summary of Fare Elasticity Information

System	Year	Elasticity	Report	
Rapid Transit				
NYCTA	1953	-.21	Ecosometrics	
	1977	-.18	Pucher	Summarized
	1970	-.17	Pucher	in
	1974	-.15	Pucher	Ecosometrics
	1948	-.15	Ecosometrics	(1980)
	1966	-.09	Ecosometrics	

Summary of Fare Elasticity Information (contd.)

System	Year	Elasticity	Report	
	1964-73	-.23	Hartgen	
NYCTA contd.	1973-81	-.10	Charles River	Summarized
	1970-80	-.13	Finch	in Charles
	1947-76	-.12	RPA	River (1982)
	1948	-.13		
	1953	-.19		Summarized
	1966	-.07		in TRRL
	1970	-.13		(1980)
	1950-74	-.15		
Mean Across All Studies		-.15		
Rapid Transit				
Boston, MA	1955	-.20	Ecosometrics	
London, UK		-.15	LRT (1984)	
Commuter Rail				
New York (unspecified)	1964-73	-.70	Hartgen	Summarized in Ecosometrics (1980)
LIRR	1976-83	-.19		
Metro-North:				
Harlem Line		-.29	Charles	
Hudson Line		-.33	River	
New Haven Line		-.26	(1986)	
Boston (Northern Suburbs)	1963-64	-.31	Ecosometrics	
London:				
Commuting		-. 3	BR working	
Overall		-.45	assumptions	

3. For rapid transit the London elasticity is based on the combined evidence of time-series analysis through the 1970's and experience of the most recent fare changes (Ref. R259). The elasticity obtained is the same as the average elasticity obtained across a wide range of studies carried out for NYCTA. This value has therefore been adopted for the larger cities.

However, Ecosometrics (1980) presents evidence that (bus) fare elasticities vary with the size of the city; large cities, taken here as New York, Chicago and Philadelphia, have lower elasticities because of problems with traffic congestion and parking availability and because they tend to have better transit options. The fares elasticity for rapid transit has been taken at -0.20 for the smaller cities reflecting the differential found by Ecosometrics and the Boston elasticity noted in the table.

REFERENCES

Bly (1976)
The effect of Fares on Bus Patronage TRRL report 733

Ecosometrics (1980)
Patronage Impacts of Changes in Transit Fare and Services (UMTA)

London Transport (1983)
The London Transport Fare Experience 1980-83 Research Report R259

Charles River (1982)
NYCTA Revenue Feasibility Study Economic Analysis and Projections

Charles River (1984)
Long Island Railroad and Metro-North Commuter Revenue Feasibility Study Economic Analysis and Projections

TRRL (1980)
The demand for Public Transport Report of the International Collaborative Study

EXTERNALITIES

SUPPLEMENTARY SECTION E
Annex 3

1. One of the important benefits of improvements to the transit system is that by attracting more passengers to public transport there will be a reduction in car usage, bringing:

   - reduced road traffic congestion (leading to shorter journeys and reduced energy consumption)
   - reduced road traffic accidents
   - reduced pollution

   Overall, it is considered that these factors account for a further 5-15% on the immediate passenger benefits. Although the importance of these factors might be expected to vary between cities, it has not been possible to identify specific factors for different cities. However, the difference may be assumed to be fairly small since in the larger cities where traffic congestion is a bigger problem there will be a greater reluctance for passengers to transfer to or from car anyway, reflected in the fare elasticity (See Section E-2).

2. In general terms the externalities are determined by:

   - The change in transit trips x the average trip length x the proportion of passengers transferring to/from car x the external costs per car mile divided by average occupancy.

   The last three factors are combined into a city-specific constant "k".

3. The change in transit usage depends on the change in passengers time costs and elasticity, as shown at the beginning of this Appendix.

- Specifically:

  Change in transit trips =

$$\frac{\text{Total Time Savings(\$)} \times \text{Fare Elasticity}}{\text{Fare Per Trip}}$$

Thus, the external costs can be considered in the form:
Total time savings ($) x N
Where N = k x fare elasticity/fare per trip = External factor

The factors determining the overall value are considered below, and summarized in the Table at the end of this Annex.

