IDEA

Innovations Deserving Exploratory Analysis Programs

Transit IDEA Program

TRACK CIRCUIT MONITORING TOOL
Standardization and Deployment at CTA

Final Report for
Transit IDEA Project 83

Prepared by:
Frank Beeck
Rail IT, LLC

December 2017

TRANSPORTATION RESEARCH BOARD
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- The Transit IDEA Program, which supports development and testing of innovative concepts and methods for advancing transit practice, is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP).

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IDEA Program Final Report

TRANSIT-83

Prepared for the IDEA Program
Transportation Research Board
The National Academies

Frank Beeck
Principal Investigator

December 1, 2017

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ABBREVIATIONS AND ACRONYMS

APTA	American Public Transportation Association
CCS	Central Control System
CTA	Chicago Transit Authority
GUI	Graphical User Interface
IT	Information Technology
LOS	Loss of Shunt
NAS	National Academies of Sciences
OCC / ROCC	[Rail] Operations Control Center
O&M	Operations and Maintenance
QEI	Provider of CTA's Central Control System. QEI is a subsidiary of CG Automation, manufacturer of SCADA (Supervisory Control and Data Acquisition) Systems.
QT	QuicTrak, a QEI solution for central control
TC	Track Circuit
TCM	Track Circuit Monitoring [Tool]
TRB	Transportation Research Board, a Part of the National Academies of Sciences, Engineering, and Medicine
USB	Universal Serial Bus, an industry standard that defines connectors and communications protocols for connection, communication, and power supply between computers and devices.
WMATA	Washington Metropolitan Area Transit Authority, aka Washington Metro

GLOSSARY

Absolute Block	A block that must not be occupied by more than one train at a time.
Loss of Shunt	Related to Shunting - The act of electrically connecting two rails together by the axles of a train. This will de-energize a "track circuit" and indicate Train Present within track circuit limits. Loss of Shunt: Track Circuit is energized, indicating Train Not Present.
QuicTrak	(QT) A QEI product for central control systems as installed and implemented at CTA.
Track Circuit (TC)	An electrical circuit, of which the rails of a track form a part, used to detect the presence of a train. An arrangement of electrical and/or electronic equipment, including a defined length of the track running rails, which permits detection of trains and broken rails within the defined limits of the running rails.
TC dropped	Drop (or Drop-Out) - A relay is said to "drop" or "drop-out" when its electricity is removed, so that the front contacts are open. Usually caused by a train entrance → Train present
TC picked-up	Pick (or Pick-Up) - A relay is said to "pick" or "pick-up" when energization of its coil(s) causes its front contacts to close. Usually caused by a train exit → Train no longer present
Train ID	A unique identification of a train in service.

CONTRIBUTORS

Frank Beeck is Principal Investigator on this TRB Grant for a Standardized Track Circuit Monitoring Tool. Frank has 26 years of experience in designing and implementing systems solutions to monitor, control, and optimize train operations. Before Frank became an independent Consultant as Rail IT, LLC in 2011, he was with Siemens Rail Automation for 20 years. Frank is a member of APTA design and research teams and is a contributor to APTA recommended practice guide-lines. Frank further works in forums of Central Control Systems and Track Circuit Monitoring specialists and supports Transit Agencies in the design/implementation, operations, and maintenance of their control systems.

Tim Shoppa is IT Manager and WMATA's Lead Designer in Washington, DC. Tim has worked for 17 years at WMATA with the rail operations central control systems and personnel. WMATA ROCC computers monitor and control not just signaling for the 117-mile railroad, but also traction power, station power, and ventilation systems. Tim is inventor of US Patent 8996208 covering the WMATA ATC Track Circuit monitoring tool, which is integral part of the TCM tool.

Robert A. MacDonald, Co-Investigator on the TRB Grant, is Transit Systems Engineering Signal Consultant and lives in Boston MA. Bob has more than 45 years of experience in the field of automatic train control systems. Bob was active in the design, implementation, commissioning and maintenance of brownfield and greenfield rail systems during his twenty years at the MBTA and retired as Division Manager for Signal and Communications. After leaving the MBTA his experience was expanded and went on to include the design, commissioning, operation, and maintenance of train control systems throughout the continental United States and Puerto Rico. Bob contributed with his vast experience throughout the project, which is also reflected in many parts of this Final Report.

Jim Hoelscher is engaged as independent consultant at the team's Expert Advisory Panel. As Sr. Signaling Engineer, Jim has provided in-depth Track Circuit design input, critical for the analysis of track circuit failure symptoms and abnormal behavior. He furthermore provided input to the APTA Recommended Practice Document and is a member of the Signaling Standards Committee. Jim worked at Alstom/GRS in Track Circuit design and development and is now retiree and busy driving his RV through the most beautiful places of North America.

Michael J Lowder is Manager of Signal Engineering at the Chicago Transit Authority and was the initiator of proposing CTA as the Pilot Agency for the TCM tool deployment as a standard software application. Michael and his peers and managers at CTA provided valuable feedback during the commissioning phase of the TCM system.

Jo Allen Gause and **Velvet Fitzpatrick** in their role as TRB Program Officers supported this IDEA program from day one and continue to do so at this day. Jo Allen and Velvet not only helped in overcoming the one and other contractual challenge in this program but further provided outstanding support in reporting, documenting, and promoting the product to the transit industry.

The TRB Expert Panel consisted of members and associates of the Transportation Research Board (a part of the National Academies of Sciences, Engineering, and Medicine). The Expert Panel members - all of which are recognized individuals in the transit industry - have invested their valuable time and thoughts into this program by reviewing concepts, progress reports, and have provided indispensable feedback that helped shaping the tool and make it a valuable asset for Transit Operations and Maintenance Organizations. A sincere thank you to the Expert Panel members:

Lou F Sanders, Senior Director Engineering Services at American Public Transportation Association (APTA)

Stephan A. Parker, Senior Program Officer at the Transportation Research Board

David Thurston, PhD, Vice President Land Transportation Division, IEEE at WSP/Parsons Brinckerhoff

Melvin Clark, Vice President Rail Operations at Capital Metropolitan Transportation Authority in Austin (TX)

EXECUTIVE SUMMARY

Modern track circuits represent the latest generation in a long line of train detection systems that identify train location, provide information regarding train maximum allowable speed, and assist in the discovery of broken rail. These are just a few safety critical functions of a train control system that must be maintained to operate reliably for every train, seven days a week, twenty-four hours per day, for as long as thirty years and can include thousands of individual track circuits.

These systems during their life cycle require constant vigilance to assure that standards for safety and reliability are being met and maintained. In order to assure a lifecycle of safe and reliable operation there is a need for a technologically experienced labor force.

The predicament of field maintenance personnel, who are often the first responders to potential safety issues, is a topic worthy of discussion. Sometimes, these line employees are conceivably not empowered to initiate immediate action, often disregarded, and possibly intimidated by any potential issue that requires action related to delays or stopping of service.

In order to assure a lifecycle of safe and reliable operation, there is a need for small, but highly technical, experienced, and centralized support group. This group should be capable of assessing problems affecting service, being empowered with the ability to make quick decisions on requirements necessary to effectively assess, test, correct, and possibly restrict signaling deficiencies, even if it means to stop train service at location where safe operation cannot be warranted. This experience is often in short supply and requires inter-department cooperation and a level of mutual trust. These people are a limited, multitasked and valuable resource, whose potential must be maximized.

A management organization with the ability to initiate the decision process, supported by systems providing critical information to operations, maintenance, and engineering departments in real time, can be a major benefit in assuring safe and reliable train operation. Maintenance and engineering employees, working on these systems, should be empowered with the ability – when necessary – *to stop train movements or implement appropriate speed restrictions to prevent collisions. [QUOTE from NTSB R-09-6 Urgent]*

The Fort Totten incident at Washington Metro in 2009 and the subsequent NTSB urgent recommendation R-09-6 prompted WMATA to initiate the developed of a "*Loss of Shunt Tool*". The tool issues alerts to Operations and Maintenance (O&M) to report potential safety critical failure conditions of track circuits. For WMATA the LOS tool has become an important track circuit monitoring tool, which is fully integrated in O&M operating procedures.

In support to NTSB R-09-6, APTA initiated a program to evaluate and develop a software-based Audio Frequency Track Circuit maintenance tool for the purpose of an industry wide recommended practice. The APTA Recommended Practice (APTA RT-SC-RP-047-17) serves as a guideline to implement a commonly accepted industry approach for a secondary Train Monitoring System with the capability to identify and alert abnormal operation of track circuits.

The purpose of this project is to evaluate the existing software of the WMATA LOS tool, segregating it from the WMATA exclusive environment and enhancing the tool in order to become a standardized and independent Track Circuit Monitoring System (TCM) available for integration into other Transit Authority's central control systems. Part of this project is to provide proof of concept by deploying the TCM product at the Chicago Transit Authority (CTA) for the Blue Line (Forrest Park to O'Hare Airport). Included in the TCM software package will be graphical user interface applications (GUI) that support the end-user in setting up the track network database, loading track circuit data for offline processing, and providing means for detection and analysis of track anomalies. The success of this project will substantiate the value the TCM tool can provide to the Operations and Maintenance department of transit agencies and to demonstrate the potential for improved systems oversight that enhances safety and reliability in vital applications of train detection systems.

Most issues affecting the safety of a system represent a series of errors, oversights, omissions and poor communications and can culminate in tragic consequences while undermining the integrity of key pieces of rail transportation infrastructure (quote from LinkedIn).

The TCM software is intended to help identifying the potential for track circuit failure and alerting the operations, maintenance, and engineering organizations to the potential threat in the shortest possible time.

INTRODUCTION

The use of track circuits in the transit and railroad industry remains wide spread. Track circuits are critical components of any train control system. They provide vital train location information, assuring safe and reliable revenue service operations. Many issues are related to the operation of the train detection system in the hostile and busy environment of rail transit that can adversely impact reliable operation. Examples include:

1. Continuous use of track circuits, vehicles, track, and traction power systems with limited time for maintenance.
2. Changes to any of these systems or their components – small or complex – can affect track circuit operation.
3. Track Circuit fail safe design principals and tight tolerances often lead to reliability problems when infrastructure cannot be properly maintained.
4. Track Circuit corrective maintenance decisions are often hampered by the number of track circuits involved and a lack of information regarding the severity and potential for affecting train operation.

The TCM Tool offers innovative algorithms and concepts to uncover abnormal behavior and critical problems in train occupancy detection by continuously monitoring and evaluating occupancy indications for integrity and plausibility – in real-time! TCM qualifies its condition as normal, irregular, failure, or potentially safety critical condition and provides appropriate alerts and notifications to individuals of Operations and Maintenance. The evaluation includes a threat analysis of the compromised area and can significantly reduce any time involved, to alert experienced staff – directly and in real-time. The Alert includes information to a persistent reliability problem or a potential safety issue including related train movements. It significantly shortens the time frame to any restriction of a threat - as needed - to protect the riding public.

