MTRAIN SIMULATION SOFTWARE AS AN AID TO SIGNAL DESIGN

Alex Chivers, B.Eng (Civil) (Hons)
Alex Wardrop, BSc (Hons), BEngSc
TMG International (Australia) Pty Ltd

SUMMARY
The design of signalling systems as an iterative process is data intensive, time consuming and possibly difficult to cover all operating situations. Generally, a signalling system needs to meet specific headway requirements that are not necessarily confined to the normal routing of trains but may include wrong road working and partial routes.

MTRAIN train performance and signal simulation software can be used as a signal design aid to test the adequacy of a signalling layout in meeting headway and braking distance requirements. Moreover it allows several signalling options to be verified relatively quickly.

Iterations in the signalling design can be tested in minutes once the track, vehicle and signal data is established in MTRAIN. The modification of input signal data between iterations can also be performed in minutes (at most hours depending on the complexity of the system and the number of changes). MTRAIN allows testing of signal layouts in significantly less time than manual methods.

The Auckland suburban railways are used as a case study to demonstrate how MTRAIN can be used to test signalling arrangement modifications to provide increased line capacity.

INTRODUCTION
MTRAIN is a numerical model used for the examination of train performance under any signalling system. Variables that can be tested include track gradient and curvature, signalling aspect sequence and headway variations, speed limits and station locations.

The signalling capabilities in MTRAIN include the simulation of up to six proceed aspects, the measurement of braking distances for various train types, and signal clearance times behind a train for headway and capacity analyses. Signalling responses can be simulated through various permanent or temporary speed limits, or signal passing speeds for trains passing restricted aspects, such as those employed throughout Australia and New Zealand.

The software is not expressly for interlocking design but may need to take into account interlocking issues as they might affect headways.

Results from signalling simulations are available in graphical and text based format for analysis. The effect of various signalling layouts on performance criteria can be analysed relatively quickly. MTRAIN can thus be used as an aid to signal design by reducing the time between design iterations.

Passenger and freight operations on the North Island Main Trunk (NIMT) line in Auckland New Zealand are used to illustrate the inputs and outputs required to test signalling arrangements which aim to increase line capacity.

1. MTRAIN REQUIREMENTS AND CAPABILITIES

MTRAIN train performance and signal simulation software requires several data inputs to perform simulations which aid signal design. Firstly, track geometry data is necessary to describe the section of railway over which signals are to be analysed. The required railway characteristics in the track geometry description are shown in Figure 1, and include

- Location
- Grade
- Curvature
- Datum adjustments
- Wayside features
- Speed Limits
- Signal data
Calculations within MTRAIN are distance based in 10 metre increments and rolling stock performance is obtained from tractive effort, dynamic or regenerative braking effort, rolling resistance and air brake effort curves. This information is input into MTRAIN for each simulation together with information on the routing and stopping patterns of selected train types, in what is known as a run file. A run file can include temporary speed limits which can be used to test the effect on traffic of a change in speed, either an increase or decrease, to one or more sections of the network.

MTRAIN can aid signal design in several ways. The tool can be used to measure the effect on braking distance for various train types for signal layouts. MTRAIN can also determine signal clearance times behind a train, the longest of which on any route represents the limit of stable headway for consecutive trains of the same type. Signal layouts may be tested on existing or new configurations and several signalling options can be verified relatively quickly using MTRAIN.

MTRAIN can simulate six proceed aspects representing a composite of Australian and New Zealand signal displays, i.e.

- Conditional
- Low Speed
- Warning Medium Speed
- Caution
- Medium
- Clear

Up to 14 aspects may be cleared at a single location, such as a junction.

MTRAIN is not limited to these aspect assignments, however convenient they may be for routine train performance and signal system simulation. If the user ignores the inbuilt aspect name assignments he/she can model alternative aspect sequences within the constraint of six proceed aspects. For example, NSW has introduced a Preliminary Medium aspect between existing Medium and Clear displays. The operational impacts of such an aspect could be explicitly modelled by sacrificing the (non-NSW) Warning Medium Speed display and displacing the Caution and Medium displays.

By the same process the Conditional clearing of two-aspect signals in the London Transport fashion if a train is proceeding slow enough can be modelled by assigning intermediate displays to successive conditionally cleared signals.