4. The average trip lengths assumed are based on RMS passenger miles and station utilization data:

Rapid Rail	5.2
Light Rail	2.4
Commuter	20.0

The proportion of new rail traffic transferring from car is assumed to be 40%. This is the assumption made in London assessments (LT,1984a) and reflects U.S. experience as presented in the Boston Study (MBTA 1983) and the Ecosometrics (1980) report, table 3 - 7.

The average car occupancy is taken to be 1.15 from U.S. Census Data.

5. In terms of the external costs per car mile it is possible to make an estimate of likely effects based on U.S. data and UK experience.

i) Congestion

A model does exist within the U.S. for estimating the effect on traffic queues of changes in car traffic levels as a result of passengers switching to/from public transport (the CTPS Expressway queuing model). This model was applied in the appraisal of the Boston Fare increase (MBTA 1983). In the time available it has not been possible to research this area in detail. For the purpose of the analysis here it has been assumed :

- city road speeds 25 mph (slightly higher than for suburban London).
- 80% of traffic is private vehicle, 20% trucks (US Highway Statistics)
- value of time for car driver/passenger at $3/hr and for commercial vehicle drivers $10/hr reflecting the fact that the latter are actually working when driving.
- Average commercial vehicle occupancy is 1.15 as for car.
- Average energy consumption is 17mpg for cars, 10 mpg for trucks (US Highway Statistics)
- price of gasoline is $1/gallon.

Thus for a typical vehicle the time cost is $0.20 / mile and the operating (gasoline) costs $0.07/mile.

The evidence from London (LT 1984b) is that a 1% reduction in traffic leads to a 0.5% increase in road speeds and hence a 0.5% reduction in time costs and a 0.1% reduction in car/commercial vehicle operating costs. The Boston Study estimated that gasoline consumption has increased by 0.7m gallons as a result of increased congestion as against 1.9m gallons resulting directly from the increased car usage, giving a factor of 0.3%. This figure has been used in estimating the external energy costs and the UK figure for the time costs.

Thus an extra car mile would be expected to lead to external costs of:

(0.5 x $0.20) + (0.3 x $0.07)= $0.12

(ii) Accidents

In the UK, the assessment of the effect of a change in car traffic on accident costs was based on an analysis of accident levels over the last 10 years to identify the particular effects of the recent drastic shifts in fare levels. However, the UK experience is not considered very useful here as the main injuries/fatalities are suffered by pedestrians and cyclists who are far less prevalent in the U.S.

Instead, average accident rates on arterial roads have been taken from UMTA statistics and the costs / accident are:

	Accidents per million vehicle mile	Direct cost per accident	Cost per car mile
Fatal accidents	.029	$45,000	$0.001
Injury accidents	1.64	8,000	$0.013
Property accidents	16.5	1,000	$0.016
			$0.030

However, these costs cover only medical costs and damage to property. In the UK the standard figures for the cost of an injury, etc, which are provided by the Department of Transport, also reflect loss of wages and "grief and suffering". Across all accidents in the UK this works out to about the same amount again on the direct costs. In this evaluation a figure of $0.06/mile has therefore been used.

(iii) Pollution

Again, the Boston Study considered in some depth the effect of increased congestion on certain types of emissions. However, there is no established methodology for putting $ values on reduced air pollution.

Overall, the external costs are taken as $0.18 ($0.12 from congestion, $0.06 from accidents).

TABLE : Build-up of External Costs/Benefits

	Rapid Rail	Light Rail	Commuter Rail
Fares Elasticity	.15	.15	.30
Average Trip Length (Miles)	5.2	2.4	20.0
Fare per Trip	$ 0.80	$ 0.50	$ 3.00
% Transfer	.4	.4	.4
Car Occupancy	1.15	1.15	1.15
External Costs Per Car Mile	$ 0.18	$ 0.18	$ 0.18
Overall Costs/ Benefits as % Total Time Savings (N)	6.0 %	4.5 %	12.5 %

Notes

(1) Values here are for larger cities although as noted above higher elasticity will make up for lower external costs / mile in smaller cities.

(2) The fare per trip figures are based on a synthesis of data from annual reports, RMS data, and UMTA section 15 reports.

Although figures (for e.g. fares) are in many cases available for individual properties, it would not be appropriate to use these where other information (e.g. elasticities) is not available at this level.

