Transit
Rolling Stock
Intercity & Heavy Rail

INDEPENDENT REVIEW

REPORT SRT LINE 3 INCIDENT

SYSTRA Canada Reference: 23038-GART-0001_D

Prepared for:
Toronto Transit Commission (TTC)

Safety & Environment Department

Submitted on:
2023-11-30

ISO 9001:2015 Certified

Revision History

Revision	A	B	C	D
Date	2023-10-17	2023-11-10	2023-11-23	2023-11-30
Prepared by	JG-CL	CL	CL	CL
Reviewed by	PLT	PLT	PLT	PLT
Approved by	YF	YF	YF	YF

- ☐ Preliminary/internal verification
- ☐ Submitted for information
- ☐ Issued for revision and comments
- ☑ Submitted for approval
- ☐ Issued for proposal
- ☐ Submitted for purchasing
- ☐ Submitted for construction/ implementation
- ☐ Cancelled
- ☐ As built

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Document

IDENTIFICATION

REPORT SRT LINE 3 INCIDENT

Référence SYSTRA Canada : 23038-GART-0001_D

ISO 9001:2015 BUREAU VERITAS Certification

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1. EXECUTIVE SUMMARY

Following the incident that occurred on the SRT Line 3 on July 24, 2023, TTC requested that SYSTRA conduct an independent review of investigation reports provided by three external engineering firms that were mandated to review the root cause of the incident. In addition, SYSTRA was mandated to investigate the root cause for the reduction of defect reports on the reaction rail over the last 2 years. Early data presented to SYSTRA show that the reporting of defects on the reaction rail dropped more than 8 times over the last 2 years (2022-2023) compared to the previous 4 years (2018-2021). Three external engineering firms were mandated to review the root cause of the incident and their reports were shared with SYSTRA for review and to aid this investigation. During the independent review and investigation, several relevant documents from TTC were reviewed and key stakeholders were interviewed. In parallel, SYSTRA was also awarded a separate mandate: a review of TTC's track maintenance practices and standards.

The following key elements were deemed to be contributing factors:

- **Data migration from MOWIS to MAXIMO**: From the on-site contacts held with different stakeholders, the defects data has dropped off in number during the migration to MAXIMO, possibly due to the erasing of duplicated defects already present in MOWIS which may have artificially increased the number of defects prior to 2022. Overall, the migration process is not clear and should be reviewed and better documented. A detailed forensic investigation of this data migration was not possible as we did not witness this process.
- **New anchor bolt design:** Several aspects of the new anchor bolt design are questionable and could have led to the fatigue failure in the threaded portion which is very difficult to detect by track patroller.
- **Reduction of preventive maintenance:** Some actions linked to preventive maintenance were no longer carried out once the line was announced to be closing. Furthermore, the anchor bolts were never subjected to preventive maintenance.
- **Top cap painting:** The top cap was no longer re-painted making it was more difficult for track patrollers to detect new areas of ''Polished Top Cap''.
- **Training of track patrollers:** The NRC report shows that the experience of the track patrollers is low, 11 out of 36 received their certification in 2021 and 17 are in the process of obtaining theirs. Track patrollers without their certification are required to patrol with a certified track patroller.
- **Priority level:** The priority level assignment for each defect is problematic since in the absence of standardized criteria, it implies a subjective interpretation from the track patroller. Also, each defect is evaluated individually, and the combination of defects is not considered in assigning a priority level.
- **Reaction Rail height measurement:** RC&S explains that the SRT Laser Inspection Train test was implemented approximately ten years ago, and the intent was to supplement proper reaction rail height inspections performed by Track and Structure, and not to supersede them. In our opinion, the periodicity is too long, it should be aligned with the inspection carried out on the rolling stock for the height of the LIM.

2. PROJECT OVERVIEW AND SCOPE OF THE STUDY

2.1 PROJECT OVERVIEW

The TTC is a public transit authority that provides transportation services within the Greater Toronto Area and adjacent municipalities using bus, streetcar, subway and rapid transit services.

The TTC operates a multimodal service that includes rail, streetcars, and buses. Ridership averages approximately 1.8 million passengers on average business days, spread across bus and streetcar routes, plus four heavy rail lines.

TTC track is installed in numerous configurations. Track beds may be a poured monolithic concrete structure with direct fixation, floating concrete pads that use Pandrol clips or traditional wooden ties on ballast using rail spikes. Maintenance processes are comprised of manual methods as well as modern means to ensure the safe operation.

2.2 SCOPE OF WORK

2.2.1 Scope of Work

A mandate was awarded to SYSTRA Canada to conduct an analysis of the maintenance procedures in order to better understand the reasons that led to the incident that occurred on the SRT line 3 on July 24, 2023, where car #3001 derailed after an impact between the reaction rail and the LIM and explore more specifically why the reporting of defects on the reaction rail had significantly diminished over the last 2 years.

2.2.2 Objectives

2.2.2.1 Objectives of the mandate

The key objectives of this project are as follows:

- Review existing track maintenance processes including, track defect management, track inspections, etc.
- Review and comment on the available incident reports.

2.2.2.2 Objectives of the in-situ inspections

This in situ inspection served equally the two mandates awarded to SYSTRA, namely:

- Track maintenance oversight (entire network).
- July 24th, Incident review (L3).

