Implementation and Use of Class I Railroad Autonomous Track Geometry Measurement System

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ABSTRACT
Since the advent of automated track geometry measurement several decades ago, Class I railroads have implemented the technology on a specialized manned vehicle, such as a specialized self-propelled car or towed coach. This paper details the first Class I railroad fully Autonomous Track Geometry Measurement System (ATGMS) which was implemented at Canadian Pacific Railway. The vehicle used was a standard boxcar which was ballasted with concrete to allow for loaded measurement. Additionally the vehicle was outfitted with solar panels, batteries, and a backup diesel generator for electrical power to operate the measurement equipment. The system was implemented to survey every time the vehicle moves. Additionally it goes into a sleep mode when not moving. While surveying, the vehicle constantly streams data to a remote server using a cellular connection. When no cellular coverage is available, data is queued until the vehicle regains cellular communication. At the server, track number, class of track, and posted speed are automatically determined. Additionally exceptions are automatically reviewed to ensure that false-positive exceptions are removed. Valid exceptions are notified to field personnel using email alerts. The vehicle survey path is directed by waybilling it between classification yards. This paper will discuss unique requirements for the vehicle to operate in autonomous operation, such as laser/camera lens protection. Additionally the paper will discuss results of field testing, lessons learned, and the future outlook of autonomous measurement for Class I railways.

SYSTEM OVERVIEW
A system overview of the Canadian Pacific (CP) Autonomous Track Geometry Car (ATGMS) system is shown in Figure 1. The onboard equipment includes a boxcar with the ATGMS and power equipment installed on it. The vehicle receives OmniStar differential correction GPS signals for positioning. Every time that the vehicle moves, it surveys track geometry and automatically transmits the foot-by-foot data to the remote servers using cellular infrastructure similar to Vehicle/Track Interaction Monitors (V/TI). At the remote servers, the data is evaluated to determine what is the track and class associated with the data. Once the associated class-base thresholds are determined and the exceptions identified, each exception is confirmed valid using an automated exception editor algorithm. Next the valid exceptions are automatically emailed to field personnel, again similar to V/TI. Data can be queried and viewed in the web application TrackIT. Within TrackIT, the user can query and export foot-by-foot data to be viewed in the offline application GeoEdit8.
Vehicle
The vehicle chosen for the CP ATGMS is shown in Figure 2. CP60 is a 286k, Plate C boxcar with 15 inch end-of-car cushioning devices. These characteristics were specifically sought in a candidate vehicle. First the 286k gross vehicle weight would allow CP to have the maximum amount of flexibility loading the vehicle to a desired weight. The vehicle height was below Plate C height. This allowed for solar panels to be installed on the roof and still be within Plate C clearance. By having the vehicle meet Plate C clearance, it ensured that the vehicle had maximum mobility on the network. Lastly, the 15 inch end-of-car cushioning devices help to reduce shock loading if the vehicle ever were to be humped.

When CP first acquired the vehicle, a few modifications were performed before equipment installation. First the body-mounted brakes were removed and replaced with truck mounted brakes. This was done to open space in the underfloor between the trucks so that the track geometry beam and fuel tank could be installed.

Next a door was installed on the A-end of the vehicle (opposite end of the hand brake). This allowed CP personnel to enter the vehicle without having to open the side doors.

Next a concrete floor was poured to provide ballasted weight for the vehicle. Figure 3 is a before and after overview of the concrete floor. Before pouring the concrete, ten vertical pipes were installed in the floor. These pipes were intended to allow cables to be run through the floor without having to drill new holes. More pipes were installed than needed for the ATGMS to allow for future expansion of additional systems to be installed on the vehicle. The floor was partitioned into three sections. This was specifically done to avoid cracking and allow the carbody to twist as it normally would. Additionally walls were installed at the side doors and at the A-end door. A matching wall as installed on the B-end of the vehicle so that the poured concrete was balanced end-to-end. The concrete used was fibermesh which includes fiber glass fibers to add strength. Later when the ENSCO equipment was installed, the concrete floor proved to be a good mounting surface using concrete anchors. The final total weight of the vehicle was 232,000 lbs.