References

MBTA — Final Environmental and Socioeconomic Impact Report. The MBTA Fare Increase

LT (1984a) — The Strategic Model: Further Amended Relationships. TN158.

LT (1984b) — The Disaggregated Strategic Model. TN159.

UMTA: — U.S. Highway Statistics 1984

UMTA: — Transportation Planning Data for Urbanized Areas Based on the 1980 Census.

UK DTp: — Highways Econometrics Note 1. Road Accident Costs.

UMTA: — Characteristics of Urban Transportation Demand - A Sketch Planner Reference for Transportation Planners.

VALUE OF TIME

SUPPLEMENTARY SECTION E
Annex 4

1. In the UK standard values of time are provided by the Department of Transport for use in appraisal of all transport projects (highway construction and public transport). No such standard values are provided in the U.S. although UMTA (1984) have recommended the use of :

   Work trips = 2/3 x wage rate = \$4 / hour (1984)

   Non-work trips = 1/3 x wage rate = \$2 / hour

   In this work it has not been possible to estimate different values of time for each segment based on the different proportions of work trips: although, as UMTA (1984), point out radial lines are likely to have a higher proportion of work trips than the system as a whole. Typically in the U.S. about half of all transit trips are to or from work giving an average value of time \$3/hour (1984 prices). This value has been used in these evaluations.

   The assumptions made above are consistent with those made in the UK where the value of time is 20% of income for all trips except those made actually during the course of business (UK DTp).

   Waiting time is valued at double the in-vehicle time above, which is in line with both the UMTA recommendations and UK practice.

2. Although the above values have been used with reasonable confidence, reflecting as they do a consistent view of the U.S. and UK Departments of Transport, there is some evidence in the U.S. research work considered by GFTE, that a higher value of time and, in particular, a higher weight on waiting time could be appropriate. Should an alternative value be justified, the modifiers provided can readily be adjusted to take account of this.

SUMMARY OF RESEARCH INTO THE VALUE OF TIME

1.	Transit Operating or Strategies and Levels of Service (Paper to 1976 - Meeting of T.R.B.) by J. J. Bakker, Alberta Mode Split Analysis of Travel in Paris.	In-vehicle time = 50% hourly income Wait time values x 3.
2.	Demand Model Estimation and Validation by D. McFadden, ITS, Berkeley (Table 20) Mode Split Analysis	In-vehicle time - 60% hourly income Wait/transfer time considerably more
3.	Benefit/Cost Analyses by Simpson and Curtia	$4/hour for travel time (1976-7). Equivalent to $6/hour current prices.
4.	Comparison of Fares and Service Elasticities for 1962-4 Boston Study (data given in Ecosometrics 1984, LTI calculations*)	$5/hour for wait time (1962-4). Equivalent to $20/hour for wait time at current prices.

* Method described in Annex 2

References

UMTA (1984) Application of the Major Investment Policy for Fiscal Year 1986: Calculation of Indices, Possible Revisions and Data Requirements

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3. The idea underlying a (behavioral) measure of the value of time is that it enables changes in the time components of a journey to be handled in the same way as a fares changes from the point of view of passengers behavior.

It is therefore possible to make estimates of passengers' valuation of time by comparing fares and service elasticities.

It is assumed in this analysis that the demand model is of the form:

$$Q = A \exp - c\,(f + vt)$$

Where

Q	=	passenger trips
A,c	=	constants
f	=	fare per trip
t	=	time costs per trip
v	=	value of time

This approach has proved successful in predicting demand changes in the UK. In the model which is used the fares and service elasticities are proportional to the fares level and the value of the base wait time respectively:

Fares elasticity = - c x fare per trip

Service elasticity = - c x wait time x value of time

(This assumes wait time varies in direct proportion to the level of service).

From this, it can be shown that:

Value of wait time =

$$\frac{\text{Service Elasticity}}{\text{Fares Elasticity}} \times \frac{\text{Fare per Trip}}{\text{Wait Time per Trip}}$$

4. Applying this to the Boston Study (1962-64) as reported in Econometrics (1984) gives:

Line	Headway old - new (avg.)	Service Elasticity	Fares Elasticity*	V.O.T
Fitchburg	67 - 35 (46)	.69	-.3	$4.3
Haverhill	48 - 33 (40)	.53		$4.0
Newbury	39 - 17 (28)	.44		$4.7
Lowell	33 - 17 (25)	.41		$4.9
Reading	21 - 10 (16)	.27		$5.1

*Across system value reported in Econometrics.
Average fare = $ 0.75

The tendency for the value of time seemingly to increase with a more frequent service is consistent with the idea that for low frequency service the wait time is a smaller proportion of the headway (as passengers schedule their journeys) than for long journeys.