PRODUCT OVERVIEW

In summary, the objective of TCM as a product is to provide a practical and cost-effective solution to Transit Agencies that addresses NTSB R-09-6 (Urgent) based on APTA Recommended Practice. This includes the following high-level requirements:

- Provide a secondary train tracking evaluation based on any track occupancy detection system
- Provide enhanced algorithms to monitor integrity of track circuit indications and train progressions
- Categorize abnormal events in notifications, warning, and safety critical alerts
- Initiates Stop of train movements or appropriate Speed restrictions to prevent collisions. [QUOTE from NTSB R-09-6]
- Enabling long-term perspective for improved asset management
- Improve Track Circuit reliability and transportation safety

The TCM product provides a means for a Transit Agency to identify abnormal track circuit conditions affecting daily operations, and provides information that allows maintenance and operations managers the ability to prioritize resources and react swiftly to restore the system to normal operation. The concepts and characteristics listed below exhibit key aspects of TCM's product design principles:

- TCM utilizes status information, delivered to a centralized facility to analyze thousands of track circuits in real time to detect irregular operation.
- TCM applies sophisticated algorithms that include wayside and train specific parameters and applies these to the laws of physics to determine the proximity of the physical location of a train at any given point in time.
- TCM separates and reports only those issues, causing problems and affecting the reliability and potentially the safety of rail system track circuits.
- Outputs from TCM can alert appropriate personnel in real time to the location and severity of track circuit problems…
    - that may affect safety requiring immediate action to restrict the area in question until additional resources can further investigate the problem.

- wayside equipment operating in an erratic manner with the ability to send information to maintenance resources to identify the severity and location of the problems affecting reliable operation.

- TCM can be programmed to assess the most severe problems for investigation, so maintenance managers can direct their resources to areas most likely to have the worst effect on daily operations.
- TCM can be used to develop reports showing the effects of erratic track circuit behavior on the daily operation of the transit system for analysis by maintenance and operations.

TCM is designed to operate in online mode (24/7) as an extension to the Agency's existing Central Control System (CCS). TCM processes the same (raw) field information that the CCS does, however, using a unique algorithm. In this online operating mode, the TCM tool provides real-time alerts for track circuits showing abnormal behavior.

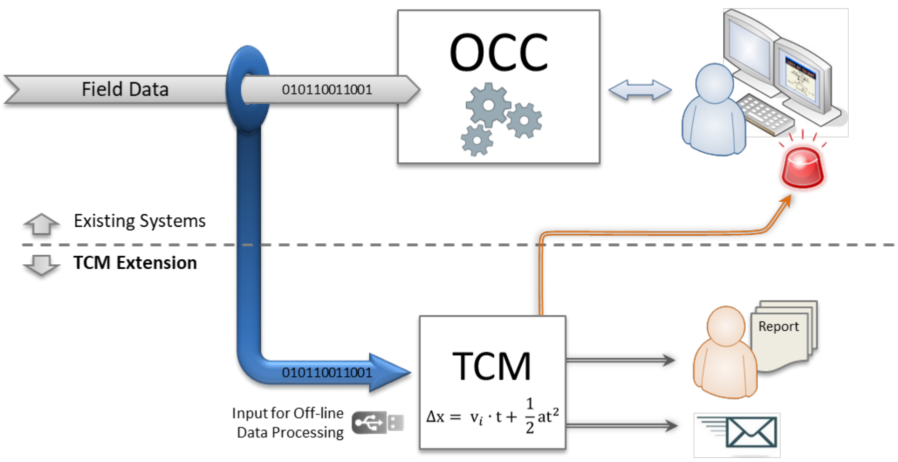


Figure 1: TCM Integration Approach

It has been found that applying TCM in stages provides multiple benefits – beginning at allowing the agencies the opportunity to customize the tool to the agency's specific needs, followed by working out inconsistencies and errors in the agency's track network database, as well as to realize an early benefit by identifying misbehaving track circuits in offline mode based on historical data. This initial off-line operating mode does not require a live-link to an existing CCS - illustrated in Figure 1 above by the blue data link – but would instead only requires off-line data import via e.g. a USB-Drive.

Gaining these early benefits of TCM can be accomplished by the following 3-stage integration approach:

Stage 1: Tool parameterization and track network database development. This stage allows for initial offline Track Circuit event data analysis and provides already valuable information to wayside signaling staff.

Stage 2: Continued data vetting and Train/Vehicle performance parameter entries for enhanced TCM integrity evaluation and quantification of the severity of faults.

Stage 3: Final configuration and integration into existing infrastructure for online operation based on live data processing and integrity evaluation including real-time alert functionality if a safety critical condition has been identified.

The implementation and deployment of TCM at CTA has been completed. Since July 2017 CTA's TCM system operates in Stage 3 online mode with 24/7 live data exchange between CTA's existing CCS (QuicTrak) and TCM.

PROJECT OVERVIEW

The primary deliverables of this Transit IDEA Project are as follows:

- Transform the WMATA TCM tool into an independent stand-alone track circuit integrity monitoring system
- Upgrade the existing software to current and state-of-the-art software platforms
- Provide TCM product features as described in the product objectives (see above)
- Interface the TCM tool to the existing CTA Central Control System and enable live data exchange
- Support CTA in connecting the TCM tool to OCC infrastructure such as email, strobe lights, and audible alarms (e.g. horns or sirens)

This project is being supported by Chicago Transit Authority (CTA), which is providing necessary hardware and alarm infrastructure. CTA will make available the necessary resources for track network data dissemination and the integration of the TCM tool into CTA's Central Control System.

The work breakdown structure of the project consists of a 2-stage project approach, broken down into 9 tasks in total. The end of Stage-1 (Task #5) includes an interims project review as a progress check point. Accomplishments and investigation results collected up to this point have been evaluated and discussed with the Expert Advisory Panel during the midterm progress report meeting on Dec. 5th 2016 in Chicago.

PROJECT TASKS AND TIMELINE

Task	Description	Duration	Completion	Stage
1	Standardization of Software; Requirements Specification	1 month	7/20/16	Stage 1
2	Product enhancement and initial testing (Level-1 test)	2 months	9/30/16	
3	Advanced testing of product based on final definition of database (Level-2 test)	1 months	10/31/16	
4	Legal aspects concerning use of software	Ongoing	10/31/16	
5	Interims Meeting with Expert Panel Stage I Report to Expert Panel and IDEA Program Office	2 months	12/5/16	
6	CTA specific enhancements, performance optimization, and offline testing	1 month	plan 1/31/17 rev. 2/28/17	Stage 2
7	TCM integration into CTA OCC network and live data test	2 months	plan 3/31/17 rev. 7/28/17	
8	Management support in revising CTA's effected SOPs; O&M manuals	1 month	plan 4/30/17 rev. 8/31/17	
9	Final Report Preparation and Program Approval	4 months	plan 8/5/17 rev. 12/15/17	

Table 1: Project Timeline (plan and revised)

As illustrated in Table 1 above, Stage-1 of the project consisted primarily of four measurable performance tasks plus the Stage-1 Report. Stage-1 of the project went as planned with a small exception that CTA database clarifications and track alignment data vetting extended into the January 2018 timeframe. Details of the Stage-1 project activities have been documented in the IDEA Program Stage-1 Report dated Dec. 15, 2016.

Stage-2 of the project consisted primarily of the staging and integration of the TCM system into the CTA Central Control infrastructure and involved close collaboration and coordination with CTA and their designated subcontractor PTG/QEI to provide the required interfaces for data exchange between CTA's existing Central Control System and TCM.

As can be seen in Table 1 above, the Stage-2 progress milestones slipped by four months, primarily in task seven (TCM integration). The cause of the delay was not so much the result of technical difficulties in the interface design and implementation but more due to delays in CTA's procurement process and the subsuppliers ability to mobilize resources for this project.

The delay was reported to the TRB Program Officer on 06/27/17 with final commitments on 07/24/17 as shown in revised milestone completion dates in Table 1 above. A no-cost extension to project schedule (T-83) was granted on 08/07/17.

PROJECT WORK PERFORMED

The Stage 1 work consisted of segregating and transferring the tool from the WMATA environment onto an independent and state-of-the-art operating system platform and enhancing the tool's software architecture to make it configurable and maintainable by typical transit agency IT technicians. It is intended the TCM tool be deployed and maintained without in-depth knowledge of software programming languages or database administration skills. The platform architecture enhancements are illustrated in Figure 2 below.

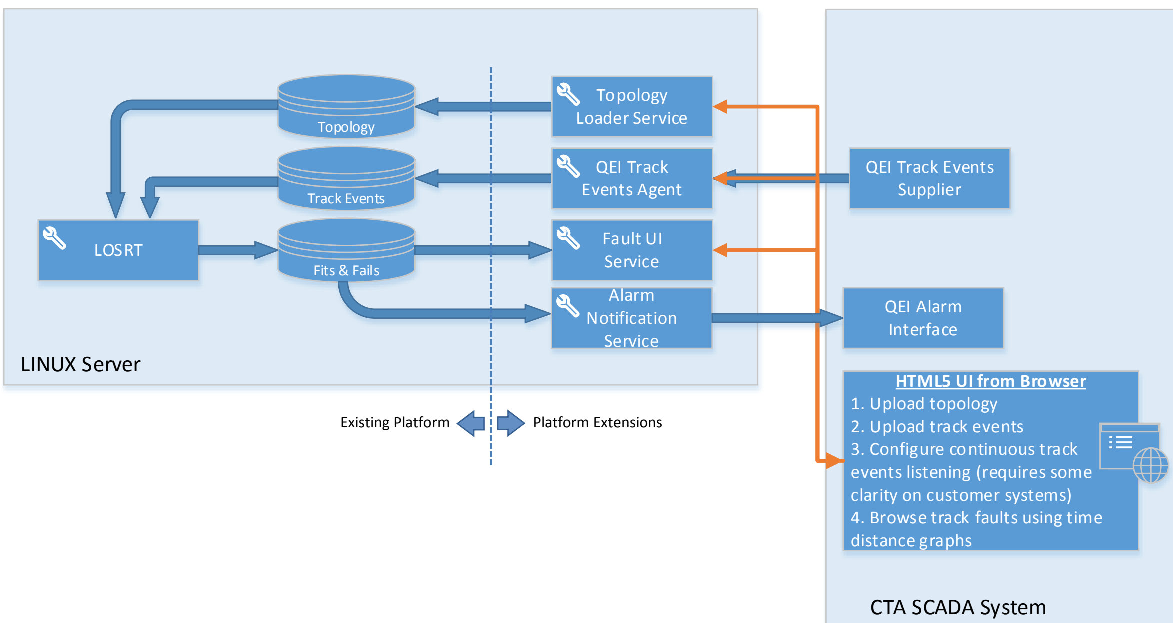


Figure 2: TCM enhanced Platform Architecture

The Stage-1 configuration of work performed for CTA is typical for a TCM deployment of any project – it provided the following features: (Note, bullet numbers correlate to numbers shown in Figure 3)

1. TCM running on the latest Linux Operating System (Ubuntu 16.04, and latest MySQL Database 14.14)
2. Track alignment parameterization. CTA Blue Line Track topology import via new TCM Topology Loader and MS Excel Spreadsheet template
3. Train Data definitions (at this point train length only) adjusted to CTA train types. Other train parameters got defined and verified during Stage-2 of the project
4. Track indications/data verification (in 24-hour blocks) via Event Loader
5. Traingraph (Time-Distance Diagram) for track data visualization of occupancies, train fits, and faults over time

6. Generating track charts in PDF format (same as at WMATA)

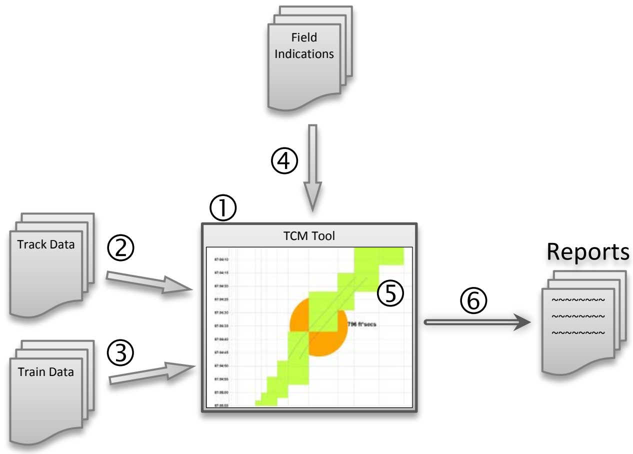


Figure 3: TCM Off-line configuration (Stage-1)

Note Figure 4, which illustrates a more detailed data flow chart for Stage-2: In transitioning from off-line to on-line operation the event data flow (bullet #4 in Figure 3) is getting replaced for the live data stream from the QuicTrak system. The ability to use offline data for historical analysis will continue to be available in the final real-time configuration during 24/7 operation.

