QUEENSLAND COMPETITION AUTHORITY

Working Paper 2

Usage-related infrastructure maintenance costs in railways

December 2000

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GLOSSARY OF TERMS

Above-rail:	Infrastructure and equipment including rollingstock required by a railway operator to operate trains.
Axle Load:	The weight limit applied to trains passing over a line by the railway civil engineer. It is the limit allowed to be applied to any one axle on the train.
Ballast:	The material upon which the sleepers bear, normally a load distributor to the formation or sub-grade.
Ballast cleaning	Restoring the elasticity (ie the ability to return to the initial position after the load has passed) and draining properties of the ballast.
Below-rail:	Infrastructure required by a railway manager to provide capacity for the operation of trains.
Capping:	A layer of fine material between the ballast and the sub-grade which prevents the sharp rocky material of the ballast from degrading the sub-grade.
Clip Fasteners:	Similar to Track Spike but are clips which secure the rail to concrete sleepers.
Consist:	A term for a train formation.
Gross-to-tare Ratio:	The total weight of a loaded wagon to the weight of the empty wagon.
Inspections	These range from regular visual inspections by section car to the measurement of track geometry and rail flaw detection by special vehicles.
Head Hardened Rail:	Rail that has been heat treated so that the head is approximately 30% harder than standard carbon rail.
Heavy-haul:	Rail transport associated with the movement of bulk commodities eg coal, iron ore etc. To be a member of the Heavy Haul Association the railway must carry over one route more than 10 million tonnes.
Rail Anchors:	On wooden sleepered track fitted with track spikes, a steel fitting that grips the rail base and prevents the rail sliding longitudinally with respect to the sleepers by wedging against sleepers. For concrete and steel sleepers, the mechanism of restraint is incorporated into the clip fasteners.
Rail Creep:	Lengthwise movement of rail forcing buckles in rail and misalignment of sleepers.

Rail Grinding:	A process performed by a machine whilst on the track where the head of the rail is shaped and surface defects removed by way of grinding wheels.
Rail:	A steel wheel guide with a head, stem and base.
Re-railing	Carried out where the rail needs replacing but the sleepers still have reasonable life.
Re-sleepering	The replacement of sleepers which are life-expired.
Resurfacing or (tamping)	Restores the elasticity (ie the ability to return to the initial position after the load has passed) and the relative positions to the tracks, which are degraded by repeated heavy loads.
Rollingstock:	Railway wagons and locomotive used for specific purpose or general haulage.
Sleepers/Ties:	The transverse members of trackwork, made of wood, concrete or steel which are used to secure the rail at the correct gauge.
Sub-grade:	The prepared earth upon which the trackwork is built.
Tamping:	The process by which ballast is packed around the sleepers of a track to ensure the correct position for the location, speed and curvature.
Track Gauge:	The distance between the inner faces of the rail heads of a railway track. A narrow gauge railway is designed for 1067mm whilst a standard gauge railway is designed for 1435mm. The measurement is made 16mm below the top of the rail on the inner face.
Track Geometry:	The position of the two rails transversely and longitudinally with respect to the alignment of the track.
Traction Current:	Term used for electric power supply used on electric railways for trains. Normally supplied by overhead wire or third rail.
Train Path:	A defined entry, exit and transit time for a train consist on a particular network or corridor.
Turnout:	Trackwork where a single track splits to become two tracks and equipped with moving rails to change the route.
Track relaying	The complete replacement of the track structure, is usually carried out using track-laying machines (except where relatively small lengths are involved).
Tamping (or resurfacing)	Restores the elasticity (ie the ability to return to the initial position after the load has passed) and the relative positions to the tracks, which are degraded by repeated heavy loads.

1. INTRODUCTION

Historically, although the allocation of infrastructure costs to various users was of interest to senior railway management and, where rates were controlled, to regulators, it had little significance in terms of day-to-day railway operation. Even where infrastructure was shared between one or more operators, the procedures for dividing the costs between the users emphasised simplicity and practicality of calculation as much as technical sophistication. However, the increased use of vertical separation, and the introduction of access charges for external users of infrastructure, has required the development of comprehensive charging schemes, in some cases at a considerable level of detail.

In such cases, where there are competing users of common infrastructure, all charges to individual users should at least cover those costs that are variable with usage (generally termed the incremental or avoidable costs) and this in turn has placed greater emphasis on their identification and attribution.

The access cost framework proposed by QR requires incremental costs for three purposes:

- to establish a base for charges where there is more than one user on a section of track (e.g. on sections of the coal network used by more than one cluster or on sections of the non-coal network carrying multiple traffics);

- to provide a procedure for adjusting the stand-alone cost of track sections to allow for marginal users (e.g. passenger and general freight services on the Blackwater system as far as Emerald); and

- to provide a basis for indicative adjustments to the reference tariffs for variations in the reference train consist.

This paper therefore derives incremental cost estimates for QR, based on evidence from QR itself, together with other systems world-wide. The first section of this paper outlines the technical characteristics of infrastructure costs and discusses their general variability with usage.

The second section summarises a range of existing studies on the overall variability of infrastructure maintenance costs with usage, covering several other countries as well as work undertaken in Australia during the formation of National Rail.

The third section discusses the specific case of QR and develops estimates of cost variability (and thus incremental costs) that can be input to the access price determination.

The final section draws on the material presented in the previous sections to develop estimates of incremental cost as a function of tonnage and train characteristics.

2. THE RAIL MAINTENANCE TASK

2.1 Introduction

This section provides an overview of the various elements of rail infrastructure maintenance and summarises their relationship to usage. Chapters 3 and 4 provide a more detailed discussion of the variation of track maintenance costs with usage, based on experience in overseas railways and in QR.

Each of the main elements of infrastructure has a number of key factors affecting their costs. The following discussion concentrates on track maintenance and renewal, as this is the most important item in the Queensland context, and then briefly discusses in turn structures, signalling and electrification infrastructure maintenance. It does not deal with communications, as this now is largely independent of rail infrastructure proper. A final section deals with train control and signalling operations.

2.2 Infrastructure-related cost functions

Infrastructure costs differ from the above-rail costs of operating trains, as they are not directly variable with the volume of train operation. Rather, they have a fixed component as well as a component that is variable with usage. In addition, infrastructure costs are a function of both the quality of the track (in terms of line speed and capacity) and the standard of construction. Different types of train have different requirements in terms of track quality, and have markedly different impacts in terms of wear and tear on the infrastructure.

In the short-term, assuming a constant track standard, any variations in maintenance cost caused through changes in the level of use of the assets may not immediately be apparent. Rail infrastructure is a long-lived asset, with a maintenance cycle of several years, and many of these cost changes will not manifest themselves until the maintenance cycle has been completed. Some, indeed, will only appear through advancing or retarding the date at which infrastructure is renewed, possibly twenty years or more into the future.

In the longer-term, changes in traffic volume will lead eventually to changes in the quantity and capacity of infrastructure (e.g. singling double track or the removal of block sections) as well as its quality (e.g. ride quality and/or maximum line speed). These may all be classed as medium or long-term variable costs, resulting from management decisions on track standards based on changes in the pattern and level of usage.

2.3 Track maintenance

Track maintenance activities consist of the following:

1. *Inspections* range from regular visual inspections by section car to the measurement of track geometry and rail flaw detection by special vehicles. The track quality indices generated from the track geometry results should be a major input to programming maintenance work but condition-based maintenance has yet to be fully introduced in Australian systems.

2. *Resurfacing* (or tamping) restores the elasticity of the track structure (ie the ability to return to the initial position after the load has passed) and the relative positions of the tracks, which are degraded by repeated heavy loads. This procedure is generally undertaken with mechanical tamping and lining machines. As well as being a stand-alone activity, it is also performed following relaying, re-sleepering and ballast cleaning.

3. Periodically, the elasticity and draining properties of the ballast need to be restored. This is done with mechanical *ballast cleaning* machines, which remove accumulated dirt and broken ballast and top up with new ballast.

4. *Rail grinding* is extensively used in Australia to remove corrugations and metal flow from the rail head. It has also been extended to modify and maintain the profile of the rail head, particularly on heavily-trafficked lines.

5. *Miscellaneous track maintenance* includes such activities as turnout maintenance, joint maintenance, weld replacement, broken or damaged rail replacement and de-stressing track which has been deformed by use

6. *Formation maintenance* covers a mix of activities including vegetation control and maintaining drainage and ancillary facilities.

When infrastructure was maintained manually, most maintenance activities were handled by large local gangs on an as-needs basis, albeit in a rather inefficient and labour-intensive manner. With the introduction of mechanised maintenance, local gangs were considerably reduced in size and mobile gangs operating high-production and specialised maintenance and renewal equipment undertook most of the major maintenance work.

When mechanised maintenance was first introduced, track inspection technology was insufficiently advanced to allow condition-based track maintenance programs to be developed. Time-based systems were still used and the in-built allowances to minimise the risk of unacceptable asset deterioration invariably led to unnecessary work being carried out. However, regular and comprehensive inspection of the infrastructure is increasingly providing data that can support a condition-based approach. Although most Australian (and overseas) systems make some use of this data, few have developed their maintenance management philosophy to the stage where they have converted to this more cost-effective approach and instead retain the less sophisticated, but more costly, time-based cyclical programs.

Generally, items 2 to 4 above are undertaken by specialised gangs using high-production machinery, assisted by the local gang, who also prepare and tidy the sites before and after the passage of the specialised gangs. Items 1 and 6 also involve specialised gangs/equipment, particularly the more substantial work requiring earth-moving, although there is a greater involvement of the local gang in item 1. Weed-spraying is undertaken, where required, by a special train. Item 5, which includes activities such as cleaning and maintaining side-drains and culverts and repairing fences, signs, road crossings and grids, is performed largely by the local gang. The local gang thus divides its activities between miscellaneous maintenance, formation and drainage maintenance and supporting the specialised high-production gangs.