The value of time obtained here is typically much higher than might be expected. This could be because the fares elasticity estimated is rather lower than indicated by other more recent research.

PRICE AND WAGE VARIATIONS

BETWEEN CITIES

SUPPLEMENTARY SECTION E
Annex 5

In developing city factors operating cost savings should be factored by the Consumer Price Index for urban wage earners and clerical workers (CPI-W) on the advice of GFTE.

The value of time has been taken as $3./hr. as explained in Annex 4 of this section. Since the value of time is calculated as a proportion of hourly income, the overall passenger related benefits are factored to reflect variations in average family income from the County and City Data Book, updated to 1985 by GFTE.

	City	Relative CPI (Oct/Nov '85)	Relative Income
1.	New York	.97	1.00
2.	Boston	1.00	.93
3.	Philadelphia	1.00	.97
4.	Pittsburgh	.96	1.04
5.	Washington, D.C.	1.03	1.13
6.	Maryland	1.01	1.00*
7.	Cleveland	1.02	.95
8.	Chicago	.96	1.11
9.	Atlanta	1.03	.81
10.	San Francisco	1.03	1.24
11.	San Diego	1.06	1.19
12.	New Orleans	1.00*	.89

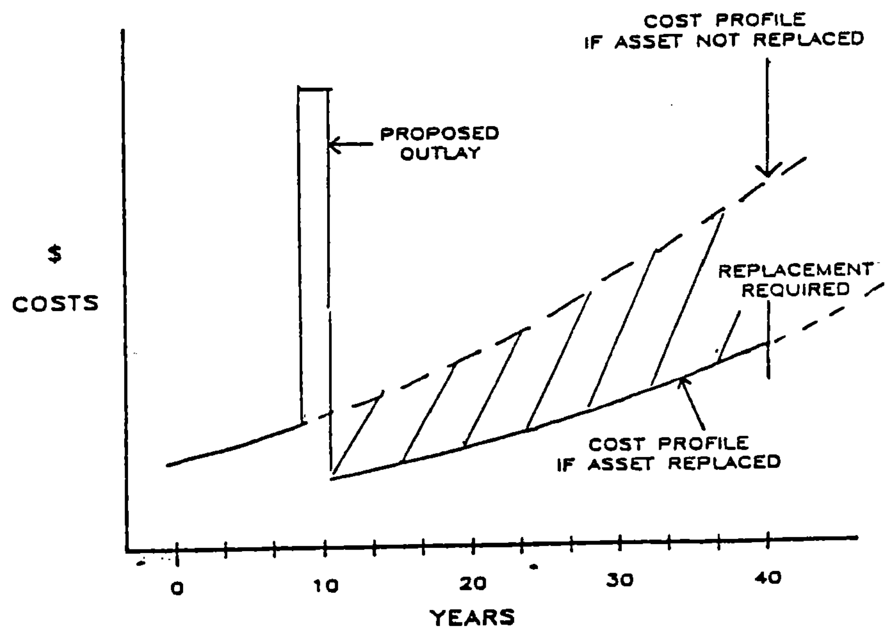
* n/a

SPAN OF TIME TO BE CONSIDERED IN PRESENT VALUE CALCULATIONS

SUPPLEMENTARY SECTION F

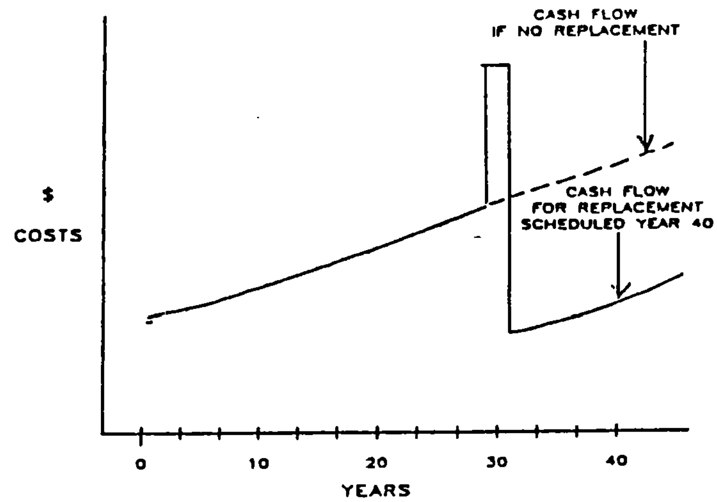
The effect of advancing the replacement of an asset is complex, and some thought needs to be given as to how the resulting costs and benefit can be roughly forecast in the absence of specific data.

Consider an asset on wich revenue costs are rising, and for which there are no plans for replacement. It is now proposed to replace it with a new asset with a life of, say, 30 years. The effect on cash flows can be summarized as follows:

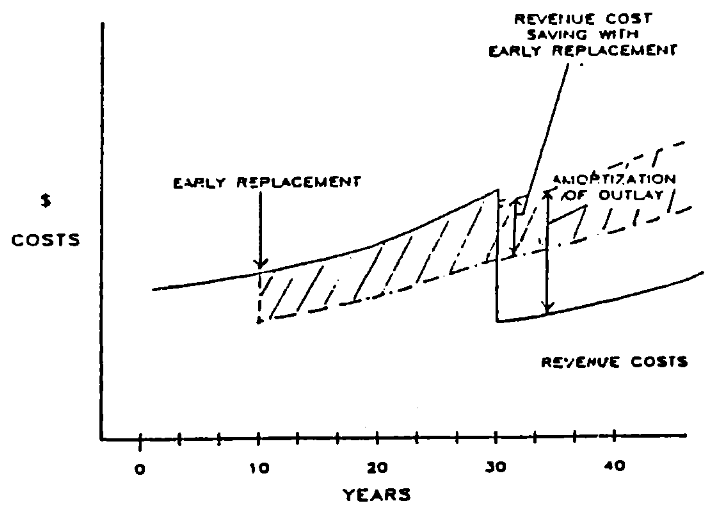