The integration of the TCM tool into the CTA Central Control Systems infrastructure includes receiving live data from the existing QuicTrak (QT) Control System, and vice versa, issuing alarms to the QT Control System, as well as exchanging systems status information between the two systems, and connecting TCM to alarm devices and email/texting servers of the CTA communications infrastructure (see Figure 4 below).

In collaboration with CTA activities for Task #6 and #7 started in January 2016. CTA mobilized the services of a systems integrator to coordinate the following tasks:

- Purchase and setup hardware platform
- Support development and test of communication protocol between existing CTA OCC (i.e. QEI Quictrak)
- Support track database cleanup and completion

The integration of TCM with QuicTrak is a tighter integrated solution compared to WMATA. Figure 4 below provides an overview of integration measures and data flows (bullet numbers correlate to those circled in red in the illustration):

1. Realtime Data – live data streaming via TCP/IP inter-process communication between the TCM server and the QuicTrak servers.
2. Alarm to Line Controller in Charge via QuicTrak Alarm popup window and use of QuicTrak alarm handling
3. Integration to OCC infrastructure such as Alarm Strobe Lights, Sirens (if requested), eMail notifications and text messaging.
4. Mutual systems status updates on health status (heart beats), communications link, events processed, etc.

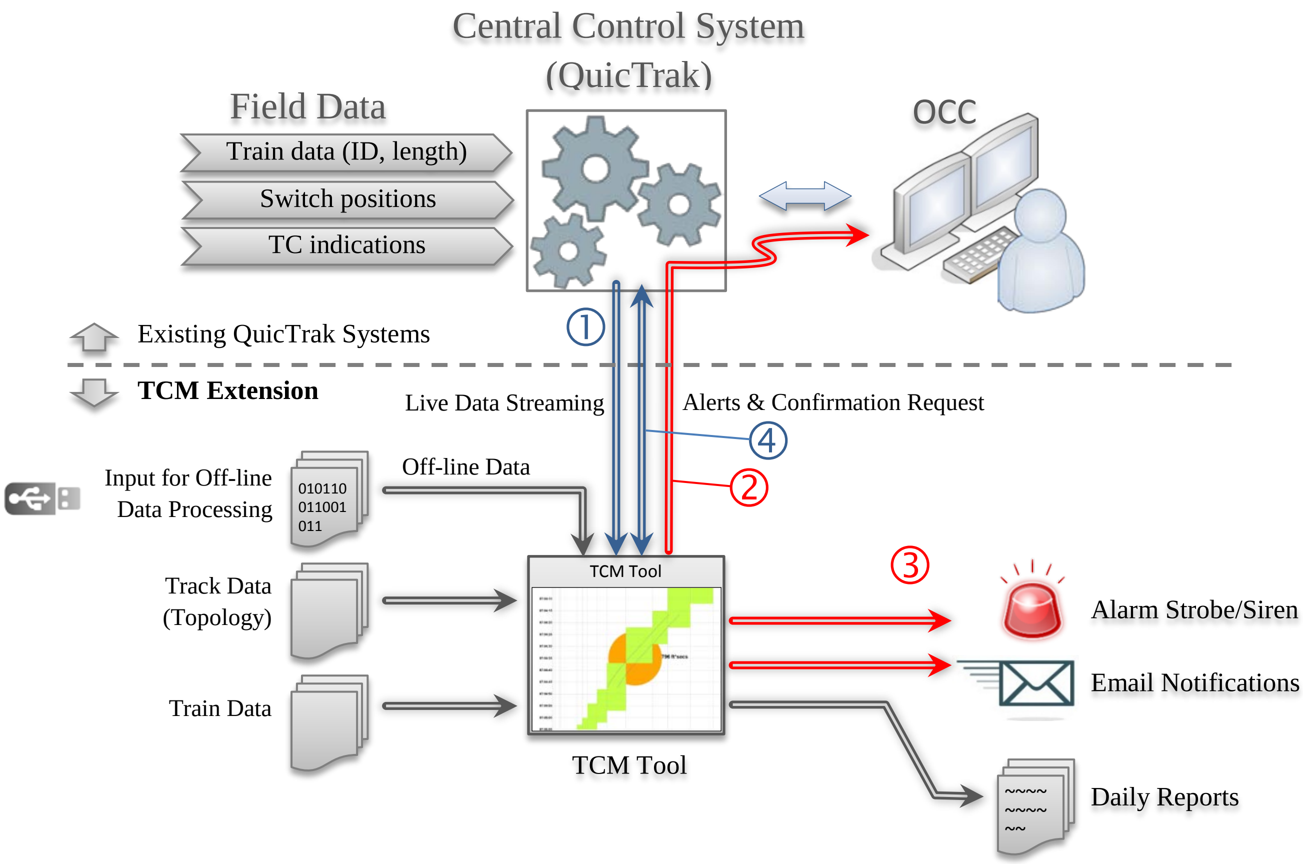


Figure 4: TCM On-line (real-time) configuration (Final Stage)

If TCM identifies abnormal operation that could potentially compromise safe and reliable revenue operation, it immediately alerts staff to the location and severity of events via TCM Alerts confirmation requests and per email to a list of designated experienced operations and maintenance personnel. Figure 5 below depicts the TCM Alert window as implemented on the QuicTrak (QT) Client workstation. The Alert dialog window is integrated into the CTA specific QuicTrak solution, actively waiting to be triggered by the TCM server. Upon receipt of a TCM alarm request, the QT system issues a corresponding alarm to the QT alarm management system and opens the TCM Alert window at the QT client for the Line Controller in charge to respond to the TCM alert request.

The TCM Alert window (see Figure 5) has the following features and meaning:
(note, italicized values in brackets and blue font are for exemplary purpose)

- Header "LOSS OF SHUNT" flashing alarm banner.
- Date and time of TCM alarm event
- Location information field:
  - Track: [*rl3150t*] - name of track circuit that set off the TCM Alarm
  - Station ID: [31400] – QT location identifier
  - Description: [rl3150t, Armitage Station – northbound track] - Track ID description
  - Incident Train: [*B101*] - the LOS incident train, i.e. the train ahead that set off the alarm in track [*rl3150t*]
  - Line: [*tpro*] – CTA Line name
- Instructions field:
  - Message to "*Stop Trains On Approach*" to the affected area - first of all, the train identified by the first train ID number directly below this message.

- Approach Trains: [*B1012*] first train following the LOS incident train
  [*B102*] second train following the LOS incident train (the train following B1012)
- Message to "*Implement SOP 653*", the Absolute Block Standard Operating Procedure (This is a configurable parameter and should to be confirmed by CTA)
- Message of [*SOP 653*] in textual form e.g. "*Implement Absolute Block on approach track*"

- Alarm Silence button - turns off the audible alarm and enables the "*Acknowledge and Clear*" button.
- Acknowledge and Clear button - when enabled, turns off the strobe alarm and closes the alarm pop-up window from line controller console. Button is initially disabled (i.e. greyed out), and enabled after clicking the Alarm Silence button.

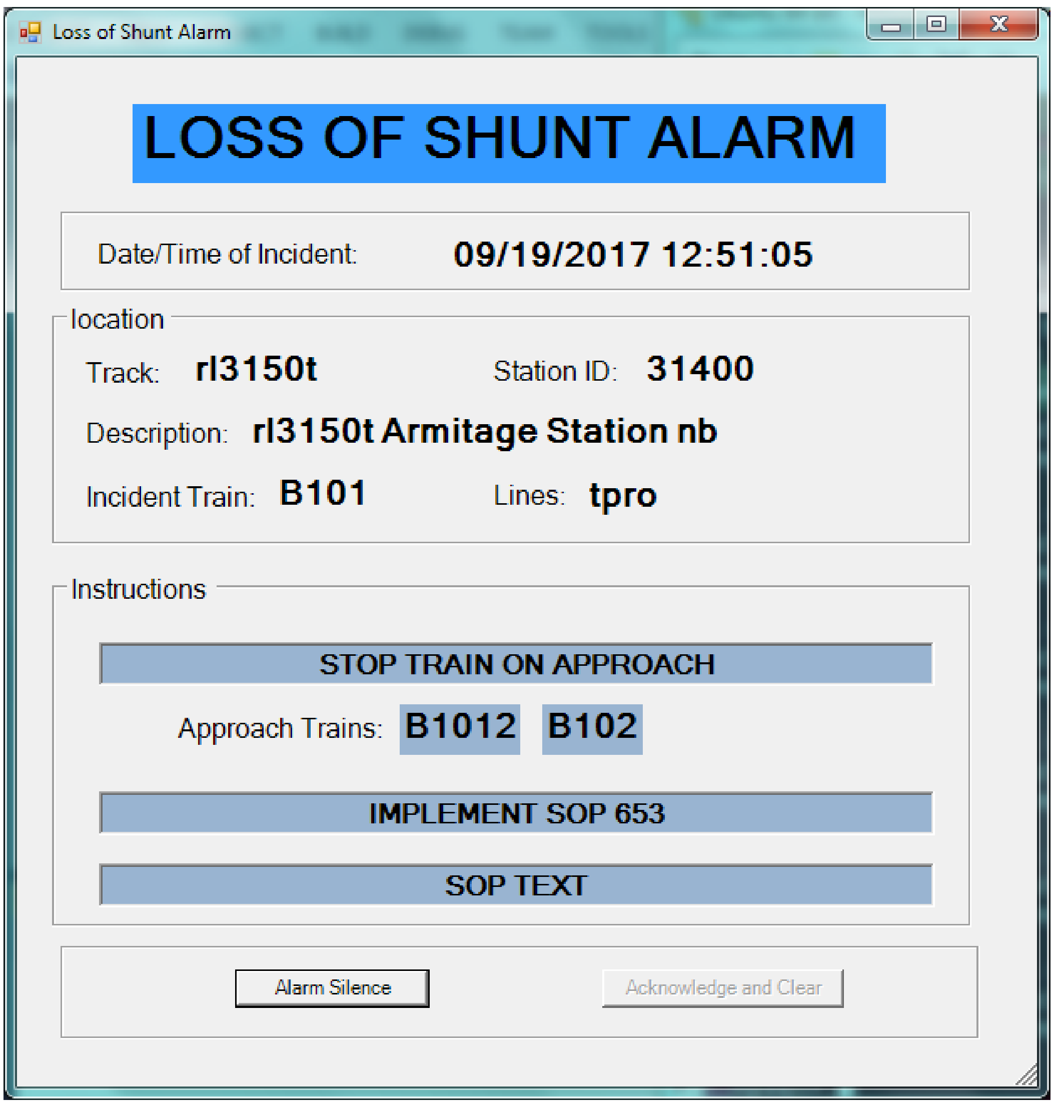


Figure 5: TCM Alert Window on QuicTrak Client Workstation

RESULTS OF DATA PROCESSING AND TESTING

The project work demonstrates that the application of the core components and existing algorithms of the TCM tool produce the results that were expected. An excerpt of a 24-hour window of raw data captured off the CTA Blue Line is shown in Figure 6. The event data in this example consists of field data captured on Monday, October 2, 2017. The time-distance diagram (Traingraph) shows track circuit indications over time (lime-green colored spaces) and train movement line (blue double lines) as calculated by TCM. Furthermore, any abnormal behavior is highlighted by solid colored circles, combined with a fault severity number of the anomaly. The Traingraph excerpt in Figure 6 shows northbound train movements starting at Forrest Park heading to O'Hare, beginning at 6:02:00 a.m.

