Leveraging IoT Technology to Optimize Friction Management in Heavy Haul Track

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ABSTRACT
The benefits of a successfully implemented friction management program for the heavy haul railroad include extended rail life, reduced track damaging forces, reduced rolling contact fatigue, and improved consist fuel economy. However, railroads often struggle in achieving a high friction management program uptime which can limit the railroad's ability to realize the maximum benefit and return on investment of the program. Internet of Things (IoT) technology can enable railroads to simultaneous maximize the benefits of their friction management program while reducing the costs associated with operating the program. This includes the ability to easily monitor the uptime of application systems, optimizing application rates, improving insight into the operational status of application systems, reducing the track time required to troubleshoot systems, eliminating return visits to systems for maintenance, and reducing the management resources required to effectively run the friction management program.

Beginning in 2017, state-of-the-art remote asset monitoring equipment was installed on 287 trackside application systems (both gauge face lubrication and top of rail friction management) along a 1,400-mile segment of Class 1 heavy haul track. Through the use this monitoring equipment, data analytics, and predictive maintenance algorithms, the program was able to efficiently identify, prioritize, and schedule service work. For 2018, the aggregated uptime for this friction management program was 95%.

INTRODUCTION
Rail friction management (FM) programs for the heavy haul railroad, including both gauge face (GF) lubrication and top of rail (TOR) friction management, have been extensively implemented, studied, and reported on. Recognized benefits of these programs include extended rail and wheel life, reduced track damaging forces, reduced rolling contact fatigue, and improved consist fuel economy. However, these purported benefits can only be achieved if both of the following conditions are true: 1) the application systems are running (i.e. operating at what is referred to as a high uptime, often expressed as a percentage of the total available time) and 2) the application rate of either the lubrication or friction modifier product is optimized and remains consistently at this optimized value.

Consistently achieving a high uptime on a large number of application systems can be challenging due to a lack of maintenance and program management resources, short track access windows for equipment maintenance and filling, and a lack of insight into the equipment operational status. Furthermore, as equipment ages the actual application rate of product can often be less than what is expected, even when using the same application rate settings as used on new equipment. Without accurate output measurements taken at each system, this sub optimized application rate often goes undetected.

Broadly speaking the Internet of Things is the extension of internet connectivity into physical devices. IoT and other connected devices are becoming more and more pervasive in the broader railway industry. Everything from modern locomotives to wayside hotbox detectors contain an ever-increasing number of sensors and data streams that are connected to the internet.

Often one of the challenges with the use of IoT technology is identifying the value capture in a company specific context (1). By utilizing IoT technology friction management programs can be optimized. IoT tools allow railroads to maximize the benefits of FM assets while decreasing the costs associated with running their FM programs.

IMPLEMENTATION AND USE OF IOT SYSTEMS IN THE RAILWAY INDUSTRY

For friction management programs IoT typically involves embedding application systems (whether trackside or mobile) with the ability to remotely communicate (typically via cell or satellite communication) with the internet. The most common form of connectivity for friction management system is remote monitoring of equipment. Under a typical configuration, the trackside system uploads data related to system health (e.g. product tank level) and recent operations (e.g. product application rates for recent activations) to a remote data center. A remote user can log into a secure website and view this data, including the full history of data associated with the application system.

Properly implemented and leveraged, IoT technology can be a powerful tool in managing friction management programs, both in terms of benefit maximization and cost reduction elements (as listed in Table 1).