The revenue cost savings will in effect be the shaded area. If the "no replacement" and "replacement" revenue cost curves are of identical profile, but just with an appropriate (horizontal) time lag between each then the vertical distance (cost saving) between the two will tend to increase. Thus to assume that savings throughout the life of the asset would be constant and no greater than the initial savings would be conservative. The total present value of the revenue benefits would be at least as great as the present value of the initial saving continuing throughout the life (30 years) of the asset.

Now consider the more complex case where the original asset was scheduled for replacement in, say, year 30. In this case the cash flow would be as follows:



In order to allow comparison of this profile with that for earlier replacement, it is simplest to consider the effects of amortizing the capital outlay. If indeed it is economic to replace in the year 30, then the amortization "payment" must be less than the consequent revenue savings and the total cost curve must therefore be somewhat lower than if the asset had not been replaced. The situation can be represented thus.



The effective cost saving from early replacement is thus the shaded area. Although the shape of the curve after the originally scheduled replacement in year 30 is rather indeterminate for present value calculation purposes (allowing for heavily discounted effects in later years), it is again reasonable to make initial annual savings x expected life of replacement asset as a first approximation.

What is certain is that to take only either:

(a) The period by which replacement has been advanced (i.e., AB, 20 years), or

(b) The period by which the subsequent replacement date for the asset has been delayed (i.e., BC, 10 years) would greatly understate the overall benefits.