As a train moves through the alignment, it occupies track blocks and its respective track circuits in a sequential manner. The respective track circuits and the duration of the occupancy is displayed by the lime-green rectangular spaces.

Based on the track occupancy indications, the TCM algorithm tracks trains and validates logical and correct sequence of occupancies as a result of moving trains. Based on timing of occupancy occurrences and additional parameters, such as train specific parameters (e.g. length, acceleration, deceleration), TCM tries to track the train's exact location within a block occupancy.

The two blue lines within the track occupancies (i.e. within the lime-green shaded areas) represent an approximation of the train tracking and its physical length of the train within the track circuit boundaries. The shorter the train, the narrower the horizontal distance of the two lines. Figure 7 below is a snapshot at a higher magnification and shows the train movement with their fitting lines more clearly.

The TCM train tracking algorithm is based on the laws of physics and applies conformance to the civil and engineering parameters set for the system in order to determine train locations. TCM's algorithms for instance include parameters such as the maximum velocity and maximum possible acceleration of a train in accordance with the civil characteristics of the track alignment. If there are any non-progressive or not consistent TC indications from what may appear to be a "failing" track circuit, it is assumed it would require that a train leaps forward or be extended backward instantly to the occupied circuit without conformation of progressive, sequential occupancy. A fault condition is shown in Figure 6, marked by a red circle and highlighted text indicating the severity of the fault (here 1874 ft.*secs). To determine whether a train is occupying a track circuit, the incoming indications must be sequential with other circuits that were occupied in approach. Any non-sequential data would indicate that the train is occupying a circuit without ever entering the previous circuit. These movements are not physically possible or will violate the operating rules. As a result, track circuit indications that are out of sequence are identified and segregated for maintenance attention and are processed differently. Track circuit vacancy indications under an existing train, however, are considered critical failures requiring immediate attention. Figure 7 below shows the highlighted example at a higher zoom-level, occurring around 6:17:08 (highlighted by the red dot), which constitutes a potentially safety critical condition.

The following traingraph shows sequences of track circuit indications as a result of train movements, including train tracking lines (blue) and fault identifications calculated by TCM. In this excerpt, TCM identified a number of track circuit indication inconsistencies, amongst them an abnormal, safety critical condition involving track circuit C198T – 577ft long at 6:17:08 and a train movement (train ID B226). This abnormal condition caused Train #B226 to completely disappear from the screen and the vital logic of the wayside signaling processor for 4 seconds (vacancy between 6:17:09am to 6:17:13am). TCM calculated a fault severity of 1874 ft*secs, which led to an alarm condition for OCC line controllers to take action.

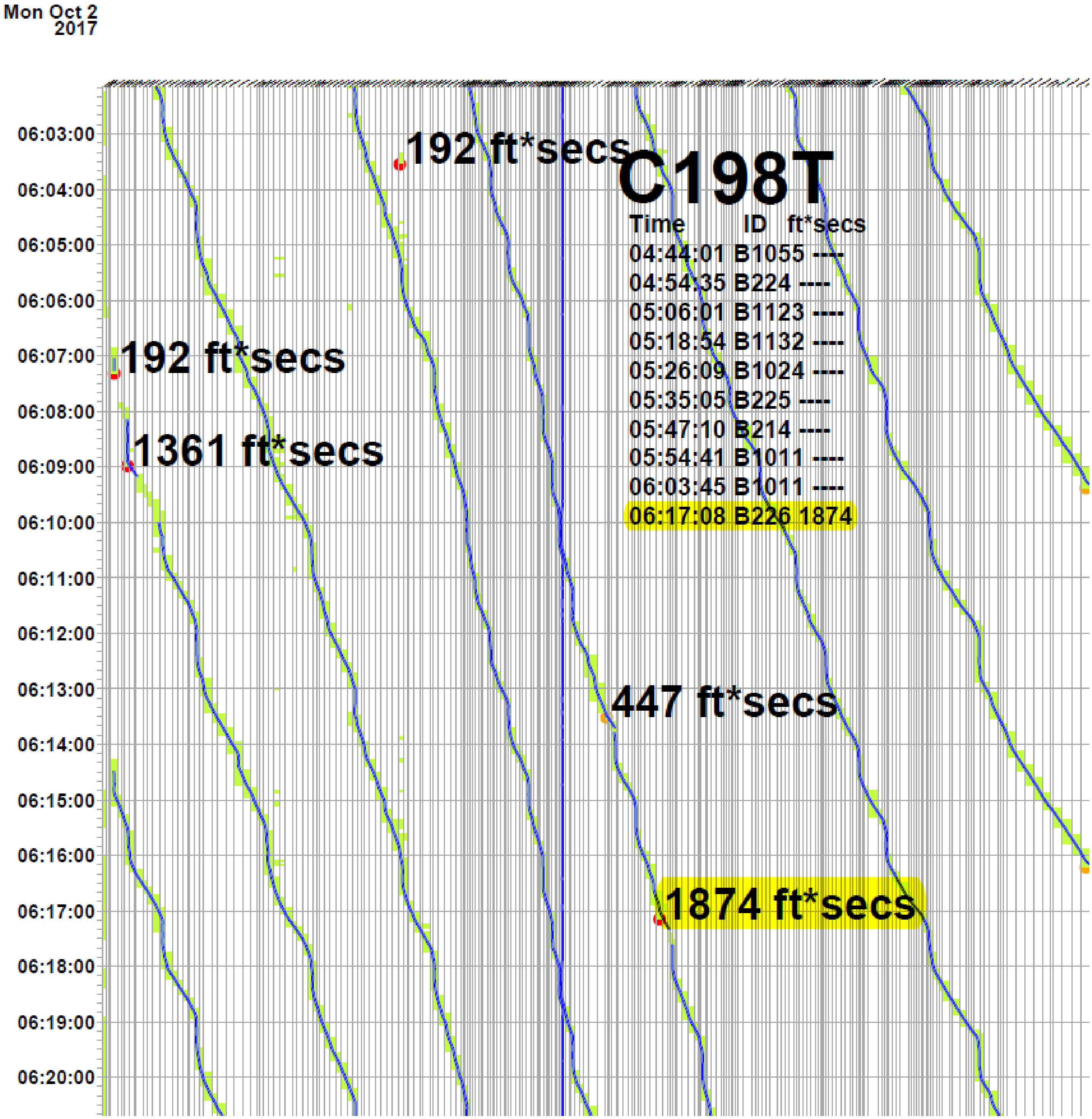


Figure 6: Train-Chart generated by TCM

Figure 7 below shows the 06:17:08am incident at C198T in more detail.

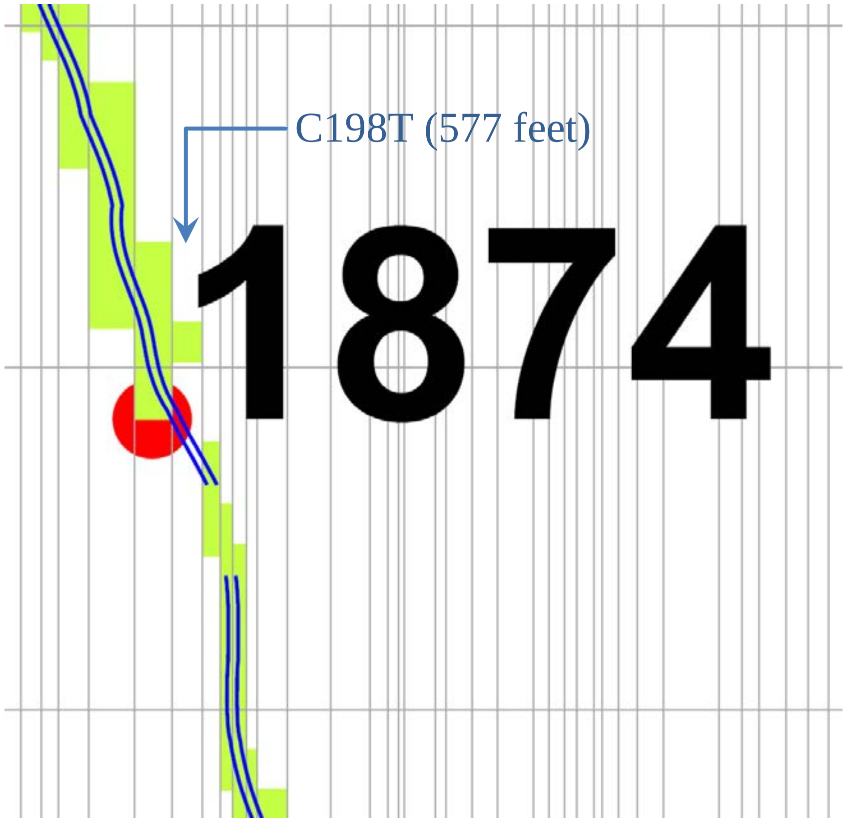


Figure 7: C198T Incident Detail (safety critical)

Other examples of track circuit anomalies identified by TCM are illustrated below.