The objectives that we set in relation to the in-situ inspections are:

- To clearly understand the maintenance organization of TTC.
- To collect additional information in-situ.
- To attend to inspections and maintenance patrols.
- To observe the application of procedures (organization, security, etc.).
- To identify maintenance –related equipment, methods and tools.
- To assess the training and qualifications of subway track maintenance personnel, including their knowledge of safety protocols and best practices.

3. ACRONYMS AND ABBREVIATIONS

Acronyms or Abbreviations	Definition
APPR	Approved
COMP	Completed
DRS/RRS	Daily Run Sheet/ Revised Run Sheet
INPRG	In Progress
KPI	Key Performance Indicator
LIM	Linear Induction Motor
LRT	Light Rail Transit
MAPS	Work Orders Management (STAMP element)
MAXIMO	Management Software used by TTC to track maintenance work and defects on the infrastructure
MOWIS	Previous Data management software
NRC	Network Rail Consulting
OSP	Operational Safety & Planning
PIC/WAC	Person In Charge/ Work Zone Area Coordinator
QA	Quality Assurance
RC&S	Railcars & Shops
SI	Subway Infrastructure
SRT	Scarborough Rapid Transit system
STAMP	Subway Asset Management Software
STARS	Subway Track Access Request System
TAR	Track Acess Request (STARS element)
TC	Transit Control
TOR	Top of Rail
TTC	Toronto Transit Commission
WAPPR	Waiting for Approval
WO	Work Order
WQA	Waiting for Quality Assurance

4. DATA COLLECTED

The table below lists the different documents collected:

Table 1: List of documents received

Status	Request Date	Reception Date	Documentary Reference	Category
Reception		08/08/2023	T&S High-level Org Chart.pdf	Organization
Reception		08/08/2023	TS-0102-14 Restricted Speed Zone Implementation.pdf	Safety
Reception		08/08/2023	TS-0102-22 T&S Training Requirement for Safety.pdf	Procedures & Works methods
Reception		08/08/2023	TTC MAP 2019.pdf	General
Reception		08/08/2023	Job Briefing Record Sample Track Structure.pdf	Procedures & Works methods
Reception		08/08/2023	RI-SOP-736-01 Track Patrol - Daily Track Inspection.pdf	Procedures & Works methods
Reception		08/08/2023	RI-WI-736-0301 Track Patrol - QA Audit Inspection Work Instruction.pdf	Safety
Reception		08/08/2023	SI-T-0014 Track Access Conformance Checks.pdf	Safety
Reception		08/08/2023	SI-T-0029 NDT.pdf	Procedures & Works methods
Reception		08/08/2023	SI-T-0087 Defect Trend Analysis of NDT Test Results.pdf	Procedures & Works methods
Reception		08/08/2023	SI-T-0089 MOWIS Defect Priority Response List.pdf	Procedures & Works methods
Reception		08/08/2023	SI-T-0092 Subway Track Access Request System STARS.pdf	Safety
Reception		08/08/2023	SI-T-0144 Track Level Safety Audits.pdf	Safety
Reception		09/08/2023	1.6 Organization Structure.pdf	Organization
Reception	24/08/2023	07/09/2023	Org. charts (from general organization of TTC to the track maintenance team organization)	Organization
Reception	24/08/2023	07/09/2023	Maintenance and renewal plans	Organization
Reception	07/09/2023	07/09/2023	Revised Runsheets September 07 2023-.xlsx	
Reception	07/09/2023	07/09/2023	Runsheets September 07, 2023.xlsx	
Reception	06/09/2023	06/09/2023	Runsheets June 28, 2023.xlsx	
Reception		30/08/2023	Scarborough Rapid Transit (SRT) Vehicle Accident Investigation Report (Hatch report) Rev. A	
Reception		31/10/2023	SRT Derailment-Ellesmere Station Forensic Assessment Report (Gannett Fleming Report) Rev. 3	
Reception		15/09/2023	Car Derailment Investigation on the SRT System within the TTC Network (Network Rail Consulting report) Final	

The table below lists the documents requested but not yet received:

Table 2: List of documents requested

Status	Request Date	Reception Date	Documentary Reference	Category
Requested	24/08/2023		Track charts with rail profile, schematic alignment, etc.	Technical information
Requested	24/08/2023		Track cross section for the tunnel, at grade sections, bridges, stations with the description of the equipment and materials (Type of rail, fastenings, sleepers, platform, etc.)	Technical information
Requested	24/08/2023		General Maintenance strategy & policies	Policies
Requested	24/08/2023		Track maintenance procedures	Procedures & Works methods
Requested	24/08/2023	07/09/2023	Safety procedures	Safety
Requested	24/08/2023		Maintenance activities: tools & Equipment register	Organization
Requested	24/08/2023		Document library	Organization
Requested	15/09/2023		Matrix of responsibilities of the different track services (RACI analysis)	Organization
Requested	15/09/2023		Up to date Track Organization Chart and workflow	Organization
Requested	15/09/2023		Restricted speed zone tracking file	
Requested	15/09/2023		Documentation associated to the training process for a new operator (Track maintenance training documentation)	
Requested	15/09/2023		Organizational document that explains what track maintenance includes	Organization
Requested	15/09/2023		Track inspection flowchart (responsibilities, who's in charge, feedbacks, approvals, etc.)	
Requested	15/09/2023		Alarms severity levels and procedures/standards	
Requested	15/09/2023		Network map with the inspection B sections detailed	
Requested	15/09/2023		Maximo flowchart data process (maintenance works and inspections sequence - defects/repair/closure)	

