INTELLIGENT TRAIN MONITOR DEVELOPMENTS

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SUMMARY
This paper will report on the developments of the Intelligent Train Monitor (ITM) which is a product of an ongoing research and development program between the Centre for Railway Engineering at Central Queensland University and QR through its QRNational Coal business. Papers have been presented at previous CORE and other conferences on the earlier research that has led to the development of the ITM in its present format. Currently there is a single prototype operating in a coal electric locomotive operating in the Blackwater coal system. The results from the ITM confirm earlier work that significant savings in energy consumption are available with optimum driving practice. The results also show that the force predictions have a high degree of correlation with the actual forces experienced along the train.

1. INTRODUCTION
Initial research into train dynamics between QRNational and the Centre for Railway Engineering grew out of need to educate train drivers about the in-train forces occurring throughout the length of long trains, particularly the coal trains operating in Central Queensland. A number of derailments were attributed to the train driver’s actions of braking and throttle control. It was established that there was a culture among some train drivers to drive according to “feel”. That is, managing the in-train forces by responding to the force experienced by the driver in the locomotive. Extensive research by the Centre for Railway Engineering (CRE) using instrumented couplings was undertaken, some of the results of this early work are presented in [1], [2], and [3]. This early research identified that the lead locomotive experienced the least amount of in-train force than any other position in the train. Consequently, the idea to develop a monitor to predict train forces was born.

The Intelligent Train Monitor (ITM) is a screen-based device that reports and predicts the forces in the train to the driver. The algorithms were developed from research using a small number of instrumented wagons and computer models. These algorithms can deliver predictions 50 seconds into the future. Extensive consultation determined that for this application the most appropriate output was a minimalist approach. This means that the display shows the driver what the forces are and what they will be but does not give advice on optimum brake and throttle application.

The initial work involved eight research areas.
- Train Testing Program
- Coal wagon instrumentation
- Freight wagon instrumentation
- Longitudinal modelling
- Energy usage monitor
- Advanced dynamic analysis and train control optimisation
- Intelligent Train Monitor

Previous papers have explained in detail the workings of the ITM in [4], [5] and [6]. This paper will recap briefly the earlier work and expand on that work by describing the developments in the past two years.

2. PROJECT CHALLENGES
The original prototype was installed in an electric locomotive originally built in the 1980s. These locomotives use analogue gauge technology in the driver’s cabin therefore transducers were used to bring conditions such as brake application, throttle setting, and speed into the ITM computer. This locomotive fleet is in the process of a half-life rebuild which includes the use of displays in the cabin to replace analogue gauges. A new version of the ITM prototype needed to be developed to suit the rebuilt locomotive.

It seemed appropriate to use the information on the locomotive computer data bus for the ITM...
rather than retro fit transducers to the locomotives. To do this a change to the locomotive software was necessary to present the required information to an external port ready for connection to the ITM. All stakeholders were in agreement with this approach, however, making this happen presented some challenges. Firstly, a contract variation was sought with the supplier to do the software amendment. This was agreed to, however scheduling that work brought the second challenge. Was QR prepared to delay work on the main locomotive upgrade project to have this work done? Clearly the answer to this was, ‘no’. The installation needed to be completed without affecting the rebuild program. Finally, the amended software needed to undergo rigorous type-testing. The type-testing of the software was scheduled to be completed in the same testing program as other software changes at an unspecified date in the future. As an interim measure, transducers were retro fitted so that the development work could continue.

From a project management perspective, getting access to the locomotive for installation proved to be very difficult. In addition to the locomotives out of service for scheduled maintenance, the locomotive upgrade program meant that operational locomotives were at a premium. On top of this the resources boom required QR to increase the coal tonnage. These issues meant that access to a valuable locomotive for a small development project was very low on the priority list. The final decision was made to fit the ITM to a locomotive that was being upgraded at the QR Rockhampton Workshop. This solution was deemed the best for both QR and CQU.

3. LOCOMOTIVE INSTALLATION

The Intelligent Train Monitor was installed in a locomotive in October 2007 and commenced field testing in the middle of November 2007. A photograph of the locomotive during commissioning is shown in Figure 1.

