QUEENSLAND COMPETITION AUTHORITY

# Working Paper 3

## Incremental Cost of Capacity

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# TABLE OF CONTENTS



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## GLOSSARY OF TERMS

| | |
|---|---|
| **Above-rail:** | Infrastructure and equipment including rollingstock required by a railway operator to operate trains. |
| **Allowance:** | A period of time identified as the difference between the period it takes to operate a train at normal speed compared to that period it takes for a train to slow to a stop or accelerate from a stop to normal track speed. Hence starting allowance and stopping allowance. |
| **Axle Load:** | The weight limit applied to trains passing over a line by the railway civil engineer. It is the limit 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. |
| **Below-rail:** | Infrastructure required by a railway manager to provide capacity for the operation of trains. |
| **Bottleneck:** | A track section that limits the throughput of the network by restricting the number of trains able to pass through it. |
| **Capacity:** | The number of paths available to trains or other occupiers of track sections on the network. For specific trains, the product flow-through capabilities of the network. |
| **Consist:** | A train formation and consisting of locomotive(s) and wagons. |
| **Delay:** | The time a train is prevented from operating at the speed it would operate if it did not need to stop at passing sidings, signals or stations. |
| **Double/dual Track:** | A railway line consisting of two parallel tracks usually used for trains travelling in opposite directions. |
| **Duplication:** | The construction of a second parallel track over section(s) of the network. |
| **Expansion:** | An increase in network or system capacity. |
| **Gross-to-tare Ratio:** | The total weight of a loaded wagon/train to the weight of the empty wagon/train. |
| **Headway:** | The distance or time between trains wishing to use the same section of track, either in the same direction of from opposite directions. |
| **Infrastructure Improvement:** | Physical works applied to the infrastructure to increase the number of paths available on the system. |
| **Intermediate Loops/Signals:** | Passing loops or signals constructed at an intermediate point between two existing loops or signals to assist in increasing the capacity of the system. |

| | |
|---|---|
| **Incremental Capacity Cost:** | A capital cost (expressed as an annuity) that is the extra cost incurred for one more path of capacity. |
| **Maintenance Window:** | A segment of time over which maintenance can be carried out involving the occupation of a section(s) of track. |
| **Occupation** | By a train, of a track section and so as to preclude the use of that section by any other train under normal circumstances. Occupation can occur by other authorities such as maintenance occupations. |
| **Passing Loop/Siding:** | A location on a single track where two trains travelling in opposite directions can pass one another through the use of a second parallel track joined to the mainline with turnouts. |
| **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. |
| **Resleepering** | The replacement of sleepers which are life-expired. |
| **Rollingstock:** | Railway wagons and locomotive used for specific purpose or general haulage. |
| **Saturated:** | Applied to a track section is where a train is constantly occupying the section. |
| **Section:** | On a single track, the distance between passing loops. On a double track, the distance between signals. It is the smallest unit of track occupation. |
| **Sectional Running Time:** | The time it takes a train travelling at the speed it would be travelling if it did not have to stop at passing loops or stations, to traverse a section. |
| **Single Track** | A railway line that consists for the most part of only one track and punctuated by passing loops. |
| **Standard Train Path (STP)** | One of a number of similar hypothetical paths, in combination representing the least time-distance trajectories of trains over a network and therefore permitting the maximum number of trains of a given specification to be operated over the network. |
| **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 Occupation:** | The presence of a train on a section of track that precludes the presence of another train in order to maintain safe separation between trains. Occupation can occur by other authorities such as maintenance occupations. |

**Train Path:** A defined entry, exit and transit time for a train consist on a particular network or corridor.

**Transit Time:** The time it takes a train to run from an origin and a destination usually over a number of sections and composed of sectional running times, stopping allowances, starting allowances and waiting at passing sidings.

**Turnout:** Trackwork where a single track splits to become two tracks and is equipped with moving rails to change the route.

# 1. INTRODUCTION

The cost of capacity in a rail system is a significant proportion of the total cost of providing the infrastructure. Users and providers of the infrastructure need a working understanding of the impact of the way in which the infrastructure is used. It is important that the parties understand the consequences of their decisions. This paper provides background to these considerations and provides a rationale for the assignment of components of an access cost. It deals with examples that are hypothetical as well as close approximations in case studies that deal with actual situations.

Capacity related costs are those costs associated with the provision of the capacity currently in place, usually expressed in terms of the number of train paths available. Incremental capacity costs are those associated with a small increase in capacity. The cost and impact of capacity increments depend on the existing configuration, in particular whether it is single or dual track, and the safeworking technology employed on that particular line.

Capacity increase strategies can take a number of directions including, more recently, the use of computer-based tools for optimising infrastructure configuration and use as well as the more traditional solution of infrastructure construction. Strategies to increase railway capacity are also increasingly examining 'smarter' solutions[1] involving communications and data management.

This paper provides background for the estimation of the incremental capital costs of capacity and provides indicative costs for typical options suitable for lines such as the Queensland coal systems. It first summarises previous work on capacity research and documents the current situation on the Queensland coal networks. It then discusses the key factors affecting capacity and how they can be addressed through capital expenditure. Finally, it estimates a generalised set of incremental capacity capital costs.[2]

[1] R.L. Sauder and W.M. Westernman (1983) Computer Aided Train Dispatching: Decision Support Through Optimization, Interfaces 13:6 December 1983 (pp. 24-37)
[2] The simulation modelling relied upon in this paper was performed by Maunsells.

## 2. PREVIOUS CAPACITY ESTIMATION RESEARCH

The significant expense of expanding railway infrastructure capacity, combined with the large increases in tonnage experienced by several railways, both in Australia and worldwide, have generated a substantial body of research concerning capacity related problems.

In recent years, simulation methods have improved owing to the greater power of computers and a number of computer packages are now available for capacity estimations. These simulations estimate the maximum capacity of a section of line, taking into account the delays that inevitably occur due to engineering and operational failures, and much research has focussed on the appropriate models for understanding disruptive events of this type.

At the 1978 Heavy Haul Railways Conference, two papers[3] concentrated on the calculation of the capacity of a single-track railroad system and the various methods for modelling capacity. This was at a time when many railways were having to consider infrastructure expansion to accommodate rapidly increasing tonnages and options for minimising this expenditure by optimising the current system were generally more cost effective. These approaches to capacity problems were among the first to bring automated methods to what had historically been a 'pencil and paper' charting approach.

Today, a variety of computer simulation tools are used to highlight bottlenecks in railway operations and propose operational and infrastructure remedies, and there are often extended to include the entire logistical chain (e.g. mine stockpiles, terminal stockpiles and port operations).

Other references[4] describe a range of other methods that have either been proposed or used to evaluate the capacity of rail networks.

[3] R.L. Purdon, J. Elbrond and J.M. Clark (1978) A Comparison of Theoretical and Actual Traffic Schedules on the Mt. Newman Railroad, International Heavy Haul Conference 1978, J. Elbrond (1978) A Method for the Calculation of the Capacity of a Single Track railroad System, International Heavy Haul Conference 1978

[4] E.R. Kraft (1988) Analytical Models for Rail Line Capacity Analysis, Journal of Transportation Research Forum Vol XXIII no1, G. Mills, S. Perkins and D. Sier (1993) Capacity Planning for a Railway Corridor, Australian National Contract Research, M. Carey (1994) Extending a Train Pathing Model from One-Way to Two-Way Track, Transportation Research, Vol 28B No. 5, A. Higgins (1996) Optimisation of Train Schedules to Minimise Transit Time and Maximise Reliability, A thesis submitted for the Degree of Doctor of Philosophy, Queensland University of Technology, J. Milan (1988) A Practical Model of a Single Track Line, Transportation Planning and Technology, 1988 Vol 12, S.F. Hallowell and P.T. Harker (1996), Predicting On-Time Line-Haul Performance in Scheduled Railroad Operations, Transportation Science Vol 30 No. 4

## 3. OPTIONS FOR INCREASING CAPACITY

Although a number of options can be used to increase infrastructure capacity, in any one situation this choice often reduces to two or three which are then subjected to detailed cost-benefit analysis.[5]

For all railways except those of very short length, options to increase capacity invariably start with rollingstock/train parameter optimisation because of its much lower capital cost compared to infrastructure expansion. 'Above-rail' options include the following:

- increasing train lengths to the full length of the existing passing loops. Where passing loops are of different lengths (such as on the NSW North Coast), selective increases in train size are possible if long trains are restricted to travel on the mainline through the shorter crossing loops;
- increasing train speed to improve transit time between crossing loops by increasing the train power to load ratio (loco HP:trailing tonnes);[6]
- increasing wagon and locomotive axle load to the maximum permitted by the infrastructure;
- improving track utilisation through train control measures, such as automatic route authorisation, decision support and train communications; and
- improving train densities by train fleeting (i.e. operating a series of following trains). This is most effective where there is a wide mix of train sizes and speeds and the fleet consists of a group of trains with similar characteristics (e.g. interstate fast freight trains).

When train operating parameters have been optimised, strategies that can be adopted for infrastructure enhancement include:

- measures to reduce sectional running times, such as:
  - selective curve straightening;
  - selective grade easing (can also increase payload);
  - upgrading loop turnouts to permit faster entry and exit speeds; and
  - electronic signalling to improve train authority to proceed and reduce transaction time.
- measures to reduce section lengths, such as:
  - installation of extra passing loops; locations are generally selected so the transit time is an even fraction of existing section times ie ½ or ¼; and.

[5] The total system capacity is also influenced by the interface arrangements with the terminals at either end of the railway components of the supply chain. Delays at the mines or ports can have a large impact on system throughput.

[6] Braking standards are adopted reflecting the worst train's performance in the worst weather and track conditions for braking.

  - dual track (or long passing loops) in locations where different types of train travel at different speeds (e.g. loaded and empty trains).

- measures to increase train size, such as:

  - strengthening track infrastructure to permit higher axleload wagons and locomotives.

  - lengthening passing loops to permit longer trains; and

  - electrification to permit higher capacity locomotives (will also improve transit times).

- measures to increase available track time, for example by upgrading the track structure to reduce maintenance down-time.

However, railway operations are also sometimes constrained, not by the linehaul capacity but instead by the terminals and in such cases the entire logistical chain needs to be analysed.

As well, other constraints may operate that impact on a wide variety of interfaces the railway has with other infrastructure or the community. For instance, the electric overhead system may be constrained in its ability to handle greater tasks because the original design did not account for the use proposed. In other areas the sensitivity to the environment may result in curfews or restrictions on railway operations. Those factors have not been considered in this paper.

## 4. CAPACITY MEASURES

The capacity of railway infrastructure can be expressed either in terms of paths or, more fundamentally (for freight trains), in terms of net tonnes transported.