However, any computer model, including MTRAIN, is only as good as the data input into it. In the area of signal design some care and attention needs to be directed towards properly describing the geometric layout of the railway as well as accurate representation of signal layouts. The algorithms within MTRAIN have and continue to be tested against actual results so it is regularly benchmarked against actual train performance and revised to reflect field experience when necessary.

Figure 2 shows the process of data input to and resulting output from MTRAIN.
2. SIGNALLING DATA REQUIREMENTS

MTRAIN requires specific information on signalling layout and behaviour. In addition to a signal name, the locations of each signal and the locations where corresponding signal aspects change are required by MTRAIN. This signalling data can be input into MTRAIN in two ways. One method is to record the signalling characteristics along a continuous baseline, in the same way a train would see the signals and pass the signal clearance points. Generally this method is used for setting up signalling data in MTRAIN and is shown in Figure 3. The second method of signalling data input is to list each signal, its location and all associated signal aspect change locations in a discrete module. The modular signal data format is shown in Figure 4. Minor changes in signalling layouts can be quickly altered in the second signal data format. However, it is recommended that more significant modifications be carried out using the continuous signalling data format.

Data in continuous format requires conversion to the modular format shown in Figure 4 for inclusion in the MTRAIN track geometry file. Programs within the MTRAIN suite can be run to switch the signalling data format from one to the other. This permits quick formatting of changes to signalling layouts and simultaneously conducts a check on whether a complete set of functional signal data is provided.
### Figure 3: Continuous Signalling Data Input (Method 1)

<table>
<thead>
<tr>
<th>Local signal clearing point chainage in metres</th>
<th>Up to 8 character signal name</th>
<th>Cleared Aspect Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>643690 64372</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>645390 PAP1</td>
<td>2</td>
<td>1Y</td>
</tr>
<tr>
<td>646540 PAP2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>647250 PAP3A</td>
<td>4</td>
<td>2Y 1G</td>
</tr>
<tr>
<td>647490</td>
<td>3</td>
<td>2G</td>
</tr>
<tr>
<td>648330 64832</td>
<td>5</td>
<td>4Y 3G</td>
</tr>
<tr>
<td>649010 64902</td>
<td>6</td>
<td>5Y 4G</td>
</tr>
<tr>
<td>650400 65038</td>
<td>7</td>
<td>6Y 5G</td>
</tr>
<tr>
<td>652150 65216</td>
<td>8</td>
<td>7Y 6G</td>
</tr>
<tr>
<td>653960 65396</td>
<td>9</td>
<td>8Y 7G</td>
</tr>
<tr>
<td>655540 65554</td>
<td>10</td>
<td>9Y 8G</td>
</tr>
<tr>
<td>656990 WIR24</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>657270</td>
<td>10Y 9G</td>
<td></td>
</tr>
<tr>
<td>657730 WIR23A</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>657920</td>
<td>11Y 10G</td>
<td></td>
</tr>
<tr>
<td>659100 65912</td>
<td>13</td>
<td>12Y 11G</td>
</tr>
<tr>
<td>660600 66060</td>
<td>14</td>
<td>13Y 12G</td>
</tr>
<tr>
<td>661670 66168</td>
<td>15</td>
<td>14Y 13G</td>
</tr>
<tr>
<td>662830 66282</td>
<td>16</td>
<td>15Y 14G</td>
</tr>
<tr>
<td>663770 OTA63</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

Local datum adjustment in metres. Blank in this case indicating there are no datum adjustments

Signal sequence number (ascending order) up to 3 digits

### Figure 4: Modular Signalling Data Input (Method 2)

<table>
<thead>
<tr>
<th>Signal name</th>
<th>Low speed clearing point location</th>
<th>Caution clearing point location</th>
<th>Clear clearing point location</th>
</tr>
</thead>
<tbody>
<tr>
<td>64372</td>
<td>643690 0 0 0</td>
<td>645390 0</td>
<td>646700</td>
</tr>
<tr>
<td>PAP1</td>
<td>645390 0 0 0</td>
<td>646700 0</td>
<td>647490</td>
</tr>
<tr>
<td>PAP2</td>
<td>646540 0 0 0</td>
<td>647490 0</td>
<td>648330</td>
</tr>
<tr>
<td>PAP3A</td>
<td>647250 0 0 0</td>
<td>648330 0</td>
<td>649010</td>
</tr>
<tr>
<td>64832</td>
<td>648330 0 0 0</td>
<td>649010 0</td>
<td>650400</td>
</tr>
<tr>
<td>64902</td>
<td>649010 0 0 0</td>
<td>650400 0</td>
<td>652150</td>
</tr>
<tr>
<td>65038</td>
<td>650400 0 0 0</td>
<td>652150 0</td>
<td>653960</td>
</tr>
<tr>
<td>65216</td>
<td>652150 0 0 0</td>
<td>653960 0</td>
<td>655540</td>
</tr>
<tr>
<td>65396</td>
<td>653960 0 0 0</td>
<td>655540 0</td>
<td>657270</td>
</tr>
<tr>
<td>65554</td>
<td>655540 0 0 0</td>
<td>657270 0</td>
<td>657920</td>
</tr>
</tbody>
</table>