5. ORGANIZATION OF THE INSPECTIONS

5.1 ORGANIZATION OF THE IN-SITU INSPECTIONS

This in situ inspection served equally the two mandates awarded to SYSTRA, namely:

- Track maintenance oversight (entire network)
- July 24th, Incident review (L3)

The schedule of our site visits and interviews is presented in the following table:

Table 3: In-Situ visit schedule

Date	Name	Tasks	Inspection Line (Section)
11/09/2023	J. Guerra	TTC Subway tour	TTC Subway Network
12/09/2023	J. Guerra	Safety training	TTC Wilson Training Centre
13/09/2023	J. Guerra	SRT track and facilities visit	LINE 3 SRT - Kennedy Station & Mc Cowan Yard
14/09/2023	J. Guerra	Meeting with track inspection unit	LINE 2 - Dundas West Station
15/09/2023	J. Guerra	Safety/Track quality walking inspection	LINE 2 - Greenwood/Victoria Park
18/09/2023	J. Guerra	Meeting with track work Planner and Yard visit	LINE 2 - Greenwood yard
19/09/2023	J. Guerra	Meeting with OSP (Operational Safety & Planning)	TTC - Inglis Building
20/09/2023	J. Guerra C. Leguet	Meeting with track maintenance teams	LINE 2 - Greenwood and Castle Frank
21/09/2023	J. Guerra C. Leguet	Meeting with track maintenance engineering manager	TTC Wilson yard
22/09/2023	J. Guerra C. Leguet	Meeting with track maintenance manager	Line 1
25/09/2023	C. Leguet	LINE 3 – SRT line : Analyze & inspection of the reaction rail system on site and rolling stock The control & adjustment for the rolling stock and the control & adjustment at track level with a rolling stock equipped with laser sighting at the front	LINE 3 - SRT line at Mc Cowan station and Mc Cowan yard
26/09/2023	C. Leguet	Inspection on site with track patroller team	LINE 2 – Accompany track patrol between Bay station and Bloor Yonge station
Night 26-27/09/2023	C. Leguet	Night worksite on Line 1 at Wilson's yard	LINE 1 – Worksites in Wilson's yard
27/09/2023	C. Leguet	Interview of roadmasters	Interview of roadmasters in Greenwood Office
28/09/2023	C. Leguet	Preliminary feedbacks + Departure	

5.2 PEOPLE MEET

TTC personnel that SYSTRA met and interviewed are listed in the following table:

Table 4: People Meet

Name	Entity	Function	Date
Sai Lavakeswaran	Wilson Training Centre	TTC - Instructor	12/09/2023
James Way	Safety Assurance	TTC - Senior Safety Assurance Officer	13/09/2023
Tauqeer Qurashi / Lyndon Badenoch	Track Inspection	TTC - Senior Inspection Engineer	14/09/2023
Jibril Tawfiq / Richard Evans	Network Rail	Track Road Master Network Rail Track consultant	15/09/2023
Michael Ruscher / James Way	Maintenance	TTC - Planner (Track)	18/09/2023
Gaetano Bonaiuto / James Way	Operational Safety & Planning	TTC - OSP Manager	19/09/2023
Davian Rose	Subway Track Supervision	TTC - Senior Foreperson	20/09/2023
Mo Ghaus / James Way	Maintenance Engineering	TTC - T&S (Track & Structure) Maintenance Engineering Manager	21/09/2023
Joe Hu / James Way	Maintenance	TTC - Track Maintenance Manager	22/09/2023
Vilim Spinoti, Safety / James Way	Safety and Environment Department	TTC - safety	25/09/2023
TTC - Lyndon Badenoch Senior Foreperson, Subway/SRT Track - Inspection TTC - Dan and Willy track patrollers	Track Patrol Unit	TTC - Track Patrol team	26/09/2023
TTC - Andrew Ball, Senior Foreperson, Subway Infrastructure	Subway Track Supervision	TTC - Senior Foreperson	27/09/2023
TTC - Bryan Polt, Roadmaster, Subway Infrastructure TTC - Tim Tavares Roadmaster, Subway Infrastructure TTC - Ken Chapman Roadmaster, Subway Infrastructure	Roadmaster (Subway Track Supervision)	TTC - Roadmaster	28/09/2023

6. PRESENTATION OF MAINTENANCE DATA

6.1 CLASSIFICATION OF DEFECTS

MOWIS was replaced by MAXIMO software 2 years ago. However, the procedure to classify defect is still SI-T-0089 “MOWIS defect priority” and is still in effect.