Path capacity is typically measured as the number of paths available for a standard train on a 24-hour basis or on a weekly basis. Train size and performance has a significant impact on capacity as slower trains tend to occupy sections of track for a longer time. It is thus important to understand the type (or mix) of trains for which capacity is being estimated.

Tonnage capacity is a more fundamental measure, as it takes into account not only the number of paths but also the capacity of the trains. Capacity can be expressed in terms of either gross or net tonnes, with the ultimate client generally concerned with the number of net tonnes transported. An important consideration is the ratio of gross to tare for the wagons, which can vary widely depending on the technology used in the design of the train. A higher gross to tare ratio indicates a greater proportion of the total haulage is for the load and not for the empty train.

The basic calculation of capacity is simple. Initially, an absolute capacity is calculated, based on the sectional running time T (for single track this is the average of the up and down times). As the sectional running times are generally based on non-stop running, they are increased to allow for the time required to enter a loop, perform the required safeworking procedures and then move off.[7] The absolute capacity is then given simply as the time available for operations after allowance for maintenance (normally about 94% of the day on average) divided by the adjusted sectional time. Thus, the daily capacity of a section with an adjusted time of 45 minutes is 32 trains (1440 minutes – 24 hours X 60 minutes - divided by 45).

This capacity is the maximum number of trains that could be operated, assuming a perfectly regular timetable and that there are no disruptions (such as temporary speed restrictions) or variations in running times caused by mechanical or operational factors. A practical capacity is therefore derived by discounting the absolute capacity by a factor to allow for this.

The factor depends on the railway; the Russian and Chinese railways have had very high factors of over 90% in the past but they operated a completely homogeneous set of trains with all other activities being tailored around maximising train frequency. Even then, once the factor reached 93%, the Russian system (at least) proved unworkable. Western railways, with a greater intrinsic variation in trains and a greater need to balance operator and customer requirements, generally use 70-75% as a reasonable factor. Using this, an absolute capacity of 30 trains/day would become a practical capacity of about 22 trains/day.

[7] Between 2 and 5 minutes are allowed for the acceleration/deceleration and from 0 to 8 minutes for safeworking, depending on the type of procedure. The adjusted sectional times for a nominal 30 minute section could therefore range from 32 minutes to 43 minutes depending on the type of train and the safeworking system employed.

## 5. INFRASTRUCTURE PARAMETERS AFFECTING CAPACITY

The factors affecting capacity that are infrastructure-related are:

- number of paths - this parameter is dependent on many other factors and unless the network being analysed is simple needs to be estimated with the use of simulation tools.

- passing loop spacing (single track) and safeworking section length (double track)[8];

- allowable train speed - this parameter could also be a function of the rollingstock type used. However the alignment and quality of the track have a large bearing on the maximum speeds of the trains.

- signalling system type - this parameter is chosen to suit the type of operation proposed. Where there are large numbers of trains or trains travelling at high speeds, more sophisticated systems are employed. Two broad systems are available: those in which the transmission of an authority to the train is electronic and those where spoken communication is involved. The transaction times associated with the non-electronic communication inhibit system capacity, whilst more automatic systems can be applied where the communication is electronic.

- signal spacing – this parameter is determined by balancing the needs of the proposed operation, the cost of the system and the characteristics of the train, in particular its braking characteristics.

- train size - this parameter is dependent on crossing loop length, ruling grade and train power to weight.

- passing loop length ; and

- axle load.

Most of these parameters are co-dependent; for instance, the allowable train speed and axle load are both a function of the structural capabilities of the track. An increase in axle load may require a decrease in train speed.

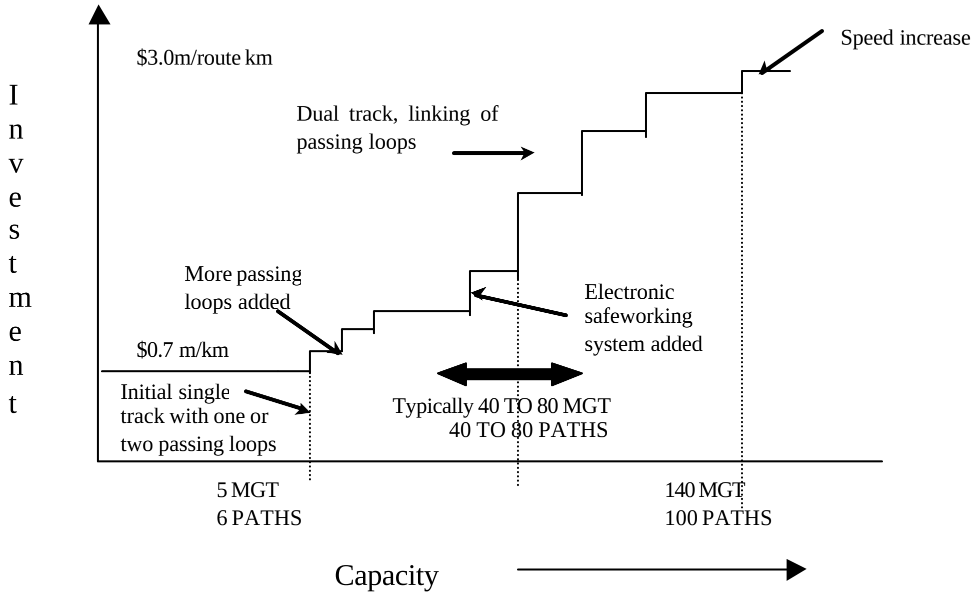
[8] Sometimes there are also intermediate signals between passing loops on single track to allow the trains to follow each other within the same section.

# 6. INCREMENTAL AND NON-INCREMENTAL CAPACITY COSTS

Railway infrastructure is an asset that inherently provides capacity in discrete quantums. An initial investment will provide a finite capacity such that all utilisation to that point is associated with a fixed cost[9]. Incremental investments, which can be large or small depending on the technology, can then progressively lift capacity until the next limit is reached. A more substantial change in capacity requires more substantial investment.

This is illustrated by the progression from a simple single-track line, with infrequently spaced loops, progressively being upgraded through the provision of more loops and upgraded signalling, until a limit[10] is reached at which it is not practical to further subdivide sections. At this point, sections of the track begin to be progressively doubled, at significantly greater cost than constructing a loop, until the whole line becomes double-track. From this point, the increments in capacity become relatively cheaper as they can be obtained by reducing signal spacings, limited only by minimum section lengths required for safe operational working (due to braking requirements etc). This process is illustrated in Figure 6.1.

*Figure 6.1 Progressive Expansion of Rail Network Capacity*




The process of moving up the curve and to the right is essentially one where bottlenecks in the system are progressively eliminated. A number of bottlenecks may operate in parallel and ensuring that the next bottleneck to be removed is the most cost effective infrastructure improvement is the challenge of effective planning. This situation will be case studied later in the paper. Once the bottleneck is removed others will emerge. Scenarios of infrastructure improvement will show the relative value of each. Once chosen as an improvement that infrastructure is then used as the base for the next round of investigations.

These concepts are illustrated by two generalised expansion scenarios discussed below, for single and double track respectively. Taken together, these enable an investment pathway to be developed from low-tonnage systems (such as Moura) to high-tonnage systems (such as Goonyella).

[9] This is in contrast to road infrastructure, say, where there is a general degradation in service level from a comparatively low level of capacity utilisation.
[10] Typically at about 10 km loop intervals

## 6.1 Hypothecated Single-track expansion

The assumed line is 160 km long, with a single intermediate passing loop, located at the midpoint, with the following operational characteristics:

- sectional running times of 96 minutes,
- yard allowance of 4 minutes,
- safeworking allowance of 2 minutes, and
- maintenance allowance of 90 minutes per day.

The adjusted section time is 102 minutes and the absolute capacity of the line is 13 trains/day. Assuming a typical reduction factor of 70% gives a practical capacity of 9 trains/day.

The capacity of the system is then increased by providing an additional two passing loops midway between the existing loop and the endpoints. This reduces the sectional running times to 48 minutes, the adjusted section times to 54 minutes and thus almost doubles the capacity to 17.5 trains/day, with 8 additional paths.

Each new passing loop, including signalling, costs \$5m[11], for a total project cost of \$10 million. The associated annualised capital charges[12], assumed as 9.5% of the replacement cost, are \$0.95 million p.a. This investment yields another 2920 paths[13] per year or 8 paths per day. Accordingly, this produces an incremental cost of approximately \$320 per path (daily).[14]

This process can in theory be repeated indefinitely. In practice, once loops are closer than around 10 km, it is generally more effective to duplicate selected sections of track, starting with those that have the longest sectional times. Table 6.1 summarises the capacity and costs for various loop spacings, giving the average and incremental capital costs, based on a capital cost for a single line with no loops of \$1 million/km.

*Table 6.1 Capacity and capital cost – 160 km single-track line*

| # loops | Capital cost ($m) | | # paths/ | Annualised Capital cost per path[15] | |
|---|---|---|---|---|---|
| | Total | Per route km | Day | Average ($m) | Incremental ($) |
| 0 | 160 | 1.00 | 5 | 3.2 | - |
| 1 | 165 | 1.03 | 9 | 1.8 | 340 |
| 3 | 175 | 1.09 | 17 | 1.03 | 340 |
| 7 | 195 | 1.22 | 31 | 0.63 | 390 |
| 15 | 235 | 1.47 | 52 | 0.45 | 520 |

The incremental cost per path increases as the number of loops increases but still remains a fraction of average cost, with the total capital cost only increasing by 47% as the capacity is increased by a factor of 10.

11 QR Estimate
12 Comprising a return on capital and depreciation.
13 A ‘path’ is a one-directional trip. A return trip thus requires two paths, one in each direction.
14 Some maintenance cost would also be incurred.
15 On a daily basis

## 6.2 Hypothecated Double Track Section

A similar calculation can be made for a double-track line. This also is assumed to be 160 km long, with 3 intermediate signals. These would enable trains to operate at 48-minute headways in each direction, providing an absolute capacity of 56 paths per day (equivalent to a practical daily capacity of 39 paths) after allowing a 90-minute maintenance period.

The capacity can be increased by installing intermediate signals (usually bi-directional on the coal systems) until a minimum headway is reached. This limit is generally determined by minimum braking distances, which are a function of train type and size. For the coal trains operating in Queensland, this minimum headway has been taken as 12 minutes, equivalent to 10 km signal spacings.

Each bi-directional signal is assumed to cost $3m per location[16] to install; as they are required on both tracks. The total cost of installing a 24-minute headway (needing 4 additional signals on each track) is $12 million and includes modifications to train control. Table 6.2 summarises the resulting average and incremental capital costs.