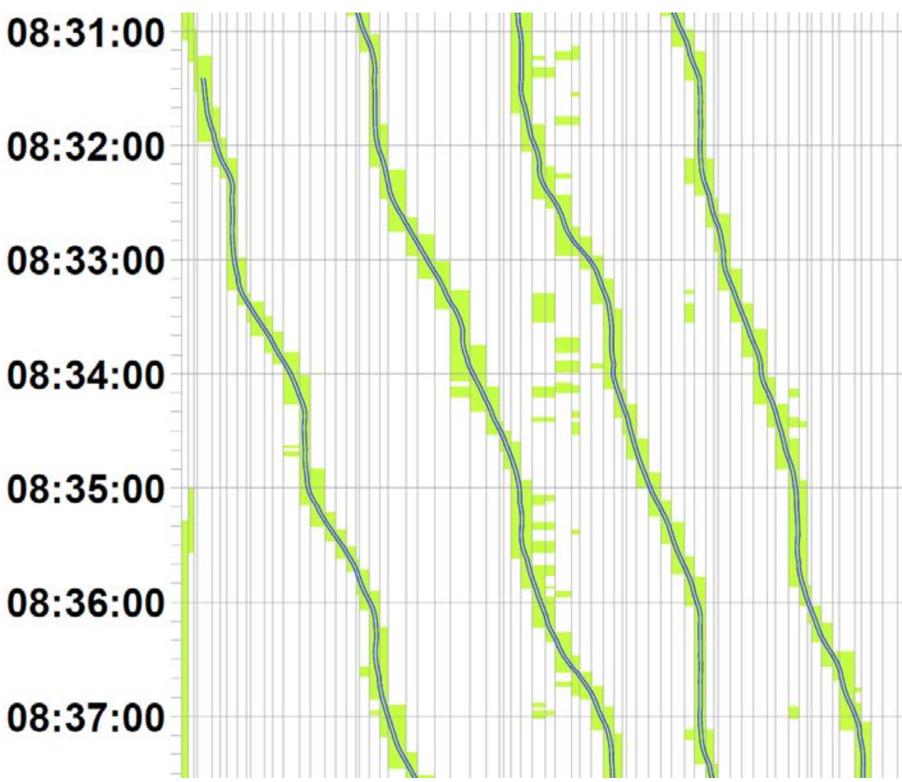


Figure 8: Irregular track circuit operation (non-critical) – bobbing track circuits

TCM's reports and Train-Charts (shown above) are a product of the track circuits performance and integrity monitoring capabilities. The information is valuable input for wayside maintenance personnel for investigating and identifying wayside equipment installation problems or wayside component problems such as circuits that were out of tolerance, with loose or broken terminations, or otherwise in need of adjustment and/or repair. Future train detection problems as a result of wear & tear or aging effects on systems and components will also be detected. TCM has the potential to reveal occupancy failures in Train Monitoring and Control Systems, regardless, if originating in wayside ATC systems or other infrastructure systems failure. TCM has proven to be a valuable tool in identifying the following problem areas:

Failures to detect train occupancy	**False occupancy**
Parasitic Oscillation	Circuits out of Adjustment
Circuits out of Adjustment	Damaged Bonds
Corrugated Rail	Broken rail
Damaged Bonds	Traction Power Imbalance
Broken rail clamps	Dissimilar Rail
Loose connectors	Bobbing Track Circuits
Rusty Rail	
Autumn leaves	
Short circuits protected by LOS timer	

CHALLENGES ENCOUNTERED IN THE PERFORMANCE OF THE WORK

The CTA Blue Line has been loaded into the TCM database end-to-end from Forrest Park to O'Hare Int'l Airport. It consists of the Congress branches, Milwaukee-Dearborn Subway, and O'Hare. The Blue Line is the longest line of the CTA rapid transit service network and extends from the West Side (Forrest Park / Des Plaines Avenue via the Eisenhower Expressway median.) through the Loop via the Milwaukee-Dearborn subway to O'Hare. The route from Forest Park to O'Hare is 26.93 miles long and consists of 33 stations. Until 1970 the northern section of the Blue Line terminated at Logan Square, during that time it was called the Milwaukee route after Milwaukee Avenue which ran parallel to it; Service was extended to Jefferson Park via the Kennedy Expressway median, and in 1984 to O'Hare. The Blue Line provides 24-hours rapid transit service and is CTA's second busiest line following the Red Line with also 33 stations (see APPENDIX B: CTA BLUE LINE for alignment details).

The development and test of the track database turned out to be significantly more time consuming than originally expected. Challenging parts of this task include the following:

- The CTA Blue Line is the longest (and second busiest) line of the Chicago Transit Authority. The signaling system was installed throughout time in various construction phases and different signaling suppliers. Signaling documentation greatly varies in terms of drawings (degree of documentation and layouts), and basis of alignment stationing numbering. Additional effort was required to "normalize" the Blue Line from end-to-end in order to conform to a common format for TCM and the ability to be automatically imported into TCM's track database.
- As already addressed in the Stage-1 progress report, the Blue Line block design (topology) required a thorough review due to a number of observed inconsistencies. While most of these inconsistencies could be resolved early on in the Stage-2 phase, a few are still remaining. The TCM database has been verified (twice) that it is consistent with the wayside signaling drawings, which is the guiding source documentation of the signaling block design. The "food-chain" of Track Circuit indications can be summarized starting at wayside Track Circuits → Wayside Processor → RTUs → Communications → OCC Front-end Processor / QuicTrak → TCM server. Remaining inconsistencies at this juncture can only be resolved with the support of CTA OCC/QEI technical assistants and CTA wayside signaling personnel.

The TCM/QT integration phase was accompanied by different types of challenges, mostly related to interface design and test. A few prominent ones being the following:

- The QuicTrak Control System has the ability to "silence" field data points. In the past it was common practice to silence track circuits that show an increased number of false or intermittent occupancies (bobbing track circuits). This way, the QT internal train tracking system didn't get confused and CTA's schedule management stayed intact. A side-effect of silenced track circuits is that these points do not get transferred to the TCM server, which is in conflict with the purpose of the TCM integrity monitoring function. TCM creates alarms for every silenced track circuit. In clarifications with QEI, some of the silenced data points have been activated again, others are still under investigation. It is expected that QEI will ensure that all incoming track circuit status indications will be transmitted to the TCM server, regardless of the QT internal "silence" filter.
- The TCM/QT interface was expected to be able to handle the data volume of not only the CTA Blue Line but all existing CTA Rapid Transit Lines plus a spare capacity of 20%. This equates a message occurrence of approx. once every 10 milliseconds or about 100 messages per second. This projected data volume should cover a typical rush-hour scenario of all CTA line plus the 20% spare capacity. See Figure 9 for an illustration of the TCM-to-QuicTrak interface data flows. During the testing phase, especially the long-term load test, it was noticed that the current interface design was unable to handle the projected data volume. This required a redesign in the interface protocol and TCM database structure. In addition, numerous SQL database optimization measures were required to handle the incoming field raw-data volume as well as the internal TCM server live-data processing calculations. The revised interface protocol design and database table structures, along with the SQL performance optimization measures finally support the interface performance requirement.
- The WMATA TCM solution acquires dynamic train specific parameters such as train ID and train length per Train-to-Wayside Communications (TWC) equipment. Since CTA's wayside equipment is not equipped with TWC devices an alternate method was required to derive train ID and the accurate length of trains as these are key parameters for TCM to process train location tracking. At the time of the IDEA Grant Proposal this was an unresolved design aspect of the CTA specific solution. The close integration of TCM with the QT system – thus gaining access to the CTA Schule management system, enabled a path to acquire this information. Besides transmitting field raw track circuit data, it was determined to be prudent and the most efficient approach for dynamic train data handling to have QT perform a train data fetch from the QT scheduler and pass along the corresponding Train ID and train length as supplemental information to the TCM server.

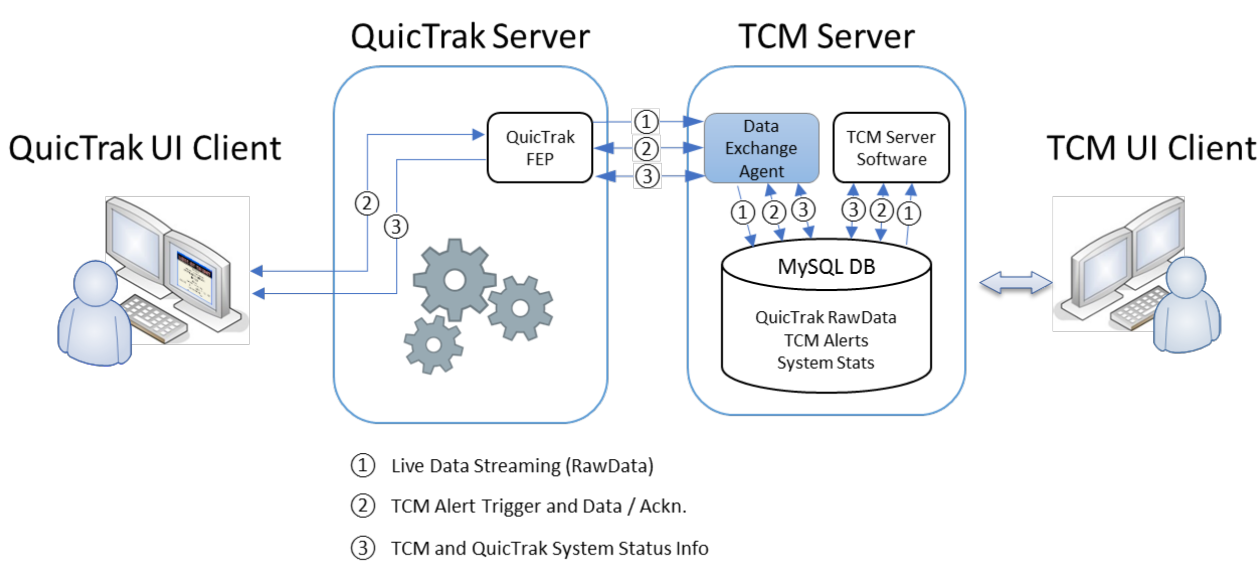


Figure 9: QuicTrak-to-TCM Data Exchange Components and Data Flows

SOFTWARE APPLICATION SOURCE CODE STATISTICS:

Subsystem	Description	Existing source code	Modified source code	New source code	Total LoC (as of 10/4/17)
Software Build and Compatibility	Software development environment scripts for compilation and linking, test scripts, and std.-lib inclusions.	0		242	**242**
Configurability	TCM configuration files related to configurable parameters, parameters itself are being used in core files, new code, and wherever required.	0		71	**71**
Installer	An abundance of files related to SW installation, OS and lib validation, installation validation files, etc.	0		535	**535**
Systems logging	Includes approx. 5% of existing core software code for systems and application logging-ctrl.	107	107	278	**385**
Core algorithms and PDF generation	Source code received from WMATA. Approx. 5% of these lines have been modified for configurability and logging purpose.	2,133	107	346	**2,479**
User Interface (base package)	Graphical user interface as HTML web application for access from remote workstations. Includes TCM tools and systems status information displays.	0		6,982	**6,982**
Interactive user interface full-graph (advanced pkg.)	Similar to PDF train graphs but interactive full graph application to display occupancies, fault locations and train (strict) fit lines along with other fault analysis tools.	0		10,931	**10,931**
Track Topology Loader	Server database tool to load new alignment sections from Excel files in standard .csv format.	0		244	**244**
Event Loader	Server database tool to load offline track circuit data from Excel/.csv files.	69		370	**439**
QT interface and alert handling	Interface software to handle data exchange between TCM and QT Agent. Includes alert notifications and systems status data.	0		468	**468**
Server Status Monitoring	Watchdog software to monitor TCM and QT Agent health status (heart beats) and message exchange monitoring stats.	0		350	**350**
Total LoC		**2,202**	**107**	**20,817**	**23,019**

PROJECT RESULTS AND OUTCOME

Our experience shows that Transit Agencies seem to develop a Love-Hate relationship with the tool, especially during the introduction of the tool, when TCM identifies and illustrates abnormal behavior to an extent that can be unexpected and surprising to the operations and maintenance departments. It is not unusual to see a considerable number of alerts and unusual behavior of track circuits - initially - that can easily lead to overwhelming liability concerns for General Management and O&M departments. After verification and deployment of TCM on CTA's production system (i.e. CTA's central control network) TCM generated hundreds of alarms per day. It should be noted, that this is a very similar phenomenon as WMATA experienced in the beginning phase of TCM deployment in the year 2010. Figure 10 below shows the historic data of LOS alerts. The number of events continuously fell from a high of almost 300 per day to about 10 per day over the period July 2010 to July 2011. We expect to see a similar trend at CTA once TCM gets incorporated into CTA's daily maintenance procedures. It is recommended to run the tool for a break-in period of approximately 4-6 months to allow users and the organization to adjust to any revised business processes that the tools may introduce to O&M organization. In order to set expectations of alert occurrences and typical alert trends to newly participating Transit Agencies, it is furthermore recommended to revise the TCM related APTA Recommended Practice guide lines with regards to the phenomenon of very large numbers of alerts initially and the resulting liability concerns for General Management and their engineering and maintenance departments.

