Remote Temperature Monitoring to Manage Rail Infrastructure during Hot Weather.

Nicholas Keogh[1]

The risk of track buckling during hot weather has traditionally been managed through the inspection of track for misalignments and restricting the speed of rollingstock when certain temperature thresholds are exceeded. Aurizon's 'Hot Weather Precaution for Track Stability' Standard formalised these temperature thresholds for different type of track structures and operating environments. However, obtaining temperature information involves weather stations that are on average 96 kilometres apart or single observations using hand held devices. As such, most heat-based speed restrictions imposed in CQCN span entire networks for long periods of the day to conservatively manage the risk of insufficient data.

For the summer of 2019/20, Aurizon Network is trialling a continuous stream of localised temperature data through installation of remote autonomous temperature monitoring devices installed approximately every 20 kilometres throughout its Central Queensland Coal Network.

Each device is capable of relaying ambient and rail temperature at high frequencies, thereby providing the ability to only inspect or restrict track that has met the appropriate thresholds. The streams of temperature data are collated into their respective maintenance districts and summarised into a series of automated alerts and live dashboards thus allowing inspections or speed restrictions to be targeted to only where they are required. This will increase the visibility and granularity of the weather conditions in the Central Queensland Coal Network, resulting in fewer restrictions during extreme conditions while appropriately managing below rail assets.

Keywords: IoT Internet of Things remote monitoring automated rail temperature

1 Introduction

Aurizon Network Pty Ltd is the below-rail operator for the CQCN (Central Queensland Coal Network), which consists of the Moura, Blackwater, Goonyella and Newlands systems devoted primarily to coal traffic. The mines connected to the CQCN provide coal to 5 export ports and a small number of internal consumers. The rail network consists of 2,817.38km of track infrastructure of which it owns or acts as the Rail Infrastructure Manager.

The risk of track buckling during hot weather has traditionally been managed through the inspection of track for misalignments and restricting the speed of rollingstock when certain ambient temperature thresholds are exceeded. These thresholds are documented in the standard, SAF/STD/0075/CIV/NET Hot Weather Precaution for Track Stability. This standard specifies the temperature thresholds of which track inspections and speed restrictions are to be imposed according to track materials. Historically temperature information involves weather stations that are on average 96 kilometres apart or single observations using hand held devices. This data results in most heat-based speed restrictions being imposed on long sections of the Network, or for a whole System, or the entire CQCN for long periods of the day to manage the risk. At present, only Air Temperatures are considered with no thresholds given for rail temperature.

To improve the management of the below rail assets during extreme weather conditions, it is necessary to improve the visibility and granularity of the weather conditions in the Central Queensland Coal Network, allowing targeted controls with respect to duration and location. To achieve this objective, a trial to capture the rail and ambient temperatures throughout CQCN between October 2019 to March 2020 has been progressing.

The concept for the trial was to install remote temperature monitoring devices adjacent to track, with each device having a wired thermometer attached to the adjacent rail via magnets as well as a second thermometer measuring ambient air temperature. Each device will transmit its ambient and rail temperatures at scheduled intervals so that these temperatures can assist in imposing heat base speed restrictions. 100 devices were planned to cover the network.

[1] N. Keogh
Aurizon, Brisane, Australia
e-mail: nicholas.keogh@aurizon.com.au

This trial commenced on Friday 02/12/2019 and the purpose of this document is to detail:

- The devices and configuration used to gather the data;
- The locations of the Devices to maximise coverage;
- The reporting and notifications to Users of compliance alerts;
- Validation and comparison with the 10 BoM Weather Stations throughout the CQCN;
- Analysis of heat-based speed restrictions of this summer against pervious summers in terms of duration of imposed restrictions, total delay minutes and number of delayed services.
- Any issues encountered with the devices' performance or with their data being used correctly; and
- Next Steps for the Remote Temperature Monitoring Program.
    - Establish relationship between ambient and rail temperature for each station
    - Establish thresholds for inspections/restrictions based on rail temperature.

Aurizon's SAF/STD/0075/CIV/NET – Hot Weather Precautions for Track Stability Standard (Livingston, 2012) sets the minimum requirements for the safety provisions to be imposed in hot weather to control the level of risk resulting from track misalignments on the CQCN.