The track patroller team classifies defects by priority level & repair requirements as following:

Table 5: Extract 1 - Defect Priority Level (SI-T-0089)

Defect Priority Level	Repair Requirement	Classification & General Description	Notification Procedure for Track Patroller
1.- Red	Within 24 hrs	Supervise operation (Posing an immediate danger to vehicles or persons at track level)	1. Call Transit Control - advise of defects and steps necessary to ensure the safe operation. 2. Request Transit Control forward information on to Subway/SRT Track on call designate for coordination of further action. 3. Notify Track Inspection Foreperson and/or supervisor. 4. Enter defect into MOWIS.
2.- Yellow	Within 10 days	Restrict speed (Requiring prompt attention to avoid a delay)	1. Call Transit Control - advise of defect and steps necessary to ensure safe operation. 2. Request Transit Control forward information on to Subway/SRT Track on call designate for coordination of further action. 3. Notify Track Inspection Foreperson and/or supervisor. 4. Enter defect into MOWIS.
3.- Purple	Within 21 days	Near urgent delay	(Not applicable to Track Patrollers)
4.- Blue	Within 45 days	Schedule repair (Requiring a repair to avoid progression to higher level)	1. Notify foreperson and/or supervisor. 2. Enter defect into MOWIS.
5.- Brown	To be reinspected within 365 days	Report required (Track deficiency requiring tracking and monitoring)	1. Enter defect into MOWIS
6.- Grey	No time limit	Housekeeping item	1. Enter into MOWIS

6.2 REACTION RAIL DATA

The height measurement, taken in reference to running rail, is 0 mm with an acceptable tolerance range of 1mm to +5mm from top of running rail to reaction rail.

The last 3 reaction rail height measurements were performed on April 14, 2023, February 10, 2023, and November 18, 2022, but did not reveal any defects, which is unusual, or at the very least unexpected, considering the many areas where reaction rail shows signs of contact with the rolling stock. Following these consecutive tests without high spots, RC&S has checked the calibration of the laser device and confirmed its conformity. RC&S did not doubt these results as they were seeing improvement regarding the report of damages to the LIM which was the original reason for running these tests in the first place. They explained that the multiple reports for

"polished top caps" could have come from an ice block dragged by the train during winter or from debris on the reaction rail dragged by the train.

Prior to the last three reaction rail height measurements, 5 locations were reported out of tolerance ranging from +7mm to +10mm on July 24, 2022, 5 locations were reported out of tolerance ranging from +10mm to +18mm on April 20, 2022.

7. REVIEW OF CONSULTANT REPORTS ON THE INCIDENT

Following the incident, TTC hired three consultant firms to investigate the incident. Each consultant firm was assigned a specific mandate; the rolling stock, the infrastructure and the maintenance and inspection processes of Line 3. The reports were submitted to SYSTRA for review as contextual inputs to its mandate. SYSTRA's reviews of relevant information contained in each of these reports is detailed in the following sections below.

7.1 REVIEW OF HATCH REPORT

Hatch investigation focused on the contributing aspect related to the vehicle. In their report, they concluded that no evidence of a conventional derailment mechanism associated with wheel/rail interface was found. They attributed the accident as a collision instead of a conventional derailment. Hatch found evidence of collision damage on one bogie on the train that ran before the incident and on 3 bogies on the same train that experienced the derailment. These damages strongly suggested they were all struck by the same object. No evidence of improper LIM height was found, all of which led to the conclusion that the vehicle did not contribute in any manner to the accident.

SYSTRA agrees with the conclusions drawn by Hatch, namely that the vehicle did not contribute to the accident. All the defects presented in the report relate to the incident but were not present prior to the events.

7.2 REVIEW OF NETWORK RAIL CONSULTING REPORT

Network Rail Consulting was tasked to review the track patrolling process, the training modules, the defects reported in MAXIMO, the defect type, and the asset defect management. They also provided recommendations to address gaps and / or improve current procedures. The mandate of Network Rail Consulting somewhat converges with the one that SYSTRA was awarded for the audit of current TTC's maintenance practices. Network Rail Consulting presented in their report the training processes used to train the track patroller and stated that the computer-based training modules introduced in 2010 is, since 2021, defunct. The training uses paper documents only. Table 2.1 of the NRC report presents the list of track patrollers and their respective certification date. Out of 36 track patrollers, 11 received their certification in 2021 and 17 are pending the completion of their mentorship before taking the track patroller training course. This suggests that most of the track patrollers have less than 3 years experience.

In MAXIMO, a total of 77 defects are classified as polished top cap of the reaction rails, this shows that the LIM train hits the top cap in many places and proves that this defect was recurring (paragraph 2.3 of the NRC report), see section 11.2 of this report where this behavior is explored further. These defects span 7 years, from 2016 until 2023. In MAXIMO, the list of 28 defects referring to "missing / loose T bolt" type defects are also showing an issue with the reaction rail top cap fastening. These defects span 10 years, from 2013 until 2023. These two recurring faults show that the track patrollers did not seem to properly assess the impact of "combined defects" in relation to the reaction rail.

7.3 REVIEW OF GANNETT FLEMING REPORT

Gannett Fleming report presents the forensic assessment of the infrastructure components involved with the incident. This report focuses on the elements of the reaction rail that could have contributed to the derailment of car 3001. A test was conducted to replicate the conditions when car 3001 derailed, a combination of failed anchor bolts with the top cap not overlapping the next section of the reaction rail. In this scenario, Gannett Fleming was able to show that the reaction rail was moving in the vertical direction, towards the Linear Induction Motor (LIM), while the car was passing over that section. The magnetic induction forces and the disconnected anchor bolts were sufficient to pull the reaction rail towards the LIM. The report also suggests that if the aluminum top cap was overlapping the following section it could have mitigated the risk of reaction rail lift.

