EVALUATING THE IMPACT OF TRAIN SIGNALLING SYSTEMS ON RAIL NETWORK CAPACITY – A SIMULATION APPROACH

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SUMMARY

Control strategies for trains are a critical part of the design of any greenfield or brownfield rail network. The selection of a control strategy has an impact on the capacity of the network, capital investment required, and ultimately the net present value (NPV) of the project.

In this paper, we discuss the use of discrete-event simulation techniques to evaluate the impact of alternative network control strategies on overall capacity. A case study where simulation techniques have been used to recommend optimal network control strategies is also presented.

Central to the decision-making process on the optimal control strategy is an accurate representation of the signalling impact on system throughput and capacity. Traditional spreadsheet-type calculations provide a useful starting point; however, these do not adequately capture all delays in the system, particularly delays caused by interference between trains. A useful comparison of the impact of different signalling strategies requires a more robust and detailed capacity evaluation approach, which can be achieved using discrete-event simulation (DES) models.

DES models are used worldwide to evaluate the capacity of rail networks. This paper describes a DES based methodology currently being used to support the planning and design for several bulk materials rail projects at various stages of their project life cycles within Australia. The described methodology can be used to assess greenfield or brownfield systems, in some cases with a mix of passenger, general freight and bulk materials traffic. Whilst DES is being used to assess a wide range of infrastructure and rollingstock options, this paper pays particular attention to the selection of a network control system. DES is used to optimise the timing of system upgrades as tonnages ramp over several years from initially low levels to the ultimate forecast tonnages.

1. INTRODUCTION

When planning a rail corridor for transporting bulk materials from one and potentially several new mines, there are many decisions that must be made. A small sampling of these decisions includes the following

- Horizontal and vertical rail alignments
- Standard train configuration
- Specifications of turnouts and points
- Number of, location of, and length of passing loops or duplications
- Network control system

A further challenge is that these decisions need to consider the full life cycle of the corridor. This means the timing of upgrades to various aspects of the infrastructure should be planned during the various design stages.

Key to developing a cost-effective design is the capability to predict system performance for any given combination of infrastructure and operational options. Indicators of system performance include the maximum system throughput, the economic system throughput, and operational delays. DES is the tool that provides the quantitative basis to these predictions allowing the design process to be quantitatively well informed.

The remainder of this paper begins with a glossary of abbreviations used throughout. This is then followed by a section that outlines the typical scope of a DES capacity modelling study follows. The simulation-based methodology is then described, followed by a presentation of the analysis and some concluding remarks.
2. NOTATION
This section outlines abbreviations used throughout this paper:

ARTC  Australian Rail Track Corporation Ltd
BRRT  Below Rail Transit Time ratio
DES   Discrete Event Simulation
ICAPS In Cab Activated Points System
Mtpa  Million tonnes per annum
RailOPS Rail Operations Platform for Simulation
RCS   Remote Control Signalling – also known as colour-light signalling
SLX   Simulation Language with eXtensibility
TPC   Train Performance Calculations
TFP   Trailable Facing Points
TMA   Train Movement Authority
TOW   Train Order Working

3. CAPACITY STUDY SCOPE
Generally, the purpose of a rail capacity modelling study is to demonstrate that the proposed design can deliver a required throughput of trains based on the agreed set of system operating, technical and physical assumptions. Furthermore, the study is used to determine the minimum infrastructure and network control requirements in order to meet agreed future performance levels as system throughput increases through the planning horizon.

This paper will focus on the application to bulk materials rail systems, such as coal and iron ore, but similar methodology can also be applied to the design of passenger/freight corridors.

There are two key decision variables that capacity studies typically focus on:

- staging the construction of passing loops and duplications
- choice of network control system and upgrade schedule

This decision matrix is explored via DES for a range of forecast throughput profiles, typically a low, medium and high profile depending on the number of mines that ultimately become users of the rail infrastructure.

An example of the network control systems that may be considered includes:

- TOW with mechanical TFP
- TOW with ICAPS
- RCS

The remoteness of the bulk materials rail corridors can mean that TOW with mechanical points is a significantly lower cost option since there is no requirement to provide power at the passing loops. However, the impact of additional operational delays imposed on throughput and performance levels must be predicted before taking the low-cost option.

The main differences between network control regimes, from a throughput perspective, include delays incurred and speed restrictions at passing loop locations. For example, under mechanical TOW there are delays incurred for driver operation of points, and speed reductions for drivers to visually confirm the lie of points. For both forms of TOW, there are short delays incurred for TMA protocols. ARTC publishes several publically available documents that provide detailed descriptions of the TOW network control philosophies, hardware and track-side infrastructure [1,2,3].