1.1 Background

Historically, Maintenance Districts monitor and receive air temperature predictions from Major Centre Sources. These predictions are used to assist in programming of track work, inspections and formulating advice to traffic operations with respect to the need to impose speed restrictions. This advice differs from depot to depot. The Air Temperature data is received in the following ways:

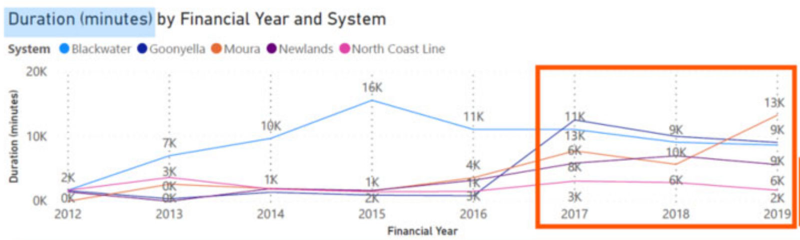
- Information direct from the local weather station via Bureau of Meteorology (BoM);
- A thermometer in a screen cabinet at maintenance depots;
- Published advice from the media (newspapers, radio, TV);
- Direct from the Bureau of Meteorology; or
- Output from Remote Weather Stations.

The Maintenance District is expected to regularly access the information to determine the need to under-take hot weather patrols or advise traffic operation of the need to apply speed restrictions. What typically happens however is a restriction is put in place earlier in the day on the assumption that a predicted maxi-mum temperature will be achieved.

When the temperatures reach a certain temperature, or threshold, Speed Restrictions must be imposed. The extent of the restriction, period the restriction is to apply and the speed restriction imposed is communicated to the rele-vant train controller who advises the relevant train crews. Blanket speed restrictions are usually imposed over a complete section, by commencing and terminating at defined station locations at the ends of these sections. Dif-ferent thresholds and speed restrictions exist for different track structures, depending on the ballast profile and sleeper material.

Historically, as the Maintenance Districts have relied on a common temperature device to make the decisions for their whole district, speed restrictions of substantial length and period have been imposed conservatively to manage the risk of track misalignment. This leads to large restriction durations as well as delay minutes of revenue services as the restriction is imposed an sections of track much longer that is required.

Historic data of heat restriction imposed has been collated. Figure 1 illustrates Duration (total time in minutes) that a system was placed under a heat restriction over the past 8 financial years.



Financial Year	Blackwater	Goonyella	Moura	Newlands	North Coast Line	Total
2012	2K	2K	0K	1K	2K	6K
2013	7K	0K	3K	0K	4K	14K
2014	10K	1K	2K	2K	2K	17K
2015	16K	1K	2K	2K	1K	21K
2016	11K	1K	4K	3K	2K	20K
2017	11K	13K	8K	6K	3K	40K
2018	9K	10K	6K	7K	3K	35K
2019	9K	9K	13K	6K	2K	38K
Total	74K	37K	37K	27K	18K	192K

Figure 1: Summary of Previous Years' Speed Restriction Durations

There has been a steady increase in duration of heat restriction and delays, most notably in the last 3 years where rail stress related incidents have led to a significant focus on rail stresses has caused a conservative change in behaviours with respect to temperature driven restrictions.

At eight specific locations, costly weather/environmental monitoring equipment has been installed on the CQCN Rail Network to monitor rainfalls, temperature and landslips at locations where environmental incidents have been experienced and thus have influenced the behaviour of the infrastructure. With the evolution of network machine to machine communication or the "Internet of Things", and improvements in the resilience and cost of equipment involved, new remote monitoring devices can be used to further these initiatives to drive further efficiencies into normal day to day activities.

To assist in moving trains faster for longer, Aurizon Network is currently using data obtained from Remote Monitoring Temperature devices throughout the CQCN with the objective of changing how heat-based speed restrictions are imposed in the CQCN. This aligns with the Corporate objective to deliver bulk commodity transport solutions for customers.

2 Remote Monitoring Temperature Monitoring Trial

The goal of the trial which aligns to corporate objectives is to reduce the impact on traffic of the heat-based speed restrictions using latest monitoring technology and communications, by positively influencing both the times the restrictions are imposed & removed as well as reducing the overall distance of track they are imposing.

The first stage of the project is to drive consistency through the maintenance districts' imposition of heat-based speed restrictions by giving them a single source of temperature. Previously, each district used different thresholds, temperature sources and overall methodology in imposing restrictions which led to overly conservative blanket restrictions of the CQCN. Therefore, the output is to:

- Spatial aspect: Focus restrictions only to be imposed where they're required, rather than entire systems or even networks;
- Removing restrictions when temperatures have dropped below thresholds rather than simply giving an arbitrary time (eg 8pm, which by then the temps have most likely been below threshold for quite some time).