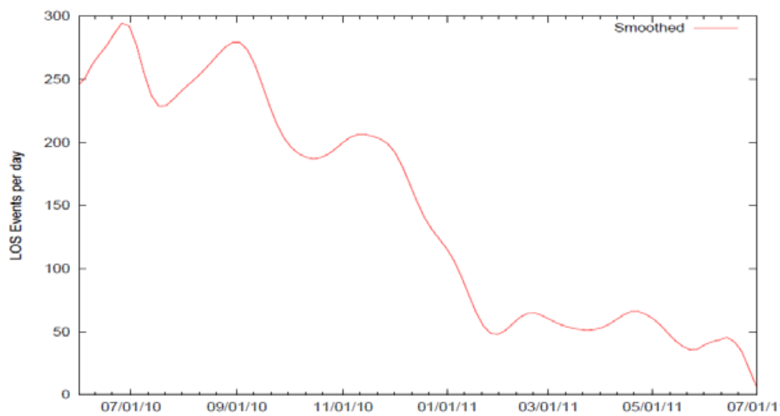


Figure 10: Alert trend line at WMATA over the period of one year from July 2010 to July 2011

Improvements – i.e. reduction in alarms – directly related to improvements in maintenance measures and subsequently, resulting in increased reliability of equipment and passenger service.

BENEFITS FOR WAYSIDE SIGNALING MAINTENANCE

The tool offers valuable information for signal system maintenance and operations managers alike. For wayside maintenance it enables continuous analysis and recording of track circuit operation (24/7) and provides insight into potentially serious problems. This feature provides critical information that helps Maintenance Managers in the prioritization of track circuit incidents, which are major improvements. TCM assists Maintenance Management by means of:

- Improved timely reaction to potentially safety critical conditions and serious incidents
- Automated daily reports on tracking anomalies and irregularities
- Early detection of track circuit malfunction or deterioration
- Maintenance prioritization for faster response to new and reoccurring problems
- Improved asset reliability and subsequently more reliable service
- Extended useful lifetime of assets

For the operations department it provides the ability to quickly and efficiently identify and evaluate track circuit locations where potentially serious occurrences may be happening, thus resulting in timely response before potentially critical conditions can impact revenue service. These features are major assets for a Transit organization striving to continuously improving their commitment to safe revenue operation.

PRODUCT TRANSFER TO PRACTICE:

The TCM tool serves as a reference and a proven solution to the Recommended Practice issued by APTA and recommended by the NTSB for a software-based Track Circuit Monitoring Tool. Target audience for tool deployment are transit agencies that currently do not have a track circuit monitoring system installed. Latest agency to introduce TCM into their Operations and Maintenance infrastructure is MARTA (Metropolitan Atlanta Rapid Transit Authority) in a 2-phase / 2-year implementation plan. It includes track circuit monitoring of all four mainlines including initial offline data processing followed by live data processing with real-time interfaces to MARTA's new TCSU Central control system provided by Alstom.

The TCM tool is getting visibility for transfer to practice by participation of the TCM team in transit industry forums such as APTA Recommended Practice meetings, Signaling Standards meetings, APTA webinars, APTA Annual Rail Conferences, and transit industry conventions and exhibitions. These forums allow for creating awareness of LOS risks and possible mitigation approaches to this matter. Recent meetings have led to discussions with BART for considering a TCM deployment at BART's new CBTC designs as secondary train movement monitoring system. Other transit agencies included in these forums are LAMTA, SORTA, SEPTA, CTA/METRA, Miami Dade, TU, RTD, TriMET, NCTD, SCRRA.

Recent activities to raise awareness:

- Developed and reviewed an APTA Recommended Practice and guideline to a commonly accepted industry approach for a secondary Train Monitoring System.
- TCM Tool Presentation at the 2016 APTA Annual Rail Conference in Phoenix
- Poster Presentation at the TRB Annual Meeting in Washington D.C. January 10, 2016
- Follow-up with LAMTA to discuss approach of TCM deployment. Upon LAMTA's request, proposal was submitted in September 2016.
- TCM Tool Presentation at the 2017 APTA Annual Rail Conference in Baltimore, June 13, 2017.
- Presentation and progress report at TCRP Oversight Project Selection committee (TOPS) meeting, June 1, 2017 in Woods Hole (MA)
- Presentation and progress report at TCRP Oversight Project Selection committee (TOPS) meeting, August 8, 2017 in Woods Hole (MA)
- Conducted APTA Webinar titled "Using Track Circuit Monitoring Technology", September 19, 2017

The long-term goal is to institutionalize a "*continued improvement and feedback loop*" for the benefit of all participating agencies, providing the option to upgrade previous installations with new functionality and features. For this purpose, a website may be developed in the future that provides TCM relevant information and articles such as TCM concepts and systems requirements, software download sites, systems references, FAQ, blogs, etc.

As part of this, it is the goal to create a self-sustaining environment for TCM tool know-how, allowing for continued tool improvements, best practice advise for tool implementation, tool support (now and in the future).

PATENTS, COPYRIGHTS, AND LICENSE AGREEMENTS

The TCM product software is protected and under copyright consisting of the following parties:

- Existing WMATA software, written and protected by Timothy Shoppa (holder of US Patent 8996208 covering the WMATA ATC Track Circuit monitoring tool)
- Software additions for the TCM standardization and product enhancements written and protected by Frank Beeck (Rail IT, LLC)

Transit Agencies will be granted a non-exclusive, nontransferable, permission-to-use software license. Copyright and IP rights will remain with the creators of the software (Tim Shoppa - WMATA, Frank Beeck - Rail IT, LLC).

CONCLUSION

The TCM tool – if included in daily maintenance planning – increases the reliability of track circuits by continuously monitoring and evaluating track occupancy indications for integrity and plausibility and is qualifying its condition as normal, irregular, failure, or potentially critical condition. In case of abnormal operation e.g. intermittent track circuit dropping, TCM provides appropriate alerts and notifications for follow on actions to inspect and maintain track circuits to a state of good repair. This way it serves as an important maintenance support tool and early warning system for corrective maintenance needs early-on as well as preventive maintenance to avoid continued degradation and premature device failure.

The TCM tool has been documented and is available to the industry as an APTA Recommended Practice. TCM meets the requirements of the NTSB urgent request to FTA R-09-7.

The TCM software package has been found to be a significant asset in the analysis, detection, and identification of track circuit anomalies, affecting the reliability and potentially the safety of these systems. If required, TCM alerts abnormal conditions to experienced and specialized staff of the operations, maintenance, and engineering organizations of the potential threat in the shortest possible time.

Rail IT is in the process of clarifying TCM requirements with MARTA. Pilot data sets of three MARTA interlocking sites have been modeled and evaluated. Those pilot runs confirmed TCM's ability to identify track circuit anomalies that MARTA otherwise evaluated in a time consuming manual process.

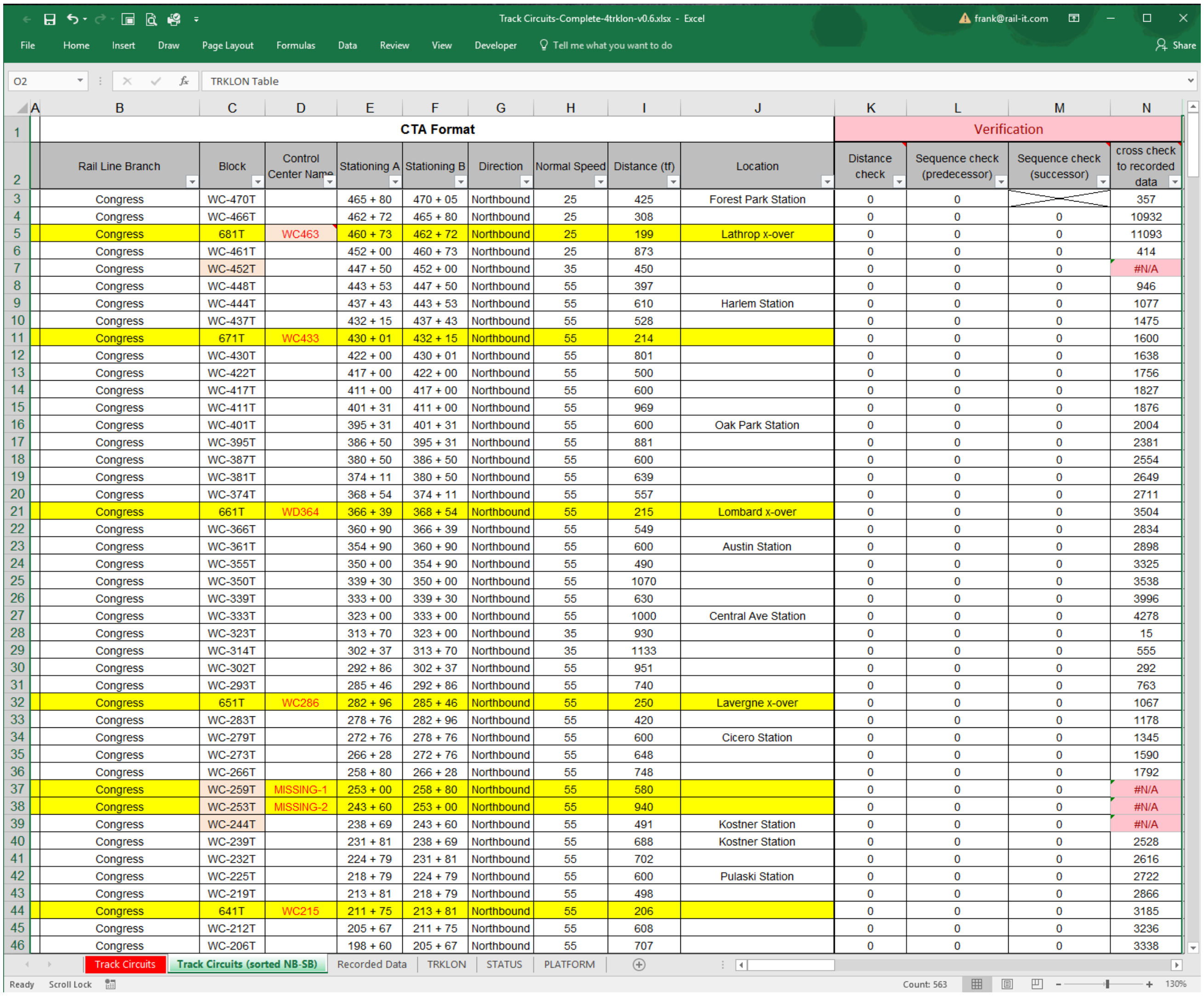
Currently, this tool is successfully operating at WMATA and since July at CTA's Blue Line. CTA has indicated to proceed with the TCM deployment for all remaining CTA rapid transit lines, the red line being the next one in line.