The report mentions several types of failure for the anchor bolts; fractured threaded rod and loose anchor, all of which were found on the system at different locations. A failure analysis of the fractured anchor bolts revealed that they failed due to cyclic loading, implying that they were already fractured prior to the accident. It seems that this failure mode was only found on newly replaced anchor bolt made from a combination of Hilti HSL-GR and a threaded stainless-steel rod. These bolts are used whenever a replacement of the anchor bolt is needed. The appendix E of the Gannett Fleming report details the analysis performed on a set of broken anchor bolt from the accident, original Hilti HSL-GR anchor bolt and a reference stainless-steel threaded rod. Although the mechanical properties of the stainless steel used for the threaded portion appeared to be similar to one another, the profile of the threads is different. The root of the thread is square on the threaded rod used by TTC whereas the Hilti is round. Such difference could have had an impact on the fatigue performance of the part and partly explains why the bolt fractured.

The report also mentions areas where the reaction rail mounting bracket hole did not align with the anchor bolt hole in the inverted concrete slab. The misalignment between the inverted concrete slab and the reaction rail mounting bracket increases the bending stress on the threaded rod which could very well be a contributing factor to a failure by the fracture.

SYSTRA agrees with the conclusion drawn by Gannett Fleming but wishes they had investigated further on what caused the anchor bolt to fracture by exploring the correlation between this failure mode and the new anchor bolt design.

8. SUMMARY OF ON-SITE OBSERVATIONS

8.1 ACTIVITIES

On September 13th, 2023, Inspection on LINE 3 - SRT line at McCowan station and McCowan yard

These visits were carried out with track patrol and track maintenance teams on site:

- In Kennedy Station, main topics covered were:
  - Track visual observation of the installed track components (rails, fasteners, platform, etc.).
  - Special focus on the reaction rail alignment and its fastening condition.
- In Mc Cowan Yard, main topics covered were:
  - Tour of the rolling stock facilities.
  - Yard visual observation of the installed track components (turnouts, rails, fasteners, platform, etc.).
  - Brief contact with the derailed car (including some damaged components and damaged reaction rail section).

- Demonstration of the gap measurement on the car between LIM and reaction rail.

On September 25, 2023, Inspection on LINE 3 - SRT line at McCowan station and McCowan yard

Main topics covered during the visit were:

- The control & adjustment for the rolling stock with a ruler and a measuring wedge (every 32 days).
- The control & adjustment at track level with a rolling stock equipped with laser sighting at the front (running every 2 to 3 months).
- The control & adjustment of reaction rail on the track with a composite ruler.
- Visit of the yard for observation.
- Examination of the reaction rail at the derailment site.

Other observations & interviews

The rest of mission on site has been dedicated to, we were interviews with other stakeholders involved in track maintenance:

- Track work Planner.
- OSP (Operational Safety & Planning).
- Track maintenance personal (Roadmasters, Forepersons, Supervisors, track worker group).
- Track maintenance engineering department.
- Track maintenance department.

We were also able to perform the following activities to get an overview of the different track installations:

- Visual observations of the installed track components (turnouts, rails, fasteners, platform, etc.).
- Observation of the reaction rail alignment and its fastening condition.
- Tour of some rolling stock facilities.
- Some yard visual observations of the installed track components (turnouts, rails, fasteners, platform, etc.).
- Contact with the derailed car (including some damaged components and damaged reaction rail).
- Demonstration of the gap measurement on the car between LIM and reaction rail.
- Observation of some Track work machinery.
- Organization of the maintenance staff.

8.2 ORGANIZATION OF THE MAINTENANCE STAFF

As per our observation the organization of the track maintenance hinges on 3 keys departments:

- Track and Structures.
- Operational Safety & Planning (OSP).
- Railcar and Shop (RC&S).

These three departments appear to operate with a transversal communication that could be improved. It is to be noted that the statement above is solely based on our observations and understanding of the roles and responsibilities of these departments, therefore it is very difficult to determine the exact interrelation between these departments.

For instance, the direct communication between RC&S and Track and Structure appears to show some potential areas of improvement. Per our discussions with key stakeholders, Track and Structure stopped the systematic measurement of the height of the reaction rail as soon as RC&S started measuring it with the help of the SRT Laser Inspection train, see section 11.2. However, RC&S considers this tool as a supplement to manual measurements and was originally implemented to reduce the number of damages to the LIM, whereas the Track and Structure department considers it to be the unique measurement tool. This apparent misalignment may have generated different expectations within the two departments.

Furthermore, the Track and Structure department has a pyramidal organization and is composed of various units such as: track patrol unit, roadmaster unit, etc. Each subgroup appears to operate independently, with relative efficiency but with little transversal communication with other departments. Indeed, the track patrol unit only communicates with the planners & the track works teams via comments in MAXIMO and in turn the planners only communicate with track works teams via WOs (work orders). Direct communication between these entities is a common practice in the rail industry, it helps with the continuous improvement of the maintenance processes.