2.1 Sensor Selection

Heat based speed restrictions are typically imposed on large sections of track using different sources of data. To provide a single source of temperature data, sensors are required to assist in these types of restrictions being imposed with a data driven approach to reduce their impact to operations.

When determining the sensor to use, the following criteria needed to be met:

- Measure ambient and rail temperatures at frequencies dependant on the data it collects;
- To be completely self-contained and self-powered;
- Have an adequate lifecycle with little to no maintenance requirement;
- Simple to install, attach to the rail and marked easily;
- Simple to remove and reinstall for maintenance activities; and
- Interfaces with existing communication systems for easy data flow and presentation to users and be current.

2.2 Remote Temperature Monitoring Device

mIoT is a company that has offers a comprehensive range of Internet of Things (IoT) data logging technology suitable for providing solutions to measure, monitor and control the entire ecosystem. For the trial, Aurizon Network has worked with mIoT to adapt the Captis sensor (mIoT, 2020) into a stand-alone capable of measuring Ambient Air and Rail Temperature and that meets the above criteria.

The mIoT Captis Range is a ruggedized remote monitoring device; that is completely self-contained with an approved IP68 case and self-powered by multiple batteries. The device is expected to remain operational for at least two years with no maintenance during their lifetime.

2.2.1 Description of the mIoT Device

The mIoT Captis data logger is a passive, self-powered, cellular, remotely configurable device that is capable of reading data from a range of sensors and then transmitting captured data periodically. Each device has been configured with two temperature sensors.

The first sensor is to measure ambient air temperature without influence from other environmental factors such as sun radiation or wind. This is achieved by mounting the sensor in a vented hood that seeks to provide the sensor with a consistent environment within which to record data in.

The second sensor measures rail temperature through direct contact with the web of the rail. The sensor is installed within a bespoke magnetic housing whose surface is curved to match the web of Aurizon's rail, ensuring consistent contact with the rail while being able to be removed for maintenance purposes. Figures 2 and 3 display both sensors respectively.

As the trial is only focused on monitoring ambient and rail temperatures either is high enough to pose a risk of track instability, the Captis device has the capability of measuring and sending data at two different frequencies that are dependent on a customisable threshold. This was implemented primarily as a battery saving strategy so that temperature data was being supplied at a high frequency when it was required and at a low frequency when it was not. These frequencies are given in Table 3.

Figure 4: mIoT Captis Range device mounted to a Star Picket. The vented hood houses the ambient temperature sensor.

Figure 3: mIoT Captis Range Sensor attached to Rail

2.3 The Proposed Trial

The proposed use of the mIoT Sensor is to trial its ability to record ambient and rail temperatures of the Central Queensland Coal Network (CQCN) accurately and consistently across a range of locations. It was proposed that, on average, an mIoT Captis device was to be installed every 10km to 15km of track throughout the entire CQCN. This equates to approximately 100 mIoT devices being installed. The data received from each of the devices is to be pro-cessed and presented to Aurizon staff to support decisions that involve temperature information.

Each device faces a risk of:

- Not being installed correctly or being damaged during installation.
- Being damaged while installed through track activities such as rail replacement, mechanised production plant, road vehicles traversing the access road, rail grinding or derailed rollingstock.
- Unexpected and/or premature failure of a device such as its internal battery losing its charge ahead of schedule
- Producing uncalibrated data that's higher or lower the actual ambient/rail temperature, leading to unnecessary speed restrictions or rail stress issues

Each of these risks may lead to the device producing inaccurate data, the device experiencing a shorter life than expected or the trial ending prematurely if the produced data cannot be used as intended. As a means of managing the risk of unexpected/premature failures, only 90 of the 100 devices will be initially installed with 10 kept as spares that can be used to replace any defective devices.

2.3.1 Identified Requirements for the Trial

The device would be deemed suitable for Aurizon requirements if it is capable of:

- Transmitting rail and ambient temperature data at intervals determined by Aurizon and that change based on established criteria;
- Having sufficient battery power to facilitate operations and data transmittal for 2 years (projected); and
- Not suffering from more than 10% loss of overall number of installed devices within 6 months.