2.4 Track renewals

The renewal of track infrastructure includes the following:

1. *Track relaying*, involving the complete replacement of the track structure, is usually carried out using track-laying machines (except where relatively small lengths are involved). As it is only scheduled when both rails and sleepers need replacing, and because of the low average rail life on lower-density lines (which thus only require re-sleepering), this activity is generally restricted to the more densely-trafficked routes.

2. *Re-sleepering* involves the replacement of sleepers that are life-expired. This is generally done using dedicated re-sleepering gangs, equipped with light-weight mechanical re-sleepering equipment. Because of the comparatively long life of concrete sleepers, this activity almost always involves the replacement of life-expired timber sleepers with either

concrete (on the main lines) or other timber sleepers. Where individual sleepers are life-expired or damaged, 'spot re-sleepering' usually is done by the local gang.

3. *Re-railing* is carried out where the rail needs replacing but the sleepers still have reasonable life. This usually occurs on sharp curves where rails might be replaced altogether or transposed or, alternatively, where concrete and steel sleepers (which both have comparatively long lives) are installed. The local gang performs this work unless long lengths of rail have to be replaced, when specialised machinery is used.

In Australia, track renewal expenditure is variously charged to either the capital or operating account, or a mixture of both, depending on local practice[1]. Typically, complete relaying of the track and major sleeper renewal programs are financed from the capital budget, while all other 'maintenance' activities are expensed, but this can vary from railway to railway and from year to year. This often leads to considerable difficulties in assessing the true volume of track maintenance expenditure. This expenditure also occurs at relatively infrequent intervals on any one section of line. Although aggregate expenditure may be relatively stable for a large system, as there will generally be some section being re-laid, it will be much lumpier on a small system (or a defined sub-system), particularly one which has a large proportion of concrete sleepers.

2.5 Variation of track maintenance and renewal with usage

A range of factors, influences the frequency with which these activities are undertaken:

- maximum line speed
- volume and mix of traffic
- elapsed time
- standard of initial construction
- climate; and
- curvature

Table 2.1 summarises the main factors influencing each of the components identified in the previous section. Volume and/or line speed (which are both traffic-related) affect all components with the exception of formation maintenance, although the relationship is often non-linear. The life of concrete sleepers, for example, is about 25% variable with tonnage, for a traffic volume of about 10 MGT per annum.

Table 2.1 also gives the approximate composition of total maintenance and renewal costs for two contrasting sections of track:

- a medium-density secondary line (with timber sleepers and jointed track on poor formation) carrying 2 MGT p.a.; and
- a medium-volume coal line (with concrete sleepers and CWR track on good formation) carrying 20 MGT p.a.

[1] In Queensland, replacement is charged to capital if the asset is upgraded as a result of the replacement e.g. if rail is upgraded from 54 kg/m to 60 kg/m or if timber sleepers are replaced by concrete.

Table 2.1 Main factors affecting track maintenance and renewal

	Line speed	Volume	Elapsed Time	Standard of constr.	Climate	Curvature	% of cost 2MGT timber	% of cost 20MGT concrete
Visual inspection	✓	✓					1	1
Other inspection		✓					0	1
Resurfacing	✓	✓		✓			11	8
Ballast cleaning		✓	✓	✓	✓		9	12
Rail grinding		✓				✓	0	3
Miscellaneous maintenance	✓	✓	✓	✓		✓	23	24
Formation maintenance			✓	✓	✓		12	11
Resleepering	✓	✓	✓		✓	✓	41	20
Rail renewal	✓	✓					3	20
Total							**100**	**100**

The higher-volume line costs more per kilometre, but only by about 15%, and its cost per gross tonne-km is thus only about 11% of that of the secondary line. Some of the benefit in performance is due to economies arising from the use of concrete sleepers and CWR rail on the coal line, and from the assumed improvement in formation, but, even if the two lines had the same specification, maintenance costs for the coal line, per unit of cargo carried, would be considerably lower than those for the secondary line.

Typically, track-related expenditure, for a track of any given quality, consists of three main elements:

- a constant component which is associated with environmentally- and safety-related tasks such as drainage, vegetation control and periodic patrolling;
- a component which partially varies with volume but which is also a function of elapsed time, which includes tamping and ballast and sleeper renewal; and
- a component that largely is directly variable with tonnage, of which the most important element is rail renewal.

The constant component includes an element, associated with inspections and other preventative maintenance, which does not alter for small changes in use. However, a large change in use will often trigger a new preventative maintenance regime that then does not alter until a further quantum step in use occurs.

The overall percentage of cost that is variable varies by track standard and by traffic volume. Low-volume lines experience proportionately little change in total cost even if volume doubles, as the fixed costs will dominate variable costs. Lines with heavy tonnages, however, (say 50 million gross tonnes per year and above) will have a very high proportion of variable cost, and particularly renewals costs, which will be largely driven by usage, and for such lines, the variability will be close to 100%. Nevertheless, the incremental cost per additional tonne may well be higher in absolute terms for the lower volume lines. For lines of similar tonnage, the incremental cost will generally also be greater the higher the track quality, although this is a function of the standard of initial construction.

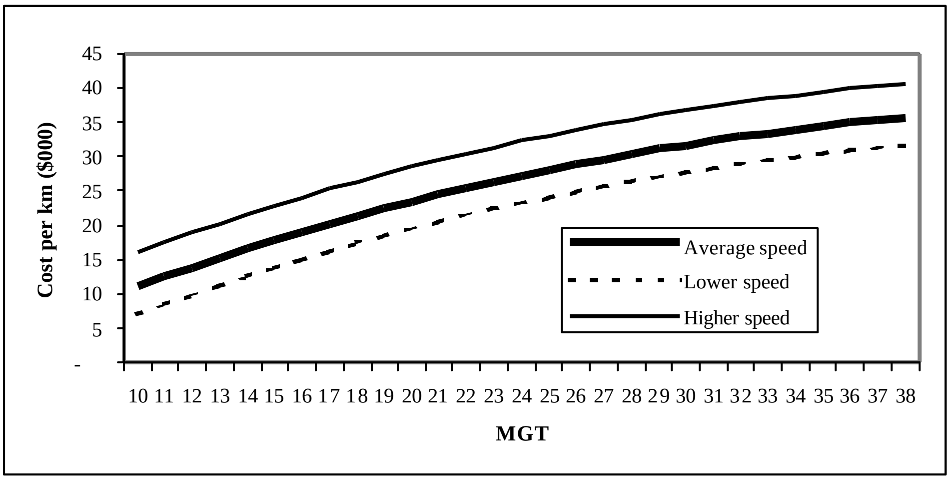
Table 2.2 shows the track elements that are affected, at least to some extent, by usage.

Table 2.2 Track costs variable with usage

Item	Description
Track geometry	Deterioration of vertical geometry is primarily due to differential ballast settlement under loading; this requires tamping to correct it. The amount of maintenance will depend on the rate of deterioration, the standard required (line speed) and the effectiveness of maintenance.
Rail	One of the major causes of rail fatigue is loading (and cumulative loading); Maintenance is required to manage defects; cumulative loading will determine renewal. Rail wear, which takes place on the rail head and on the side of rail in curves, is also a direct function of usage.
Sleepers	Affected by impact loads and (for concrete sleepers) abrasion due to contact with ballast.
Ballast	Accumulation of fine material generated from usage (including the maintenance process itself, such as tamping).
Switches & crossings	Subject to the same damage mechanisms as plain line track.
Maintenance	Inspection rates vary if total traffic passes threshold levels. Some minor maintenance activities, such as changing rail pads, are also usage-dependent.

These components are also functions of track quality: for example, a higher-quality track will generally require a greater frequency of tamping. In practice, as illustrated in Figure 2.1, track maintenance costs as a function of volume can be represented by a series of parallel lines, each line representing a different track standard, over a given range of volume.

Figure 2.1 Effect of track speed/quality on maintenance costs



In general, the marginal cost associated with the use of track infrastructure is much less than the average cost and cost allocation procedures can thus deal definitively only with the proportion of costs that is variable with usage (generally in the range 20-50%). The remaining costs are common to all users and can only be allocated on a more general basis.

2.6 Structures

Although a number of structures are not affected by usage, including tunnels, embankments and overbridges, usage-related costs may be significant for some underbridges, particularly cast iron, timber and some masonry structures. Age, corrosion and environmental factors are significant drivers of degradation for these structures, but their maintenance requirements are also influenced by increases in axle loads (where relevant) as well as the frequency with which a load is applied.

Cast iron structures may be beyond their design lives but still serviceable at existing traffic levels; additional activity, particularly with heavy axle loads, may require substantial remedial or strengthening works. Although masonry structures were originally designed with considerable redundancy, increasing the frequency of loading sometimes causes component failure and/or the imposition of axle load and speed limits. Timber bridges can also be subject to significant usage-related maintenance costs.

2.7 Signalling

Signalling maintenance essentially consists of the periodic inspection and servicing of components, largely a function of elapsed time, and the 'rapid response' servicing of faults, such as signal failures, that directly affect operations. The degradation of many signal components is primarily driven by chemical and physical ageing and these, particularly electronic items such as relays, are generally inspected and renewed on a time-based maintenance schedule. Some track-based equipment, such as track circuits for train detection and shunt signals near ground level, is subject to many of the same sources of degradation as track components and their maintenance costs therefore may partly vary with usage. A few minor equipment failures are also a function of usage (e.g. signal filament wires ageing due to continued usage).

Signalling renewals are generally driven by technological obsolescence, the need for significant layout changes or capacity enhancements, serious structural defects or large scale degradation, for example of wires and cables, rather than usage.

2.8 Electrification

The maintenance and renewal of electrical infrastructure that is in physical contact with the train, the overhead contact wire in the case of the Queensland 25 KV AC system, has a significant usage-based component. The same holds true, but to a lesser extent, for the catenary and the connections between it and the contact wire. Other electrical equipment such as substations, feeder cables and supporting structures is less affected by variations in traffic level.