Lastly CP painted and re-stenciled the vehicle.
Figure 2. Overview photographs of completed CP60 ATGMS boxcar.
Figure 3. Before and after photographs of CP60 poured concrete ballast floor.
Onboard Power
Because CP60 is intended to be completely autonomous and be operated anywhere within a train consist, it required its own autonomous power source. After careful consideration a solar, battery, and diesel generator hybrid system was chosen. It was also decided that the system should have ample power because operating in Canada would prove to be challenging. Therefore the power system was intentionally overbuilt to ensure that there would not be a shortage of power.

When designing the solar panel array, the seasonal solar radiation of Canada was evaluated. Figure 4 depicts example solar radiation data for Canada. As expected, the solar radiation in Canada is significantly lower than in the USA. The design team used Edmonton, AB as a worst case location to design the system to. It was determined that the best method was to maximize solar capture capability and use a diesel generator to provide the remaining needed power.

An overview of the solar panels is shown in Figure 5. A total of 32 solar panels were installed. The solar panel brackets were design to allow for easy replacement of a panel if required. Additionally the brackets had the solar panels pitched at 5 degrees to allow for water to drain off of them. The installed solar panel equipment was ensured to be within Plate C clearance.

Each solar panel has a maximum power output of 130 watts. With 32 solar panels, the maximum power output is 4160 watts. It’s important to note that this maximum power output is rarely met. The solar panels were wired in such a way to avoid current backflow, which can occur when wired panels don’t receive the same amount of solar radiation.

![Figure 4. Solar radiation data used to design solar panel system.](image)
Figure 5. Overview of solar panels.
Figure 6 depicts the power control wall inside CP60. The solar panel cables collect at junction boxes. The “brain” of the power system is the charge controller. It regulates the charging of the batteries from the solar panels and diesel generator. It also health monitors the batteries and solar panels themselves.

Figure 7 depicts the diesel generator and battery bank. The diesel generator is the smallest commercial and industrially proven diesel generator available, which is 6 kilowatts. A diesel generator controller is installed which controls turning on and off the generator. The generator exhaust and hot radiator air is vented through the side wall of the car.

The generator controller will automatically start the diesel generator if:
- the battery voltage reduces down to a certain threshold
- the generator low temperature sensor measures a below a certain threshold
- or if the generator hasn’t run within the past two weeks. If it hasn’t run, it will operate a one hour “maintenance cycle” to keep the generator ready for operation.

Because the diesel generator creates more power than the battery bank can consume, a heat element was added to consume the extra power. This was needed to make sure that the diesel generator has the proper electrical load on it. An inverter is added to convert the AC electrical power from the diesel generator to the DC power needed to charge the batteries.

The battery bank is a 940 amp-hour system. The batteries are sealed Absorbent Glass Mat (AGM) type batteries. AGM batteries were chosen for this application since they are maintenance free, leak resistant, and operate well at low temperatures and deep depth of discharge. The size of the battery bank was intentionally oversized. This was done for two reasons. First when the batteries are very cold, they have a reduced capability to be charged. Secondly with the larger bank will have lower depth of discharge during night time operation, which extends the life of the batteries.
Onboard Measurement Equipment
The onboard measurement equipment consists of the beam, tachometer, antenna, and rack computer. Figure 8 is an overview of the track geometry beam. It encloses the inertial and laser/camera...
measurement sensors needed to measure track geometry. The beam is specially designed so that it could be installed on the carbody, not the truck. This is required because the three-piece truck needs unrestricted movement between the side frames and bolster. Mounting equipment on the three-piece truck components that inhibit this motion would not allow the truck to steer properly. Added benefits of being on the carbody and not the truck are that when truck maintenance is required, the beam does not need to be touched by maintenance shop personnel. Also, the shock and vibration environment is much less severe as compared to the truck. During curving, the track will be aligned to the truck, but not the carbody. Therefore the carbody mounted beam was setup to have a wider field of view of the laser/camera systems during curving. With this wider field of view, it allowed the laser/camera lenses to be further away from the rail, which helps keep the lenses clean from dirt and debris.