2.3.2 Evaluation Methodology of the Trial

The evaluation of trialling the mIoT devices would involve using several approaches:

1. Direct comparison of mIoT Captis ambient temperature and BoM ambient temperature

10 mIoT devices' locations will be determined such that they will be in proximity to existing Bureau of Meteorology weather stations. By directly comparing the ambient temperatures recorded by each pair of devices and compared to the BOM weather stations, the accuracy of mIoT's ambient temperature readings can be evaluated. A summary of these locations and distances is provided in table 2.

Table 1: Summary of IoT and BoM devices to be used for validation

BoM Weather Station	IoT Location	Distance (km)
Gladstone Airport	Callemondah	1.728
Emerald Airport	Nogoa	4.543
Blackwater Airport	Burngrove	5.349
Rockhampton Aero	Rocklands	8.258
Bowen Airport Aws	Pring	8.498
Moranbah Airport	Moranbah	8.559
Clermont Airport	Blair Athol	15.159
Rolleston Airport	Rolleston	16.774
Thangool Airport	Dakenbah	17.273
Mackay Aero	Daly Bay Jct	22.386

2. Direct comparison between mIoT Captis rail and ambient temperatures

As each device will be on average 10 – 15 km from its nearest neighbour, it's intended that each device will have two independent ambient and rail temperatures to compare against its own recorded data.

An engineering assessment will be conducted as data is captured to identify and rectify anomalies in each location.

2.4 IOT Locations and Installation

2.4.1 Locations

Initial proposed locations were based primarily on creating an even coverage of devices throughout the entire main-line CQCN, such that devices would be spaced approximately 15 kilometres apart.

The above locations were then correlated against a range of existing track conditions as a means of ensuring each device is positioned optimally, by considering:

- each mainline grade over a rolling 1600m block to represent the length of a train, then identify locations where loaded trains would be anticipated to impart high amounts of friction to the rail. This includes but was not limited to extended descents and signals that experience high amounts of traffic, both of which would require pneumatic braking to be applied. The majority of these locations were driven by their potential for generating heat separate to what ambient temperature is responsible, mostly through wheel/rail adhesion;
- the location of fixed-point assets within proximity of the proposed location, such as level crossings, bridges and turnouts; and
- locations that have a documented history of rail stress related tack instability.

Table 2: Summary of Temperature Sensors per Maintenance District

District	BoM Stations	IoT Stations
Merinda	Bowen Airport, Moranbah Airport	16 devices between Abbot Point and North Goonyella.
Moranbah	Clermont Airport, Moranbah Airport, Emerald Airport	18 devices between South Walker Junction, Oaky Creek, Blair Athol Mine and North Goonyella Mine.
Jilalan	Mackay Airport, Moranbah Airport	11 devices between Hay Point and Hail Creek inclusive.
Blackwater	Emerald Airport, Blackwater Airport, Rockhampton Airport	16 devices between Dingo, Minerva, Rolleston and Oaky Creek.
Gracemere	Blackwater Airport, Rockhampton Airport, Gladstone Airport.	16 devices between Dingo and Yarwun
Gladstone	Gladstone Airport, Biloela Airport.	13 devices between Yarwun and Moura Mine
District	BoM Stations	IoT Stations
Merinda	Bowen Airport, Moranbah Airport	16 devices between Abbot Point and North Goonyella.
Moranbah	Clermont Airport, Moranbah Airport, Emerald Airport	18 devices between South Walker Junction, Oaky Creek, Blair Athol Mine and North Goonyella Mine.
Jilalan	Mackay Airport, Moranbah Airport	11 devices between Hay Point and Hail Creek inclusive.

2.4.2 Installation of mIoT Devices

The target date for the installation to be completed was the 1st December 2019 so to have all the devices installed and operational ahead of summer allowing for trending and analysis of the hottest part of the year. During November 2019, teams installed the devices throughout the CQCN at already determined locations. An Installation Methodology was used to ensure risks detailed in Section 2.2 were managed. At the completion of the installation, devices were tested and the relevant information about the device's location, identification, rail and track captured into applicable documents.

3 Reporting

3.1 Live Dashboard

An initial report was created using BOM data allocated to stations which allowed the tracking of temperatures in comparison to the Temperature Thresholds in the "Hot Weather Precautions for Track Stability" Standard as a dashboard within Power BI.