Figure 1: ITM Equipped Locomotive

Figure 2 shows the driver’s controls. The ITM display is on the far left. The type of display used was the same as the other two displays used for the normal locomotive operation. This is beneficial in that the drivers are already familiar with the type of display and there is no need to carry spares of a different type of display.

Figure 2: ITM Display (on far left)

The computer used in the ITM system is installed under the bench behind the driver. A facia was added so the installation would match the locomotive’s interior, as shown in Figure 3. One of the aims of the installation was to integrate the ITM into the locomotive as seamlessly as possible.

Figure 3: ITM Computer Installed Behind Facia

Figure 4 shows a general schematic of the current installation. The shaded items indicate the additional equipment installed into the locomotive. The throttle and brake pressures are measured using external transducers. The GPS position is supplied by the existing GPS receiver and antenna.
on the locomotive. The ITM display is linked to the ITM computer using Ethernet, which provides a reliable low noise connection. A modem and antenna was fitted to the prototype so that data could be easily and frequently obtained during the testing phase.

Future installations of the ITM will be based on the simplified system shown in Figure 5. The system only requires two components, the ITM display and the ITM computer. The throttle and brake control information will be obtained from the locomotive computer data bus. This information is forwarded through the ITM display to the ITM Computer. The ITM does not need a modem to operate, so the modem has been omitted from the design of future installations. It would be still possible to connect a modem, which would allow remote monitoring of the ITM system. Future designs could be further simplified by incorporating the display and ITM computer into one unit.

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**Figure 4: Current ITM Installation**

**Figure 5: Future ITM Installations**
4. SYSTEM OPERATION

The main role of the Intelligent Train Monitor (ITM) is to provide drivers with past, present and future information on the longitudinal dynamics of the train. It also provides information on the current and future track geometry and energy usage. The main aim being that drivers improve their driving styles to best minimise train dynamics and energy usage.

The ITM software is modular in nature and so the display layout can be readily modified to provide the most relevant information to the driver. The layout of the current ITM display was described in [5] but is repeated here for completeness. An example output of the display is shown in Figure 6. The ITM display has five main areas these are marked on Figure 6 and described in the following text.

Area 1a and 1b, shows both past and future longitudinal coupler forces at five positions in the train. Each position in the train is represented by an individual trace. The past 50 seconds of forces are shown in the dark area (1a) labelled ‘History’. The future 50 seconds of predicted forces are shown in the light grey area (1b) labelled ‘Future’. The current point in time is where the history and future areas join.

Area 2a and 2b – Similar to the coupler force information, this section shows the past and future speed of the train. Area 2a shows the past speed and Area 2b show the future predicted speed.

Area 3, shows an aerial view of the track and train. The thick line represents the train with the dot indicating the position of the lead locomotive.

Area 4, shows the grades the train is currently traversing. Again, the thick line represents the train with the dot indicating the position of the lead locomotive. This provides the driver with an indication of approaching grades and the grades currently under the train.

Area 5, shows the energy usage of the train’s locomotives. Current energy usage is shown as a sliding bar and cumulative energy usage is displayed as a number. The driver can reset the cumulative energy by using one of the displays function keys. This feature enables drivers to compare energy usage for different trips. This feature’s aim is to help drivers identify which driving strategies produce the lowest energy usage.

Figure 6: ITM Display Example
5. FIELD TEST RESULTS

This section presents data collected by the Intelligent Train Monitor while it has been operating during normal haulage operations in the Blackwater Coal System. The Blackwater Coal system is in Central Queensland and carries coal from the Emerald region to the port located in Gladstone. The train configuration for this operation has two head-end locomotives, 48 wagons, two remote locomotives, and 48 wagons. Each wagon is 106 tonnes when loaded, giving a maximum train mass of over 10,000 tonnes.

Currently data is recorded for a 160km section of track for each haulage trip. This track section is common for all trains operating on the Blackwater Coal System. As the train configuration and track section remains constant this allows the comparison of different trips.