Figure 8. View of track geometry beam mounted on carbody.

The only equipment installed on the truck is the tachometer, as shown in Figure 9. A specialty mount was design to install the tachometer on the 6.5 x 12” Class F bearing that would endure a wheel flat, but would also not interfere with hot box detector’s ability to measure bearing temperature. Included in the car are work instructions and spare parts for the tach for wheel shop personnel to use during truck maintenance.

Figure 10 depicts the interior of the car where the computer rack and equipment storage is located. The cellular/GPS antenna is installed on the end wall near the roof. The GPS has OmniStar HP differential correction service for high accuracy GPS. Additionally the ATGMS has built in dead reckoning which uses inertial data to increase accuracy and provide GPS coordinates in GPS loss zones. The interior of the car also includes lights and wall power outlets. Additionally exhaust fans were installed at side wall air vents to push hot air out in the summer.
Figure 9. Wheel tachometer.

Figure 10. Car interior overview showing computer rack and storage.
Basemap Construction
When CP60 sends its ft-by-ft data to the remote servers, it includes the GPS location information associated with the survey data. The GPS points are automatically compared to a track centerline basemap to determine which track the survey occurred on. At the time of vehicle construction, CP did not have a track centerline basemap built for Positive Train Control. Therefore ENSCO built the basemap using past CP Track Evaluation Car (TEC) manned survey data as shown in Figure 11. Three survey runs for each track were used to identify what was the true track centerline. Once the track centerlines of all mainline tracks and operational sidings were determined, they were identified with metadata including subdivision code, milepost, class of track, and posted speed of track.

The automated serverside process was setup to take the GPS coordinates from the incoming survey files and query against the basemap to determine subdivision code, milepost, class of track, and posted speed of track. Then the automated process would add the locational data to the survey data, just as if it were made by a manned inspection vehicle. This process all occurs in real-time as data arrives at the server.

Figure 11. Track centerline basemap overview.
Data Processing and Output

Once the class of track and posted speed has been determined for a given survey, the exceptions are then generated using the associated thresholds. CP60 was setup to process all Transport Canada, FRA, and CP custom exception types. After the exceptions are identified, they are evaluated with the automated exception editor, which checks each exception to determine if it is valid or not. The algorithm looks at the foot-by-foot data surrounding the exception on specific geometry channels. Valid exceptions are then posted to the TrackIT web application as shown in Figure 12.

An additional feature is the ability to query and export to GeoEdit8 format foot-by-foot data based on subdivision, milepost start/stop and survey date. This is very helpful to allow TrackIT to be a repository of foot-by-foot data that can be obtained when needed to do overlays of track geometry data.

Figure 12. Overview of TrackIT.

CP currently has two email methods to send alerts to field personnel. CP is currently evaluating these methods and may choose to modify them in the future based on needs. Email alerts are sent to designated field personnel based on the subdivision and milepost that the exception occurred at.

- **Urgent Exceptions**: An automated email report is sent every two hours, which lists all the Urgent exceptions that occurred since the last report and grouped by subdivision as shown in Figure 13. In the email report, there is a link to view the individual brush charts within TrackIT. Additionally, each exception has a Google Maps link to view the exception location.

- **2-Class Drop Exceptions**: Each 2-Class Drop exception is sent in near real-time individually. The email body has the same content as shown in Figure 13, but with only one exception shown. A PDF brush chart is attached to the email, such as the example shown in Figure 14.
### Figure 13. Example exception list email.

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</table>

Please click this link to access the brush chart.