Once the IoT devices were installed, the report was created to show the combination of ambient and rail temperature data from BoM, IoT and SCADA sources within the CQCN. In total, there are now 90 IoT devices, 6 SCADA based temperature stations and 10 BoM weather stations providing data to the dashboard. The temperature data from the IoT devices is captured from Telstra and imported into servers with fresh data available in almost real time. In addition to graphical overviews of each of the 6 maintenance districts within the CQCN, temperature data also offers in-depth data on any combination of the devices, both in graphical and spatial representation. They respectively show each device's last 2 days of data and detailed map of each device. Hovering the mouse over the map will also show that location's last 24 hours of data.

The report automatically refreshes itself at 5-minute intervals to ensure it's displaying the most current information, with each of the three separate sources providing new information in accordance with Table 3:

Table 3: Summary of Data Logging Frequencies

Source	Record Data Frequency	Transmit Data Frequency
IoT Regular Mode: • Ambient <= 33ºC and Rail <= 50ºC	30 minutes	4 hours
IoT Fast Logging Mode • Ambient >= 33ºC or Rail >= 50ºC	15 minutes	30 minutes
Bureau of Meteorology: • Air Temperature	10 minutes	10 minutes
Bureau of Meteorology: • Forecasted Minimum & Maximum Air Temperatures:	12 hours	12 Hours

IoT devices will enter a low power mode when ambient is under 33 degrees Celsius. They are still recoding data at their allocated frequencies however they will only transmit data on a much lower frequency. As a means of communicating this to the viewer, data that is older than 2 hours is greyed out to indicate it may not be relevant to decision making.

The coloured shading of the data symbols will change when certain triggers are passed, which are in line with the Hot Weather Precautions for Track Stability Standard. The dashboard essentially translates the Standard's thresholds into a traffic light system; Grey and Green are acceptable, Yellow warns the user that temperatures are approaching a threshold that requires a response, then Orange and Red indicate which thresholds have been crossed in order of severity.

Below is the CQCN Temperature Monitoring Power BI showing live stream data on the 24th February 2020at approximately 10:50am. Figures 5 and 6 demonstrate the different data reports available in the one Power BI.

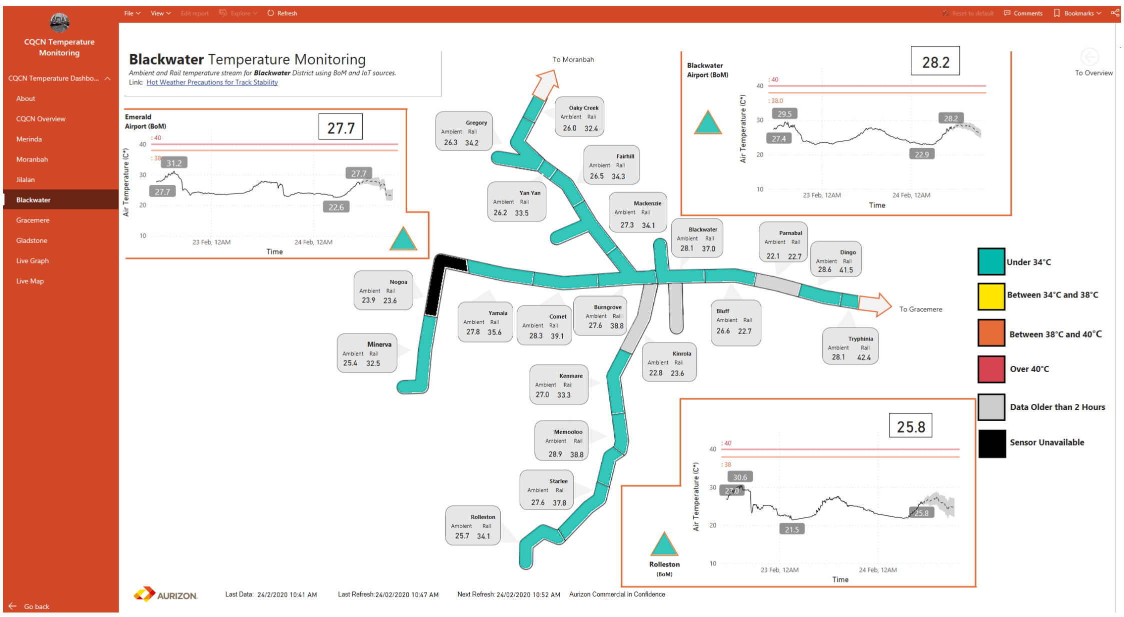


Figure 5: Ambient and Rail Temperature for a Specific Area (Blackwater) using BOM and IoT Sources