*Table 6.2 Capacity and capital cost – 160 km double-track line*

| Section | Capital cost ($m) | | # paths | Annualised Capital cost per path[17] | |
|---|---|---|---|---|---|
| Length (km) | Total | Per km | | Average ($m) | Incremental ($) |
| 40 | 352 | 2.2[18] | 39 | 0.9 | - |
| 20 | 364 | 2.275 | 79 | 0.46 | 82 |
| 10 | 388 | 2.425 | 158 | 0.25 | 83 |

Tables 1 and 2 both demonstrate the capacity of an established railway, either single track or dual track, can be increased at a very small incremental cost as long as duplication or multiple-tracking is not required. However, if single-track that is fully utilised has to be converted into dual track, there is a significant increase in the investment required, although there is a correspondingly large increase in potential capacity from this investment.

## 6.3 Application on a Hypothetical Basis

This section applies the results of the previous section to estimate the incremental capacity costs associated with hypothetical coal systems which have as their basis the QR systems. Actual case studies of the QR systems will be discussed later. This section will discuss the theoretical framework for an analysis.

Typical data will indicate spare capacity, which is the extra capacity over what is currently consumed compared to the theoretical maximum for each system. Branches and loops with low utilisations (typically below 20% of practical capacity) will be omitted from such an analysis. Parts of the Blackwater system are moderately close to practical capacity and additional growth will eventually require progressive duplication of some of the single-line main-line sections. For trains using only the section of track between Callemondah and Rocklands an incremental capacity analysis is not appropriate at this time for two reasons. Firstly, the optimisation of the corridor results in some double track sections being omitted from the analysis and secondly, the actual double track section has a capacity much higher than the foreseeable requirements. Also on this basis most of the Goonyella system has substantial reserve capacity but some of the single-track sections may require intermediate loops. Both the Moura and Newlands systems

[16] QR estimate
[17] On a daily basis
[18] QR estimate

have substantial reserve capacity as well as the potential for intermediate loops should they be needed.

A weakness of an analysis of this type is that transit times of trains will deteriorate as the system is required to handle greater numbers of trains. If transit times were to remain constant the actual proportion of spare capacity would decrease. However in this circumstance operators[19] would be required to make a decision as to whether to invest in more track capacity, more reliable and faster trains, or more train consists. The Authority wishes to provide appropriate pricing signals to the stakeholders so that sensible rational decisions can be made and this paper provides the framework for this analysis.

Although under normal operating conditions, there is substantial spare capacity over most of the coal network, there may be problems on some sections if major formation and ballast cleaning works are required. This will generally only occur on line sections that are heavily trafficked, which are typically double-tracked with the exception of the single-track sections on the Blackwater system. Concentrating traffic on one track and working on the other does such work most efficiently. Under such circumstances, the capacity of the line will be greatly reduced and additional intermediate signals and crossings may be required to maintain the system throughput while the maintenance is being performed.

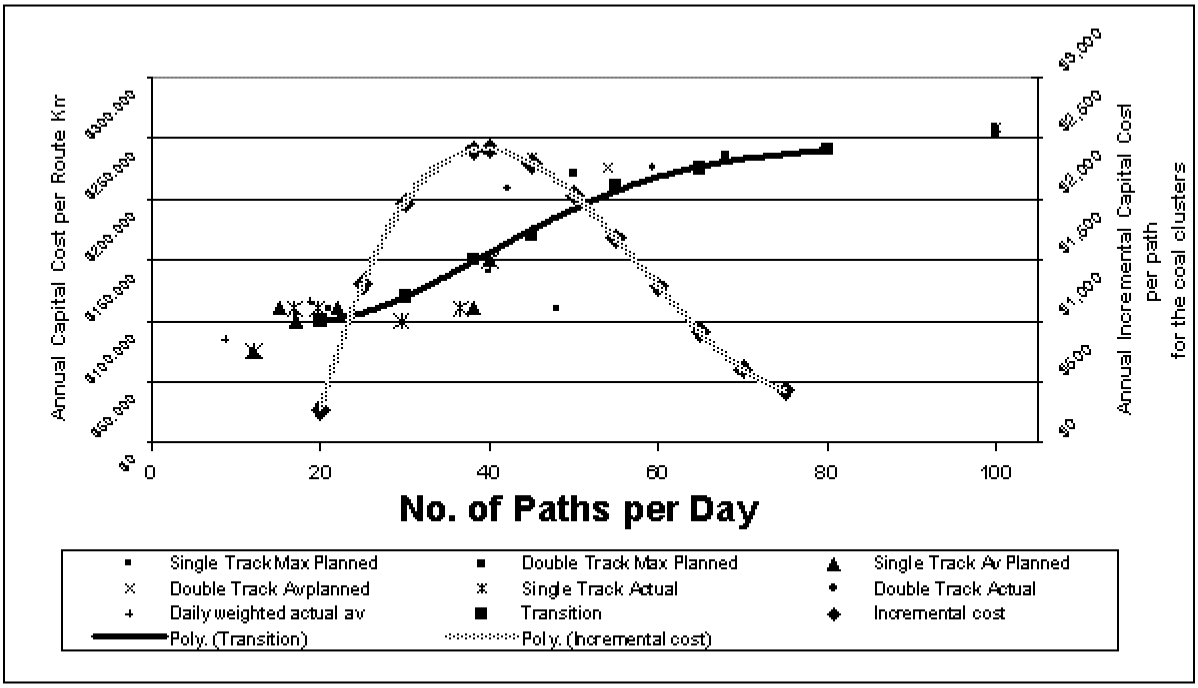
Incremental capacity for at least the medium-term can thus be provided by:

- modifications to the signalling on the double track sections of the Goonyella system and partial duplication on the single track sections of the Goonyella system.
- intermediate loops on the Moura and Newlands sections; and
- intermediate signals on the Blackwater double-track sections, continuing duplication on the main-line single-track sections and intermediate loops on the branches.

Figure 6.2 combines the capacity and utilisation data with the incremental capacity costs developed in the previous section. It gives the capital cost of various levels of capacity for single and double track as well as a composite curve[20] covering the transition from single to double track. As increments in capacity are likely to be achieved in a step-wise fashion, the actual slope of the incremental cost curve at any single point can only be achieved by considering actual circumstances. Case studies later in the paper will assist in the establishment of the incremental costs for the Goonyella and Blackwater systems.

[19] Operators will drive the decisions necessary for investment even if the railway infrastructure owner provides more infrastructure capacity and subsequently charges operators for that capacity. In some instances individual operators will invest in infrastructure suitable to improve their efficiencies.
[20] Source: Rail Management Services Pty Ltd & Bullpin Pty Ltd

*Figure 6.2 Theoretical total and incremental capacity costs*




NB: Poly in the legend relates to the polynomial trendline used to regress the data.

The single-track costs assume a constant track standard which is capable of handling the higher volumes of traffic without significant upgrades to axle-load, sleeper type, depth of ballast etc In practice, a single track designed to carry a very low number of trains might only have an initial investment of $0.7 million per km[21] but this would need reconstruction at a cost of up to $0.5 million per km if it were to be capable of carrying 30-40 trains per day.

The composite cost represents the costs involved in a strategy of progressive duplication of the track as demand increases and has been developed assuming that this process begins when the corridor demand reaches 30 paths/day and is completed by the time it reaches 60 paths/day.

The figure also includes the current capacities of the various sections of the QR coal network, together with their estimated replacement capital costs. The scatter around the synthesised trend-lines reflects variations from the model assumptions on the number and variability of intermediate section lengths and variations in transit time (because of grades, geometry and speed restrictions).

Figure 6.2 shows the incremental path cost for low capacity single-track is around $500 per (daily) path per annum. This increases sharply during the transition phase to double track, to around $1,000 – $2,000 per path per annum but then falls back to around $500 per path per annum once duplication is underway and capacity can be increased by intermediate signals at low cost. Avoidance of the sharp part of the investment curve by way of cost effective infrastructure expansions is the objective of the infrastructure manager. The incremental cost curve, shown in Figure 6.2, is generated by considering individual increments as isolated projects. The case studies will show that when expansion projects are considered in the appropriate sequence some economies are possible to achieve the least cost path to expansion.

The foregoing analysis relies heavily on the determination of a network's capacity and on the increases in capacity provided by particular infrastructure improvements. Although the

[21] This would be a minimal track structure, without electronic signalling and built to low quality, but with the capacity to pass trains running in opposing directions.

framework of an evaluation has been brought out by this analysis case studies involving actual capacity enhancement scenarios on the Blackwater and Goonyella systems are required to determine reference train tariff components. Actual case studies will be developed in a later section of this paper.

# 7. RECENT CAPACITY DETERMINATION ANALYSIS

## 7.1 QR Re-evaluation of System Capacity

Queensland Rail has recently embarked on a re-evaluation of their systems' below rail capacity using new simulation tools. The methodology consists of two discrete parts. Firstly the theoretical maximum or 'saturated' capacity is determined and secondly, various factors are applied to determine the 'practical' capacity.

QR's method involves choosing a section of the infrastructure that represents the bottleneck of the system taking into account the performance of the dominant train[22] to run on the system[23]. On other parts of the QR system where many different types of train operate the dominant train may not be the type of train that runs most often but a train that 'dominates' by taking a large portion of the capacity over the bottleneck.

The bottleneck is most likely to be the section of single track that has the longest sectional running time or in an adjacent section where queuing and other terminal effects may take dominance. In practice the bottleneck will be determined by the interaction of trains operating on the system. Train interaction occurs when two or more trains wish to use a common section of track such as in trains running in opposite directions and trains following or preceding other trains in the same direction. This interaction may affect the location of the bottleneck and be influenced by other infrastructure or terminal issues. The longer the sectional running time, the fewer trains are able to operate over a 24 hour period.

On this bottleneck the reference train is operated in both the empty and loaded directions so that the section is saturated with trains. That is, a train running either empty or loaded always occupies the section. If the sectional running time is 30 minutes, then 48 trains per day at most will be able to operate over the section. In practice, starting and stopping allowances for those trains will reduce the number of trains able to operate.