### Figure 14. Example PDF brush chart attached to 2-Class Drop exception email alerts.
SYSTEM EVALUATION

Track Geometry Reproducibility
On May 15th and 16th 2013, CP and ENSCO performed a reproducibility test on CP60 near Lethbridge AB. The reproducibility test involved selecting a portion of track approximately 5 miles long that included reversing curves. The test was conducted by traversing over the test track segment repeatedly at various speeds, in both directions. The measured foot-by-foot track geometry was then compared between the various runs to quantify reproducibility. The quantified reproducibility for each track geometry channel (curvature, crosslevel, gage, etc...) was then compared to the agreed upon performance requirement. The results of the testing proved that all track geometry channels met the performance requirement.

Automated Exception Editing
As previously mentioned exceptions that are detected by the ATGMS go through an automated exception editor to confirm they are valid and mark them invalid if otherwise. The automated process uses an algorithm to review the signatures of the foot-by-foot track geometry channels surrounding the exception. Figure 15 depicts example false-positive exceptions that were detected by the algorithm.

![Dirty Lens](image1.png)

![Narrow Gage at Road Crossing](image2.png)

![Gage Spike at Turnout](image3.png)

Figure 15. Example exceptions caught by automatic exception editor.

To evaluate the performance of the automated exception editor, 4144 CP60 exceptions were evaluated by a trained human reviewer. Of the 4144 exceptions 1827 exceptions were “System Confirmed” and 2317 exceptions were “System Deleted”. During the review the human reviewer manually went through all the exceptions and noted them as being “Human Confirmed” or “Human Deleted”. The accuracy of automated exception editor detecting confirmed exceptions was 95.1%. The accuracy of automated exception editor detecting deleted exceptions was 97.4%. This resulted in an overall accuracy of 96.1%.

Automated Track Determination
To evaluate the performance of the automated track determination system, CP60 was coupled in consist with CP’s manned track geometry CP64. The two track geometry cars surveyed together for a few months. The track determination determined by the manned crew was then compared to the results of CP60. During the process a few areas of improvement were identified and updated to the system. These included modification of settings in the GPS inertial dead reckoning, siding detection, and unrealistic track changes. Following these updates the system was able to achieve 97% track determination accuracy on
mainline tracks and siding between yards. It was determined that further work is required for accurate track determination within yards.

Data Comparison to Manned Car
To ensure that CP60 measured similarly to CP’s manned track geometry cars, an analysis was performed to compare the autonomous and manned track geometry. The foot-by-foot track geometry was overlaid and compared. Figure 16 is an example overlay of CP60 with the manned track geometry car CP64. Results indicated that the two vehicles compared very well. Additionally an exception comparison was done between the autonomous and manned cars. Again, the correlation was very good and gave CP high confidence in the autonomous system.

![Figure 16. Comparison of CP60 (Autonomous - GREEN) and CP64 (Manned - BLUE).](image)

Equipment Reliability
To date, CP60 has surveyed over 44,000 miles of track and has had over 10 “coast to coast” surveys. It has had some significant successes but of course as a first-of-its-kind system it had aspects that needed to be adjusted to operate as intended.

The challenges that CP60 encountered are as follows:
• The vehicle CP60 had a malfunctioning brake valve which caused an impacting wheel on the tachometer wheelset. The tachometer failed due to the repeated impacts; however, the brackets did not fail. No other instrumentation equipment was effected by the impacting wheel. The wheel set and brake valve were replaced and has since operated correctly.
• During a cold period the diesel generator failed to start on its own. The diesel generator manufacturer visited the car and made adjustments to the generator and has since operated correctly.
• An interior work light fixture loosened and caused a circuit breaker to trip causing power to be shut off. All fixtures were inspected and adjusted to prevent a similar failure and no such undesired power shut off has occurred since then.
• The laser/camera lens protection system worked remarkable well. However, it was discovered that during heavy snow storms, snow would collect inside the port and block the view of the lens. Further options are being investigated now to determine how best to deal with this issue.
• It was discovered that a hard drive was vibrating and causing issues. It was adjusted and has operated correctly since then.