Conditional clearing point location

Warning clearing point location

Medium clearing point location

Takes the form of nnnA where “nnn” is a signal sequence number and “A” is the code for a proceed signal aspect.

The permitted aspect codes are:
- “C” – Conditional
- “L” – Low Speed
- “W” – Warning Medium Speed
- “Y” – Caution
- “M” – Medium
- “G” – Clear

A record is required for each distinct signal aspect cleared at the current local chainage. Cleared aspects must be presented in descending order of signal sequence number.

**Note:** All locations are shown in metres
3. CASE STUDIES

In the case studies that follow trains are run between Papakura and Westfield, south of Auckland, on the North Island Main Trunk (NIMT) line in New Zealand. Three signalling cases are provided to demonstrate how line capacity can be expanded to accommodate an increase in passenger services and illustrate the braking distance, signal clearance and headway capabilities of MTRAIN. The first case represents a base case where signalling is arranged for through freight traffic. The second case introduces additional signals to handle stopping passenger trains and increasing line capacity without removing freight access. The third case provides the operational requirement of Case Study 2 but delivers it on better terms.

The track configuration, alignment and dwell times (all 30 seconds) are the same in each of the Case Studies. Only the signalling layouts are altered.

### 3.1 Case Study 1: Signalling for Through Freight Trains

The Auckland Regional Transport Authority (ARTA), in conjunction with the New Zealand rail infrastructure owner, ONTRACK, is undertaking a programme to provide a significantly increased level of rail passenger services throughout the Auckland region. The North Island Main Trunk Line (NIMT) between Britomart and Papakura is a key corridor for both freight and passenger services, but historically the signalling system has been set up for non-stopping freight and long distance passenger movements. Case Study 1 looks at the headways achieved by the present three aspect signalling and how this affects the ability to introduce increased frequencies of stopping passenger services.

It is important to know how the geography of an alignment affects the performance of trains running on it. In particular, grades affect the stopping distance of trains and therefore signal spacing.

![Figure 5: MTRAIN Track Geometry between Papakura and Westfield Showing Freight and Passenger Train Performance](image-url)
For train performance calculations braking is assumed to be effective once the application delay has been consumed. There is an implied assumption that application delay is absorbed within the normal operation of the train.

For the calculation of braking distances the user can apply two different delays. The first delay is the power lead time to take account of the fact that a certain amount of time has to elapse before the train is coasting after powering. The second delay is brake lag which is the additional time for the brakes to become effective once it is assumed the train is coasting. Calculation of the distance to stop then incorporates the distance the train travels when in transition from powering to coasting plus the distance from coasting to full braking plus the distance to come to a stand from the current speed at the end of coasting. Both delay times are parametric user inputs, each with a maximum value of 9.9 seconds and defaults of zero and two seconds respectively.

More detail on braking distances is available in a tabular format, particularly where trains pass signals at danger.

Signal headway can be determined using MTRAIN by simulating various train types that use a given section of railway and analysing the signal clearance times behind each train.

Signal subsets can be specified to test the ruling headway on sub sections of a particular railway. For example, the railway between Papakura and Westfield may be divided at Wiri. MTRAIN will then report the headway between Papakura and Wiri (i.e. signals PAP3A to WIR24), and the headway between Wiri and Westfield (i.e. signals WIR23A to 66506).

Figure 5 shows the performance of two trains in each direction on the NIMT route between Papakura and Westfield. One train is an 800m long locomotive hauled freight train with 1100 tonnes trailing load limited to 80km/h. The other train is a two-car diesel multiple unit (DMU) passenger train limited to 90km/h. Train performance information is available as both graphic and text based outputs from MTRAIN.

The effect of grade can be seen between Te Mahia and Manurewa, in the Auckland bound direction, with the freight train unable to maintain a maximum speed of 80km/h.