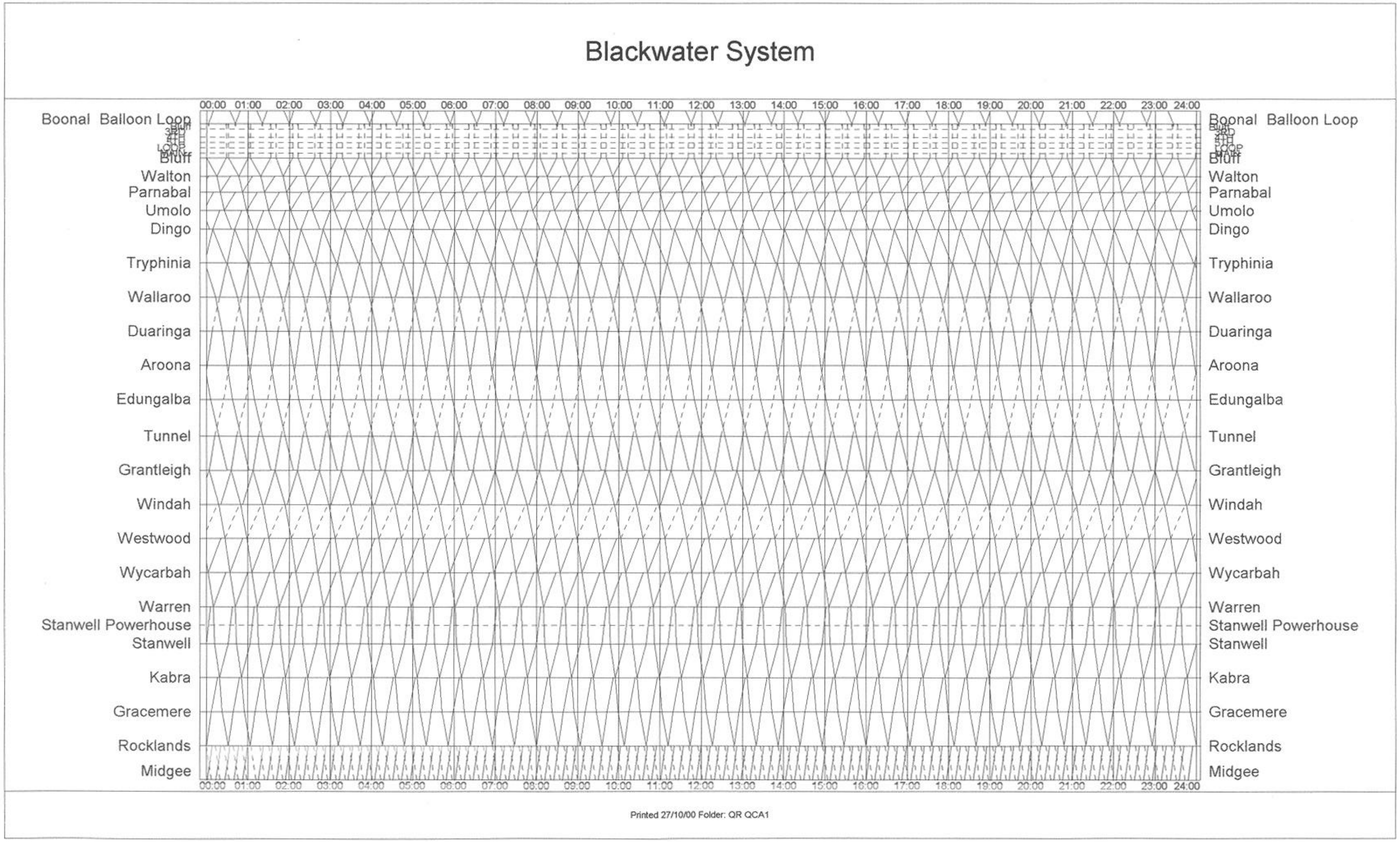
Starting with the train paths (time distance related) on the bottleneck section, those paths are then extrapolated either side to other parts of the network. The extrapolation is based on the dominant train's performance[24] in order to ensure that the bottleneck's train running can occur. The extrapolation consists of extending those 'saturated' paths onto the sections either side of the bottleneck section. Typically, the resulting train paths will be parallel to one another and separated by a time at least equal to the sectional running time of the bottleneck section. The scheduling of the trains in both directions has to take into account any other passing of trains on single track sections.

Figure 7.1 shows the resulting saturated train diagram. The diagonal lines represent the time/distance trajectory of trains. Those sloping upwards to the right are empty trains from the

[22] A dominant train is the one most likely to be encountered on the system at the present time. This may change with time. The dominant train has been referred to by QR as the reference train but QCA proposes to use an STP train as the reference train for the purposes of capacity consumption. The individual sectional running times of the STP train and the 'dominant' train are not different. However the transit time that takes into account any passing loop delays and train priority does differ.
[23] The longest sectional running time section is not always the section that causes the initial bottleneck. Convergence of trains from branch lines and terminal constraints can be more restrictive on a system initially.
[24] Sectional running times.

port and those sloping downwards to the right are loaded trains from the mine. This diagram represents the absolute maximum number of trains that the system can accommodate assuming no interference of any kind. Below rail incidents including maintenance work and failures as well as above rail incidents including locomotive breakdowns would always reduce the capability of the system and the paths shown on this diagram are therefore theoretical in nature only.

*Figure 7.1 Saturated Train Diagram for the Blackwater System: Source QR*



The paths estimated in this process are called 'standard train paths' (STP). Actual train performance will determine how many STP's are consumed. In the case of the Rocklands to Bluff section in the Blackwater system 90 theoretical standard train paths are available. This is derived by taking the sectional running time, which for that section is 11 minutes, and adding a starting allowance of a further 5 minutes to make a total of 16 minutes. The starting allowance relates to the time it takes the stationary train, which has had to wait at the passing siding, to accelerate and obtain normal speed. This time of 16 minutes is then divided into 1,440 minutes in a day resulting 90 paths being available as the theoretical maximum capacity of the system. These paths represent the maximum number of trains able to traverse the section of track with the longest running time.

## 7.2 Real Train STP Consumption

A coal train is required to proceed empty to the mine and loaded to the port, thereby consuming at least two STP's. In practice, because trains do not run perfectly and infrastructure is not always available for use, trains will consume more than one STP. As well, in order to cycle trains in a different manner to that computed by the application of this method, such as applying higher priority for passing or higher or slower speeds, trains will consume more than one STP.

In addition a 'reduction' factor is applied to account for weather conditions, temporary speed restrictions, minor signalling faults and other infrastructure related aberrations. This factor has been observed by QR to be approximately 15%. That is a 'reduction' in capacity from the theoretical maximum of 15% is determined as being the practical infrastructure capacity, not taking into account regular maintenance activities. For the Rocklands to Bluff section this reduction factor results in 76 STP's from the original 90 being available for actual trains.

To determine the system capacity in terms of the total transport system it would also be necessary to recognise that train performance can be reduced through breakdowns and other above-rail issues. However these 'above-rail' factors are not constraints on the 'below-rail' capacity as such. Nevertheless, operators will need consider the reliability of their trains and the availability of terminal resources in their overall assessment of capacity utilisation and rollingstock efficiency.

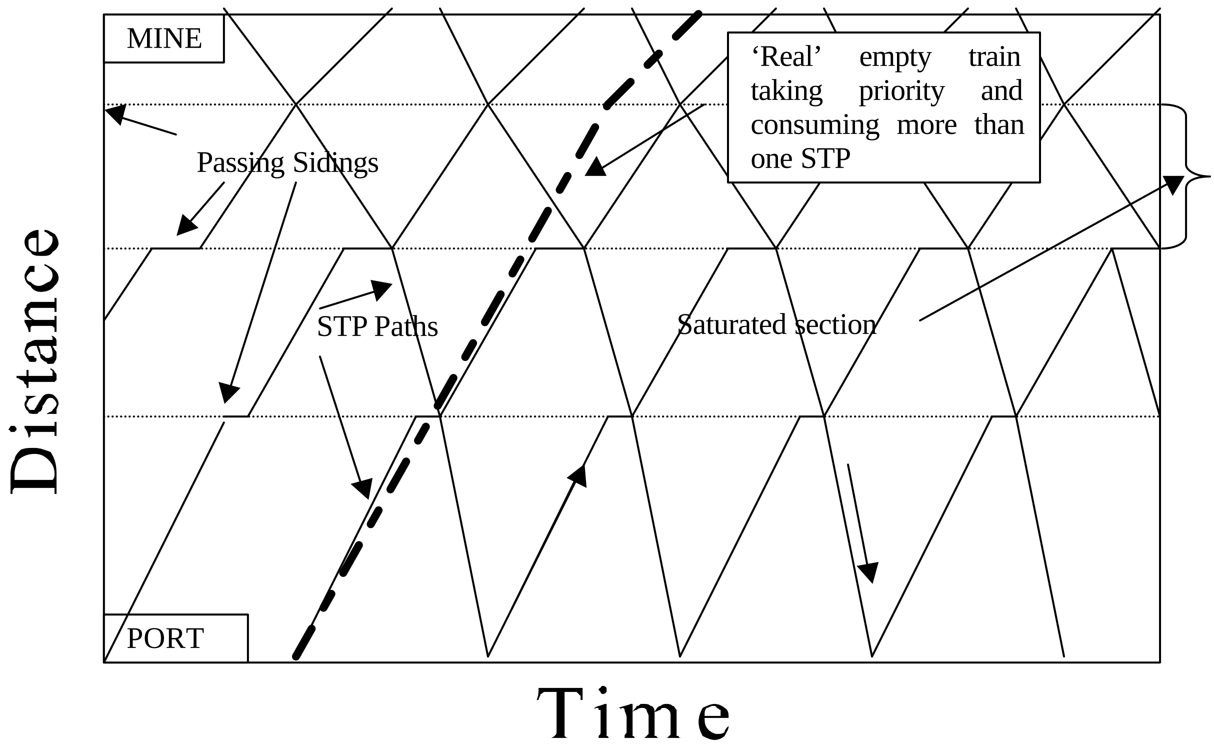
As well as the reduction of 15% in capacity for unplanned infrastructure events, there is also the planned maintenance events estimated by QR as being 14% of the theoretical maximum. In the Rocklands to Bluff section a total of 13 STP's are consumed by maintenance activities each day further reducing the available STP's for actual trains to 62.

Finally, the actual trains scheduled and operating on the system are overlaid on the STP calculation. In the case of Rocklands to Bluff, the currently scheduled empty coal trains consume 1.61 STP's per train because QR's schedule demands that an empty train run faster than the STP in order to meet operator driven cycle time objectives. The transit time of the train is one component of that cycle time. The loaded train on the Bluff to Rocklands section consumes an estimated 1.03 STPs because its transit time more closely matches that of the STP train's transit time. Non-coal trains on the section consume between 1.36 STP's per train and 1.13 STP's per train on average depending on the direction of running. These estimates of STP consumption are based on the premise of many of these trains running over the system. This tends to redefine appropriate paths and lessens the impact compared to a single train being introduced onto the system.

Any strategy that reduces system capacity, including the strategy of improving train cycle time, will bring capacity augmentation forward in time. Ultimately operators will need to balance strategies that reduce above rail costs with the below rail consequences which will be reflected in the incremental cost of capacity charge.

This process of calculating STPs and the consumption of STPs by 'real' trains is shown if Figure 7.2. The diagonal lines represent the time/distance trajectory of a train. The train travels from one passing siding to the next. When the two trains pass one another, one from one direction and one from the other, one of the trains must wait for the other to arrive. A horizontal line represents this waiting because no distance progress is made over a period of time. Occasionally trains pass one another without any discernable waiting by any of the trains. An empty train travels from the port to the mine and is represented on the diagram by an upwards sloping line, while the loaded train is represented by a downward sloping line.