9. DEFECT DATA ANALYSIS

Regarding the reaction rail defects, during the migration from MOWIS to MAXIMO, the defects listed dropped off very significantly. Apparently only new defects and defects to be repaired before closing the line to revenue service remained listed. Another possibility was the removal of duplicated defects already present in MOWIS which may have artificially increased the number of defects prior to 2022. Overall, the migration process is not clear and should be reviewed and better documented. A detailed forensic investigation of this data migration was not possible as we did not witness this process.

The fact that the closure of the line was postponed by one year, originally announced for November 2022 but then moved to November 2023, could have led to defects not being repaired on time because they no longer appeared in MAXIMO, a situation that was unverifiable after cleaning up the defects. For instance, the scenario where a defect detected by the track patrol which would have been classified 5 (Brown) in December 2021 would have had to be re-inspected before December 2022 (365 days). Considering the imminent closure of the line, in less than a year, we can assume the possibility of this defect may not have been reported or followed up upon.

The drop in the number of defects may also be explained by the difficulty for track patrollers to see a fractured new anchor bolt design, see Section 13. In fact, the inspection is carried out during revenue service hours, with a third rail supplied with electricity, which does not allow the track patroller to lie down on the track to see the condition of the bolts. In addition, the Track and Structure team confirmed that they were no longer repainting the top cap during their maintenance operations, even after addressing areas that have been reported to have a ‘’Polished Top Cap’’. This has contributed to trivializing this phenomenon and could have been overlooked by track patrollers.

Concerning the other track defects, during the migration from MOWIS to MAXIMO, the defect listings remained as is without cleaning, hence the relatively stable level of defects. It is important to note that the great majority of the defect reported in the last 5 years on the reaction rail are either ‘’Polish Top Cap’’ at 52.9% and ‘’T-Bolt/Anchor Bolts’’ at 28.1 %. Also, 56.3% of defects were categorized as priority 5 or Brown in the last 5 years.

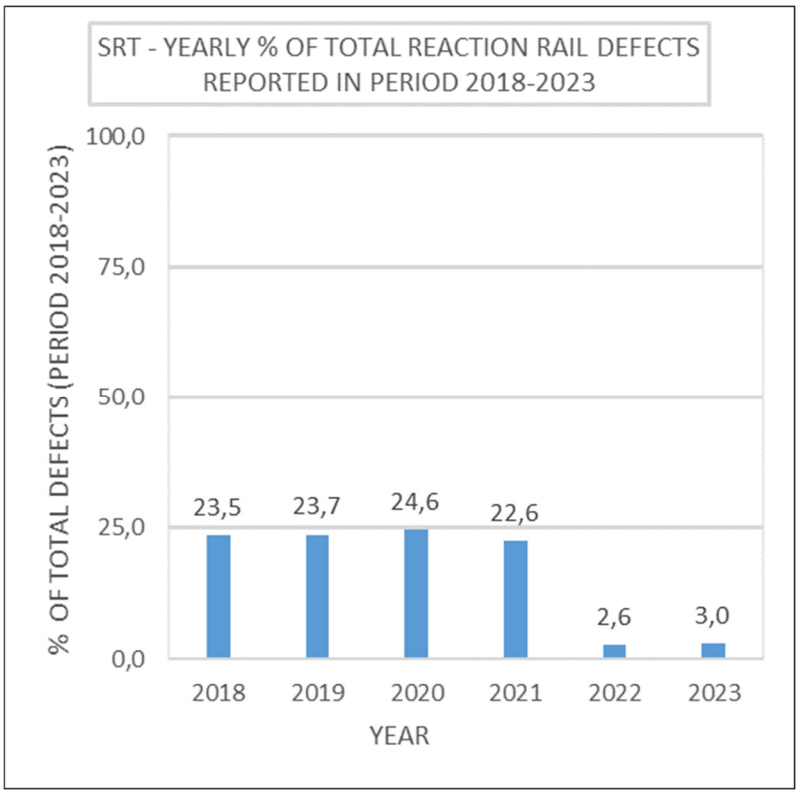

Figure 1: Defect distribution on the Reaction Rail over the last 5 years

Table 6: Reaction Rail Defects from 2018-2023

ALL SRT DEFECTS ON REACTION RAIL 2018-to-2023		
Year	**# of Defects**	**% Defects**
2018	126	23,5
2019	127	23,7
2020	132	24,6
2021	121	22,6
2022	14	2,6
2023	16	3,0

10. WORKFORCE TRAINING

As the NRC report demonstrates, the training of track patrollers needs to be improved (see NRC report page 13, chapter 4.2 Track Inspection Training and Mentoring). This process is in progress as TTC is reviewing the training modules.

As for the track maintenance training, as witnessed on September 21, 2023, in Wilson's yard, it spans over a week and seems adequate and efficient.

11. MONITORING/INSPECTION PROCESS

11.1 TRACK GEOMETRY

The track geometry is checked once a year by a track geometry recording. The date of the last passage has not yet been confirmed by TTC, but it seems to be in 2018 or 2019, which is a long time until 2023 without geometry survey.

11.2 REACTION RAIL / LIM GAP

Normally, by design, the train must not have any contact with the reaction rail, but on site, there are many areas where the train rubs on the reaction rail, see Figure 2 and a few areas where the nuts are not tightened or missing, see Figure 3.