The braking distance of trains under the Case Study 1 signalling layout were tested using the MTRAIN train performance and signal simulation tool. Both service and emergency braking were tested. For example, using the freight and passenger train types above, a non-stop train service between Papakura and Westfield was simulated. The respective brake rates of the freight and passenger trains are 0.3 ms⁻² and 0.67 ms⁻². The braking distances of the two trains were calculated and can be presented in tabular or graphical format. Figure 6 illustrates the braking behaviour of the two trains, where the freight train stopping distance is labelled “A” and the passenger train stopping distance labelled “B”.

For calculation of braking distances the user can apply two different delays. The first delay is the power lead time to take account of the fact that a certain amount of time has to elapse before the train is coasting after powering. The second delay is brake lag which is the additional time for the brakes to become effective once it is assumed the train is coasting. Calculation of the distance to stop then incorporates the distance the train travels in transition from powering to coasting plus the distance from coasting to full braking plus the distance to come to a stand from the current speed at the end of coasting. Both delay times are parametric user inputs, each with a maximum value of 9.9 seconds and defaults of zero and two seconds respectively.

More detail on braking distances is available in a tabular format, particularly where trains pass signals at danger.

Signal headway can be determined using MTRAIN by simulating various train types that use a given section of railway and analysing the signal clearance times behind each train.

Signal subsets can be specified to test the ruling headway on sub sections of a particular railway. For example, the railway between Papakura and Westfield may be divided at Wiri. MTRAIN will then report the headway between Papakura and Wiri (i.e. signals PAP3A to WIR24), and the headway between Wiri and Westfield (i.e. signals WIR23A to 66506).

Note: A refers to limit of freight train stopping distance, B refers to limit of passenger train stopping distance

Figure 6: Case Study 1 Braking Distance Under Service Braking between Papakura and Westfield
As an example of how MTRAIN can be used in determining the signal headway, four trains in Figure 7 are run between Papakura and Westfield allowing the signals to separate them. The trains are staged as a non-stop freight train (Train A), a non-stop passenger train (Train B), a limited stop (Train C) then an all stops passenger train (Train D). Note that the front and rear of each train is shown. However, this is only obvious on the long freight train due to the scale of the graph.

The tabular results of the Case Study 1 headway test timetable measured between signal PAP3A at Papakura and signal 66506 at Westfield are shown in Table 1. The ruling headway refers to the maximum full clear clearance time for the signals within the given subset. Absolute clearing time refers to the longest time to reach the first restrictive aspect in any of the signals within the signal subset. Operating headway is the first time at which at least 85% of all signals have cleared to full clear. The 85th percentile is a rule of thumb to account for the majority of signals clearing to full clear but with a few having only reached caution or medium but generally on the approach to a station stop. It is to give timetablers some idea of the headways they could work to in planning train services, depending upon how delay sensitive they are.

Further details are provided after each simulation including the time and distance travelled between stations or nominated timing points and maximum and average achieved speeds.

<table>
<thead>
<tr>
<th>Train</th>
<th>Non-stop freight train (Train A)</th>
<th>Non-stop passenger train (Train B)</th>
<th>Limited stop passenger train (Train C)</th>
<th>All stops passenger train (Train D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruling Headway (sec)</td>
<td>206</td>
<td>214</td>
<td>402</td>
<td>477</td>
</tr>
<tr>
<td>Absolute Clearing Time (sec)</td>
<td>127</td>
<td>117</td>
<td>233</td>
<td>248</td>
</tr>
<tr>
<td>Operating Headway (sec)</td>
<td>188</td>
<td>158</td>
<td>278</td>
<td>338</td>
</tr>
</tbody>
</table>

Table 1: Case Study 1 Headway Test Results between Papakura and Westfield

![Image of Time Distance Graph of Train Travelling between Papakura and Westfield for Case Study 1]
3.2 Case Study 2: Signalling for Through Freight and Stopping Passenger Trains

The objective of signalling changes for Case Study 2 is to reduce the headway and reduce the variation between signal clearance times to meet the headway requirement for freight and the new headway requirement for passenger services. To do this Case Study 2 introduces a fourth aspect to close signals to below the braking distance of freight trains (minimum 823 metres plus 10% for error on level tangent track).

In addition to meeting headway requirements the new signalling arrangement must meet braking distance requirements. As for Case Study 1, a freight and passenger train were modelled to determine whether their braking distance is within that provided by the signalling layout. The resulting braking distance is shown in Figure 8. Neither train over-runs any signal.