This IDEA project was a breakthrough for putting TCM on the map and getting attention from Transit Agencies across the nation. CTA, in particular Michael Lowder, was instrumental in supporting this effort and creating the environment for providing the proof of concept of TCM as a standardized software package. A big thank you to Michael and his team for taking the initiative to introduce TCM to the CTA Rapid Transit systems infrastructure and for the extraordinary collaboration in bringing this project to a successful end.

APPENDIX A: MISCELLANEOUS TCM SUPPORT TOOLS AND TRAINGRAPHs

Excel Template for Track Topology Editing

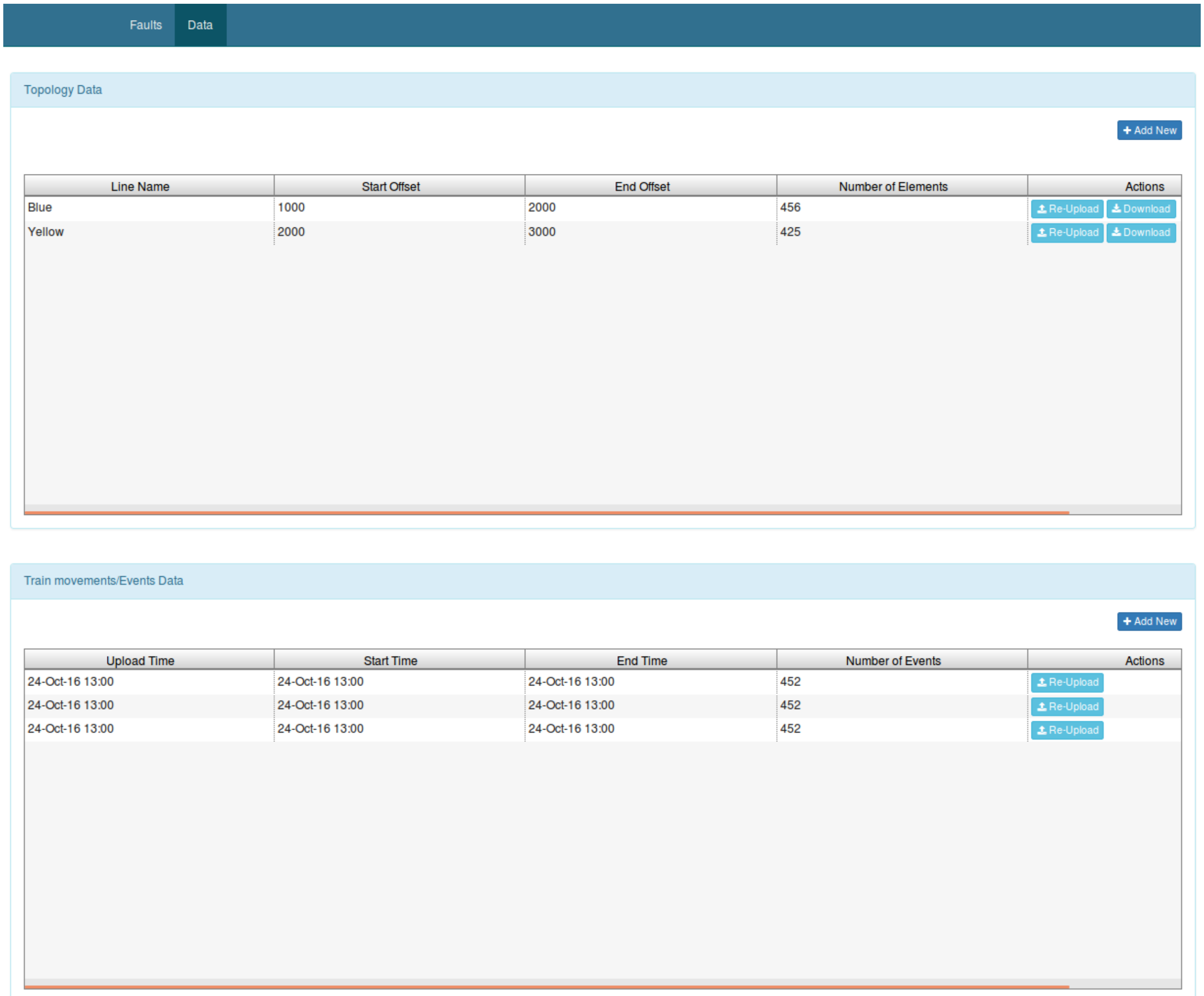
The Microsoft Excel template supports TCM Database development and track block consistency validation as data are being entered into the table. Automated validation indicates and highlights consistency problems in tan colored and pink colored cells, which helps resolving problems before loading the track topology into TCM. The Excel spreadsheet generates a .csv file (comma separated values) that is being used by the TCM Topology Loader as import file to create the track alignment in the TCM database and TCM graphics.



1	CTA Format									Verification			
2	Rail Line Branch	Block	Control Center Name	Stationing A	Stationing B	Direction	Normal Speed	Distance (tf)	Location	Distance check	Sequence check (predecessor)	Sequence check (successor)	cross check to recorded data
3	Congress	WC-470T		465 + 80	470 + 05	Northbound	25	425	Forest Park Station	0	0		357
4	Congress	WC-466T		462 + 72	465 + 80	Northbound	25	308		0	0	0	10932
5	Congress	681T	WC463	460 + 73	462 + 72	Northbound	25	199	Lathrop x-over	0	0	0	11093
6	Congress	WC-461T		452 + 00	460 + 73	Northbound	25	873		0	0	0	414
7	Congress	WC-452T		447 + 50	452 + 00	Northbound	35	450		0	0	0	#N/A
8	Congress	WC-448T		443 + 53	447 + 50	Northbound	55	397		0	0	0	946
9	Congress	WC-444T		437 + 43	443 + 53	Northbound	55	610	Harlem Station	0	0	0	1077
10	Congress	WC-437T		432 + 15	437 + 43	Northbound	55	528		0	0	0	1475
11	Congress	671T	WC433	430 + 01	432 + 15	Northbound	55	214		0	0	0	1600
12	Congress	WC-430T		422 + 00	430 + 01	Northbound	55	801		0	0	0	1638
13	Congress	WC-422T		417 + 00	422 + 00	Northbound	55	500		0	0	0	1756
14	Congress	WC-417T		411 + 00	417 + 00	Northbound	55	600		0	0	0	1827
15	Congress	WC-411T		401 + 31	411 + 00	Northbound	55	969		0	0	0	1876
16	Congress	WC-401T		395 + 31	401 + 31	Northbound	55	600	Oak Park Station	0	0	0	2004
17	Congress	WC-395T		386 + 50	395 + 31	Northbound	55	881		0	0	0	2381
18	Congress	WC-387T		380 + 50	386 + 50	Northbound	55	600		0	0	0	2554
19	Congress	WC-381T		374 + 11	380 + 50	Northbound	55	639		0	0	0	2649
20	Congress	WC-374T		368 + 54	374 + 11	Northbound	55	557		0	0	0	2711
21	Congress	661T	WD364	366 + 39	368 + 54	Northbound	55	215	Lombard x-over	0	0	0	3504
22	Congress	WC-366T		360 + 90	366 + 39	Northbound	55	549		0	0	0	2834
23	Congress	WC-361T		354 + 90	360 + 90	Northbound	55	600	Austin Station	0	0	0	2898
24	Congress	WC-355T		350 + 00	354 + 90	Northbound	55	490		0	0	0	3325
25	Congress	WC-350T		339 + 30	350 + 00	Northbound	55	1070		0	0	0	3538
26	Congress	WC-339T		333 + 00	339 + 30	Northbound	55	630		0	0	0	3996
27	Congress	WC-333T		323 + 00	333 + 00	Northbound	55	1000	Central Ave Station	0	0	0	4278
28	Congress	WC-323T		313 + 70	323 + 00	Northbound	35	930		0	0	0	15
29	Congress	WC-314T		302 + 37	313 + 70	Northbound	35	1133		0	0	0	555
30	Congress	WC-302T		292 + 86	302 + 37	Northbound	55	951		0	0	0	292
31	Congress	WC-293T		285 + 46	292 + 86	Northbound	55	740		0	0	0	763
32	Congress	651T	WC286	282 + 96	285 + 46	Northbound	55	250	Lavergne x-over	0	0	0	1067
33	Congress	WC-283T		278 + 76	282 + 96	Northbound	55	420		0	0	0	1178
34	Congress	WC-279T		272 + 76	278 + 76	Northbound	55	600	Cicero Station	0	0	0	1345
35	Congress	WC-273T		266 + 28	272 + 76	Northbound	55	648		0	0	0	1590
36	Congress	WC-266T		258 + 80	266 + 28	Northbound	55	748		0	0	0	1792
37	Congress	WC-259T	MISSING-1	253 + 00	258 + 80	Northbound	55	580		0	0	0	#N/A
38	Congress	WC-253T	MISSING-2	243 + 60	253 + 00	Northbound	55	940		0	0	0	#N/A
39	Congress	WC-244T		238 + 69	243 + 60	Northbound	55	491	Kostner Station	0	0	0	#N/A
40	Congress	WC-239T		231 + 81	238 + 69	Northbound	55	688	Kostner Station	0	0	0	2528
41	Congress	WC-232T		224 + 79	231 + 81	Northbound	55	702		0	0	0	2616
42	Congress	WC-225T		218 + 79	224 + 79	Northbound	55	600	Pulaski Station	0	0	0	2722
43	Congress	WC-219T		213 + 81	218 + 79	Northbound	55	498		0	0	0	2866
44	Congress	641T	WC215	211 + 75	213 + 81	Northbound	55	206		0	0	0	3185
45	Congress	WC-212T		205 + 67	211 + 75	Northbound	55	608		0	0	0	3236
46	Congress	WC-206T		198 + 60	205 + 67	Northbound	55	707		0	0	0	3338

Figure 11: Excel table for track block editing

The new TCM Graphical User Interface (GUI) supports the production of Traingraphs based on time and location as well as data import support functions for track alignment data and offline field event data.