DEVELOPMENT OF METHODOLOGY

Documents Consulted

SUPPLEMENTARY SECTION G

The key reference documents listed in this report are categorized as follows:

1. General
2. Travel Patterns and Trends
3. Public Transportation Policy
4. Evaluation of Improvements
5. Cost Benefit Analysis
6. Externalities
7. Rail Modernization Study Reports

In addition to the specific reports identified above, a large amount of information on capital programs, revenue expenditure, performance indicators, etc. was provided by the various transit properties visited. Our particular thanks for support and cooperation in our data collection go to the following properties:

New Jersey	NJTC
Massachusetts	MBTA
New York	MTA, NYCTA, LIRR
Pennsylvania	SEPTA
Washington, DC	WMATA
Illinois	CTA, RTA
California	BART, MUNI

1. GENERAL

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Service & Methods demonstration Program UMTA

Service & Methods Demonstration Program

UMTA Industry Uniform System of Accounts and Records and Reporting System

UMTA Transit Service Reliability

Free-Fare Transit a Comparative Study of Two demonstrations in Trenton & Denver

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2. TRAVEL PATTERNS AND TRENDS

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4. EVALUATION OF IMPROVEMENTS

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The (Global) Strategic Model
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Tn 158

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ASSESSMENT OF BENEFITS METHODOLOGY
SUPPLEMENTARY SECTION H

Ideal Evaluation Method

Methods of cost benefit appraisal are well established in some areas of policy formulation. Transportation is different from many other areas because of the difficulty of identifying and measuring the value of the changes caused by a project. However, various features are fundamental to the approach, and -- within the timespan of the study -- some of these have been dealt with, some were not and some only approximately. Each of the features is discussed below.

Identification of Measurable Benefits

For example, for any project the main aspects it is necessary to know are:

- change in condition;
- change in costs;
- passenger generation;
- effect on safety and security.

While these are difficult to measure, it is by no means impossible to do so.

Taking track improvements as an example:

Maintenance Costs may reduce after improvement ranging from a higher degree of mechanization to reduced work on retamping and dealing with fatigue fractures;

Operating costs can be assessed if the current condition causes speed restrictions (removal of restrictions will lead to reduced track transit times with, ultimately, fewer vehicles and staff required to provide a given frequency of service);

Passenger generation can often be assessed. This is seldom possible by reference to before and after studies as the generation is usually very small (as a proportion) and statistically unmeasurable. Instead, it can be forecast with reasonable confidence by a combination of measurement of social cost to passengers multiplied by fares elasticity. In the track example, the removal of speed restrictions will reduce passenger transit time to which standard values of time can be applied. Track improvements may also improve reliability and schedule adherence. In addition, improved ride will be perceived as a benefit and valued by passengers. London Transport has pioneered a great deal of work in this whole field of valuing benefits to passengers, using priority evaluation surveys;

Safety and security improvements are difficult to quantify and even more difficult to value. The basic approach is often to try to quantity types of risk, e.g., death, injury, assault. Putting a cost on such aspects may well be easier in the USA than in the UK because of different litigation practices. However, it is our experience that it is the fear of such problems (especially assaults) rather than their actual occurrence that causes passenger alarm and therefore affects ridership. In this regard, work using conjoint analysis of paired comparison situations has given London Transport some feel for the general magnitude of this factor. Some improvements, e.g., improved lighting, may well alleviate this fear.

Passenger generation itself is comprised of three parts from an evaluation point of view:

- the direct effect on revenues;
- the benefit to passengers which has caused the generation;
- the saving in community costs caused by more people using public transit. This externality effect comprises principally reductions in road traffic accidents and road congestion costs.

Summarizing in mathematical language, we have:

$$B = Cm + Co + Gf + S + Gd$$

Where:
B is annual benefit
Cm is annual saving in maintenance costs
Co is annual saving in operating costs
S is social benefit to passengers
G is passenger journeys generated, (passengers will use the system more if the service is better and vice versa)
f is fare per journey
d is proportion of trips diverted from car multiplied by (congestion and accident) cost per trip

Clearly, in an ideal world, each of the above would be separately estimated for each modernization investment.

Discounting Over the Life of a Project

In a simple case where, say, the investment (I) in improvement has a life of n years, then standard amortization tables can be used to discount the investment cost to give:

$$A = \frac{I}{F(n)}$$

Where:
- A is annualized investment cost
- I is investment cost
- F(n) is the amortization factor for life n

$$= \left(1 - \left(\frac{1}{1 + r}\right)^{n}\right) \times \frac{(1 + r)}{r}$$

Where: r is the discount rate (i.e., with 10% discount, r = 0.10)

The railway modernization investment is not quite so simple in that, although the investment causes a rise in condition and thus a change in benefits, the condition will deteriorate again. This could also be evaluated fairly simply if we assume that when the condition again reaches the start condition the modernization will be repeated. This, however, is still too simple, as it is possible that the element concerned reaches the end of its safe life before then. In normal appraisal, one evaluates a series of discrete alternatives, comparing them in terms of net present value of investment costs and annual benefits. The ideal method, though, is to use a dynamic programming technique to explore all decision alternatives from the present day forward, terminating when some end-of-life condition is indicated (e.g., track over 60 years old and subject to fatigue fracture).