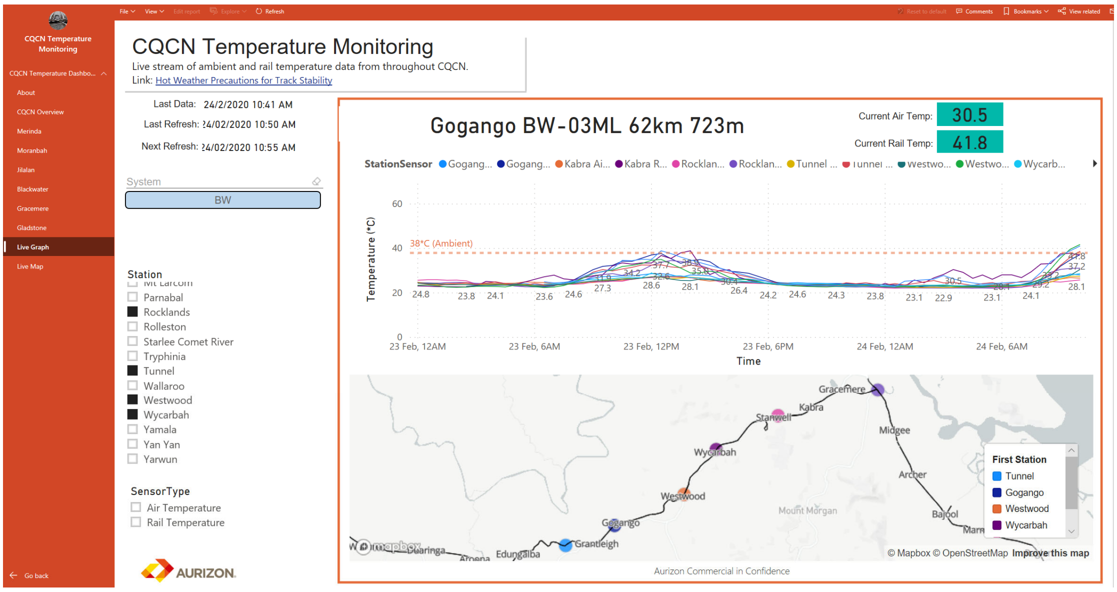


Figure 6: Live Stream of Ambient Temperature per IoT Device over Time

3.2 Autonomous Alerts

An automated alert system has been created that uses both live and forecasted ambient temperatures in conjunction with thresholds based on Hot Weather Precautions for Track Stability. These alerts are sent to Superintendents and Track Infrastructure Workers that are either involved or responsible for instigating hot weather inspections and imposing heat-based speed restrictions. Both the alerts and corresponding dashboards will group the relevant locations into their respective maintenance districts. Table 4 provides a summary of alerts provided.

Alerts take the form of both emails and SMS messages to relevant parties. Each alert contains relevant location, ambient and rail temperature information, a link to the Hot Weather Precautions for Track Stability and a link to the relevant Temperature Dashboard for further monitoring in real time. Once an alert is received, the recipient is to check the Temperature Dashboard and respond in accordance with the Hot Weather Precautions for Track Stability. In addition to the ambient air temperature alerts specified in the Hot Weather Precautions for Track Stability, alerts based on rail temperature have also been supplied.

The existing Hot Weather Precaution Standard only stipulates operational responses based on ambient temperatures; there is no formal advice on rail temperature thresholds.

This trial will give Aurizon Network the ability to measure both ambient and rail temperature, thereby further under-standing the relationship between ambient and rail temperature with respect to local track conditions. As such, any alerts generated by rail temperature thresholds are for information purposes only until such time that conservative thresholds are selected. Only ambient temperature alerts are to be used in conjunction with the Hot Weather Pre-cautions for Track Stability standard.