2.9 Train control and signalling operations

Historically, signalling operations were undertaken by individual signalmen, located either at stations or purpose-built signal boxes, who were responsible for controlling a specific section of track. Section lengths were a function of traffic volume but could not be altered without significant capital works. There was some room for varying short-term manning levels by amalgamating sections when volumes were low but, in general, signalling costs were relatively fixed.

With the introduction of CTC (Centralised Train Control), train control costs were significantly reduced but remained relatively fixed, with one controller responsible for a specific 'board' covering a given stretch of line. There is some scope for boards to be amalgamated during periods with lighter traffic but this is not done on an ad hoc basis throughout the day. Overall, these costs can be attributed reasonably straightforwardly on a geographic basis but historically have been 'sticky' in terms of reacting to traffic volume, requiring significant changes before operating costs were affected.

Classic CTC is now being increasingly replaced by UTC (Universal Train Control). This is a development of CTC in which the 'boards' are controlled by software and thus can easily be redefined to reflect changes in activity. This allows a much greater tailoring of train control resources to workload on a relatively short-term basis and enables train control costs to be more closely related to traffic volume.

3. SUMMARY OF RESEARCH INTO VARIABLE TRACK USAGE COSTS

3.1 Introduction

Although track maintenance requirements are a complex function of both elapsed time and traffic-related parameters, a number of studies in a range of countries have related the maintenance effort to the infrastructure type and traffic characteristics.

Considerable work has been undertaken by railway authorities throughout the world on the relationship between infrastructure maintenance costs and the variables summarised in the previous section. The work includes:

- models of cost attribution and allocation, of which the best-known is probably Uniform Rail Costing System (URCS), developed by the Interstate Commerce Commission (ICC); such models combine historical experience, engineering assessments and econometric analysis.
- engineering-based analysis of asset degradation, such as the ORE work in Europe as well as the engineering work undertaken by AREA in the US and various railways in Australia and other countries;

This chapter briefly reviews this work. It first discusses the work undertaken outside Australia, concentrating on work in the US and, more recently, in UK. It then discusses cost variability in Australia, based on work done at the time the National Rail Corporation (NRC) was established

3.2 Overseas studies

US rail engineers have been developing cost variability for over a century[2]. The Interstate Commerce Commission (ICC) used in its regulatory work a large amount of econometric analysis of relationships between railway costs and usage in its regulatory work. The origins of this work lay in a desire to control the widespread price discrimination that was practised by the rail industry at that time. Accordingly, it developed standard costing systems (known for several years as Rail Form A, replaced in 1980/1 by the Uniform Railroad Costing System (URCS)) against which rate changes proposed by the railways were assessed. Guided by the Transportation Act of 1940[3], the main emphasis of the ICC was probably as much on preventing rate decreases (which it saw as the possible prelude to ‘destructive competition’) as on controlling rate increases and it thus placed great emphasis on ensuring proposed rates covered costs. Its costing methodology thus tended towards long-term variable costs that implicitly included (in the case of track) the impact of quality and capacity changes in response to volume changes.

The cost relationships in URCS were developed by statistical analysis of the expenditure of the (then) 37 Class 1 US railways for the four years 1978 to 1981[4]. This analysis showed ‘Running Track Maintenance’[5] and ‘Track Maintenance – Overhead’ to be 55% and 58% variable respectively with gross ton-miles.

The Association of American Railroads (AAR) also undertook analyses using substantially the same data sets[6]. Their statistical analysis assumed expenditure on buildings, facilities such as wharves and power plants and on signals was effectively independent of traffic volume but

[2] The creation of the Interstate Commerce Commission (ICC) in 1887 and the introduction of mandatory financial reporting in a standard format generated a vast body of railway financial and operating statistics in the US that has proved a fertile source for railway economic analysis.

[3] This directed the ICC, inter alia, ‘to encourage the establishment and maintenance of reasonable charges for transportation services, without unjust discriminations, undue preferences or advantages, or unfair or destructive competitive practices’

[4] Uniform Railroad Costing System : 1980 Railroad Cost Study ICC 1982

[5] ‘Maintenance’ in this context includes cyclic renewals.

[6] A guide to Railroad Cost Analysis Bureau of Railway Economics AAR 1964

related the remaining 'way and structure' expenses to length of track, shunt locomotive-miles and gross ton-miles. It also developed 'engineering estimates' from professional experience. Both these approaches showed variability of about 60% for medium-high density lines (20 MGT). However, the commentary to the analysis included a number of caveats that continue to apply some 30 years later:

- the difficulty of establishing the traffic volume associated with the work carried out in any one year because of the cyclical nature of much of the work undertaken

- the impact of constrained budgets on the maintenance of way, which is generally the first item to be deferred when there is a shortage of funds. These deferred works will then be undertaken when traffic recovers. Simply relating annual expenditure to the traffic volume in that year thus over-emphasises the purely physical impact of traffic volume on track maintenance

- while statistical procedures can be helpful in understanding the behaviour of infrastructure maintenance expenses, they must be applied with an understanding of the inherent deficiencies of the input data and the validity of the results should be tested by logic and engineering judgement based on experience.

Both the URCS and the AAR work were based on the cross-sectional analyses of railways of different sizes and densities and thus implicitly include the longer-term effects of traffic volume on the quantity and capacity of infrastructure. The results should be used with caution, as they will overestimate the variability of the cost of maintaining a fixed quantity of infrastructure as volume changes.

Another set of data is included in the AREMA[7] Manual for Railway Engineering, which provides a series of factors (Attachment 1) relating track maintenance costs to changes in tonnage, speed and construction materials used. These were last reviewed in 1994 and thus are more up-to-date than the ICC/URCS analyses, although they naturally reflect North American freight track characteristics, traffic loading and track maintenance practices. Many of the 'standards' quoted reflect the views of the Federal Railway Administration (FRA), the legislative authority for these matters in USA. The factors are based on a substantial body of field research and controlled trials and show a variability with tonnage of between 30 and 40%, all other things being equal, more or less independently of track standard. The cost increase if passenger train speed increases from 100 to 150 km/hr is estimated at 30%, equivalent to a variability of 60%. Increasing axle loads from 20 tonnes to 25 tonnes on track with a maximum speed of 150 km/hr is estimated to increase maintenance costs by just over 10%. This is equivalent to a variability of 50%; variability for lower speed tracks is lower at around 35%.

In addition to these published sources, there have been many internal analyses by or for individual railways, either using engineering estimates or statistical analyses of past expenditure. These almost all produce results which consistently show track variability in the 30-60% range e.g. the Canadian Transport Commission[8] estimates 55% of track maintenance expenses are variable with gross ton-miles, with the remainder invariant with traffic. Other studies in Australia have found variability of 30-40%.

Infrastructure cost research on Russian and Chinese railways shows a high variability with tonnage. However, the average densities on these systems are so large (the average density on the Russian system was 40 MGT pa in 1989 and even today is over 25 MGT pa) that they are towards the high end of the cost curve, where the fixed costs of maintenance are a small proportion of the total cost. One interesting feature of the Russian system is that the allocation

[7] American Railway Engineering and Maintenance-of-Way Association
[8] Railway Costing: A Review 1984

of costs between passengers and freight for reporting purposes (but shortly to be also for access pricing as well) discounts passenger tonnage by 20%, presumably to reflect the generally lower axle loads (typically about 12-15 tonnes) and less damaging bogie characteristics of passenger vehicles.

A significant body of research into track behaviour and costs was undertaken by the ORE (Office for Research and Experiments) of the UIC during the 1980's, building on previous work undertaken by various European railways. This work, amongst other things, related track maintenance costs to track condition, speed, axle load and volume and showed[9] track costs vary at approximately 60-65% of the rate of change in both speed and axle load. The rate of change was also sensitive to track condition, with the increase generally being greater the poorer the quality of the track.

The current review of Railtrack by the UK Rail Regulator has investigated the variation of usage costs by vehicle type as part of its work in determining variable access charges, using results for a range of different vehicles using a detailed model of track forces. The most recent published report includes the following relationship:

$$\text{Cost} = \alpha.\ F\ (\text{tonne/axle})^{\beta 1}.\ (\text{speed})^{\beta 2}$$

where α is a constant, the β parameters are given by

$$\beta_1 = 0.43$$
$$\beta_2 = 0.52$$

and F, a vehicle-type specific factor that allows for the differing effect of various types of bogies, is given by:

F = 1.08 for freight locomotives
1.11 for passenger locomotives
0.84 for passenger multiple-units and loco-hauled passenger vehicles
1.10 for 2-axle freight vehicles
1.0 for 4-axle freight vehicles
1.10 for loaded coal and mineral hoppers (to reflect the role of spillage in contaminating ballast)

The same document gives estimates (Table 3.1) for the variability of different types of infrastructure; these are for a network with an average density of about 5 MGT (but about 10 MGT for the AC electrified network).