TABLE 1: IoT enablers for maximizing ROI for friction management programs

ROI Component	IoT Enabler
Benefit Maximization:	
Measure Uptime	Constant monitoring of equipment allows for both high-level and detailed insight into effectiveness of FM program.
Maximize Uptime	Constant monitoring of equipment health with alarms raised on data streams that may indicate problems, either pre-emptively (e.g. tank nearing fill level) or immediately (e.g. power turned off).
Maintain optimized product application rates	Constant monitoring of FM product usage versus theoretical or anticipated rate. If required, application rate setting changes required to restore rate back to optimized can be submitted to service technicians or sent to systems remotely.
Cost Reduction:	
Optimized resource scheduling	Optimize maintenance crew schedules through use of predictive maintenance algorithms. e.g. filling schedules based on predicted tank low level thresholds.
Fewer site visits	Ability to remotely diagnosis problems and send service technicians with correct components to fix (on first trip).
Shorter maintenance visits	Ability to direct maintenance efforts at remotely diagnosed problems, reducing amount of troubleshooting in field.
Fewer management resources	Ability to automatically generate reports, aggregated data, data insights through analytics or machine learning. Ability to automatically or semi-automatically generate optimized maintenance schedules and distribute these to maintenance crews.

Optimized supply chain	Spare parts required for maintenance or repairs automatically generated from maintenance reports and shipped to maintenance crews.

USE OF IOT TECHNOLOGY IN CLASS 1 HEAVY HAUL – A CASE STUDY

In 2017, CSX Corporation and L.B. Foster Company installed 287 trackside friction management systems along 1,400 miles of track from Chicago to Philadelphia. These systems comprised of 222 top of rail friction management system (including 189 dual track and 33 single track configurations) and 65 gauge face lubrication systems (including 7 dual track and 58 single track configurations). In total this friction management program contained 483 distinct assets connected to a remote monitoring and asset management platform (single track systems are viewed as a single asset and dual track units represent two assets).

The goal of the program was the implementation of total friction management (GF + TOR) along this corridor, with a targeted total aggregated uptime percentage of 90%.

Challenges and Lessons Learned

The friction management program encountered a number of challenges related both to general railroad operations and relating to the IoT technology. This paper will only address the latter. The IoT challenges are not unique to this project and are common across many IoT technology implementations. The challenges faced can be summarized in two categories: a) generating data insights in a timely manner and b) dealing with data growth. To achieve the targeted uptime, addressing the first challenge was seen as the most critical. However, it was important that any solutions implemented to solve the first problem (generation of insights) had to be as automated as possible and scalable prior to implementation in order to prevent the data growth from become unmanageable.

In order to achieve the targeted uptime, this FM program employs two strategies. First the state of each system is continuously bucketed into a finite number of categories based on the latest data received from the system. Each state and the allocation of time spent by each asset in each state is continuously monitored. If a state other than 'Working/Operational' is allocated an amount of time above a given threshold the asset is flagged for further investigation or an alert is sent to the field service team. Figure 1 shows this process of continuous categorization of states.