Table 4: Summary of Alerts driven by Temperature Data

Alert Details	Actions Required	Received by Who.
When: 5:00pm Daily. Alert sent if the district's fore-casted ambient temperatures are above 37°C for the next day.	• Superintendent to plan for staff to perform track inspections. • Network Controllers to anticipate unplanned road runs re-strictions and speed restrictions	Superintendent Track Inspectors Network Control
When: Real time.	• Superintendent to monitor district temperatures, • Track Inspector to instigate Road Run as per Hot Weather Precaution standard.	Superintendent Track Inspectors

Alert Details	Actions Required	Received by Who.
Trigger: First District IoT device measures Ambient Temperature > 37°C.		
When: Real time. Trigger: First District IoT device measures Ambient Temperature > 40°C.	• Instigate speed restrictions based on Hot Weather Precaution standard. • Monitor district temperatures at 30-minute intervals to update extent of restrictions.	Superintendent District Engineers
When: Real time. Trigger: Last District IoT device measures Ambient Temperature < 39°C.	• Confirm temperatures throughout district are below threshold, • Remove restrictions.	Superintendent District Engineers

The CQCN Temperature Monitoring Power BI and the Alert System allows the opportunity to see ambient and rail temperature at almost every station throughout the network, in near real time and notified users of temperature thresholds. To make full use of this and to lessen the impact of speed restrictions, it enables:

- Moving from a system wide restriction to targeting only the affected areas, and
- Moving from using only a fixed end time for heat restrictions to removing the restriction once temperatures drop below the threshold.

4 Trial Success and Future Vision

Setting up the capability to monitor the temperatures of the rail network and manage the risk of track misalignment due to heat using actual data has allowed analysis and comparison of current practice in comparison to requirements as per SAF/STD/0075/CIV/NET Hot Weather Precaution for Track Stability Standard.

Validation between the IoT devices' accuracy and existing BoM weather stations was completed and the results deemed satisfactory for Aurizon's uses. Each official weather station has been directly compared to its closest IoT sensor and found to have minimal differences between the two sources.

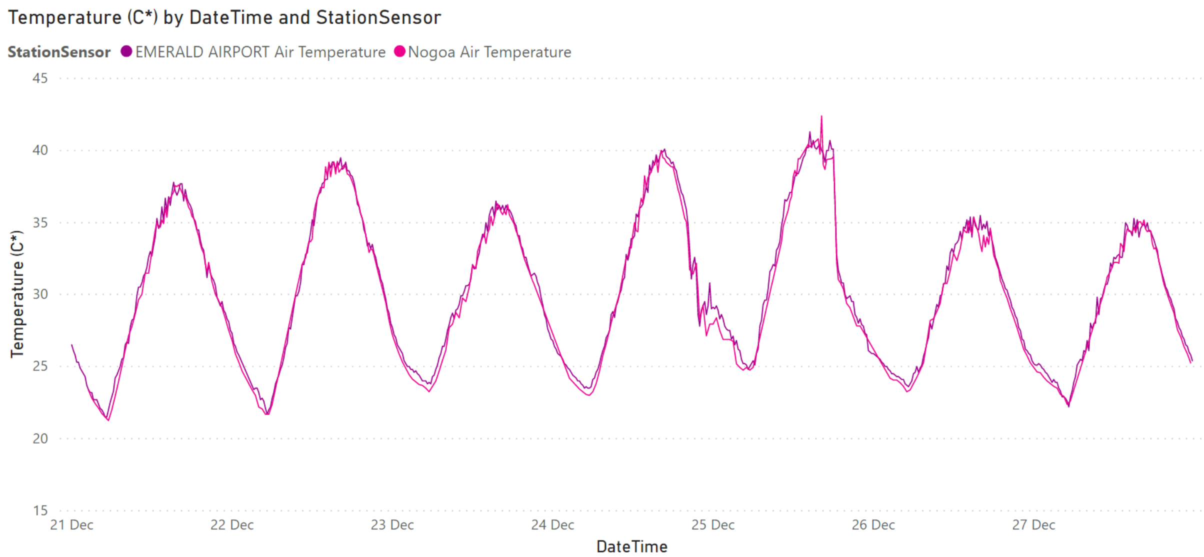


Figure 7: Comparison Between Emerald's BoM weather station and Nogoa's IoT installation

By monitoring the number of heat-based speed restrictions imposed and each restrictions' start and end times, it ap-pears that:

- The overall duration which Aurizon's rail network was under a restriction remained constant, as Blackwater's duration increased enough to make up for the savings seen in the other three systems (figure)
- The total number of services that experienced delays due to heat restrictions dropped by 56%, from 2,396 to 1,337.
- The total number of delay minutes of each delayed service was reduced by 217%, from 27,043 to 12,409 minutes.