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Table 3.1: Variability by asset type (ORR)

	% variability
Track	
Maintenance	30
Renewals	
Rail	95
Sleepers	25
Ballast	30
Switches & crossings	80
Structures	10
Signals	
Maintenance	5
Renewals	0
AC Electrification	
Maintenance	10
Renewals	35

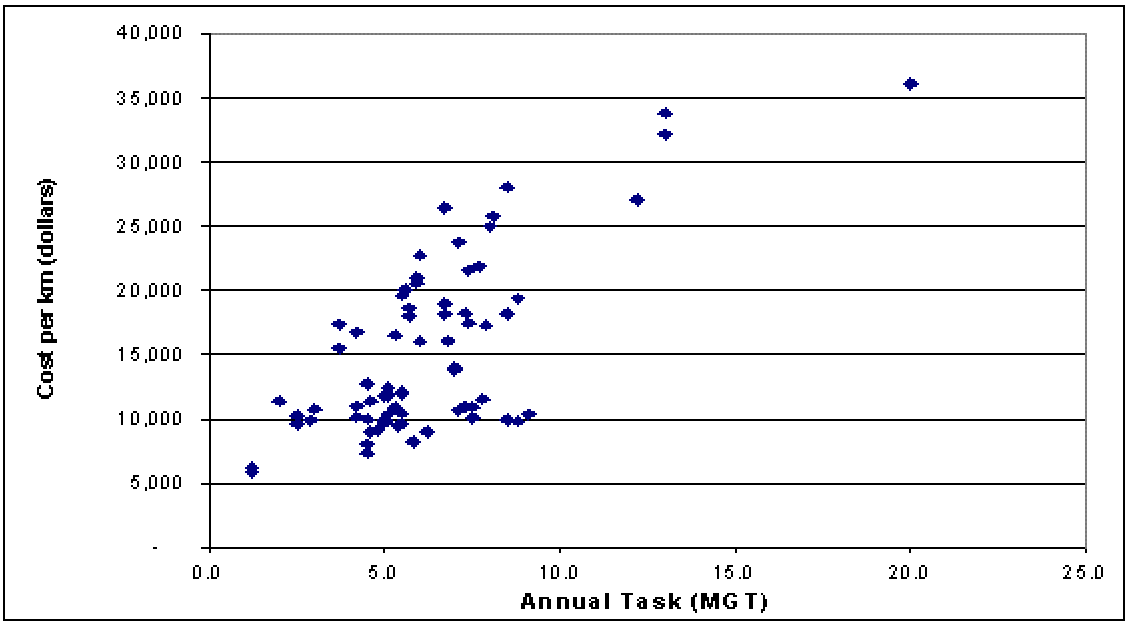
In summary, the results of cost research on other railways demonstrate a uniform pattern, with the variability with volume of track-related expenditure being typically in the range 30-60% (with the higher variabilities associated with higher tonnages) and with significant relationships between axle load and speed and maintenance activity. Little published research has been undertaken anywhere on the variability of structures costs with traffic (although they are often included by default in the US analyses). The maintenance and renewal costs of fixed signal infrastructure are generally assumed to be constant and electrification-related costs are rarely addressed, other than in the recent ORR work.

3.3 Australian estimates of variability

There has been comparatively little published on the overall variability of track costs with tonnage, although there is a large quantity of literature dealing with detailed studies of a technical nature. A study of track costs in Victoria in the 1980's claimed a variability of about 30% with tonnage based on cross-sectional analysis and a detailed study of infrastructure maintenance costs on the interstate rail network was undertaken for National Rail in 1994. This estimated the maintenance costs of each line section assuming 'efficient' maintenance policies and work practices, taking into account the physical characteristics and tonnage passing over each line section (Figure 3.1).

The interstate network has a range of different types of infrastructure and tonnage but can be characterised as 110 km/hr track carrying 21 tonne axle loads, with a mixture of timber and concrete sleepers, and with tonnages generally below 10 million gross tonnes per year. It is similar to parts of the QR North Coast line but generally is not directly comparable to the heavier-tonnage Blackwater and Goonyella systems.

Figure 3.1, Track and Structures Maintenance Cost - Interstate Mainline Network



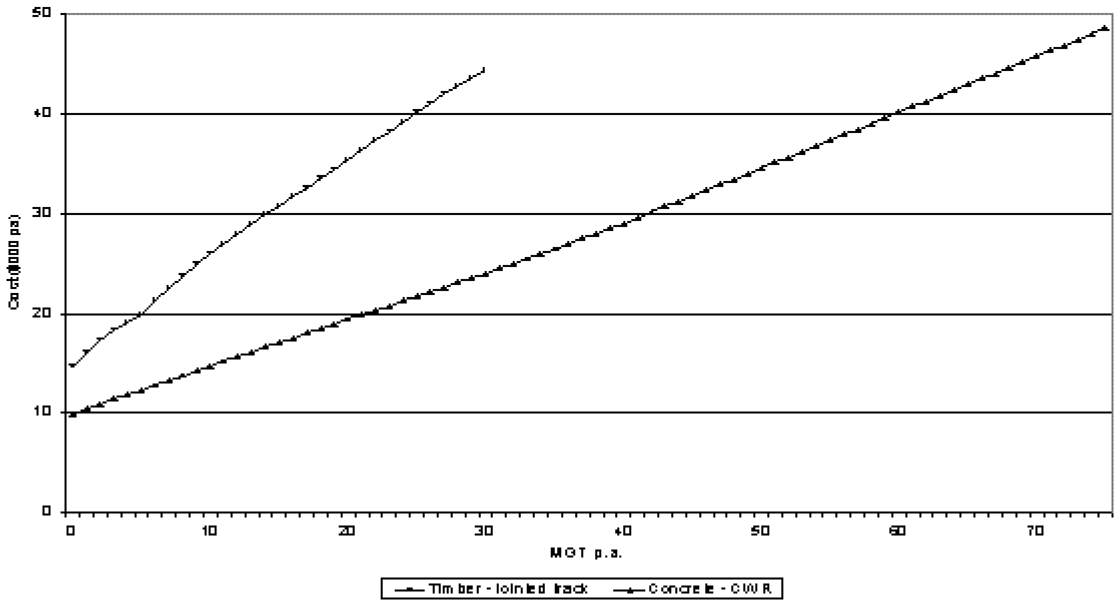
Source: Standard Costs Symonds Travers Morgan 1995

The figure shows a clear relationship in which costs steadily increase with tonnage but at a steadily decreasing rate. However, it is also clear that there is also a wide variation at any given tonnage level reflecting the different physical characteristics of the infrastructure.

The influence of tonnage alone is demonstrated in Figure 3.2, in which life-cycle costs are estimated for a range of tonnages under Queensland climatic conditions; this is done for two sections of track at opposite ends of the track quality spectrum:

- 47 kg jointed track on timber sleepers, on poor formation
- 60 kg CWR track on concrete sleepers, on good formation

Figure 3.2 Indicative variation of track life-cycle costs with tonnage



Both types of track have cost curves that can consist of a constant component plus a component that broadly varies with tonnage. As tonnage increases, the costs are increasingly dominated by the renewal of track components (rail, sleepers and ballast) and after about 40 MGT, these costs are largely driven by tonnage. However, the poorer-quality timber track is consistently over 50% more expensive than the higher-quality track[10], and the variation would be even more marked if the concrete track had been assumed to be in a dry area. This difference, with timber track carrying 5 MGT costing about the same as concrete track carrying 20 MGT, explains the variation in costs for line sections carrying similar tonnages seen in Figure 3.1.

Figure 3.3 shows, for the concrete track in Figure 3.2, the variation in total cost, average cost and marginal cost as tonnage increases. The marginal cost fluctuates as tonnage increases; initially it reduces as the marginal cost of activities such as tamping decrease but then it increases as tonnage rather than elapsed time becomes the dominant driver for sleeper and ballast replacement.

[10] At low tonnages, around 50% of the cost of the timber track is caused by the need to replace life-expired timber sleepers (assumed to have a life of only 16 years in the subtropical climate); this would be significantly reduced in a drier area.

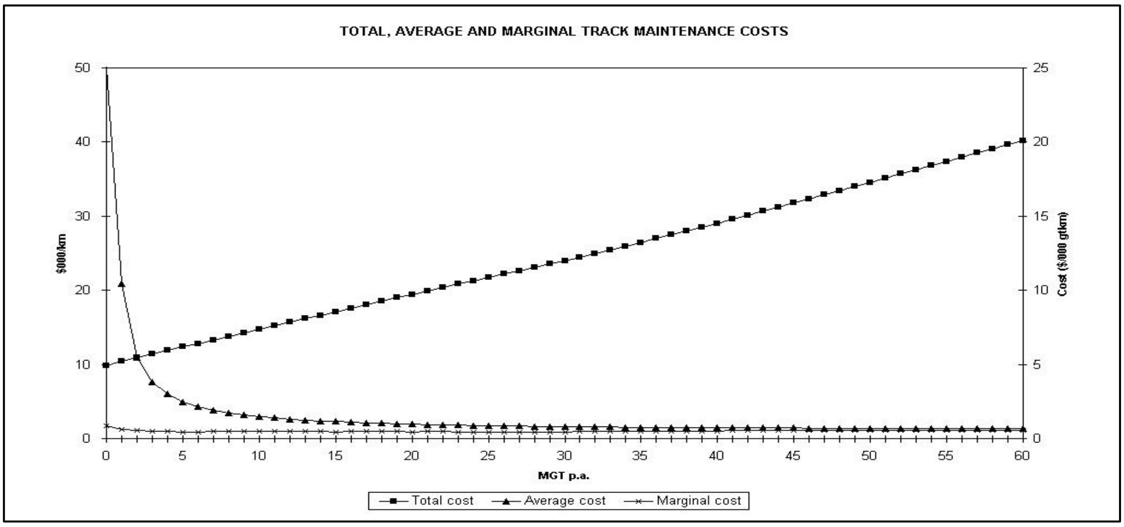


Figure 3.3 Average, marginal and total cost variation with tonnage (concrete)

The variability of track maintenance cost (defined as the ratio between marginal and average cost) is used extensively as a short-cut method for calculating the marginal cost of additional traffic. Figure 3.4 shows the variabilities for the two types of track in Figure 3.2.