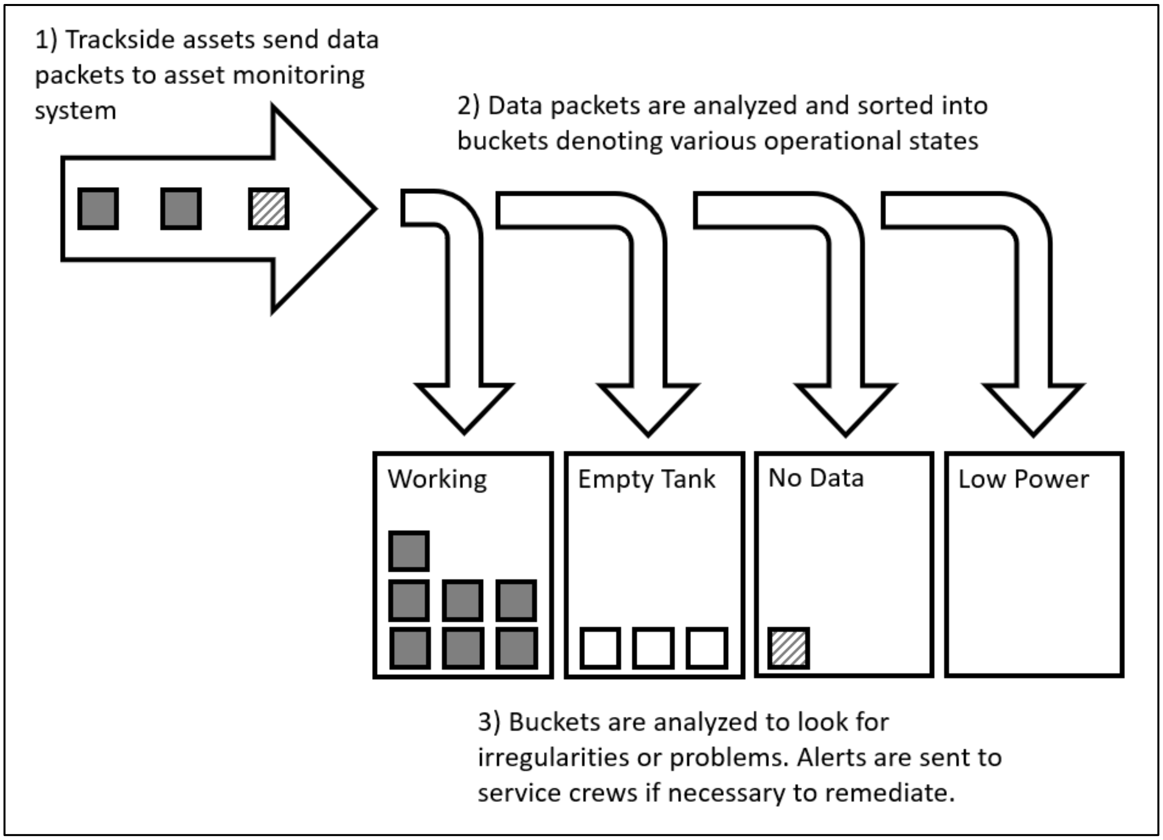

FIGURE 1: State of each asset (trackside system) is continuously monitored and categorized

The second strategy employed is analysis of the data streams to prevent the accumulation of time within any category other than 'Working/Operational'. This strategy involves setting thresholds on each applicable data stream which flags the system immediately to either the program manager or service team when the threshold is reached. Additionally, data analytics are used to predict when the data will cross the threshold in the future. For example, consider the system's tank volume or product level. The product level is continuously monitored for each system. A low-level threshold is set, to warn the service team of tanks that may run empty (i.e. accumulate in the 'Empty Tank' time allocation category). Furthermore, analysis of the data trend over time predicts when the tank level will cross the low-level threshold, so bulk fillers can schedule their filling activities accordingly. Figure 2 shows an example trackside application system tank volume over time, including the low-level threshold, alarms raised, and prediction of future states.