The successes that CP60 encountered are as follows:
• The track geometry quality has been very good and has matched very well to CP manned car CP64.
• As previously mentioned, the laser/camera lens protection system worked remarkable well. It was impressive to see how well it did against dirt, mud, and grease. It was originally anticipated that the lenses would need to be cleaned every 90 days, but on average they were lasting up to 180 days. Figure 17 is a lens photograph during a trip to clean to clean lenses but they were found to still be clean.
• The system has proven that it has ample power supply and has not had issues with having insufficient power production.
• Initially there was concern that the solar panel glass would break and/or become dirty. To date, none of the panels have broken and they have not needed to be cleaned yet.
• Although obviously when there is heavy snow, the solar panels are completely covered. However, there has not been a time when this caused a shortage of power in the system.
• No hardware failures have occurred. All underfloor equipment and all roof installed equipment performed very well. No equipment failed due to vibration or impacts, including hard couplings. All laser/camera and inertial sensors have operated without failure.
• The concrete ballast floor held up well and did not crack. All the equipment anchored to the concrete performed very well.
• The equipment has successfully operated in extreme hot and cold conditions.
• The equipment has successfully operated in various locations within large mixed manifest consists.
SYSTEM OPERATION

Measurement Equipment Operation
To aid in ongoing operation of the equipment, two features were included in the system. First a feature was added to turn on and off email alerts, exception processing, and the whole system remotely through the TrackIT application. This allows CP to be in full control of the system and adjust its settings if required. Secondly a feature was added to allow CP to upload new class of track and posted speed data. Obviously class and speed data changes routinely and this feature allows CP to updated the latest information to the ATGMS system.

Waybilling
As previously mentioned, CP waybills CP60 in mixed manifest and intermodal consists without regard for train position. This waybilling was performed as one would suspect by working with the Transportation department to move the car from point A to point B. CP has found success bouncing the car back and forth between two points a long distance from each other (e.g. Vancouver and Montreal). During this process it was found that the car could make a round trip between Vancouver and Montreal in under two weeks including the time in the classification yard.

One challenge encountered with waybilling was that the fastest transit speed was achieved by putting the car in a high priority intermodal train. However, it was found that this train rarely went through sidings. This required CP to diversify what types of trains CP60 is put into to get coverage on mainlines and sidings (high speed intermodal and slower speed mixed manifest). Another challenge CP discovered was that the car quickly entered and exited classification yards at the ends of surveys. However, if the car was pulled out of consist in an unusual location, it could take a significant amount of time to have it picked back up and put back into a consist.

Data Overlay
An interesting finding with CP60 is because it can survey repeatedly over a relatively short period of time, the overlaid data yields is able to display track deterioration and effects of maintenance. Figure 18 is an example overlay using GeoEdit8 of four surveys over a four month period. Remarkably the overlay is very good. But it also illustrates the variations caused by deterioration and repair. As CP continues to operate CP60, more data will be collected which will provide more opportunity to understand and identify track deterioration and maintenance performance.
CONCLUSIONS

In summary, the Autonomous Track Geometry Measurement System (ATGMS) has been successfully implemented on Canadian Pacific's CP60 boxcar as the first ever Class I autonomous track geometry system. Canadian Pacific is looking forward to further utilizing CP60 in its objective to achieve optimum track safety.

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Implementation and Use of Class I Railroad Autonomous Track Geometry Measurement System

Ron Gagne – Canadian Pacific Railway
Matthew Dick P.E. – ENSCO Rail
Rafael Maldonado – ENSCO Rail
Overview

- Canadian Pacific (CP) and ENSCO Rail have deployed the first freight railroad, fully autonomous track geometry measurement system (ATGMS).
- ATGMS provides the opportunity to CP to supplement its manned operation with increased track geometry surveys.
- This presentation will detail the construction, evaluation, and operation of the system.