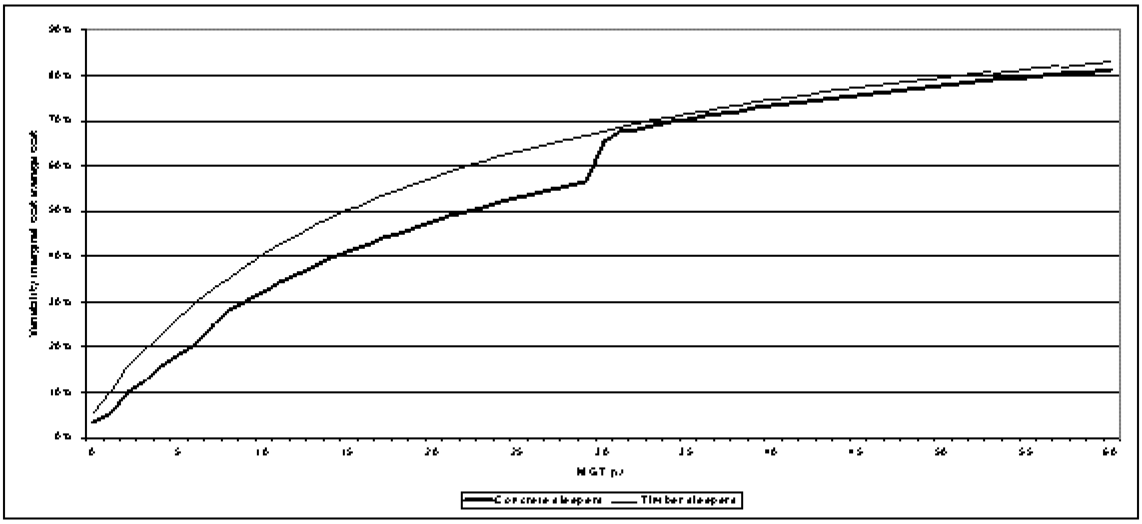


Figure 3.4 Variability of track life-cycle maintenance cost

Timber track is significantly more variable at low tonnages, partly because timber sleepers are more sensitive to tonnage than concrete sleepers, partly because the assumed poorer formation increases the volume of tamping (which is partly volume-driven) and partly because jointed track is more tonnage-sensitive than CWR.

At low tonnages, only a small part of the maintenance cost is variable but this increases to around 20% at 5 MGT and 30% at 10 MGT for concrete and about 10% more for timber. By 20 MGT, the variabilities have increased to about 45% and 55% respectively and they then increase steadily, until they are over 80% at 60 MGT, as asset renewal becomes increasingly tonnage-based. The kink in the variability of concrete-sleepered track at 30 MGT is caused by concrete sleeper renewal ceasing to be driven by elapsed time (with an assumed maximum life of 40 years) with tonnage instead becoming the driver for replacement[11]. A smaller kink at about 8 MGT is where ballast cleaning similarly starts to become affected by tonnage; this

[11] Allowing concrete sleepers at low tonnages to have lives greater than 40 years would smooth the kink and increase the variabilities for tonnages less than 30 MGT.

happens at a much lower tonnage for the timber-sleepered track because of the assumed poorer formation.

4. INCREMENTAL RAIL INFRASTRUCTURE MAINTENANCE COSTS IN QUEENSLAND - A COMPARATIVE STUDY

4.1 Introduction

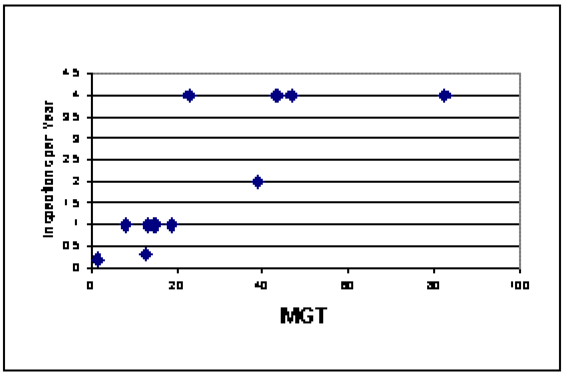
The previous chapter provided an overview of evidence from outside Queensland of the variability of infrastructure maintenance costs with usage. This chapter supplements these conclusions by analysing QR's own costs and comparing the observed regional variation with that predicted by the results discussed in the previous section.

The first section discusses some of the QR maintenance guidelines, demonstrating that, consistent with the general patterns described in the earlier chapters, they are generally increasing functions of tonnage but with significant variations caused by track quality requirements. The second section analyses the QR regional maintenance budgets for 1999/2000, showing that they follow a similar pattern to those for the interstate mainline network shown in Figure 3.1. The final section explains the differences between the regional costs by applying the AREMA adjustment factors documented in Attachment 1, thus enabling the separate effects of tonnage and track quality to be identified.

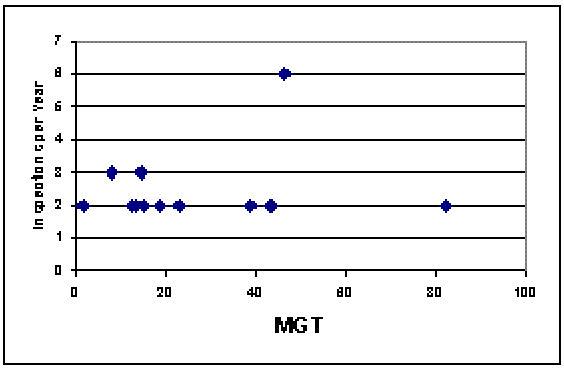
Given the high degree of correlation of variability between the costs that have been observed elsewhere, derived variability from much larger populations of data (AREMA) and QR's costs, the cost variability observed in QR's data and the conclusions reached are applicable across the likely variations evident in the coal systems. The range of variation in axle load between 20 tonnes and 26 tonnes as well as the increase in tonnage estimated over the next 5 years are well within the limitations of this correlation and therefore make these conclusions applicable to the regulatory period in question.

4.2 Maintenance effort as a function of volume

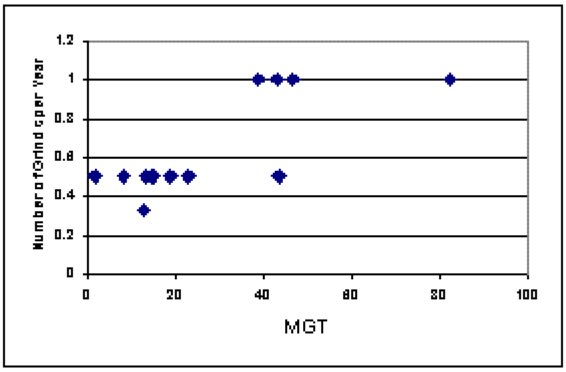
The Network Access Group, as asset manager, provides the Infrastructure Services Group with guidelines for the frequency of inspection and maintenance work to be performed on the various sections of track on the QR network (Figure 4.1). These guidelines have been developed over years of experience with the particular tracks involved, taking into account the track structure, the risk of disruption to services and 'good' engineering and safety practice.



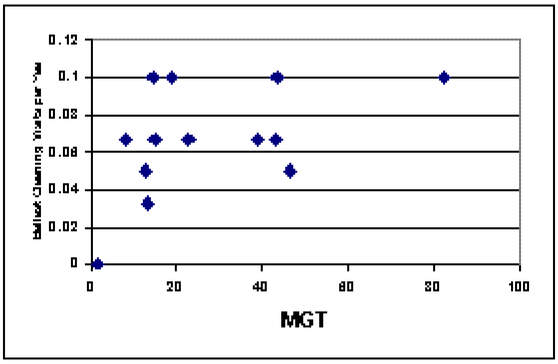
Ultrasonic Rail Testing



Track recording



Rail Grinding



Ballast Cleaning

Figure 4.1 Frequency of maintenance procedures on selected sections of QR network

Figure 4.1 shows typical inspection and maintenance frequencies, as a function of tonnage, for selected sections of the QR network. They cover four of the activities described in general terms in Section 2.3:

- Ultrasonic Rail Testing monitors the current condition of the rail
- Track Recording monitors track geometry. It measures the deviations from design of its horizontal and vertical alignment and is thus a major input to the programming of major maintenance. Its frequency reflects the track structure, the track quality required (which is a function of intended use) and the rate of deterioration of the geometry over time.
- Rail grinding maintains the wheel-rail interface to reduce wheel impact and wear through wheel tracking. The rail surface condition and the associated maintenance effort are normally closely correlated with train tonnage, axle load and speed.
- Ballast deteriorates with traffic through a range of mechanisms. Crushing by the sleepers, the operation of tamping machines and coal contamination all generate fine particles that trap water and lubricate the ballast, causing instability of the track structure. The load from passing traffic also slowly breaks down the sub-grade, causing fine clay particles to infiltrate the ballast. Ballast cleaning is designed to remove these particles and thus return the track structure to its original standard.

The frequencies of these activities, which are all broad indicator of the overall quantity of maintenance work required, all show broad increases as tonnage increases. However, they also demonstrate the variability, caused by track structures and traffic use, in the work required for different line sections carrying the same overall tonnage. In particular, the impact of high-speed passenger services on the North Coast line south of Rockhampton (with an average annual tonnage of 45 million MGT) can be clearly seen in the sharply increased track recording frequency required to monitor track condition.