Interrelationships Between Projects

It is rare to find that a project can be evaluated entirely on its own. For example, it makes no sense to improve the track on A segment, but leave structures in so bad a condition that the line has to be closed on safety grounds. Again, it may be that no benefits can be achieved from power supply improvements while track is in bad condition. Alternatively, some projects may be more easily carried out together, e.g., consecutive sections of track where engineering track possession time can be combined. Sometimes this works the other way around where, for example, closing the escalators at adjacent stations will cause delays to passengers with no good alternative routes available.

Generally appraisals try to cover the more important of these relationships by packaging modernization projects together and by considering alternatives, e.g., looking at power changes with and without structure improvements - often with the aid of a computer package. Decision theory or linear programming approaches may sometimes be useful to clarify a complex set of alternatives and limitations.

Alternative Investments

A crucial part of the normal capital appraisal process is the search for alternatives that will, perhaps, achieve a large part of the benefits for a small part of the cost. For example, instead of modernizing five maintenance facilities from bad to good, it may be more worthwhile to modernize two, close three and build a large modern new facility in a better location.

Alternatively, it may be that -- instead of spending $10 million to improve a station from bad to good -- $1 million should be spent to improve it from bad to fair. In particular, if it were a station with little patronage the latter would usually be a better decision.

In certain circumstances an alternative might involve closure of a part of the system. For example, consideration might be given to closing a small dilapidated station rather than rebuild it; or the closure of a whole section of line rather than incur massive expenditure on structures, track and possibly vehicles.

Summary

In summary, therefore, the fundamental features of an ideal evaluation method are:

- identification of measurable benefits;
- discounting over the life of a project;
- interrelationships between projects; and
- alternative investments

The next section will describe to what extent these features can be adequately handled in the short-term methodology to be applied within the timescale of this study.

Preliminary Methodology

Some of the features needed for the evaluation are already present within the work done in the Engineering Cost Estimate Phase. Coupled with the further work described in this Appendix, this should enable most aspects of the ideal evaluation method to be retained. Each of the features is discussed below.

Identification of Measurable Benefits

It is believed that for many categories of benefit, it will be possible to make estimates which will closely approximate those which would be produced by a detailed scrutiny. The main exceptions will be the effects on operating and maintenance costs where individual circumstances are normally very important; and areas where approximations have to be made because of lack of accurate data (e.g., lack of detailed knowledge of passenger miles, vehicle miles, ton miles). Steps were taken to guard against the distortion that could otherwise be caused by some benefits being more readily measured than others. The methodology development process was also conscious of the dangers of extrapolation from UK to USA because of key differences (e.g., car ownership) and therefore, made the maximum possible use of US experience and research. Different maintenance policies of the operators also affected the way in which some benefits arise (e.g., potential maintenance savings might be reinvested into preventive maintenance, thus increasing reliability rather than reducing costs).

Taking track improvements purely as an example, some of the benefits that might arise are:

		Benefit Relationship
Avoidance of speed restriction	=	(reduction in time per mile) x miles of track
Reliability and adherence to schedule	=	reduction in times passengers are forced to allow for their journeys x passenger journeys
Improvement of ride	=	(passenger benefit per passenger mile) x passenger miles
Reduction of track maintenance costs	=	average cost per vehicle mile x (percent reduction due to change) x vehicle miles

Cost of closure (if left in bad condition) =	(passenger time lost per passenger mile transferred to other modes) x passengers on the section x average journey length

Values in parentheses are system-wide inputs which will depend on condition -- the others are specific to segment or section.