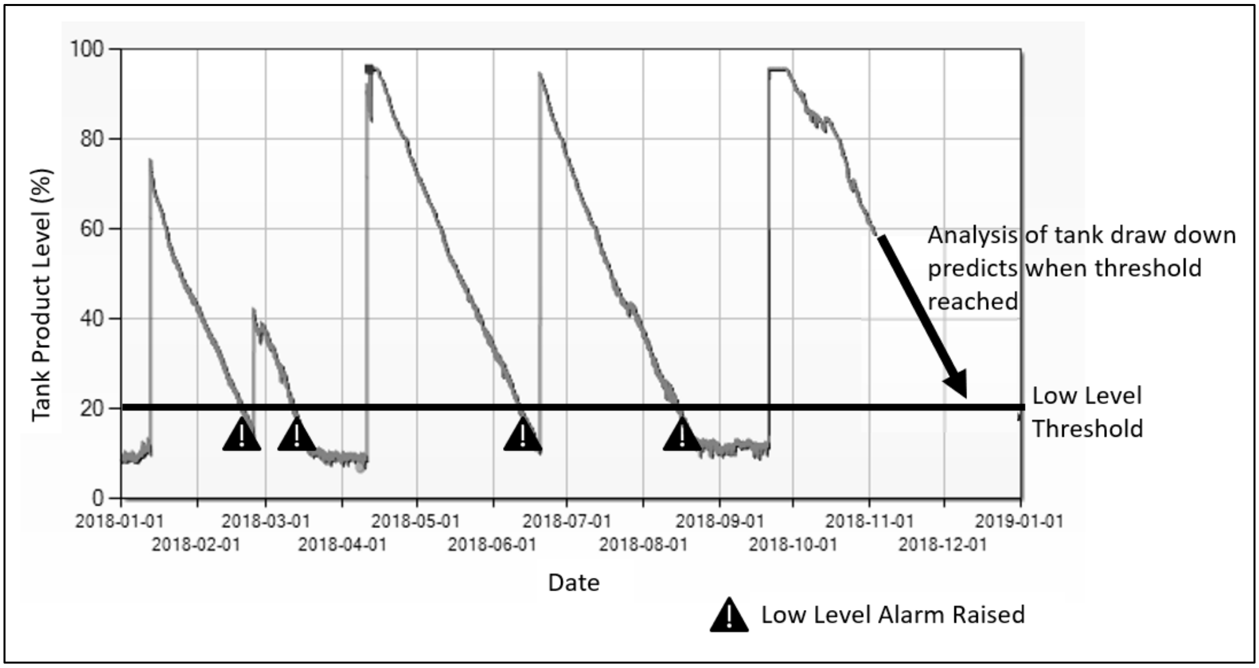

FIGURE 2: Data monitoring including predictive analytics prevent accumulation of non-operational states

Program Results

For the 2018 calendar year (corresponding to the first full year the program was in 100% in operation), the aggregated uptime for all 483 assets was 95.0%. Of this, 15.1% of the time was allocated to out-of-service time due to the railroad such as track maintenance where the application systems are removed from the rail). The units were operational for 79.9% of the total available time. Of the 5.0% of time allocated to the system not operational, 2.8% was due to empty tanks, 1.2% was due to missing wheels, and the remaining 1.0% of time due to connectivity issues, low power, or miscellaneous reasons.

The program has been beneficial to CSX with increased fuel savings on the operational side. There are rough estimations of what the fuel savings have been, but the exact numbers are yet to be determined as there were several other operational and locomotive initiatives in place to also save fuel at this time. The maintenance side is also seeing benefits as well. Although GF units existed on CSX before, the proper spacing and coverage was re-evaluated and adjusted for proper coverage. The opportunity to monitor these units remotely has also produced better uptime and responses to issues. Previously issues with the trackside system would only have been found during routine filling or reported by a track inspector, now most of those issues are reported immediately with the remote monitoring system. CSX does expect further savings through rail surface quality and even possibly savings in wheel replacement. These two benefits are being monitored and may take several more years or additional deployment to fully see the benefits and savings.

Cost Benefit Analysis

The implementation of IoT technology in a friction management program carries additional costs over a traditional, non-connected implementation. A cost-benefit analysis (CBA) was conducted to quantify the value of using IoT technology in this environment. In order to properly quantify the benefits of a total friction management program implemented in heavy haul track, a literature review of published case studies was conducted. From these a CBA model for total friction management using IoT connected trackside application systems on a representative track-mile can be conducted.

For this CBA, it is assumed that a gauge face trackside application system and a top of rail application system are both installed at one end of what is referred to a representative track mile. This representative track mile is made up a distribution of tangent track and curves of varying degrees of severity in equal parts to what is representative of an entire territory of track. As such, the CBA can easily be scaled across a longer section of track, a subdivision, a division or an entire railroad by simply ensuring that the representative mile consists of the same makeup as the greater territory.

For this CBA the following representative track mile was used based on an analysis of the 1,400 miles of CSX haul track in which the case study was based. For each degree of curvature, the maximum rail life used in the model is also shown (2).