Accumulation of network control delays results in a reduction in both absolute capacity and economic capacity. In Queensland, BRRT is often used as a key metric for system performance [4]. Within DES capacity analysis, BRRT is calculated individually for each train as follows, and aggregated to an overall system average:

\[
\text{observed transit time + delays} / \text{minimum transit time}
\]

Economic capacity of the rail corridor is taken to be the tonnage throughput at the point where system BRRT was equal to a threshold that is specified as a design parameter. For example, the BRRT threshold for the Blackwater system is 1.27.

4. SIMULATION APPROACH
Predicting system throughput and performance based on a specified infrastructure configuration and set of assumptions is difficult. Static, spreadsheet style models require many simplifying assumptions which fail to capture many of the delays and interferences that naturally occur on real networks. Static analysis often tends to significantly overestimate system capacity.
Other approaches such as explicitly timetabling the system are an improvement on the static analysis, but can fail to capture disturbances due to the stochastic nature of the operation. The timetabling approach also significantly limits the number of alternatives that can be practically considered because of the onerous nature of manually constructing a timetable for every variation of tonnage profile, infrastructure arrangement, network control systems, and business rules.

For capacity studies we have conducted, the most suitable approach was to use DES with dispatching logic, route finding, operational rules, and conflict resolution all encoded within the model. This approach captures operational delays due to train conflicts and avoids the onerous timetabling because inbuilt model intelligence can route trains and resolve conflicts efficiently and without deadlocks.

Before the DES capacity study begins, a TPC study is conducted. The TPC study determines whether train speed profiles over the proposed alignment are within acceptable limits. TPC also allows candidate locations for passing loops to be determined. Candidate passing loop locations will be such that grades and curvatures are within limits for stopping/starting a train, and such that sections are delimited with a reasonably even distribution of section running times.

The difference between a TPC and DES study is that TPC models the movement of a single train on the corridor, focussing only on calculating speed profiles, fuel burn, etc. DES models the network operationally, with many trains interacting with each other over a long time horizon. The DES model can predict the level of normal operational delays primarily resulting from meets and conflicts, which result in a degradation of achievable throughput.

Typically the TPC study is conducted using commercial off-the-shelf packages such as RAILSIM [5]. Output from the TPC study feeds into the subsequent DES study in two ways. Firstly, the candidate passing loop locations are assembled into various combinations to provide a set of infrastructure scenarios. Secondly, the train dynamics data, speed profiles, acceleration/deceleration, feed into the DES to ensure correct timing of movements within the operational simulation.

Figure 1 summarises the process of rail corridor design with simulation as a key component of the process. Outputs generated from both the TPC and DES analysis feed into the detailed design to help optimise the trade-off between minimising capital investment and maximising corridor performance. It is also common for simulation to play a similar key role in taking a project from concept to preliminary design.

![Diagram Figure 1. Summary of simulation in-the-loop design process.]

A proprietary ISO9001 certified rail simulation platform called RailOPS (developed in Australia) is the DES tool we use for rail network capacity analysis. RailOPS has played a role in a wide range of rail infrastructure projects in locations including Queensland, New South Wales, Western Australia, New York, California, and Indonesia.

5. SIMULATION ANALYSIS

When conducting a simulation analysis, it is necessary to define the range of simulation scenarios to be investigated. A simulation scenario is defined by the combination of track infrastructure, network control system, rolling stock fleet and tonnage profile. Large simulation projects can present results collated from several hundred individual simulation scenarios.

Figure 2 shows a typical example of simulation results generated as part of a larger rail design project. This chart is taken from an actual project, with details obscured to honour a commercial confidentiality agreement.

The x-axis of this chart shows the year of operation, with forecast throughput plotted as
the solid series. Forecast throughput is an input to the simulation analysis, and is shown ramping from initial levels to the ultimate forecast tonnage as the mines increase their production over time. The set of dashed series are plotted against BRTT on the secondary y-axis. These series show the system average BRTT against tonnage/year of operation.

Rather than construct the corridor to handle the ultimate tonnage from day one, it is prudent to delay the injection of capital into infrastructure development with an informed strategy. After constructing a minimal baseline corridor design, infrastructure upgrades would be periodically carried out on the corridor in response to ever-increasing tonnages without compromising required levels of performance.