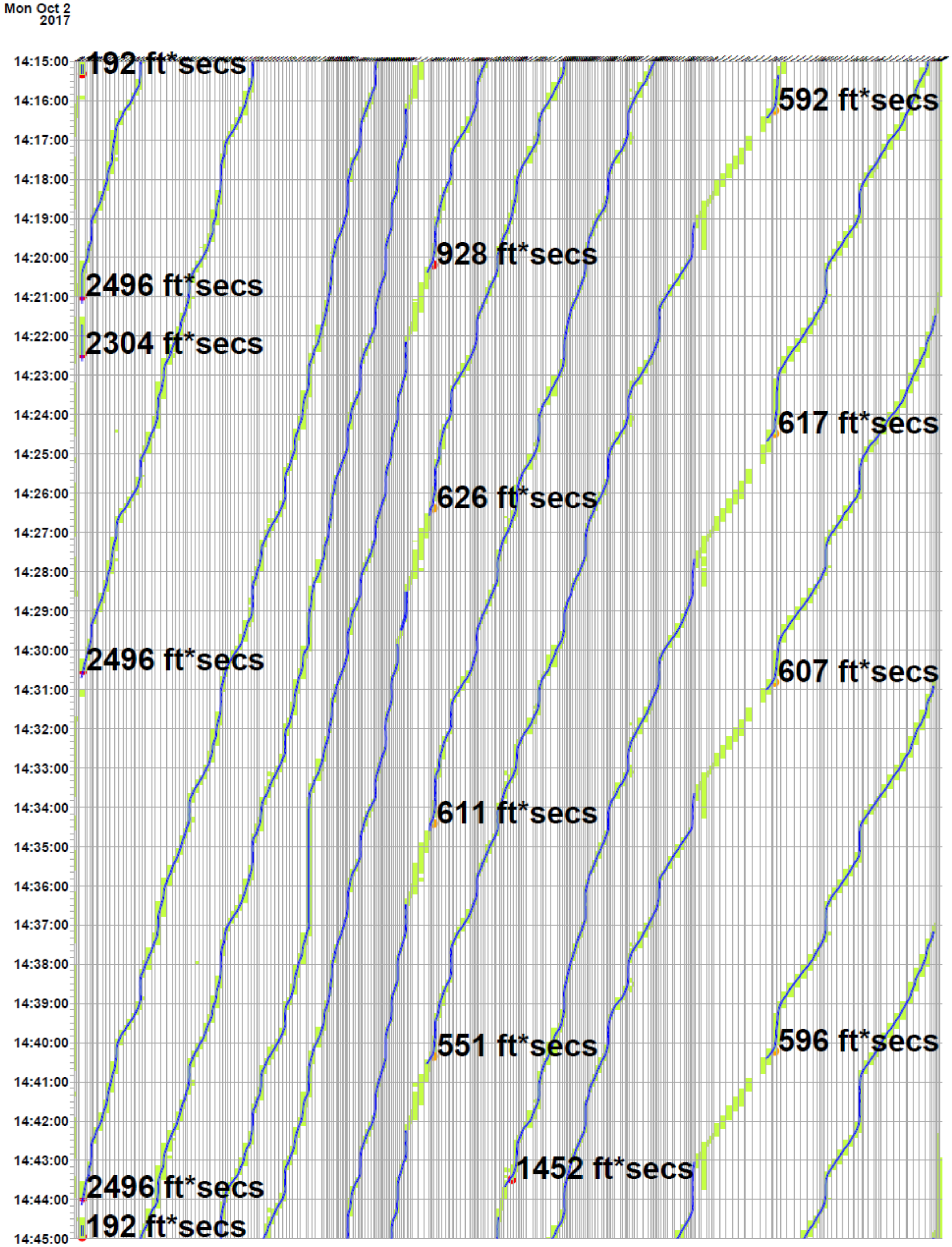


Line Name	Start Offset	End Offset	Number of Elements	Actions
Blue	1000	2000	456	Re-Upload Download
Yellow	2000	3000	425	Re-Upload Download

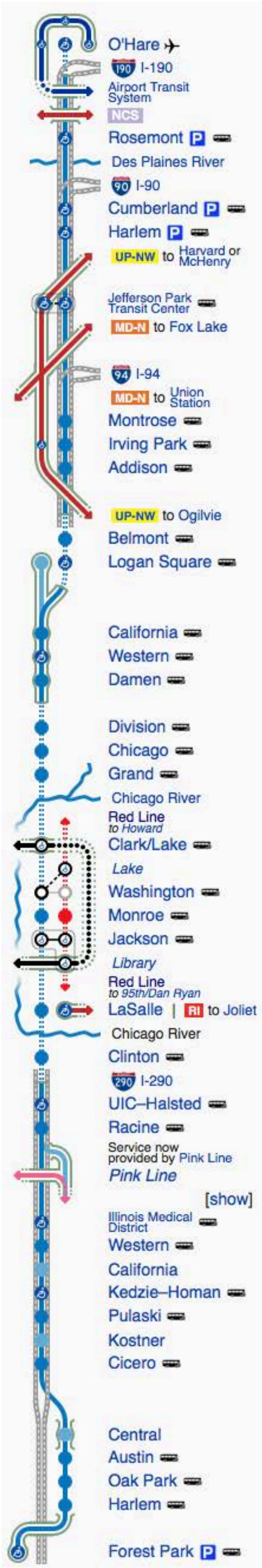
Upload Time	Start Time	End Time	Number of Events	Actions
24-Oct-16 13:00	24-Oct-16 13:00	24-Oct-16 13:00	452	Re-Upload
24-Oct-16 13:00	24-Oct-16 13:00	24-Oct-16 13:00	452	Re-Upload
24-Oct-16 13:00	24-Oct-16 13:00	24-Oct-16 13:00	452	Re-Upload

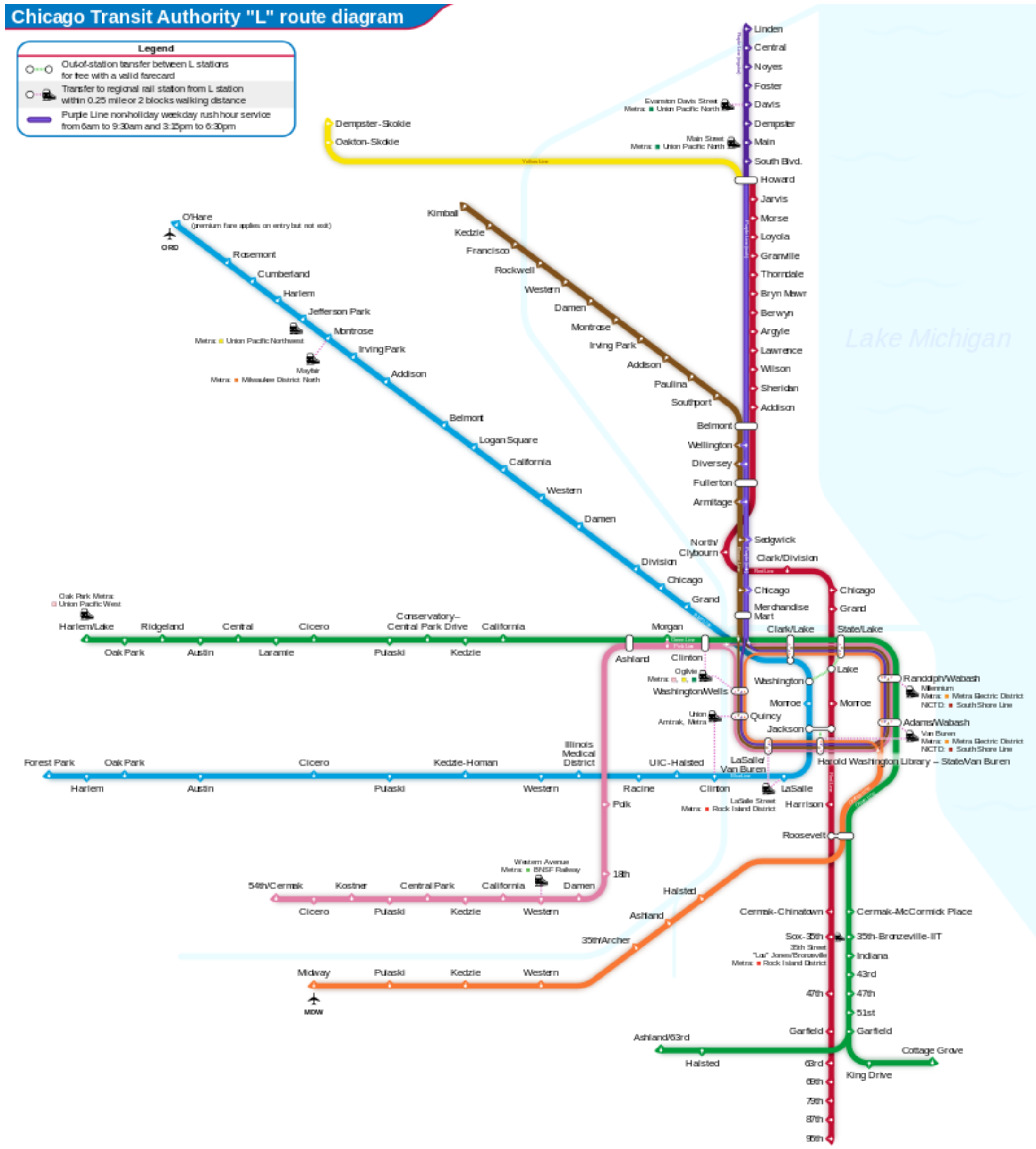
Figure 12: TCM GUI – Topology Loader and Event Loader

Figure 13: Southbound Train Tracking and Fault indication - Traingraph generated by TCM in PDF format



APPENDIX B: CTA BLUE LINE





APPENDIX C: PROJECT WORKPLAN

Stage 1: Product Standardization and Enhancements for CTA (duration 6 months)

TASK 1: Standardization of Software to a state-of-the-art hardware and software platform (2 months)

1. Familiarization and code inspection of the existing TCM tool as currently implemented at WMATA
2. Setup Collaboration teams with WMATA and CTA
3. Determine required product enhancements and analyze existing code structure to develop requirements specification.

TASK 2: Product enhancement and initial testing (Level-1 test)

1. Software design, implementation, and module test
2. Acquisition and setup of platform for software development and test
3. Loading system with existing test data from WMATA and CTA

TASK 3: Advanced testing of product based on final definition of database (2 months)

1. Verification of the LOS Tool Level-1 and Level-2 functionality
2. Test reports

TASK 4: Legal aspects concerning use of software

1. Investigate legal aspects related to intended source code management (liability statement, copyrights, indemnification, disclaimer, etc.). Write-up of initial Terms & Conditions for use of source code, (Note: a legal review of T&C is not included in scope of work)

TASK 5: Stage I Report: (2 months)

1. Following this review, a Stage I final report will be submitted to the IDEA program office, along with written review comments and responses. The Stage I final report will detail the results and findings of this stage and identify strategies for Stage II to address any issues.

Stage II: Deployment of Product at CTA (duration 9 months)

TASK 6: CTA specific enhancements, performance optimization, and offline testing (3 month)

1. Clarification of CTA specific requirements
2. In Collaboration with CTA, design and implementation of CTA enhancements
3. Loading CTA Blue Line (26 miles and 33 Passenger Stations)
4. Test of product on CTA target platform for Level-1 and Level-2 functionality

TASK 7: Product integration into CTA OCC infrastructure and live data test *(2 months)*

1. Systems integration of the product with the CTA central control system
2. Establish connectivity and control to OCC infrastructure for email notifications, warnings and safety critical alerts to operations and maintenance personnel
3. Testing of product in level-3 real-time operation (receiving live data from CTA's central control system)

TASK 8: Management support in revising CTA's effected SOPs; O&M manuals (1 month)

1. Clarification and support as needed in implementing effected/revised SOP with CTA
2. Development and delivery of product manuals and supporting CTA for required training materials

TASK 9: Final Report Preparation and Approval (3 months)

The principal investigator will prepare and submit a draft final report documenting the results of this project. The draft final report will be written in accordance with the IDEA Report Guidelines and will include the results of all stages of this project. The principal investigator will distribute the draft final report to the expert review panel for this project for review and comments. The investigator will address the review comments in a revised draft report and submit the report, along with written responses to review comments, to the IDEA program office no later than 60 days before the completion of the contract.