TABLE 2: Representative mile of track

Degree of Curvature	Percentage of Rail (%)	Maximum Rail Life (MGT)
Tangent	79.6%	1460
0 – 0.99 deg.	9.0%	1255
1.00 - 1.99 deg.	8.1%	1050
2.00 - 2.99 deg.	1.6%	640
3.00 - 3.99 deg.	1.0%	540
4.00 - 4.99 deg.	0.3%	510
5.00 - 5.99 deg.	0.1%	440
6.00 - 6.99 deg.	0.1%	390
7.00 - 7.99 deg.	0.1%	380
8.00 - 8.99 deg.	0.1%	370
9.00 - 9.99 deg.	0.0%	350
>10.00 deg.	0.0%	330
Total	100%	

Friction Management Benefits

A comprehensive literature review of published results was conducted to develop the following table of total friction management benefits. Note that the studies used a variety of consumable products (both GF lubricants and TOR friction modifiers) and application systems. Different baseline conditions were also employed – typically dry if a GF lubricant was tested and with GF lubrication on if a TOR friction modifier was evaluated. As such a conservative benefit value was chosen based on the data to be representative of the effects of combined GF and TOR friction management versus a dry baseline.

TABLE 3: Friction management (GF + TOR) benefits versus dry baseline

Benefit	Range of Values	Value Used in CBA
Wheel wear reduction (3)(4)	~ 15% - 50%	15%
Rail wear reduction (5)(6)(7)(8)(9)	~ 20% - 90% for low rail TOR (vertical) ~ 20 % - 80% for high rail TOR (vertical) ~ 25% - 100% for high rail GF	40%
Fuel Savings (4)(10)(11)	~2% - 5%	2%

Note that for rail wear reduction the lower values are attributed to studies where TOR+GF friction management was compared to a GF lubrication only baseline. Studies of GF lubrication only over a dry baseline show similar reductions except on the low rail TOR surface. As such, equal benefits were attributed to GF over dry and to GF+TOR over GF only baselines for a cumulative total of 40%.

Other noted benefits of friction management programs include rail grinding interval extensions due to the reduction in rail wear rates and a reduction in track degradation (e.g. rail fastener failures, ballast maintenance, tie replacements) due to the reduction in lateral forces. Neither of these benefits were included in the cost benefits analysis due to a lack of published data.

It was also assumed that the benefits of friction management are directly correlated to the uptime of the application systems. That is to say that 100% of stated benefits are achieved at 100% uptime, 0% of benefits are achieved at 0% uptime.

Fiction Management Costs

The ongoing operational costs of running a friction management program can be assumed to be directly proportional to the uptime of the trackside application systems. Systems that are not operational are not consuming lubricants or friction modifiers and are not requiring spare parts or maintenance resources. The following table contrasts the annual operating costs of running the GF and TOR trackside FM application system pair at 90%, 70%, and 50% uptime. These values were validated using data taken from the CSX case study.

TABLE 4: Friction management program cost (GF + TOR) for varying system uptime

Cost	Annual Cost at 90% Uptime (per lubricator pair, GF + TOR)	Annual Cost at 70% Uptime (per lubricator pair, GF + TOR)	Annual Cost at 50% Uptime (per lubricator pair, GF + TOR)
Spare Parts	$900	$700	$500
Consumables	$11,300	$8,800	$6,300
Total Maintenance Labour	$2,700	$2,200	$1,700

Note that the CBA model assumes that GF and TOR systems are effective for 4 miles (6.4 km).

Other CBA Model Inputs

The following table lists other critical inputs used in the CBA.

TABLE 5: Additional CBA model inputs

Variable	Value
Incremental tax rate	38%
Capital depreciation rate	25%
Weighted average cost of capital	10%
Cost of fuel	$2.50 / USG
Annual tonnage	65 MGT

Results

The 10-year Net Present Value (NPV) and the annual pre-tax income (i.e. benefits or savings) were calculated for a pair of trackside friction management application systems (GF + TOR) at various uptime values. Note that for comparative reasons the cost of IoT technology implementation has not been included into any of these cases.