Key CP Requirements:
- Track determination is automatic
- False-positive filtering is automatic
- Laser lens protection system
- Dedicated power supply system
- All data transmitted to server (ft-by-ft and exceptions)
- Email alerts similar to V/TI
- Data can be viewed and exported from web application (TrackIT)
- Operate anywhere in revenue train

Vehicle Overview

- 286K Boxcar
- End-of-Car Cushioning
- Plate C Clearance
- Truck Mounted Brakes

28 inch thick concrete floor was poured for ballast weight.
The final total weight of the vehicle was 232,000 lbs.
**Vehicle Overview**

28 inch thick concrete floor was poured for ballast weight.

The final total weight of the vehicle was 232,000 lbs.

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**Onboard Power**

- Solar, diesel, and battery hybrid power system.
- Solar panels were evaluated for Canadian conditions.
- 32 solar panels provide sufficient power the majority of the time.
- The backup diesel generator provides power during insufficient sunlight days.
- Battery bank powers system during nighttime.

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**Onboard Power**

- Solar panel system: 32 solar panels provide sufficient power the majority of the time.
- Backup diesel generator is used during insufficient sunlight days.
- Battery bank powers system during nighttime.

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**Measurement Equipment**

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**Measurement Equipment**

**Basemap Construction**

- ENSCO created the CP Basemap which is used automatically with the ATGMS.
- Basemap includes individual track centerlines of mainline tracks with linear referenced information including MP, Class, Posted Speed.

**Data Processing and Output**

**TrackIT**
- Web application for viewing data
- Export ft-by-ft data

**Email Reports:**
- List of Urgent Exceptions grouped by subdivision sent every 2 hours
- Near Real-Time Individual 2-Class Drop Exceptions

Google Map links for each exception

Link to TrackIT to view waveforms
Data Processing and Output

Individual 2-Class Drop exception emails include brush chart PDF (strip chart) of the exception.

System Evaluation

1. Track Geometry Reproducibility
   - Conducted repeated surveys on same track
   - Data was compared between surveys
   - CP60 was found to meet the reproducibility performance requirement

2. Automated Track Determination
   - CP60 was pulled in consist with a CP manned geometry car (CP64).
   - Track determination was compared between the two cars.
   - CP60 was found to have 97% accuracy of automated track determination.
   - Remaining challenges exist for yards.

3. Automated Exception Editing
   - 4000+ exceptions were evaluated by the algorithm and human.
   - “Confirmed” and “Deleted” status were compared.
   - The algorithm was found to match the human 96% of the time.

4. Data Comparison to Manned Car
   - CP60 was pulled in consist with a CP manned geometry car (CP64).
   - Track geometry was overlaid between the two cars.
   - Correlation was very good.

5. Equipment Reliability
   - Challenges:
     - Failed brake valve caused flat wheel which caused tach failure.
     - Adjustment to diesel generator for cold starting
     - Inadvertent circuit breaker trip
     - Heavy snow storms would block lenses
     - Hard drive required additional vibration protection.
System Evaluation

5. Equipment Reliability

Successes:
- Very good track geometry quality
- Lens protection worked very well against dirt and grease.
- Ample power from solar and diesel, even in Canadian winter.
- No equipment failures of the onboard power, measurement equipment, or concrete.
- Successful operation in extreme hot and cold conditions.
- Successful operation in any position within a mixed manifest train.

System Operation

1. Measurement Equipment Operation
- Added ability for CP to turn system on/off remotely
- Load new track class & posted speed information through TrackIT site

2. Waybilling
- Best success was found with bouncing back-and-forth on long routes (Vancouver & Montreal round trip in 2 weeks).
- While in high priority trains, sidings were not surveyed enough.
- Diversity in train types was required to survey on main and sidings.

System Operation

3. Data Overlay
- Frequent surveys allowing for overlaid data to indicate early onset deterioration.

Conclusions

- ATGMS has been successfully implemented on Canadian Pacific's CP60 boxcar.
- It is the first ever Class I autonomous track geometry system.
- Canadian Pacific is looking forward to further utilizing CP60 in its objective to achieve optimum track safety.

Questions?