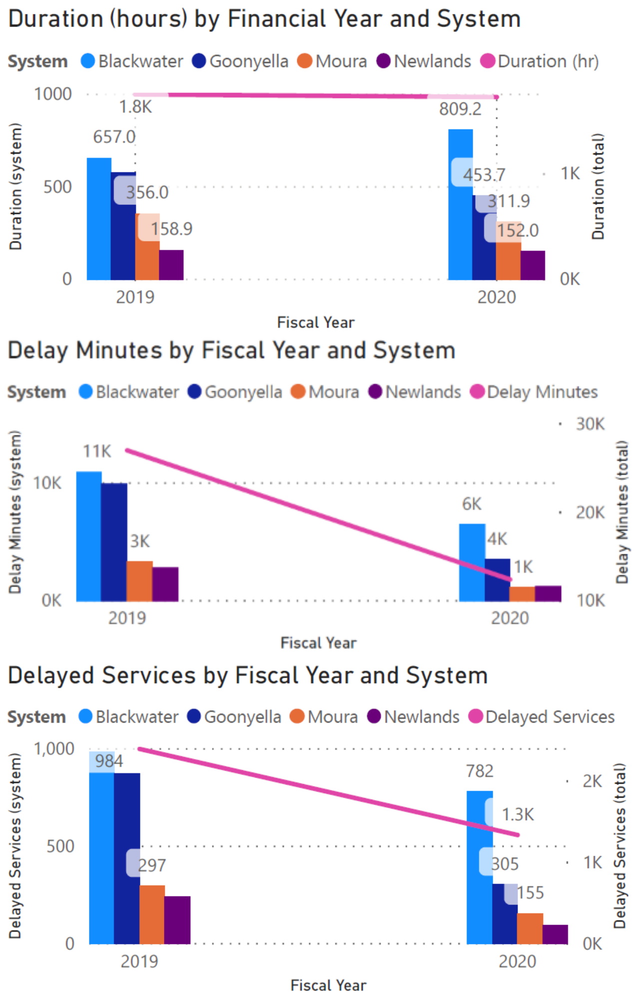


Figure 8: Summary of Restriction Duration and affected Services

In summary, the implementation of remote temperature monitoring paired with an autonomous notification system increased Aurizon's compliance with its Hot Weather. This is evident with the first metric showing an increase in Blackwater's overall duration of restrictions. Interestingly, the actual impact of the restrictions was reduced significantly; this is because the extents of the restrictions in both time imposed and the distances have been positively influenced by Standard by increasing the visibility of data in near real-time.

Consultation with the Maintenance Field Staff who impose the heat-based speed restrictions has provided an under-standing of current conservative practices which has resulted in modifications to the reporting and alerts during the trial to make them user friendly. This consultation has also created the opportunity to amalgamate each district's approach regarding how heat-based speed restrictions are imposed and relying on the data to make predictions and decisions.

The rail and ambient temperature data being recorded by the devices will be used to understand the correlation between the two measures and move the Hot Weather Precaution for Track Stability Standard to prescribe compliance to temperature thresholds for rail temperatures instead of ambient temperatures.

The lifecycle of the device itself and its performance is also being monitored to determine suitability of the device going forward. Results are positive at the time of writing. Improved technology is being investigated such as solar power to increase life of the device as it is currently dependent on battery life. This will reduce the total lifecycle cost for the devices.

The future vision for heat-based speed restrictions is to move from reactive responses to predictive decisions based on data. Using the historic and daily data recorded from the mIoT devices and forecast weather from the BOM, it is planned to provide predictive heat based speed restrictions, locations and time, to Train Control and Train Planning prior to day of operations to manage the risk due to Hot Weather and reduce impact on the operation of trains due to Hot Weather. It is also planned to fully automate the process thus further removing human involvement for total consistency across the CQCN.

5 Listing References

Please use proper parenthetical referencing, i.e. Harvard referencing (anon, 2014). Referencing can be done either manually or by using “Insert Citation”-tool found in “References”-toolbar. Include list of references in the end of your paper. Use “References heading” as the heading style.

References

Aurizon, 2012. *Hot Weather Precautions for Track Stability.* [Online] Available at https://intranet.aurizon.com.au/sites/ingauge/Documents/SAF-STD-0075-CIV-NET.pdf

mIoT, 2020. *Captis Pulse Applications.* [Online] Available at: https://www.miot.com.au/devices/captis-pulse/