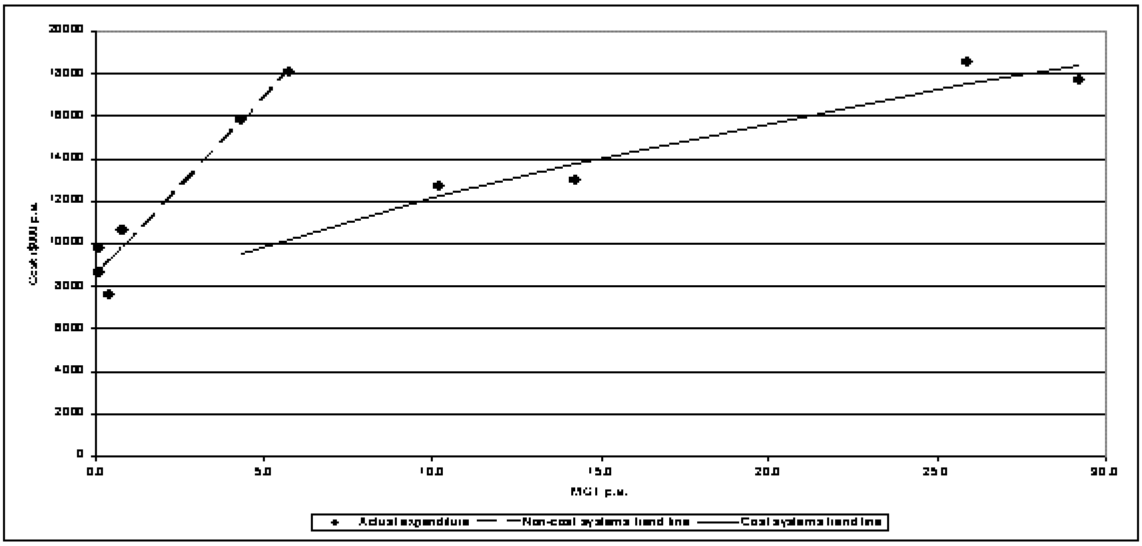
4.3 QR Infrastructure Maintenance Costs

Analysis at a more aggregate level has been based on a comparison of the track maintenance cost for 1998/1999 for the different regions of the QR network, taking into account their varying tonnages. Annual data needs to be used with some caution, as this type of cross-sectional analysis implicitly assumes that it is sufficiently representative of the medium and long-term maintenance activities, consistent with a logical long-term logical strategy. In practice, the more annual data is disaggregated, the greater the risk of encountering distortions caused by short term increases and decreases in major maintenance activity as well as maintenance 'holidays' associated with major upgrading and expenditure on the track in the recent past[12].

The costs were derived from the 1998/1999 management accounts (Figure 4.2). They exclude regional costs and corporate overheads, but inclusion of these costs would increase the absolute level of expenditure by broadly the same proportion for each region.

The maintenance costs of the coal systems, which are typically concrete-sleepered track, are clearly of a different nature to those of the remainder of the remainder of the system and separate average cost curves have been fitted to these two groups, assuming that average tonnage is the only variable that influences costs. The non-coal systems line is a linear trend, which assumes a fixed cost and a constant increment per unit of additional tonnage; that for the coal systems is a non-linear trend that allows for the incremental tonnage to be at varying (in this case, reducing) incremental costs. Individual rail corridors and line sections, particularly for low tonnages, vary significantly from both trend curves because of varying physical characteristics and track quality requirements; the reasons for this are discussed in the following section. In general, the curves have the same shape and order of magnitude as that for interstate main lines.[13]

Figure 4.2 Infrastructure Working Expense by region QR 1999/2000



[12] These often bring the track up to such a good standard that the maintenance costs in the years immediately following are artificially low in comparison with other 'fit for purposes' maintenance practices.

[13] Note, however, they are comparable in detail as the QR data covers signals, structures and facilties, but does not include regional and system-wide overheads. There are also differences in the classification of major maintenance into capital and working expenditure.

Table 4.1 gives the average and incremental maintenance costs for different tonnages, derived from the slopes of the curves in Figure 4.2. Thus, at an average tonnage task of 10 MGT, for which the total cost is around $20,000/km, the incremental maintenance cost per 000 gtk is approximately $1.00. As the tonnage increases, total cost increases to about $40,000 at 30 MGT, with an incremental cost in the non-linear model of about $0.70/000 gtk. Variability naturally depends on the shape of the assumed trend, particularly at the higher tonnages. At low tonnages, variability is estimated at 15-20%, increasing to about 50% at 10 MGT. At 30 MGT, the linear model estimates a variability of 74%, compared to 55% for the non-linear model.

Table 4.1 Incremental maintenance cost(1) – QR all regions

MGT	Non-coal model				Coal model			
pa	Total cost ($000/km)	Av. cost ($/000gtk)	Incr. cost ($/000 gtk)	Variability (%)	Total cost ($000/km)	Av. cost ($/000 gtk)	Incr. cost ($/000 gtk)	Variability (%)
0	8.7	87.21	1.67	2				
1	10.2	10.23	1.67	16				
2	11.9	5.95	1.67	28				
5	16.9	3.38	1.67	49	9.8	1.97	0.50	25
10	25.3	2.53	1.67	66	12.1	1.21	0.42	35
15					14.1	0.94	0.36	39
20					15.8	0.79	0.32	40
25					17.3	069	0.28	41
30					18.6	0.62	0.25	40

(1) Excluding communications and electrical infrastructure

The patter and further adjusted for ballast contamination by 1.10 to 49.5%. n is broadly consistent with those developed from other sources. There is a minimum level of maintenance required with steady increases the in total maintenance cost per kilometre of track as the tonnage increases.

The percentage of overall maintenance cost that is variable with tonnage (i.e. the ratio of incremental cost to average cost) increases with tonnage. This reflects the relatively fixed cost structure at low tonnages, where there is very little wear and renewal, and the relatively variable cost structure at high tonnages where the majority of maintenance is concerned with the replacement of worn out components. However, even after disaggregation into two groups, the apparent variation in maintenance cost with tonnage also includes the effect of differences in the standard and quality of construction of the different track sections as well as the effects of changes in tonnage per se.

4.4 Reasons for QR's cost variability

The previous section demonstrated the relationship between below rail costs and traffic volume for QR's rail network broadly conforms to the domestic and international experience of maintenance costs per kilometre of track increasing, but at a decreasing rate, as tonnage increases. In practice, this relationship is complicated by the interaction between track quality and tonnage; generally, the heavier-used lines are constructed to higher standards and the variation in costs that is shown by cross-sectional analyses is therefore due not only to the change in tonnage but also because of the change in standard and quality of construction.

The interaction between these factors in the case of Queensland can be demonstrated using the AREMA factors discussed in Chapter 3 (and given in detail in Attachment 1). These provide a method for determining the relativity of track maintenance costs for a range of operating conditions and infrastructure types. Factors are provided for various types of infrastructure (e.g. rail weight and sleeper type) and for a range of operating speeds and tonnages.

These factors have been applied to the QR maintenance cost data at a regional level. As the AREMA parameters are designed for North American conditions, many of their minimum values (axle-load, rail-weight etc) are well above those on the lower-density sections of the QR network; in these cases parameter values have been obtained by extrapolation. Table 4.2 gives the physical characteristics assumed for each region. The speed is the maximum freight train speed; the North Coast line has been adjusted upwards to allow for the maximum speed of the tilt train

Table 4.2 Track characteristics used in AREMA analysis

	Km		Gtk	MGT	Speed	Sleeper	Ballast	Rail	Curva-	Axle	# unit
	Route	Track	(bn)	p.a.	km/h	Type	quality	weight	ture	load	trains
NC branches	772	772	67	0.1	40	Timber	Poor	40	Medium	16	0
Northern	660	660	58	0.1	40	Steel	V poor	40	Medium	16	0
Central West	1333	1333	511	0.4	60	Timber	Poor	40	Slight	16	0
South West	2188	2240	1765	0.8	80	Timber	Fair	47	Slight	19	1
Mt. Isa	1040	1040	4473	4.3	80	Steel	Fair	54	Slight	19	4
North Coast	1486	1509	8676	5.7	120	T/C	Fair	54	Moderate	19	0
Moura	225	225	2301	10.2	60	Concrete	Fair	54	Slight	22	10
Newlands	191	191	2724	14.3	60	Concrete	Good	54	Slight	22	12
Blackwater	504	648	16797	25.9	80	Concrete	Good	60	Slight	26	20
Goonyella	571	734	21462	29.2	80	Concrete	Good	60	Slight	26	30

Table 4.3 gives details of the AREMA factors used and the derivation of the composite factors shown in Figure 4.3

Table 4.3 AREMA Equated Mileage Parameters[(1)] by Region

	Factor									Composite factors		
	Speed	Sleeper type	CWR/jointed	Ballast	Rail	Curve	Axle load	Unit trains	Tonnage	Track	Tonnage	Total
N Coast brchs	0.56	1.15	1.00	1.30	1.20	1.10	0.88	1.00	0.37	0.97	0.37	0.36
Northern	0.56	1.15	1.00	1.30	1.20	1.10	0.88	1.00	0.37	0.97	0.37	0.36
Central West	0.80	1.30	1.00	1.08	1.19	1.00	0.88	1.00	0.37	1.17	0.37	0.43
South West	0.93	1.30	0.85	1.00	1.16	1.00	0.95	1.00	0.43	1.13	0.43	0.49
Mt. Isa	0.93	1.10	0.76	0.96	1.16	1.00	0.95	1.05	0.64	0.82	0.67	0.55
North Coast	1.18	1.15	0.80	0.98	1.20	1.05	0.95	1.00	0.68	1.28	0.68	0.87
Moura	0.80	1.00	0.76	0.93	1.05	1.00	0.98	1.10	0.77	0.58	0.85	0.49
Newlands	0.80	1.00	0.76	1.00	1.05	1.00	0.98	1.10	0.83	0.62	0.91	0.57
Blackwater	0.91	1.00	0.78	0.96	1.05	1.00	1.10	1.20	0.95	0.79	1.14	0.90
Goonyella	0.91	1.00	0.78	0.96	1.05	1.00	1.10	1.30	0.98	0.79	1.27	1.00

(1) The AREMA equated mileage parameters provide a means to establish comparability of track maintenance. They allow the user to compare the track maintenance task for sections of track that are changing in use and/or physical composition and between existing or planned track sections. The parameters establish a ratio, reflecting the factors that represent each section of track being studied. The ratio is the comparative level of maintenance required for one section of track relative to another. The relevant section of the AREMA handbook is reproduced at Attachment 3.

The factors have been calculated in absolute terms using the AREMA look-up tables given in Annex 1. For comparison, the factor for typical Australian main-line consisting of single tangent track consisting of 54 kg/m CWR and concrete sleepers on crushed rock ballast, carrying 10 MGT at a maximum speed of 80 km/hr would be 0.74.