TABLE 6: 10-year NPV and annual pre-tax income for friction management implementation

	10-year NPV	Annual Pre-Tax Income
Operating at 90% Uptime	$42,700	$13,100
Operating at 70% Uptime	$28,400	$9,400
Operating at 50% Uptime	$14,200	$5,600

The consequence of reducing the system uptime from 90% to 50% is therefore an approximate difference of $28,500 in terms of the 10-year NPV and a different of $7,500 in terms of annual pre-tax income per system pair. Similar difference in benefits can be calculated depending on the beginning and ending uptime conditions. As friction management programs are scaled across entire divisions or rail networks and encompass hundreds or thousands of application systems, the value lost by not maintaining the systems at their maximum achievable uptime is significant and far outweighs the additional cost of adding IoT technology to the application systems.

Conclusions

By using IoT technology, specifically remote monitoring of equipment in rail friction management programs, the program's maximum benefit and return on investment can be realized. IoT technology allows FM program operators to continuously monitor the status of their assets, achieve a high aggregated system operational uptime, and minimize costs through efficient use of management and field service resources.

References

(1) Every. Thing. Connected. A study of the adoption of 'Internet of Things' among Danish companies (PDF). Ericsson. Retrieved 15 April 2019.
(2) Guins, T. (2005) Economic Analysis of Top of Rail Friction Control – Walong, CA, TTCI Technology Digest TD-05-019, August 2005, 4pp.
(3) Roney, M., Eadie, D., Oldknow, K., Sroba, P., Caldwell, R. and Santoro, M. (2009) Total Friction Management on Canadian Pacific, Proceedings of the International Heavy Haul Association, Shanghai, June 2009, 10pp.
(4) Elvidge, D., Stock, R., Hardwick, C. and Oldknow, K. The Effect of Freight Train Mounted TOR-FM on Wheel Life and Defects, Proceedings of the Third International Conference on Railway Technology: Research, Development and Maintenance, J. Pombo (Editor) Civil-Comp Press, Stirlingshire, UK, Paper 174, 2016.
(5) Sroba, P., Roney, M., Dashko, R. and Magel, E., (2001) Canadian Pacific Railway's 100% Effective Lubrication Initiative, Presentation for AREMA 2001 Conference & Exhibition, Chicago, Illinois, September 9-12, 2001, 14pp.
(6) Sroba, P., Oldknow, K., Dashko, R. and Roney, M. (2005) Canadian Pacific Railway 100% Effective Friction Management Strategy, Proceedings of the IHHA Conference, Rio de Janeiro, Brazil, June 2005, 9pp.
(7) Reiff, R. (2007) Wayside-Based Top of Rail Friction Control: 95 MGT Update, TTCI Technology Digest TD-07-019, June 2007, 4pp.
(8) Eadie, D., Maglalang, L., Vidler, B., Lilley, D. and Reiff, R. (2005) Trackside Top of Rail Friction Control at CN, Proceedings of the IHHA Conference, Rio de Janeiro, Brazil, June 2005, 8pp.
(9) Stock, R., Santoro, M. and Paradise, S. (2017) Friction Management and Rail Wear on CPs Western Corridor: 2008-2016, Proceedings of Wheel Rail Interface Conference, Montreal, Canada, June 2017.
(10) Cotter, J., Eadie, D., Elvidge, D., Hooper, N., Roberts, J., Makowsky, T. and Liu, Y. (2005) Top of Rail Friction Control: Reductions in Fuel and Greenhouse Gas Emissions, Proceedings of the International Heavy Haul Association Conference, Rio de Janeiro, June 2005, 7pp.
(11) Reiff, R., (2008) Mobile-based Car Mounted Top of Rail Friction Control Application Issues – Effectiveness and Deployment, TTCI Technology Digest TD-08-039, October 2008, 4pp.

List of Table Captions

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