Under the modified signalling layout the ruling headway behind the all stops passenger train is reduced by over four minutes. The comparison between Case Studies 1 and 2 shows how the signalling layout and number of aspects can have different impacts on headway. Figure 9 and Table 2 indicate the improvement in headway of Case Study 2 compared with Case Study 1.

Aside from the signal layout design time, the input and processing time required to deliver the results below are estimated to be available within several hours.

![Figure 8: Case Study 2 Braking Distance Under Service Braking between Papakura and Westfield](image-url)
Table 2: Case 2 Headway Test Results between Papakura and Westfield

<table>
<thead>
<tr>
<th>Train</th>
<th>Non-stop freight train (Train A)</th>
<th>Non-stop passenger train (Train B)</th>
<th>Limited stop passenger train (Train C)</th>
<th>All stops passenger train (Train D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruling Headway (sec)</td>
<td>142</td>
<td>131</td>
<td>183</td>
<td>215</td>
</tr>
<tr>
<td>Absolute Clearing Time (sec)</td>
<td>91</td>
<td>88</td>
<td>112</td>
<td>112</td>
</tr>
<tr>
<td>Operating Headway (sec)</td>
<td>128</td>
<td>98</td>
<td>173</td>
<td>188</td>
</tr>
</tbody>
</table>

3.3 Case Study 3: Economic Signal Layout for Through Freight and Stopping Passenger Trains

On long sections where trains run at speed the section clears quickly. Under such circumstances it is possible that a four aspect sequence is wasted where a three aspect sequence will meet safety and operational requirements. The fourth aspect is, however, needed when trains approach station stops.

While this is not the case here, Case Study 3 investigates rationalising the signal layout to provide the equivalent operational requirement of Case Study 2 but more efficiently.

Originally the aim was to reduce the number of signals needed to achieve the Case Study 2 headway. However, Case Study 3 does result in an operational benefit of reduced headway with the same number of signals as Case Study 2 but many have been kept as three aspect signals rather than extended to four aspects.

Table 3 indicates the improvements in headway gained through modifying the signal locations.
Case Study 3 demonstrates that, depending on the layout, improvements in headway can be achieved with the same number of signals. Better performance through reduced headway is achieved without an increase in the number of signals in the layout.

Again, the input and processing time to derive the Case Study 3 results above are estimated as several hours. Minor signal relocation changes could be tested within an hour, particularly in the case of moving a signal to meet braking distance criteria if there is only a slight over-run.

A particular set of trains were used in the case studies. This analysis could easily be done with different or additional trains. However, the selection of trains to test signal layouts needs to reflect the best available information on a realistic traffic mix. The current trend is to increase train length while possibly maintaining the power to weight ratio.

The process of signalling design changes because a signal designer can use MTRAIN to test the efficacy of layouts much quicker than manually calculating and plotting layouts. Design compliance can be tested as the designer proceeds, creating a better feedback loop in the design process. MTRAIN also allows the designer to modify the design where it might not have initially been modified. Overall, MTRAIN makes it easier to refine signalling layouts resulting in a better design process.

Note that signalling layouts will still be compromises. The designer can make educated guesses about what types of trains might be using a stretch of railway 5-10 years hence. However, reading the future gets trickier further out. Yet, wayside signalling often has a considerable life way past that of the foreseeable train technology using it. There certainly have been examples of signal layouts with lives of 70 years or more simply because they have managed to accommodate changes in train technology.

4. CONCLUSION

MTRAIN train performance and signal simulation software can be used as an aid to signal design to test the adequacy of a signalling layout in meeting operational requirements, and allows several signalling options to be verified relatively quickly. Generally, signalling designs are over fixed alignments. After setting up the alignment detail in MTRAIN, signalling design layouts can usually be input and tested in a matter of hours to determine whether they meet headway and braking distance requirements. Signalling designs that nearly achieve design requirements and only require minor modification can be verified in even less time.

The case studies of Auckland described in this paper show how MTRAIN can be used to test signalling arrangement modifications to provide increased line capacity.

5. ACKNOWLEDGMENTS

The Authors would like to thank Mr Simon Wood of ARTA for permission to use the Auckland network as a case study in this paper. The Authors’ example signalling arrangements in the case study do not necessarily reflect actual or proposed arrangements of ARTA, ONTRACK or other agencies involved with the Auckland rail network.