Wear marks on the reaction rail or “polished top cap” as reported by track patroller could be explained by:

- Ice block dragged under the train;
- Debris dragged under the train;
- A direct contact between LIM and reaction rail.

Therefore, these “polished top cap” are not only caused by the top cap contacting the LIM which could explain why they were only classified as priority level 5 or brown. Previously, whenever the maintenance team was inspecting a “polished top cap” area, the top cap was repainted white, unfortunately, this practice was stopped a few years ago.

Consequently, it is currently difficult for track patrollers, who perform visual inspection, to know what causes these “polished top caps” without proper tools and the ability to thoroughly inspect reaction rail anchors during revenue service with power supply on.

Figure 2: Wear marks on reaction rail

Figure 3: Broken anchor bolt

The control and adjustment for the LIM on the rolling stock is done with a ruler and a measuring wedge every 32 days, see Figure 4 and Track and Structure uses a composite ruler to inspect the height of the reaction rail whenever a work order is generated, see Figure 5.

Figure 4: Adjustment method on LIM

Figure 5: Composite ruler

Additionally, RC&S instated specialized testing to detect high spots on the reaction rail to mitigate an increasing reporting of damages to the LIM. The first iteration of this test used a sacrificial block in front of the LIM to mark the reaction rail whenever it was higher than the defined threshold. This method was proven inefficient as the block would wear down on the first few occurrences and therefore would not be able to detect further high spots. The methodology was modified to use laser distance sensor mounted near the LIM.

The position of the laser distance sensor is shown in the figure below:

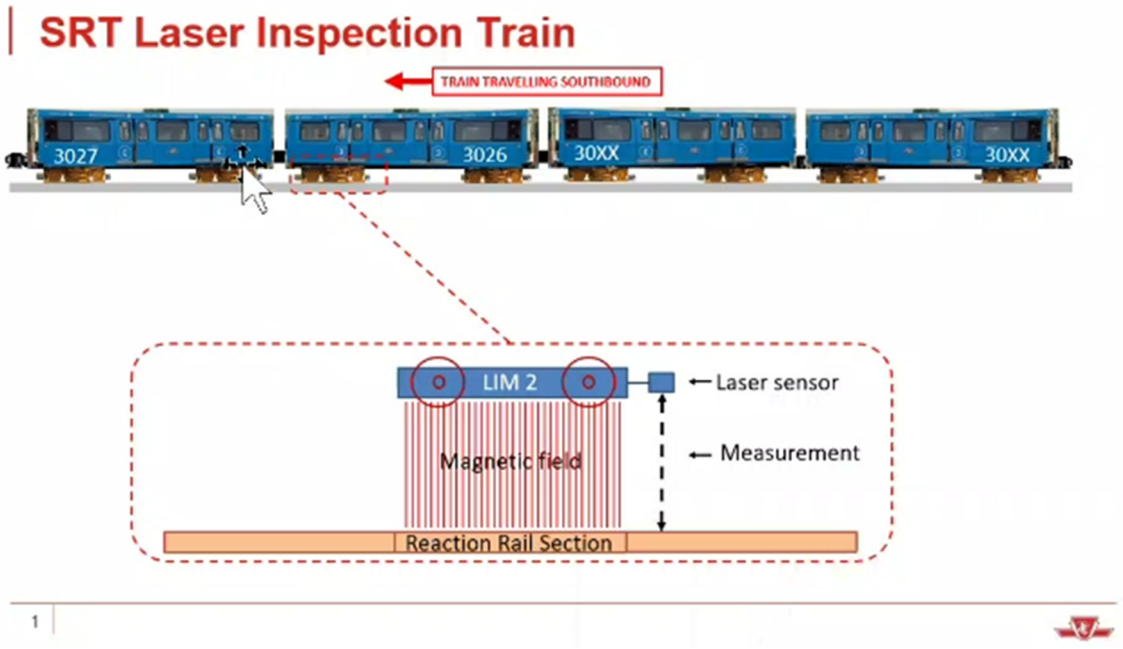

Figure 6: Position of the laser device

The laser device is installed near the LIM towards the center of the car. This test is conducted by RC&S every 2-3 months but did not have a clear requirement for periodicity since it was only justified by the quantity of damages found on the LIM.

The investigation videos from Gannett Fleming's show as the LIM passes over a section of reaction rail, the magnetic lifting force stops near the edge of the LIM and the reaction rail would immediately fall to its original position. Unfortunately, this test was not conducted with the laser measuring equipment to determine whether it was able to detect a loose reaction rail. It could be assumed that mounting the laser sensor between the LIM and the reaction rail could have enabled the detection of loose reaction rail section, but such mounting solution is not possible given the available space. Also, the magnetic forces generated by the LIM are varying depending on the phase the car is going through (acceleration braking or coasting). All these factors make it difficult to conclude if this inspection could have detected a loose reaction rail.

In addition, RC&S explains that the SRT Laser Inspection was started approximately ten years ago and was intended to supplement regular reaction rail height inspections performed by Track and Structure, and not to supersede them. According to the Track and Structure department the measurement of reaction rail height is only performed by the SRT Laser Inspection Train, the track patrol inspection is only visual without tools. This demonstrates that there is a clear misunderstanding between these two departments regarding the expected robustness of that procedure.