Expressed mathematically, the annual benefit for condition change (i) for track (Bi) is:

Bi	=	Lip track miles
	+	Yip passenger journeys
	+	Rip passenger miles
	+	Zip Ap vehicle miles
	+	Tip passengers x whole journey length

Lip is loss of time per mile
Yip is time allowed per passenger journey
Rip is passenger benefit per mile traveled
Zip is fractional reduction of maintenance cost
Ap is average maintenance cost per vehicle mile
Tip is average time lost per mile if passengers transfer to other sections or modes (Tip is zero if current condition is not "bad")
p represents the property factor, reflecting the different values of demand elasticities, externalities, labor costs in the different cities

The study team has information for each section and segment on track miles and passenger miles but not passengers on the section or journey length (though these could no doubt be estimated).

The annual benefit could be re-expressed as:

Bi	=	Li track miles
	+	(Rip + Zip Ap V + Tip W) passenger miles

Where: V is vehicle miles/passenger miles
W is passenger miles x whole journey length/passenger miles

V and W should be able to be estimated for properties and segments and their relation to other properties attributes established.

We could, therefore, replace all in brackets by Vip, giving:

Bi = Lip track miles + Vip passenger miles

We can further reduce this to:

Bi = (Lip track miles/passenger miles) passenger miles

= Mip passenger miles

Where: Bi is the annual benefit from improvement (i).

Generalizing we have for element type i:

Bij = Mijp x passenger miles j

Discounting Over the Life of the Project

The approach here is also very close to reality. Data is available on the relationship of condition to age and further estimated remaining life related to age and condition. This analysis was used, together with the annual benefits related to condition, to determine the appropriate amortization factor Dijk, dependent of age k.

Then the benefit cost ratio (Rij) of a project is given by

Rij = Mij x passenger miles j x Dijk/Iij

or, bringing it into the form that GFTE has set up software to analyze

Rij = change in condition i x Mod ijk passenger miles j/Iij

Mod ijk is the modifying weight = $\dfrac{\text{Mij x Dijk}}{\text{condition change i}}$

Mod ijk depends not only on the type of element of modernization j and degree of condition change i, but also on age k and the ratios of track miles, etc., to passenger miles.

Project Packaging and Interrelationships

It was not possible to take the project interrelationships into account in any detailed way. However, in putting projects into priority order, it is necessary to define appropriate project packaging and also some sensible ground rules on interrelationships. The packaging for reporting should be:

Element	Appropriate Packaging Level for Reporting
Track	Segment
Vehicles	System/segment
Power Distribution	Segment
System-Wide Controls	System/segment
Stations	Segment
Structures and Facilities	Segment
Maintenance Facilities	System/segment

It is important to stress that, because this is a simplification of the relationships and the data is on a sample basis, this packaging is an aid to sensible prioritization and cannot represent what properties would actually do. For this purpose, far more detailed data would be necessary on a much longer time frame, if indeed it was thought an appropriate role for Federal Government.

Sensible ground rules for interrelating packages were formulated, however, during this study. An obvious one is to prevent any track work on a segment if there are any structures on that segment which will be left in a poor or bad condition. This type of restriction avoids absurdities of spending expensively on stations, track and power and then being forced to close the line on account of unacceptably high cost of remedying unsafe structural defects.

Operating and evaluation experience from London and that gleaned from discussion with US properties was used to formulate such rules.

Alternatives

The nature of the data collected precludes consideration of alternative solutions. However, it was possible to put in the broad alternatives of segment closure, using assumptions of time cost per mile of passenger forced onto other sections or modes.

Summary of Proposed Methodology

The benefit cost ratio (Rij) for a project is calculated as:

$$Rij = \frac{\text{change in condition } j \times \text{Mod } i, j, k, g^1, g^2, g^3 \times Pj}{\text{Modernization cost } i, j}$$

Where: i is improvement level
j is subelement
k is subelement age
p is passenger miles affected by the project (not necessarily all of the passenger miles on the segment)

Mod (i, j, k, g^1, g^2, g^3) is a modifier factor to be calculated by LTI where g^1, g^2, g^3 are a series of factors such as:

track miles/passenger miles
passengers/passenger miles for the segment
station factor to cover different elasticities, etc.

This is not, therefore, a simple two-dimensional modification table. Although, by assuming average values for parameters k, g^1, g^2, g^3 a two-dimensional table could be produced, it would not in practice simplify the work involved. Furthermore, the method as proposed helps to avoid subsequent conflict with the desirable longer term assessment methodology.

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Rail modernization study

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