*Figure 7.2 Calculation of STP Consumption on Time-Distance Chart*




The 'real' empty coal train consumes more than one STP because it encroaches on the pathways of 2 empty STPs. In the example shown in the diagram, the empty train takes priority over the loaded trains and does not stop at the passing sidings. If this is the preferred path of the 'real' empty train, it remains the challenge of the train schedulers to re-orient the loaded trains and minimise the impacts on the system.

The example provided only deals with the impact of one train where the effect can be clearly seen. However when a number of 'real' trains operate their combined average effect may be different to that of the single train. This is because as the number of trains of a particular performance increase over the system, their influence increases resulting in less overall disruption to their operation and more disruption to the train that was previously the dominant train.

The analysis[25] conducted by QR using their existing coal and non-coal train characteristics, concludes that the number of spare paths on the Rocklands to Bluff section is 5 STPs where an

[25] Blackwater System Path Utilisation, August 2000, Network Access Group QR.

average number of non-coal trains operate. This analysis has taken into account existing train performance and configuration as well as unplanned events and maintenance allowances.

## 7.3 Adoption of STPs as the Benchmark

QR's approach in their capacity re-evaluation, to start at the fundamental level of capacity, is a method that establishes an objective reference point for all further considerations.

Although the development of an STP diagram is not a task for the layperson, its concept is simple, to load the system to absolute theoretical maximum capacity. There can be no controversy about the theoretical calculation of the number of STPs on a system.

In contrast, the calculation of capacities for the purpose of establishing a benchmark for other types of train by using an existing or proposed 'real' train is somewhat subjective. Questions arise as to what level of variability in sectional running times, what effect maintenance windows may have and whether it is reasonably practical to load a system to saturation point. The above rail influences on a 'real' train also cloud the issue of actual running performance.

Therefore, in order to ensure that any further assessments of the effect of varying train types operating on the system may impose in terms of capacity consumption, the STP is the preferred benchmark for that analysis and the subsequent signal that may be given to the market.

# 8. INCREMENTAL CAPACITY COST CASE STUDIES

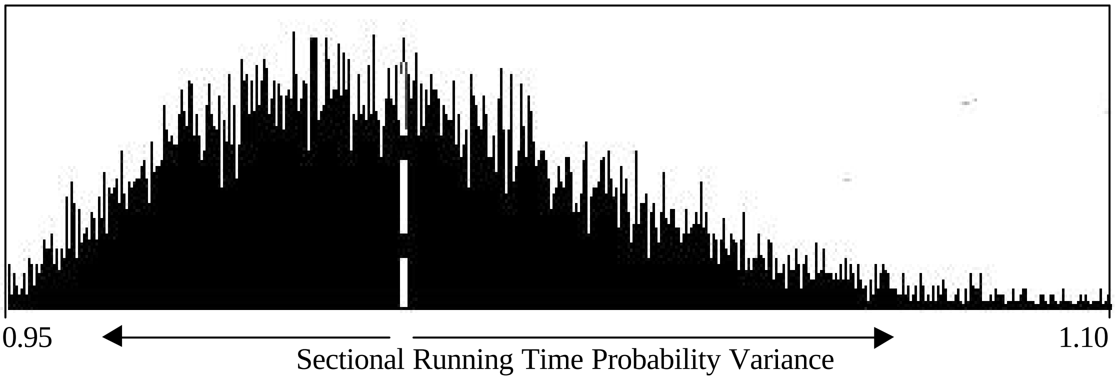
## 8.1 Methodology

The Authority sought independent advice from Maunsell regarding the determination of incremental capacity increases through infrastructure improvements on the Blackwater and Goonyella systems. The Authority then matched those capacity increases with the cost of providing the infrastructure improvements to calculate incremental capacity costs.

The Maunsell brief was to duplicate the results of QR's analysis described in the previous section by simulating train operations using their Planimate simulation tool. Although Planimate is a tool that is designed to simulate actual train running performance as distinct from the theoretical analysis undertaken by QR, the results of the Maunsell simulation were matched by running the same number of trains over the system as QR's factor based method assumed, around 19 coal trains. As well, the total cycle time was held constant.

Unlike the strict sectional running time regime used to determine STPs the Planimate tool applies some variability to the running time situation so that rather than producing an absolute and repeatable set of transit times it produces 'real' train performance that can be expressed as an average situation. The variability in sectional running is influenced by many factors and a distribution of variability is applied on a probability basis. A probability plot of the simulations conducted is shown in Figure 8.1 below. On an infinite number of simulations the distribution would be regular (i.e. be a smooth line). This distribution only takes the below rail variability into account. For actual daily train planning other above rail variability may also need to be taken into account.

*Figure 8.1 Distribution of Sectional Running Time Variability*




Source: Maunsell McIntyre Pty Ltd

An increase in the number of coal trains on both the Blackwater and Goonyella systems was simulated and the delays experienced by those coal trains monitored. The simulations were performed with a background of non-coal movements, 8 per day for the Blackwater system over the Rocklands to Blackwater section and 4 per day for the Goonyella system over the Jilalan to Coppabella section. These are average loadings over the systems with some days experiencing more and some less.

In order to ensure a proper comparison could be made with simulations to be carried out on the improved infrastructure the number of delay minutes experienced by the trains was used as the comparison parameter. Therefore in order to ensure that the new infrastructure improvements actually increased capacity, the number of trains operating was increased in the simulation, until the average delay minutes was reached corresponding to the original infrastructure configuration. The delay minutes chosen ranged between 20 and 40 minutes, the results being reasonably consistent across that range.

Maunsell then used the same 'base' simulation parameters and applied them to a new track configuration that included infrastructure improvements, which were designed to increase the capacity of the systems. In as much as Maunsell found that as long as reference trains were used for the task, little infrastructure improvement for capacity was required for 10 years, the increments identified represent a relatively long term view of incremental capacity costs. However, as tonnage levels rise further, increments in capacity will need to be investigated and other infrastructure solutions found which will require recalculation as to the incremental cost. The general framework developed in section 6 points to incremental costs in the $500 to $1,000 per path range.

Incremental capacity scenarios were developed by aggregating in a stepwise method the infrastructure improvements and the corresponding capacity benefits.

In both systems, the number of trains simulated started at the 10 year forecast coal tonnage levels using the sectional running times of the reference train as the operating base. These tonnage levels correspond to 'expanded' tonnage forecasts where the total Central Queensland railing is approximately 150 million tonnes. This contrasts with QR's original forecast of approximately 125 million tonnes and used as the 'base case' scenario[26]. The use of the 'expanded' tonnage forecasts permits scenarios to be examined where lower tonnage[27] trains may use the system and consume relatively more capacity than the reference train. The current situation on both the Blackwater and Goonyella systems is that on average, the task is performed using smaller trains than the reference train.

For the Blackwater system, the number of trains currently operating is approximately 18 trains (return trips) per day but these trains consist of a lower payload than a reference train. The simulation starts at 16 trains per day, corresponding to the 10 year forecast using reference trains. Any use of trains with lower payload than the reference train will consume more pathways and the actual number of trains will be greater than 16. Hence the simulation examined up to 25 trains so that a variety of operating scenarios likely to develop in the future would be encapsulated.

For the Goonyella system, the number of trains currently run is approximately 22 trains per day and some of these trains consist of lower payloads than a reference train. The simulation starts at 27 trains per day corresponding to the 10 year forecast using reference trains and examines up to 42 trains per day so that a variety of operating scenarios likely to develop in the future would be encapsulated.

## 8.2 Blackwater System

Both QR's and Maunsell's previous analyses indicated that on the Blackwater system, the locations where capacity is constrained were in the vicinity of Boonal to Blackwater and Bluff, Dingo to Tryphinia and Tunnel to Grantleigh.

A diagram of the simulated network is given in Figure 8.2 below

[26] Forecasts of throughput for the Central Queensland coal systems are discussed in Chapter 9 of the Draft Decision.
[27] A lower tonnage train may be one that uses lower capacity wagons or consists of less wagons than the reference train.

*Figure 8.2 Simulated Blackwater Network*

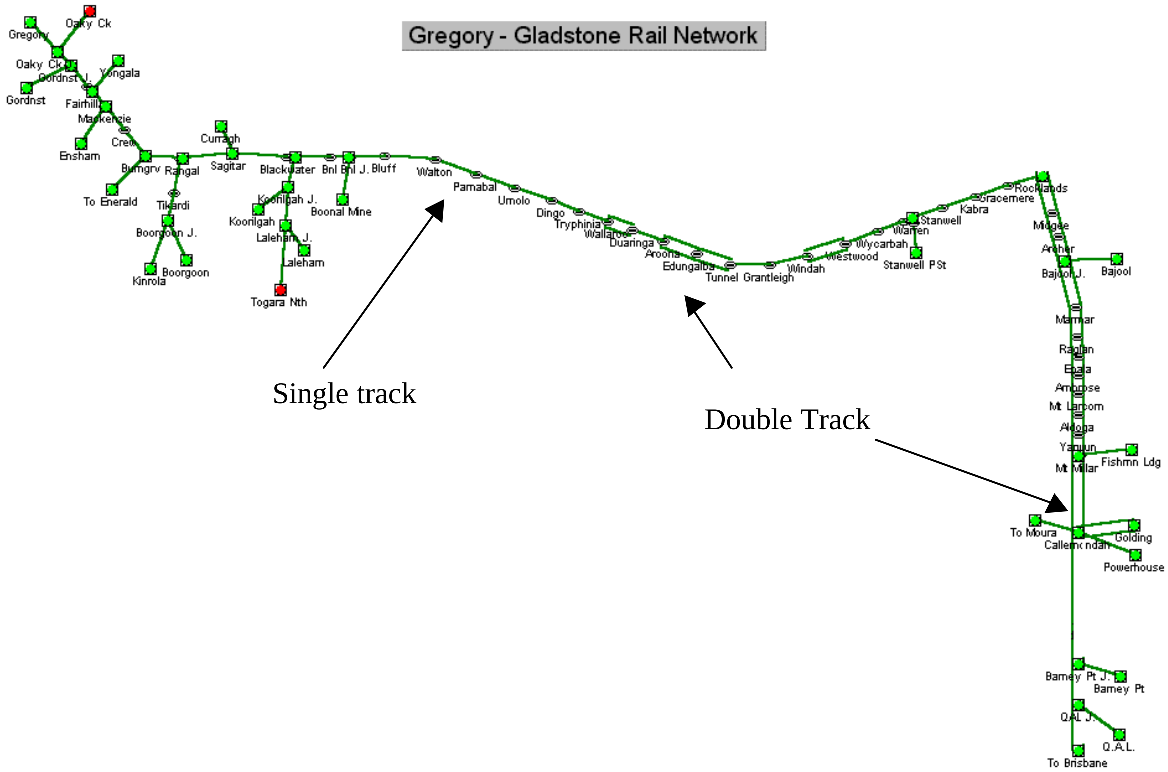



Table 8.1 summarises the increase in capacity brought about by the infrastructure works and the capital needed to undertake the work. Infrastructure improvement costs vary with section of track. Unit cost of works assumptions have been derived from the replacement costs previously identified by the QCA and applying a ‘brownfields’ increase of 20% premium. The projects shown in Table 8.1 are exclusive of one another. Therefore the infrastructure improvements of some of the projects do not result in substantial increases in capacity because other more urgent works are needed first. However this type of analysis does produce a hierarchy for the first increment of infrastructure improvement.