Upgrades to the corridor may include upgrading the network control system from TOW to ICAPS and RCS, or constructing additional passing loops or duplications. DES can be used to determine potential schedules for upgrading the corridor’s capacity by constructing more infrastructure. Simulation scenarios should be configured to represent specific combinations of track infrastructure and network control. The DES model then simulates each scenario over a range of target tonnages to determine corridor performance in response to increasing tonnage levels. Plotting the performance curves for each scenario against the forecast year, allows potential upgrade schedules to be traced directly onto the graph.

Figure 2 provides an example of how a potential upgrade schedule can be plotted on a performance curve graph. The upgrade path shown is purely reactive and is intended as an illustration rather than representing the most economical upgrade schedule. Note that each point marked on the performance curves corresponds to a single simulation run for one year of operations at the specified tonnage level.

The reactive upgrade schedule begins with a three loop mechanical TOW system which experiences a fairly high rate of performance degradation as tonnage increases. This is mainly due to the significant delays incurred through manual operation of points. The threshold for acceptable BRTT is shown as a horizontal line across the chart.

At the time that BRTT is exceeded, the upgrade schedule switches to a three loop ICAPS arrangement which achieves an acceptable performance level for a longer period of time. In reality, due to the short period of time that mechanical TOW would be in operation, commissioning ICAPS from day one would likely be a more economical option.

The upgrade path then introduces an additional passing loop for a four loop ICAPS configuration. This is followed by the introduction of RCS, and finally the move to a seven loop RCS configuration.

Based on a tonnage growth forecast, these corridor upgrades can be mapped to specific points in the operational time horizon. Alternatively, the upgrade triggers can be expressed as tonnage levels rather than specific points in time.

The potential savings in capital costs resulting from quantitatively informed, targeted development of infrastructure, and future upgrades, are significant. Furthermore, quantitatively informed selection of infrastructure reduces the risk of the system underperforming once constructed.

A simulation model on its own is of limited value. It is a tool, and the value added to a project depends on how the tool is used. Simulation is at its most useful when it can paint a complete picture of the design landscape. To do this, it must be capable of evaluating many combinations of design alternatives, and capable of capturing enough operational detail to allow comparison between subtly different options.

The real value a simulation model adds to a project is the analysis that it is applied to. However, there is danger of misleading or false results if that analysis is not conducted with the...
required scientific rigor. For example, a commonly overlooked aspect of simulation analysis is verifying statistical convergence of the results. The time horizons for simulations we have conducted for capacity studies are typically between one and 10 years of operations. Statistical convergence analysis is conducted to ensure that system averages have reliably converged to a steady-state well within the simulation time horizon. Longer time horizons are used when it is required to model long period disturbances such as unplanned failures. Many rail simulation tools in the market are computationally inefficient and therefore do not have the capability to run such long time horizons.

6. OTHER SIMULATION OUTPUTS

In this section, some additional simulation outputs are demonstrated. RailOPS by default creates extensive log-files which describe every train movement in minute detail. For typical simulation runs (e.g. several years of operations) on large networks (e.g. Moura/Blackwater), these log files can amount to gigabytes of data.

A number of post-processing tools have been developed to extract a wide range of statistical analytics from the log files. The post-processing tools, which help to visualise the dynamics playing out within the simulation are important for validating the simulation. Train charts are useful for visualising operations over a period of time and give a quick impression of the pattern of movements and where delays are occurring. An example of this is shown in Figure 3 for a simulated day of operations.

There are two separate animations created for each simulation run. The most informative animation is the schematic animation, which resembles the monitor displays in any network control room. This animation shows schematically, the positions of trains, the sections of track those trains have authority over, the lie of points and the states of signals. Figure 4 gives a sample screenshot of the schematic animation.

In parallel to the schematic animation, a 3D animation to-scale is generated. The scale animation is particularly useful when the train length in relation to track length is having an influence on system dynamics. Figure 5 gives a sample screenshot of the 3D animation.

7. CONCLUSIONS

This paper has described how the use of DES as a key component of rail infrastructure design projects provides for quantitatively-informed decision-making throughout the design process. This type of analysis has been particularly insightful as it highlights the differences in system performance between a

![Figure 3. Sample train chart post-processed from simulation log-files.](image1)

![Figure 4. Screenshot of schematic animation.](image2)

![Figure 5. Screenshot of 3D to-scale animation showing a train stopped at a signal waiting for a pass.](image3)
range of track infrastructure and network control options. Evaluation of performance allows for an informed decision on the best alternatives and appropriate timing for system upgrades.

8. REFERENCES

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[2] Points, version 1.2, Australian Rail Track Corporation Ltd

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