5.1 Reduction in Energy Consumption

One of the aims of the ITM is to reduce energy consumption. In the new installation, the ITM display was not available for drivers for a continuous length of time that would enable a reliable indication of fuel savings. By the time of the presentation more data on the energy consumption will be available. Figure 7 shows the energy consumption of loaded trains on the same section of track. While the trains are of the same mass and length the energy consumption varies.

The data from empty trains is not accurate enough to be used for comparison, as it is uncertain when the remote locomotives are used. It is standard driving practice for the remote locomotives to be disabled for empty trains. Currently the ITM does not receive throttle levels of the remote locomotives. The ITM is equipped to receive the remote locomotive data but it requires a change to the locomotive software as mentioned earlier. This feature will be enabled in the near future, which would allow the accurate calculation of energy usage for all driving practices.

5.2 Reduction in Coupler Forces

The ITM is designed to reduce the longitudinal coupler forces in the train by supplying force information to the driver. The effectiveness of the display will be seen as the drivers are made more aware of the response of the train over the route’s track topography. In this way, the driver is continually learning about the behaviour of the train. It is believed that a well trained driver will drive the train smoother with lower longitudinal coupler forces. Ideally a fatigue damage score would provide a means to quantify improvements. Due to the limited exposure of drivers to the ITM, the reduction in coupler forces cannot be quantified at the time of the finalisation of this paper.

5.3 Predicted Speed Accuracy

The ITM displays a prediction of the train speed up to 50 seconds into the future. This prediction assumes that the locomotive controls will remain constant for the next 50 seconds.

5.3.1 Speed prediction example

A plot of the predicted speeds overlayed on the actual speed for a data block of 700 seconds long is shown in Figure 9. In this time period the driver kept the driving controls constant.

The predicted speed for 10 seconds into the future is the most accurate. The 50 second prediction has the greatest error and is within 10kph of the
actual speed for the majority of the time. In the figure, the oscillation of the 50 second prediction about the actual speed can be traced back to rolling resistance adjustments made in the prediction. It is believed that these oscillations can be reduced significantly in the future to provide a predicted speed accuracy of better than 5kph.

5.3.2 Speed prediction frequency distributions

The accuracy of the predicted speed for all the measured data is similar to that shown in the previous figure. The comparison of predicted speeds to actual speed for a whole train trip is shown in Figure 10. Only results are shown for data when the locomotive controls were held constant. While the amount of data makes it difficult to see, the comparison between predicted speed and actual speed is similar to that shown in the previous figure, Figure 9.

To investigate the accuracy of the speed prediction over a longer time, data from six loaded trips were used and the error between predicted speed and actual speed was presented in a frequency distribution, Figure 11. The vertical axis uses a logarithmic scale to show the very small frequencies of errors greater than 10kph. For this figure, the data used was only for when the locomotive controls was held constant which is expected to provide the best accuracy. The data when the locomotive was stationary was also omitted. From the figure, the 10 second and 20 second speed predictions had an accuracy better than 10kph. The 50 second prediction had an accuracy of better than 10kph for 95% of the time. This shows that the ITM prediction method is sound.
In normal operation the locomotive controls will not be held constant for the entire trip. Inaccuracies will occur in the future predictions when the locomotive controls are changed. The error in predicted speed was analysed for the complete data set of six loaded trips, irrespective of whether the controls are held constant or not. This provides an indication of the accuracy of the ITM displayed to the driver for the entire trip. The resulting error distribution is shown in Figure 12. This shows that the speed prediction up to 20 seconds remains accurate to better than 10kph. The error in the 50 second speed prediction increases slightly so that 88% of the time the prediction is better than 10kph. This result is quite encouraging in the fact that even though the ITM assumes that the controls will stay constant the prediction shown on the ITM display is still relatively accurate.

5.4 Predicted Force Accuracy
One of the major functions of the ITM is to show drivers the future and past longitudinal force information. Similar to the speed predictions the future force predictions are based on the assumption that the locomotive controls will remain constant.

5.4.1 Force prediction example
To show the accuracy of the force prediction a section of recorded data was extracted where the locomotive controls was held constant for a loaded train. The GPS map of the track section for this data is shown in Figure 13. It is about 10km in length and contains a number of curves about 800m in radius. The train starts on the left and travels to the right in the direction shown.