*Table 8.1 Infrastructure Costs and Capacity Increases for the Blackwater System*

| Case No. | Track Section | Method of Infrastructure Improvement | Incremental Capacity Improvement (Paths per Day) | Cost of Infrastructure Improvement $m | Cost per Simulated Path (Per day and annualised) | Cost per STP |
|---|---|---|---|---|---|---|
| 1A | Bluff to Boonal to Blackwater | Duplication 13.833 kms | 12 | $21.6 | $445 | $340 |
| 1B | Walton to Blackwater | Duplication 20.346km | 16 | $37.2 | $575 | $440 |
| 2A | Tryphinia to Dingo | Duplication 10.983kms | 4 | $20.4 | $1,270 | $975 |
| 2B | Walleroo to Dingo | Duplication | 4 | $45.6 | $2,785 | $2,140 |
| 3 | Westwood to Wycarbah | Duplication | 4 | $20.4 | $1,250 | $960 |
| 4 | Tunnel to Grantleigh | Duplication | 2 | $18.0 | $2,195 | $1,690 |

Of the various options considered, the most cost effective increase in capacity would come from the duplication of the Bluff to Blackwater section at an incremental cost of $340 per STP for QR's current operational arrangements. An extra 12 paths are created each day. The paths created are 'actual' paths and not QR STP's because the simulation used by Maunsell deals with 'actual' trains that experience delays and performance variations. QR treats these impacts as factors that are applied to their STP calculation.

Assuming the first increment in infrastructure improvement is complete and then identifying the next constraint derives the next increment in capacity. This increment occurs for the Tryphinia to Dingo section (10.983km) where the duplication of that section at a cost of $20.4m will provide 6 extra paths, at an average incremental cost of $650 per STP. Note that 6 paths are released rather than 4, as in the original assessment, because the first increment in improvement between Bluff and Blackwater creates further opportunity for optimum use of the network.

Whilst the next increment becomes less straightforward, because many different scenarios exist to improve capacity, a typical improvement relates to the duplication between Bluff and Walton, a distance of 6.513km at a cost of $12m providing 6 extra paths at an incremental cost of $385 per STP. The full advantage of the duplication of this section cannot be realised until the Tryphinia to Dingo section is duplicated. Its unit incremental cost appears to be lower than the preceding expansion but this advantage is only gained after the previous expansion.

For the next few increments, a typical incremental cost is approximately $500 per STP. The order in which expansion projects emerge is summarised in table 8.2

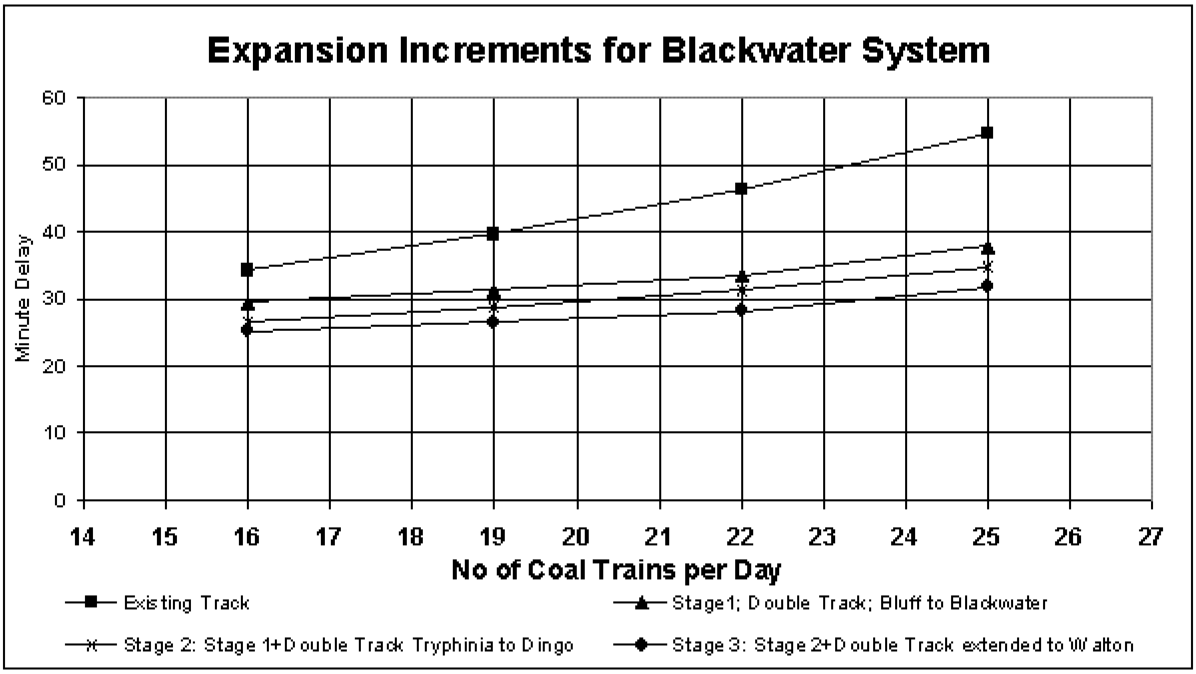
*Table 8.2 Sequence of Infrastructure Works to Increase Capacity*

| Track Section | Method of Infrastructure Improvement | Incremental Capacity Improvement (Paths per Day) | Cost of Infrastructure Improvement $m | Cost per Simulated Path (Per day and annualised) | Cost per STP (Per day and annualised) |
|---|---|---|---|---|---|
| Bluff to Boonal to Blackwater | Duplication (13.833kms) | 12 | $21.6 | $445 | $340 |
| Tryphinia to Dingo | Duplication (10.983kms) | 6 | $20.4 | $845 | $650 |
| Bluff to Walton | Duplication (6.513kms) | 6 | $12.0 | $500 | $385 |

A graphical representation of the improvements to train delays brought about by infrastructure improvements is shown in Figure 8.3

In terms of Standard Train Paths (STP's) the cost per increment in capacity brought about by these infrastructure improvements is somewhat different to the incremental cost for actual train paths because actual trains consume more than a single STP. Loaded coal trains consume a little greater than 1 STP while an empty consumes approximately 1.6 STP's. Therefore the incremental cost of a Standard Train Path is approximately $500 and the cost of a simulated path is $500 multiplied by the average of 1.6 and 1.03 (1.32), or $650.

*Figure 8.3 – Blackwater System Train Delays and Expansion Increments*



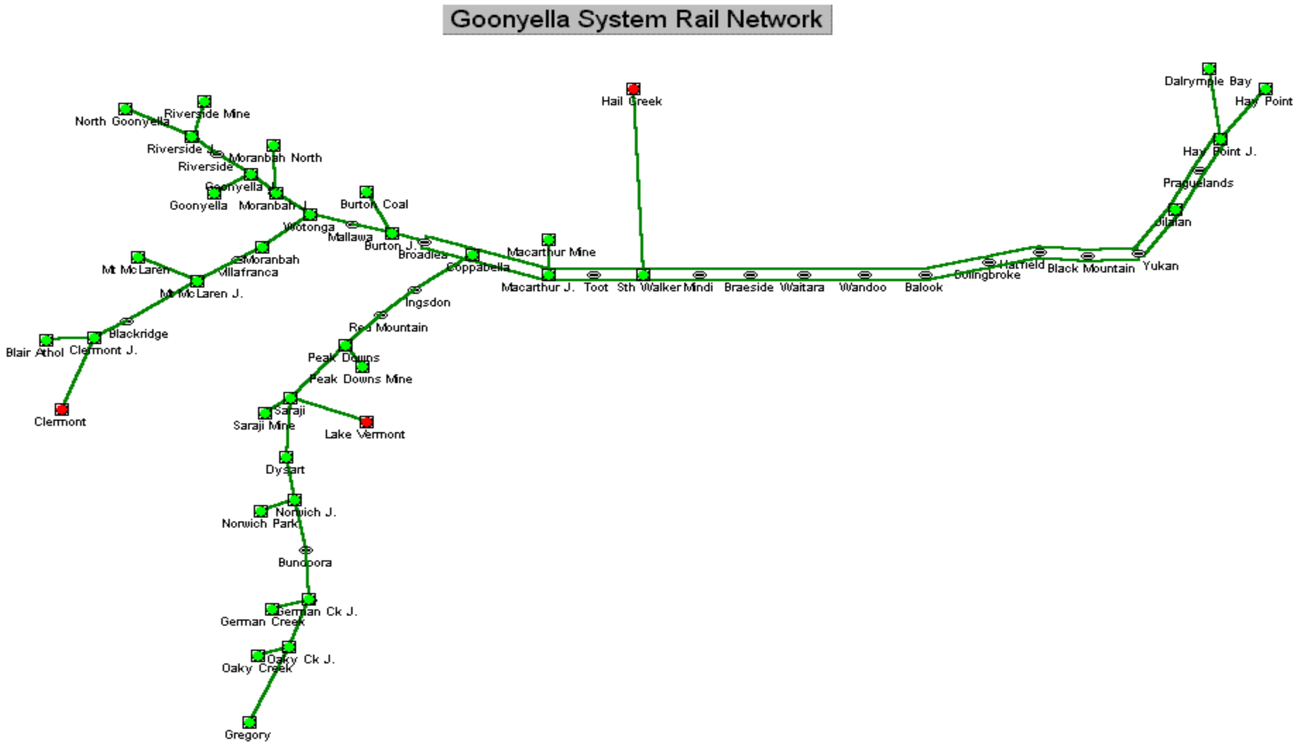

The analysis shows that, as long as reference trains are operated on the Blackwater system, there should be no need to provide for extra capacity within the next 10 years particularly for the ‘base case’ tonnage scenario. However, if greater growth than the base case forecasts occur or if less efficient trains are operated and expansion is needed, then expansion could occur at a capital cost of approximately $20m and provide an extra 12 train paths. Taking all of the incremental scenarios into account on a long term basis, an incremental cost of approximately $500 per Standard Train Path is an appropriate incremental cost of capacity. Accordingly, the costs of QR’s current paths on this basis are approximately $515 per loaded train path and $800 per empty train path.