Figure 4.3 Differential effects of tonnage and track quality on maintenance costs - QR regions

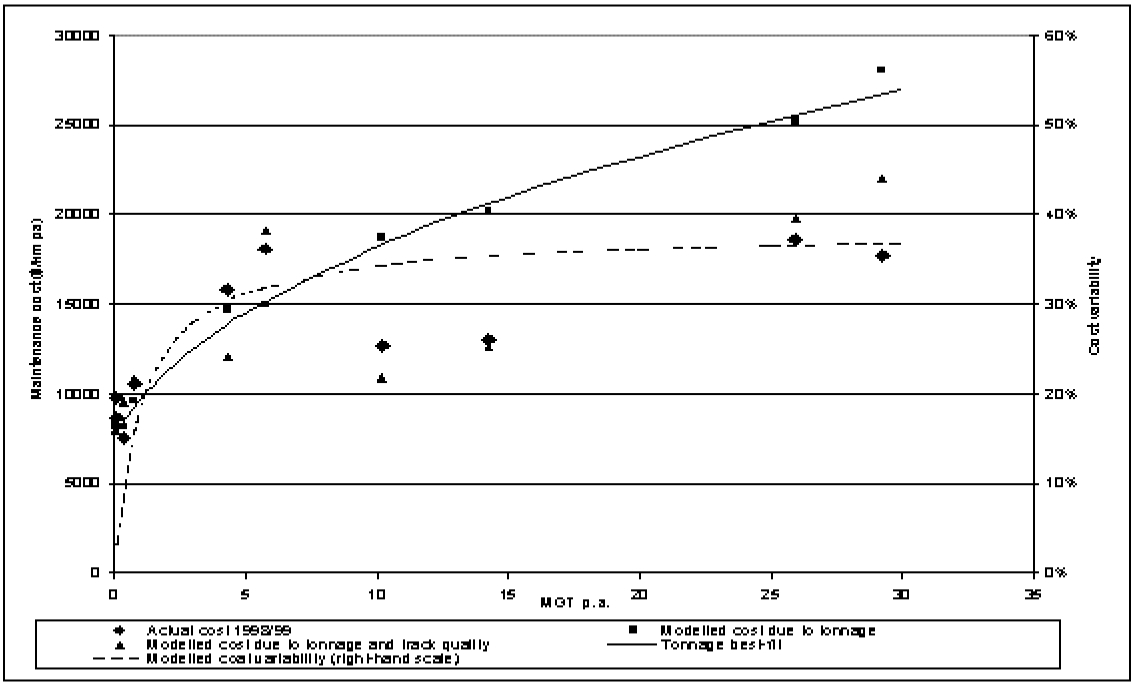


Figure 4.3 shows the cost variability for track maintenance predicted by the AREMA factors, compared with the actual direct costs for 1998-99. The tonnage trend line shows the costs predicted after applying the tonnage factors alone to an 'average' unit cost per kilometre; the modelled costs are rather higher than actuals for the coal system lines and rather lower for the North Coast line. When track standard and type of track construction is taken into account, the modelled and actual costs become much closer. Modelled costs are rather higher for the Goonyella system and rather lower for the Mt. Isa line but the general correspondence is close. At low tonnages, the cost variability is generally similar to that shown in Figure 3.4 for concrete track but flattens off rather more at tonnages over15 MGT.

An important consideration is that the expenditure included in the analysis largely excludes major track renewal (rail, sleepers and ballast cleaning), which is generally regarded within QR as capital expenditure if it has an element of upgrading. As these costs can represent up to 50% of the life-cycle costs of track, the absolute cost levels used in this analysis, which are based on working expenditure, are thus not necessarily indicative of all the long-term costs. This understatement is proportionately greater at higher tonnages and this is almost certainly a contributory factor in the actual cost recorded for Goonyella being somewhat less than the AREMA-based forecast. If these expenditures, which have an increasing level of variability with tonnage at 20 MGT + were taken into account the overall cost variability would move much closer to that demonstrated in Figure 3.4.

The maintenance plan adopted by QR, and the format that the QCA analysis will follow, does not attempt to discriminate between capitalised maintenance and recurring expenditure maintenance. The analyses in the 'case studies' section later in this document will similarly deal only with maintenance cash flows as this current analysis has done.

5. CONCLUSIONS AND APPLICATION

5.1 Introduction

This chapter summarises the findings discussed in previous chapters and proposes a set of parameters for use by QCA. It then demonstrates their application in the calculation of the incremental costs of non-cal traffic on each of the various coal systems.

5.2 Cost variability

The evidence from the QR expenditure data is consistent with the findings from other railways: at low tonnages, there is a relatively high increase in maintenance cost per kilometre for every additional tonne but this incremental cost steadily reduces as tonnage increases. At low tonnage, the percentage of the total cost that is variable with tonnage is relatively low, as there is little wear and renewal but this percentage increases at high tonnage where the majority of maintenance activity is replacement of worn out components. Table 5.1 summarises the findings from the various studies.

Table 5.1 Summary of findings on cost variability (%)

	NR concrete	NR timber	URCS	AAR	QR + AREMA	UIC	UK	Proposed
Tonnage (MGT)								
1	5	10			15			10
5	15	30			30			15
10	30	40			35			30
20	45	55	55	60	35			45
30	60	70			40			60
50	80	80						80
Speed					60	60	50	50
Axleload					50	60	45	45
Adjustment factors								
Locomotives							1.10	1.10
Passenger cars							0.85	0.85
Coal hoppers (1)							1.10	1.10

(1) Ballast contamination from spillage

The proposed variation with tonnage is based on the factors derived from the NR model; these are based on Australian conditions and input costs but are also intermediate between the factors derived in URCS/AAR and AREMA. The URCS/AAR factors almost certainly include the effects of track standard as well as the pure tonnage effect and should therefore be discounted; the AREMA data shows a constant level of variability that seems unlikely as tonnage-based asset renewal becomes increasingly important at high tonnages.

The three sets of speed and axleload factors are in reasonable agreement; the UK results are based on detailed modelling of a range of vehicle types and have been adopted, together with the vehicle type factors, as the most thoroughly researched.

The Authority has undertaken detailed analysis of the maintenance costs of the Central Queensland coal systems. Although this level of analysis has not been undertaken for QR's other systems, Table 5.1 provides a general guide for assessing incremental maintenance costs for QR's non-coal systems.

5.3 Incremental Maintenance Hypothetical Cost Case Studies

Blackwater System – Axle Load Variation

A new operator on the Blackwater system wishes to operate at an axle load of 20 tonnes rather than at the reference tariff datum of 26 tonne axle load.

The reference train has a payload of approximately 6,640 and the 'new' train plans to have the same so that extra train consists are not required and no additional train path capacity is consumed. The 'new' train will consist of 110 wagons each with a payload of 61 tonnes and a tare of 19 tonnes and 4 locomotives. This train utilises more of the available train length than does the reference train.

From Table 5.1, the variability of maintenance cost with axle load is estimated as 45% and further adjusted for ballast contamination by 1.10 to 49.5%. Therefore for a 6 tonne reduction in axle load (20/26 or 16.6%), a corresponding 8.3% (16.6% * 49.5%) reduction in maintenance cost is anticipated. By reference to Figure 5.1 the maintenance cost component of the tariff can be adjusted accordingly from $0.54 per '000 gtk to $0.495 per '000 gtk.

Goonyella system – Variation in Train Speed

As long as the train speed is neither too fast or too slow the alignment and geometry of the track structure is able to accommodate trains of varying speed. Clearly, for a train that is operating at high speed, the alignment of the track may be unsuitable and large capital works to straighten out the curves may be required. There are situations where if a train travels too slowly through curves it can impose higher than normal forces on the rails that results in higher maintenance costs. The variations in speed considered here will not attempt to deal with those macro effects.

A new operator on the Goonyella system wishes to operate at an average train speed of 50 km/hr rather than at the reference tariff datum of 60 km/hr.

From Table 5.1, the variability of maintenance cost with train speed is estimated as 50%. Therefore for a reduction in average speed of 10kmph (50/60 or 16.6%), a corresponding 8.3% (16.6% * 50%) reduction in maintenance cost is anticipated. That is, a reduction in speed from an average of 60kmph to 50kmph should decrease maintenance costs by approximately 8%. The maintenance cost component of the tariff can be adjusted accordingly from $0.37 per '000 gtk to $0.34 per'000 gtk.

Moura Line – Axle Load Increase

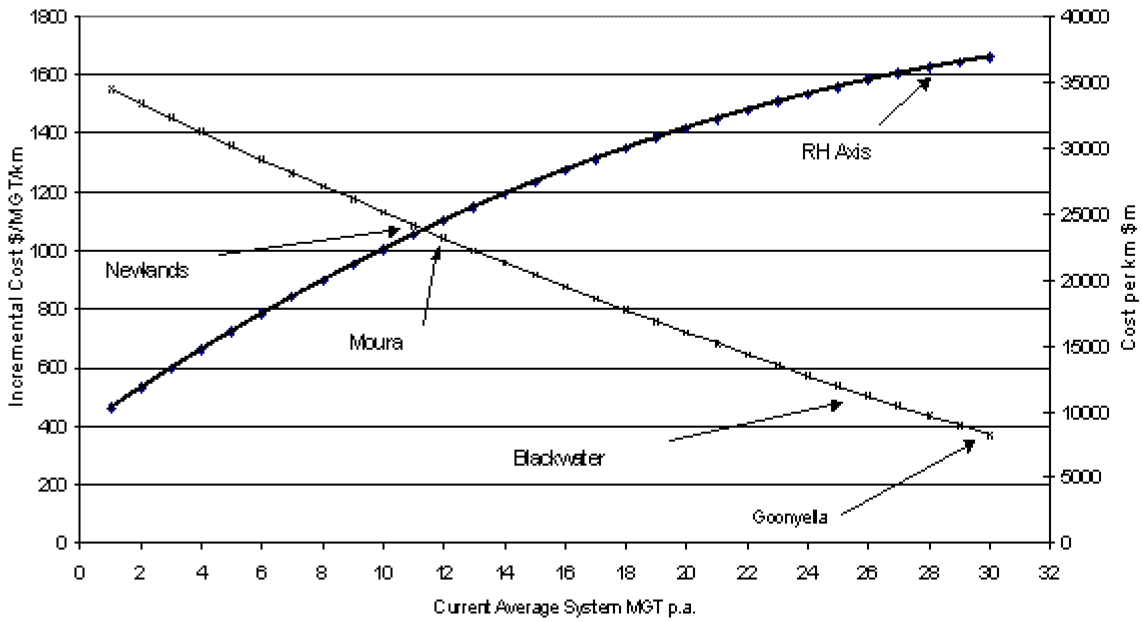
A new operator on the Moura system will provide substitutional tonnage and operate the trains at 26 tonne axle load instead of at the 22.5 tonne reference train load. No variation in capacity requirement (paths) is anticipated which means that the operator will be running smaller trains.