The elevation of the sample track section is shown in Figure 14. The train encounters a relatively constant grade of 1%. During the whole time the throttle is held at 100%.

The speed of the train through the track section is shown in Figure 15. The train approaches the track section at 74kph and due to the grade slows down to 47kph by the end of the track section.
The force prediction displayed on the ITM is for five positions in the train:
- 0% : behind the lead locomotives;
- 25% : in the middle of the first set of wagons;
- 50% : behind the remote locomotives in the middle of the train;
- 75% : in the middle of the second set of wagons;
- 100% : the coupler force of the last wagon.

The predicted forces at 10, 20 and 50 seconds are shown for each of the five positions along the train, Figure 18. The predicted forces match very well to the actual forces (force: 0 seconds) determined by the ITM shown by the thin black line.

The dynamics that occur from 100 seconds to 250 seconds in the train at positions 25%, 50% and 75% down the track are produced by the negative grades in the middle of the track section. It is interesting to note that these dynamics are not observed at the 0% position, which is the head of the train. This highlights the fact that the driver of these long trains will not feel the full effect of the dynamics in the train. This is one benefit of the ITM, in that, the driver will be made aware of what is occurring throughout the whole train.

With the development of supporting software it would be possible that using a desktop computer the driver could re-drive the same train configuration over the same section of track. This means that the driver would be free to try a number of alternative driving methodologies in an attempt to reduce the longitudinal train forces. Because this is done on the desktop computer, there would be no possibility of damaging a real train.

5.4.2 Force prediction frequency distributions

To present the overall accuracy of the predicted force information, data from six trips were combined into a frequency distribution. Only taking data where the locomotive controls was held constant will show the accuracy of the prediction. Six trips were analysed and 10, 20 and 50 second predictions were compared to the forces finally determined by the ITM. The forces could not be compared to the actual longitudinal coupler forces, as these are not measured on the test train. Previous research at the Centre for Railway Engineering has showed that the prediction of forces correlate well with actual forces measured in field tests, [8].

The data for all the train positions shown on the ITM display were combined into a single frequency distribution in Figure 16. This provides an indication of the accuracy of all the train positions combined. As with the previous frequency distributions shown in this paper, the vertical axis uses a logarithmic scale to show the smaller frequencies of errors. The figure shows that the force prediction for 10 and 20 seconds is accurate to 100kN for 99% of the time. The 50 second prediction is accurate to 100kN 97% of the time. The accuracy displayed indicates that the ITM is predicting the longitudinal train forces well.

In a similar way, the predicted forces for all the data was compared to the final force determined by the ITM. This provides an indication of the accuracy of information displayed to the driver even when the locomotive controls are not held constant. Data from six loaded train tests were combined in a frequency distribution that included all five train positions, Figure 17. Data recorded when the train was stationary was not used in the analysis so it would not bias the results.
Figure 18: Predicted Force Comparison
As expected the accuracy for all the data was lower than in data where the locomotive controls were held constant. The 10 and 20 second predictions are accurate within 100kN for 97% and 93% of the time respectively. The 50 second prediction is accurate to 100kN for 83% of the time and is within 200kN for 96% of the time. This shows that for normal operation where the locomotive controls are not held constant, the force information displayed to the driver is of a suitable accuracy for an in-cabin display.

6. FUTURE DEVELOPMENTS

The ITM system will continue to be trialled in the installed locomotive. In addition, the ITM will be installed in a further two different locomotive types and used in normal haulage operations. Review and further development of display format will occur as more input from the drivers is received. This will increase the usefulness of the ITM display providing drivers with the most relevant information about the train’s behaviour.

7. CONCLUSION

Overall the ITM system has performed well in the field trials. The hardware has performed very well, operating continuously since its installation.

The speed prediction displayed on the ITM is of a reasonable accuracy, further development will see the accuracy improved. Force prediction has been shown to be of a high accuracy. Through the field trials, collection of more data will enable the quantification of savings in energy and savings due to the reduction of longitudinal dynamics.

The software platform used in the ITM is flexible and is able to display a variety of information in many different forms. This will enable comments from train drivers and operators to be quickly incorporated into the system.

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9. REFERENCES