## 8.3 Goonyella System

Both QR’s and Maunsell’s previous analyses indicated that on the Goonyella system, the locations where capacity is constrained were in the vicinity of Hatfield to Yukan for the loaded train, as well as Coppabella to Ingsdon and Red Mountain to Peak Downs on the southern line. However the Goonyella system is characterised by a signalling system on the duplicated track that has its origins in the original single track layout. The section lengths are those that correspond to the original single track configuration with passing loops and therefore the full benefits of the double track arrangement have not been exploited.

A diagram of the simulated network is given in Figure 8.4 below

*Figure 8.4 Simulated Goonyella Network*




The capacity improvement path is one of continuously shortening the signal sections lengths on the double track section and a considerable amount of this type of work would be undertaken before duplication of single line branches need occur. When duplication of those sections did finally occur, the benefits realised will be much greater than the benefits available now because the double track sections still suffer from the long signalling section lengths.

Table 8.3 summarises the increase in capacity brought about by selected infrastructure works and the capital needed to undertake the work.

*Table 8.3 Infrastructure Costs and Capacity Increases for the Goonyella System*

| Case No. | Track Section | Method of Infrastructure Improvement | Incremental Capacity Improvement to System (Paths per Day) | Capital Cost of Infrastructure Improvement $m | Cost per Path (Per day and annualised) |
|---|---|---|---|---|---|
| 1 | Hatfield to Yukan | Resignaling | 5 | $6m | $300 |

The Hatfield to Yukan section is constraining the operation of the system before the influence of the other sections is felt. Its current configuration restricts the number of trains because the signalling and the grades for the loaded train restricts their operation by way of a prohibitively long headway. The headway or 'gap' between trains is in the order of 26 minutes. Consequently a theoretical maximum of 55 trains per day (1440 minutes divided by 26 minutes) can negotiate the section and this number is reduced by infrastructure events and maintenance. As well, as far as system capacity is concerned, above rail events further reduces the practical maximum capacity.

This type of bottleneck constraint is typical of the constraints that exist on duplicated track and is in stark contrast to single line infrastructure. The consequential effects of the bottleneck are much clearer to see because the interaction between trains is much simpler. For most duplicated track situations a 'soft' path of expansion is available utilising signalling, train control or terminal management systems to improve capacity that, compared to track construction is a relatively cheap expansion strategy.

This signalling improvement is indicative of the improvements needed along the double track section between Coppabella and Yukan. Therefore its incremental rate applies to all trains operating on the Goonyella system until the next increment in capacity is needed.

The next most constraining section on the Goonyella system occurs between Red Mountain and Peak Downs where a 20km length of single track causes considerable delays where trains need to meet at those sidings.

Therefore the next increment in capacity will come about by the construction of a passing loop between Red Mountain and Peak Downs. The passing loop will reduce the length of the section from approximately 20 kms to 10 kms thereby reducing sectional running times. The increase in capacity brought about by the construction of the passing loop is 6 paths, over and above the increases in capacity brought about by the signalling of the first stage increment. The cost of installing the passing loop is estimated at $5m[28]. Therefore the incremental cost of capacity is $210 per path.

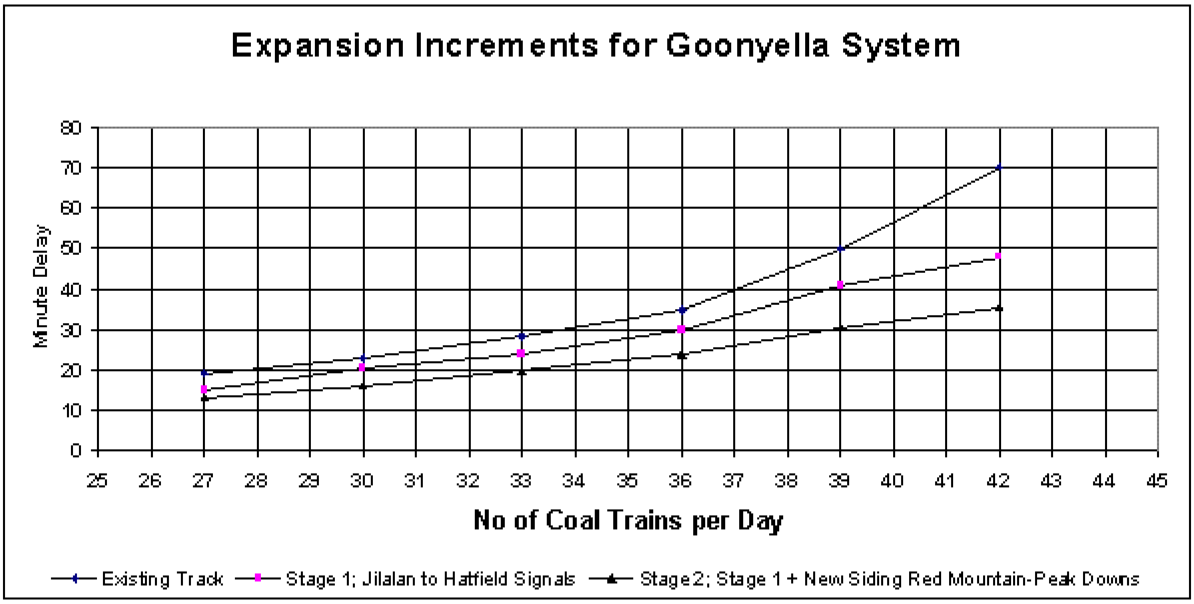
In the Goonyella system there are three clusters, North, West and South. The Northern and Western clusters have capacity well beyond that of the South. Therefore the incremental cost of capacity for the North and West in the timeframe considered for the regulatory period is appropriately the incremental cost for the first increment alone, the signalling improvement near Hatfield at a cost of $300 per path. On the Southern cluster the incremental capacity cost is more appropriately the sum of the first and the second increment, that being $500 per path.

A factor to be considered in the incremental capacity scenarios is the location from which the coal will be originating in the future. In general, mines further from the port will be the origin and it is not surprising that apart from the more general increases in tonnage the trains will be travelling longer distances. These 'branches' start to assume the status of main lines.

A diagrammatic representation of the improvements in Goonyella system capacity is shown in Figure 8.5.

[28] QR estimate

*Figure 8.5 Goonyella System Train Delays and Expansion Increments*




The analysis shows that, as long as reference trains are operated on the Goonyella system, there should be no need to provide for extra capacity within the next 10 years, particularly at the 'base case' tonnage forecasts. However, if higher levels of growth occur, if less efficient trains are operated or extraordinary maintenance occurs and expansion is needed, this could incur a capital cost of less than approximately $12m and provide an extra 5-11 train paths.

The staging of capacity expansion works on the Goonyella system follows the progress indicated and detailed in Table 8.4.

*Table 8.4 Sequence of Infrastructure Works to Increase Capacity*

| Track Section | Method of Infrastructure Improvement | Incremental Capacity Improvement (Paths per Day) | Cost of Infrastructure Improvement $m | Cost per Path (Per day and annualised) |
|---|---|---|---|---|
| Hatfield to Yukan | Resignaling | 5 | $6m | $300 |
| Red Mountain to Peak Downs (South Goonyella) | Passing Loop | 6 | $5.0 | $210 |
| Coppabella to Ingsdon (South Goonyella) | Duplication (11.00kms) | 6 | $16.0 | $730 |

Once again note that the extra capacity brought upon by say the Red Mountain to Peak Downs passing loop is not fully realisable until the earlier bottleneck in the Hatfield to Yukan section is relieved.

Taking all of the incremental scenarios into account on a long term basis, an incremental cost of approximately $500 per actual train path or $400 per Standard Train Path for the Southern cluster is appropriate. On this single track section the actual train path is different to the STP in the same way as occurred on the Blackwater line. On the Northern and Western clusters where infrastructure expansion will not be considered for some time to come and where there is the over-riding influence of the double track section, approximately $300 per path is appropriate. On the double track section the STP and the actual train paths are the same. This consideration along with the existing capacity of the Northern and Western 'branches' suggests that no incremental capacity premium above that for the double track section is warranted.

## 8.4 Moura and Newlands Systems

The Moura and Newlands systems have not yet been included in this review as priority for analysis was given to the systems where the most immediate and likely need for capacity increases will occur.

Nevertheless, the principles developed in the hypothetical examples and the case studies apply equally as well. The Authority will further consider its position.

## 8.5 Transit Times

It is apparent that there are a number of different ways to view train paths and the capacity of a system. A Standard Train Path as used by QR in their analysis presents a theoretical solution and is valuable in the analysis of a system while a 'real' train path provides a basis for an expectation of outcome.

The paths generated by both methods have different time versus distance trajectories. For the purposes of rollingstock asset utilisation a trajectory involving overall minimum travel distance could be the preferred option. While for mine presentation, a trajectory involving minimising empty train transit could be the preferred option.

Therefore the Authority has provided transit times in Table 8.4 generated by the range of approaches so that an operator may judge what may be the best solution for their particular circumstance. Negotiations between operators and Network Access could be expected to produce similar information relevant to the operator's proposed operations.

Table 8.4 indicates various transit times for both the STP approach and the 'Maunsell simulated' approach as well as for the sectional running times only.

*Table 8.4 Transit Times on the Blackwater and Goonyella Systems*

| System - Origin and Destination | Sectional Running Times[29] | Standard Train Path (STP)[30] | Average Simulated Path |
|---|---|---|---|
| **Moura – Callemondah to Moura Mine (Empty)** | 3 hrs 13 mins | Not Available | 3 hrs 42 mins |
| **Moura – Moura Mine to Callemondah (Loaded)** | 3 hrs 47 mins | Not Available | 4 hrs 20 mins |
| **Blackwater – Callemondah to Bluff (Empty)** | 3 hrs 59 mins | 6 hrs 05 mins | 4 hrs 21 mins |
| **Blackwater – Bluff to Callemondah (Loaded)** | 3 hrs 54 mins | 4hrs 40 mins | 4 hrs 13 mins |
| **Goonyella – Jilalan to Coppabella (Empty)** | 2 hrs 13 mins | 2 hrs 13 mins | 2 hrs 17 mins |
| **Goonyella – Coppabella to Jilalan (Loaded)** | 2 hrs 49 mins | 2 hrs 49 mins | 2 hrs 55 mins |
| **Newlands – Pring to Collinsville (Empty)** | 1 hr 25 mins | Not Available | 1 hr 31 mins |
| **Newlands – Collinsville to Pring (Loaded)** | 1 hr 48 mins | Not Available | 1 hr 53 mins |

The table reveals that in the Blackwater system, paths generated where the objective is to maximise the capacity of the system results in significantly increased transit times than the operation of ‘real’ trains over the system. This is because a significant amount of time is lost by trains having to wait at passing loops for other trains approaching from the other direction. In hindsight this means that the passing loops are slightly out of alignment with an idealised system and this causes trains to slow down, stop and then accelerate as they cross other trains on the system. This is not surprising, as the Blackwater system has only recently been upgraded to permit trains to travel at a maximum speed of 80 kph where previously the maximum speed was 60 kph. The design of the system was set some time ago.