From Table 5.1, the variability of maintenance cost with axle load is estimated as 45% and further adjusted for ballast contamination by 1.10 to 49.5%. For the 3.5 tonne increase (15.56%) an increase in maintenance cost of 7.7% (15.6% * 49.5%) is anticipated. By reference to Figure 5.1 the maintenance cost component of the tariff can be adjusted accordingly from $1.00 per'000 gtk to $1.08 per'000 gtk.

5.4 System Incremental Cost of Maintenance

Application of the observed variation in maintenance and the theoretical basis for maintenance costs to vary with tonnage leads to an incremental cost function variation with tonnage which is an approximation for the QR systems discussed in this paper and forms the basis for incremental maintenance cost signals in any multi-part tariff. Figure 5.1 displays that function.

Figure 5.1 Incremental Cost Functions for Infrastructure Maintenance Derived from Various Regressions of QR Data



The resulting incremental maintenance cost for the various systems is:

Moura	$1.00 per ‘000 Gtk
Blackwater	$0.54 per ‘000 Gtk
Goonyella	$0.37 per ‘000 Gtk
Newlands	$1.04 per ‘000 Gtk

The impact of the fixed infrastructure cost components is evident, but also the variable cost component contributes to the difference in incremental cost because the variability itself varies with tonnage.

ATTACHMENT 1

American Railway Engineering and Maintenance-of-Way Association

Part 11

Equated Mileage Parameters[1]

— 1994 —

TABLE OF CONTENTS

LIST OF TABLES

[1] References, Vol. 92, 1991, p. 84; Vol. 94, 1994, p. 146.

SECTION 11.1 INTRODUCTION

11.1.1 PURPOSE (1994)

The equated mileage parameters provide a means to establish comparability of track maintenance. They allow the user to make comparison of track maintenance for sections of track that are changing in use and/or physical composition and between existing or planned track sections.

11.1.2 DEFINITION (1994)

a. The parameters consist of decimalized numbers representing the type of track, track components, track geometry and traffic loadings. The factors assigned to each of these items are further refined for the effect of speed and distributed by the Federal Railroad Administration (FRA) speed classifications. Unity (1.00) has been assigned as the factor for Class 4, first main track. Other factors were derived by comparing the fixed and variable expenditures required for maintaining the particular item relative to that of Class 4 first main track.

b. Track maintenance comparisons are made by totaling the factors that represent each section of track being studied. The resulting numbers are related to provide a ratio. The ratio is the comparative level of maintenance required for one track versus the other. Cost comparison can be made if the maintenance cost for one of the track sections being studied is known. The comparable cost is obtained by applying the ratio.

c. The equated mileage parameter factors are to be used as a starting point for analysis. It is also suggested for today's world of roadway rationalization and rapidly changing traffic flows, axle loadings and densities, that assessment of economics must be site specific and time sensitive. For the most part electronic information systems, track assessment systems and computer systems permit many roads to measure, distribute and redistribute resources in a business like manner. Specific items that should be considered when using these parameters include:

   (1) This approach, implies a steady-state life cycle condition for major track components. For railroads or major corridors, the implication may be true; however, between specific study areas, conditions and the associated labor and materials cost differentials can be significant. If maintenance programs are cyclical, component condition assessment is necessary to determine the point in the cycle for each specific study area.

   (2) Many factors important to the overall maintenance requirements of a rail line are not included in these formulas and are not uniform from one track segment to the next. They include:

      (a) Structures.

      (b) Grade.

      (c) The nature of the subgrade (track support modulus).

      (d) Prevailing weather; including snowfall and rainfall.

      (e) Type of tie.

   (3) Tables only reflect annual tonnages of up to and above 35 mgt. The maintenance requirements created by tonnages over 35 mgt annually are significant. The effect of this additional tonnage is non-linear and unquantifiable in this kind of exercise.

   (4) Tables reflect unit train usage of under 5 trains per day and over 5 trains per day. As in (3) above, they are not adequate to cover unit train utilization at higher levels. Tables do not reflect the implications of high volumes nor the implications of traffic mix, i.e. the costs of maintaining heavy haul routes to also accommodate high-speed intermodal and passenger traffic. An expanded analysis based on these parameters should deal with the entire traffic and wheel load spectrum.

SECTION 11.2 TABLES

11.2.1 TRACK TYPE AND TRACK COMPONENTS (1994)

Table 11-1 shows the total factor for track type and its components is found by adding the factors representing the track section to be studied.

11.2.2 TRACK COMPONENT, TRACK GEOMETRY AND TRAFFIC LOADING (1994)

The factors in Table 11-2 are applied to the factors in Table 11-1 to adjust for their effect on track maintenance. No upper limit for over 5 unit trains per day has been provided. This factor is intended to be used with reason and not for the extreme.

11.2.3 TRAFFIC LOADING (1994)

Table 11-3 permits a comparison between various FRA track classes in relationship to the annual tonnages the track carries. It uses Class 4 track with 20 to 25 million gross tons per year as the unity figure. This is to be used independently of Table 11-1 and Table 11-2. No upper limit for over 35 MGT has been provided. This factor is intended to be used with reason and not for the extreme.

Table 11-1. Track Type and Track Components

Track Type	Frt/Pass	Factors by Speed Classification					
		1	2	3	4	5	6
		10/15	25/30	40/60	60/80	80/90	110/110
Main Tracks	1st	0.55	0.69	0.87	1.00	1.13	
	2nd	0.45	0.58	0.78	0.89	1.01	
	3rd and 4th	0.37	0.52	0.67	0.77	0.95	
Branchline Tracks	–	0.50	0.52	0.72	0.90		
Other Tracks	Passing and Thoroughfare	0.32	0.43	0.50	0.80		
	CTC Passing	0.40	0.63	0.83	0.95		
	Yard and Side	0.39	0.50				
Turnouts	Main Track (each)	0.04	0.05	0.12	0.12	0.15	
	Side Track (each)	0.03	0.08	0.09			
	Power or Spring (each)	0.06	0.07	0.17	0.19		
Railway Crossings	Each	0.10	0.15	0.18	0.20	0.24	
Road Crossings	Paved Street or Highway (Ea/Tr)	0.09	0.09	0.09	0.10	0.10	
	Unpaved Street or Highway (Ea/Tr)	0.04	0.05	0.05	0.06	0.06	
	Unimproved Road (Ea/Tr)	0.02	0.02	0.03	0.03	0.03	
	Farm or Private (Ea/Tr)	0.02	0.02	0.02	0.02	0.02	

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Table 11-2. Track Component, Track Geometry and Traffic Loading

Track Component	Frt/Pass	Factors by Speed Classification					
		1	2	3	4	5	6
		10/15	25/30	40/60	60/80	80/90	110/110
Ballast	Crushed Rock	0.90	0.93	0.96	0.98	1.00	
	CR Washed and Screened	0.95	0.96	1.00	1.20		
	CR Pit Run Gravel	1.04	1.04	1.12			
	Pit Run Gravel	1.06	1.11	1.22			
Railweight	Under 100 lb/yd	1.08	1.09	1.16	1.43		
	110-116 lb/yd	1.05	1.05	1.05	1.20		
	116-132 lb/yd	1.00	1.00	1.01	1.02	1.02	
	Over 132 lb/yd	0.83	0.90	0.92	0.95	0.97	
CWR		0.59	0.70	0.76	0.80	0.82	
Curves	Degrees 0°-2°	1.03	1.03	1.04	1.05	1.06	
	2°-4°	1.20	1.22	1.25	1.30		
	4°-6°	1.40	1.42	1.50			
	Over 6°	2.00	2.02	2.23			
Axle Loads	45,000 lb	0.95	0.95	0.95	0.96	0.97	
	55,000 lb	1.02	1.02	1.02	1.06	1.09	
	66,000 lb	1.24	1.30	1.30	1.40	1.45	
	Over 66,000 lb	1.50	1.50	1.50	1.70	2.07	
Unit Trains – Each Direction	1-5 Per Day	1.02	1.02	1.02	1.06	1.09	
	Over 5 Per Day	1.09	1.09	1.13	1.18	1.29	

Table 11-3. Traffic Loading

Traffic Loading	Frt/Pass	Factors by Speed Classification					
		1	2	3	4	5	6
		10/15	25/30	40/60	60/80	80/90	110/110
Million Gross Tons Per Year	0-5	0.39	0.50	0.56	0.70	0.75	
	5-10	0.44	0.56	0.64	0.74	0.83	
	10-15	0.51	0.62	0.73	0.84	0.93	
	15-20	0.56	0.67	0.81	0.90	1.03	
	20-25	0.63	0.75	0.89	1.00	1.14	
	25-30	0.73	0.81	0.95	1.07	1.23	
	30-35	0.74	0.89	1.00	1.12	1.32	
	Over 35	0.82	0.93	1.05	1.22	1.41	