On the Blackwater system the ‘average simulated path’ represents a ‘real’ train and consumes 1.6 paths for the empty direction and 1.03 paths for the loaded direction. On the Goonyella system the duplicated track configuration results in the STP path being the same as the ‘real’ train path and there is no extra consumption by the real train. This STP analysis has however not concerned itself with the Goonyella Branches where as train numbers increase similar results to the Blackwater system will eventuate.

[29] Blackwater System Path Utilisation QR August 2000 and Goonyella System Path Utilisation QR September 2000
[30] Blackwater System Path Utilisation QR August 2000 and Goonyella System Path Utilisation QR September 2000

The influence of transit time on the overall system capacity is to vary the number of train consists required for a particular task. In effect, the operator must choose whether to pay more for extra capacity used or to invest in more rollingstock. QR’s present operation involves the consumption of more capacity in order to keep the number of consists to a minimum. The empty train is operated so as to reduce its transit time while the loaded train operates at close to the path of an STP.

In the Goonyella system, the transit times are all close to the aggregate sectional running times because the system is double track between Jilalan and Coppabella. Any variation in running times between the simulated trains and the sectional running times relates to the random nature of train arrivals onto the system and the delays caused by trains running too close to the preceding trains and having to wait for the first train to clear the section. On the parts of the system that are not double track similar issues arise as those encountered on the Blackwater system. From the point of view of rollingstock utilisation, the maximum capacity train planning scenario results in less than optimal transit times. However the effect is less marked than on the Blackwater system because the train densities are lower on those sections.

On the Newlands and Moura systems the simulated train transit time is close to the sectional running times even though the track is nominally single track, because the density of trains and therefore the interaction between trains, is low.

# 9. CONCLUSION

A theoretical framework for the incremental cost of capacity on a railway network has been established.

Hypothetical examples of capacity expansion have been used to determine the profile of incremental capacity costs and to bring into perspective the challenges that are faced by planners wishing to accommodate possible expansion scenarios.

Actual expansion case studies on the Blackwater and Goonyella coal systems have been modelled to determine the likely timing of expansions needed in the context of the forecast tonnages for those systems and the quantum of the incremental costs. These case studies assume a consistent approach to transit times so that as the number of trains increase the transit times of those trains remain constant. This assumes that operators will wish to retain the quality of the service provided by Network Access. If operators are willing to suffer increased delay times as the number of trains increase, then capacity improvements may be able to be deferred.

The results of the simulations conducted and of the hypothecation have been broadly consistent and it is possible to allocate an incremental capacity cost for the consumption of coal train paths according to Table 9.1. The impact of single line operation and the consumption of greater than one STP is evident on the Blackwater and South Goonyella systems. Although West & North Goonyella systems comprise some single track, the impact of capacity increase requirements is well beyond the timing (10 years) of this analysis so that conversion factors have not been applied. An incremental cost of capacity is applicable to these systems because of their use of the double line section that is under capacity pressure.

*Table 9.1 Incremental Cost of Capacity*

| System | Incremental Cost per Standard Train Path[31] | Incremental Cost per Current QR Train Path[32 33] |
|---|---|---|
| **Blackwater[34]** | $500 | $660 |
| **South Goonyella** | $400 | $500 |
| **West & North Goonyella** | $300 | $300 |

Since an STP is an objective and accurate, though theoretical base, from which all trains can be measured against, the STP will be used in the determination of the reference tariff element concerned with incremental cost of capacity. The Authority believes that the best approach is to adopt a standard that is consistent with optimal use of the infrastructure, that is, the consumption of minimal resources to perform a transport task in the long run. The complexity arises in making such a judgement in an environment where competitors' interactions with one another will be critical to their relative performance and the performance of the system as a whole.[35]

The Authority concludes that this approach is appropriate to avoid amongst other things, strategic behaviour by an incumbent that raises entrants' costs.

[31] As defined by QR and detailed in section 7
[32] Reference Train Path and simulated by Maunsell
[33] Taking an STP as the base, an empty QR train would cost approximately $800 ($500*1.6) per path and a loaded train $515 ($500*1.03) per path on the Blackwater system.
[34] Not including trains using the Callemondah to Rocklands section solely.
[35] In this respect, rail differs materially from other natural monopoly industries such as gas or electricity, which involve a homogeneous product in gas molecules or vibrating electrons.

In as much as the construct of the STP standard is QR's, and the evaluation of actual or proposed train paths in terms of the number of STPs consumed can, at this stage, only be performed by QR, it will be necessary for an operator with a proposed train service to submit their details to QR for evaluation.

The process available to operators concerned with a determination as to the impact their specific train may have on system capacity and the consequential incremental cost could take the form of the following set of steps.

1. Determine sectional running time for the proposed train consist.

   This step will require the proponent to simulate the proposed train using a train simulator such as MTRAIN or other suitable calculation method over the sections transited. A realistic train performance and driving profile will need to be used for the simulation taking into account normal driving behaviour and the effects of average ambient conditions. In addition an estimate is required for the times associated with starting and stopping the train consist for the purposes of simulating train passing.

   Alternatively an estimate of the sectional running times could be deduced by comparison with existing consists if the proposed consist is very similar. As well, experience on similar infrastructure could assist in determining order of magnitude sectional running times.

   Most probably a new operator will wish to test a number of different consists to determine their performances and their impact on incremental capacity charges to decide which consist is optimal in a total cost context. QR will be required to provide information to an operator on the simulation results of various options.

2. The operator determines the desirable transit times between the origin and destination for the train service.

   The transit times will provide the operator with information to determine the total cycle time, including mine and port times, and then the number of train consists required for the task.

3. The sectional running times and desirable transit times from mine to port are made available to QR to overlay on the STP standard.

   This step involves QR overlaying the proposed train service which is technically specified by the sectional running times, starting and stopping times and the transit time between the mine and port and back.

4. The comparative running of the new train with the known running of the STP and QR's existing trains[36], provides an STP measure.

   This step involves identifying the paths consumed by the new train that can be judged by inspecting the trajectory of the new train with those of the STP and QR's existing trains. QR has a range of train types operating on the system producing comparative performances.

   These are two dimensions to the assessment of this trajectory, sectional running times and the priority a train is given at a passing location.

[36] Where an existing Blackwater QR empty train consumes 1.6 STPs and a loaded train consumes 1.03 STPs.

A train's sectional running times are determined by the power, braking and weight characteristics of the train. Consequently, an operator can change the sectional running times for its proposed configuration by altering these variables, such as by the addition of locomotive power.

In contrast, a train's priority is determined by the number of times its journey is interrupted by waiting at a passing loop for another train, either to be passed by an opposing train or overtaken by a following train. Accordingly, for a given configuration, sectional running times are constant but an operator could 'purchase' varying levels of priority based on achieving specified transit times for its train's journey.

In arriving at the 'benchmark' path, the STP, QR's own train performance has been used for the individual sectional running times and therefore the STP is somewhat biased in the current status quo. However the priority afforded to the current QR train contrasts sharply with that generated in the calculation of the STP and therefore priority has the greatest influence in the construction of the objective benchmark.

Some caution is needed in this step because, since QR's service is so dominant it has redefined the 'slope' of all of the paths on the system. When one isolated train is then added to the system that train will appear to be at a large variance with those existing trains. As more 'new' trains enter the system, those 'slopes' will be again redefined and will further influence the capacity of the system.

When viewed in isolation a single train that has high priority and high speed will consume many STPs. However when all of the trains on the system have the same characteristic their average consumption may not be much greater than one STP. In travelling between Callemondah and Bluff in 4 hrs 21 minutes, the empty 'real' train would appear to consume 4 STPs by transgressing across 3 STP paths. However, when all of the trains operate in this manner the actual average consumption is approximately 1.5 STPs. Instead of only 22.5 trains (90 divided by 4) being able to operate, approximately 60 trains can operate. The trajectory of the preceding train determines the path consumption of the following train.

Therefore the operator with the greatest number of trains will influence the trajectory of other operators' trains except that as the proportions of trains change, so too will the degree of influence and the resulting consumption. Over time, an operator's train may vary in its consumption simply due to the influence of other trains.

There are several approaches to the determination of consumption:

- assess every train against the objective standard. This would strongly enforce adherence to the "standard" adopted as the most appropriate;

- assess performance against the dominant train, which would provide the incumbent with the "de facto" right of establishing standard operational arrangements for the system as a whole; or

- apply the "minimum trauma" approach, where the operators' train is assessed against both the actual and theoretical train schedule and the lesser number of train paths applied.

The determination of the quantum of consumption of STP's is therefore proposed to be the lesser of the two traumas imposed on either the existing dominant service or on the STP. If an operator proposes a train that has a performance exactly that of QR's dominant train, then it consumes the same as the QR train. If the operator proposes a train that has a performance exactly that of an STP then the train has consumed only one STP even though this train is very different to the existing QR train. An STP train should not be 'penalised' for using the system optimally.

It must be recognised however that the approach can be expected to evolve significantly in the future.

When a train is proposed that is only slightly different from the QR train it will consume more STPs than QR's train even if the trajectory of the train is closer to the STP than QR's train. When a train is proposed that is only slightly different to an STP it will consume more than an STP but not as much as QR's train.

5. Agreement between the access provider and the operator as to an appropriate level of capacity consumption to be allocated to the proposed service.

   The examples given in this paper and the various influences that complicate the issue of capacity consumption have been provided so that an operator can interpret the output from the process of QR overlaying their proposed service onto the existing STP capacity and the dominant train implied capacity. As the configuration of the infrastructure changes so too will the capacity of the system. Also, as the proportion of trains of one particular type changes so will the trauma imposed on the system by the next train type.

   The operator and QR must evaluate the outcome of the simulations in the comparative light of the existing situation; both STP and dominant train service, and jointly reach a determination for the purposes of pricing.

   In the absence of an agreement, the Authority's approach to resolving this issue in a determination is as set out in this paper.

The determination of capacity consumption in objective terms is therefore not a simple matter and reinforces the Authority's intent to ensure that the process of determining capacity consumption is transparent and that operators will be able to embark on planning their services with confidence.

This paper has presented the basic methodology and guidance to operators as to the order of magnitude their trains impact the coal systems in terms of capacity. Trains will be able to be assessed against the 'standard' of the STP. Over time, the number of train configurations and their impact on the system will form a comparative set of performances, so that the relative impact of any new train configuration can be judged against those previously specified.