In summary, the track patrol team makes visual observations without any measuring devices or special tools. A train equipped with laser measuring devices passes and identifies high spots in the reaction rail. Afterwards, a team of workers and a supervisor are dispatched to rectify the areas where the rail reaction is too high, this occurs approximately every 2 to 3 months. Therefore, the SRT Laser Inspection Train is critical to the track and structure team. However, the frequency of such rectifications should have been increased and occurred ideally monthly, in line with what is performed with the rolling stock.

In addition, it is not clear if the SRT Laser Inspection Train was able to detect loose reaction rail sections leaving a gap in the overall inspection process. Those observations could have been resolved if the expectation of that test were mutually understood and agreed upon.

12. EFFECT OF THE PENDING CLOSURE

12.1 REDUCED TRACK MAINTENANCE

One of the effects of the closure of the line was the reduction of the capital project investments planned on the line, which is typical during such events. However, the various stakeholders interviewed confirmed that this had no impact on corrective maintenance.

Furthermore, with the reduction of capital project investment this also meant that the reaction rail was no longer maintained in a preventive way leaving only the 72 hours track patrols to detect any potential issues.

12.2 TRACK PATROLLER TRAINING

As the NRC report demonstrates, the training of track patrollers should be improved. But beyond this training, it is necessary, as a prerequisite, that the track patrollers have already worked on the track. Their curriculum should include integration into a track work team to fully understand how the various infrastructure components function and interact, how maintenance is carried out and how their role is critical in the detection of non-conformity.

12.3 RETIREMENT + COVID

The interviews of track managers show that the covid pandemic and retirements of senior staff have not impacted the quality of maintenance and track patrol inspection. Nevertheless, the NRC report shows in table 2.1 page 5, that for a workforce of 36 patrollers, 11 received their certification in 2021 and 17 are pending the completion of their mentorship before taking the track patroller training course.

13. NEW ANCHORS DESIGN

In 2016, TTC started using a new anchor design to replace the original anchor used to attach the reaction rail to the inverted concrete slab. This new solution was progressively deployed as a replacement for broken of damaged original design anchor. Not much detail was made available to SYSTRA on the design of the original anchor other than the information from the original infrastructure drawing showing an inverted 7/8-9 UNC bolt installed inside a hole with some sort of anchor sleeve with cement grout pored over.

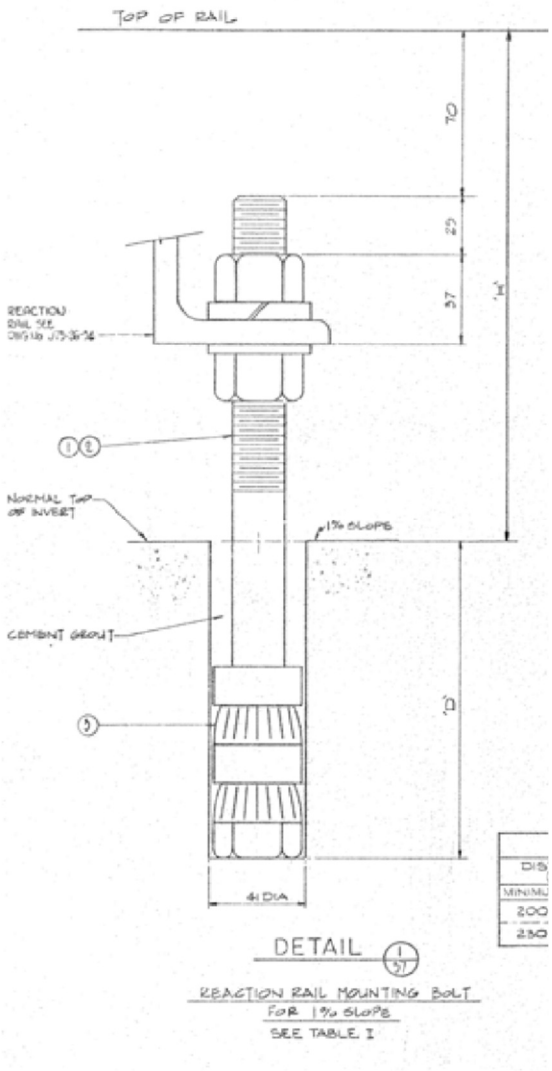

Figure 7: Original Anchors from Drawing J75-26-37

The new anchor design uses a Hilti HSL-GR anchor bolt where the main bolt is discarded by TTC and replaced by a longer stainless-steel threaded rod. The longer stainless-steel threaded rod allows the mounting of the reaction rail to be at the correct height. The Hilti HSL-GR uses an expansion sleeve to maintain the assembly in place. This type of anchor is normally used to clamp down a thick metal plate where Hilti offers wide range of available fixture thickness to accommodate the installation. For the application on the SRT Line 3, the anchor is used without the fixture thickness and is tightened directly onto the concrete slab which is not how this anchor is intended to be used according to the manufacturer. No engineering reports were made available to SYSTRA to evaluate if this anchor solution is suitable for this application. The Gannett Fleming's report mentions a vertical pull test to ensure sufficient anchor strength in the vertical direction, but no test in the horizontal direction or fatigue assessment of this anchor in this application was conducted.

Figure 8: New Hilti HSL-GR anchor with threaded stainless-steel rod
(from Gannett Fleming's report)

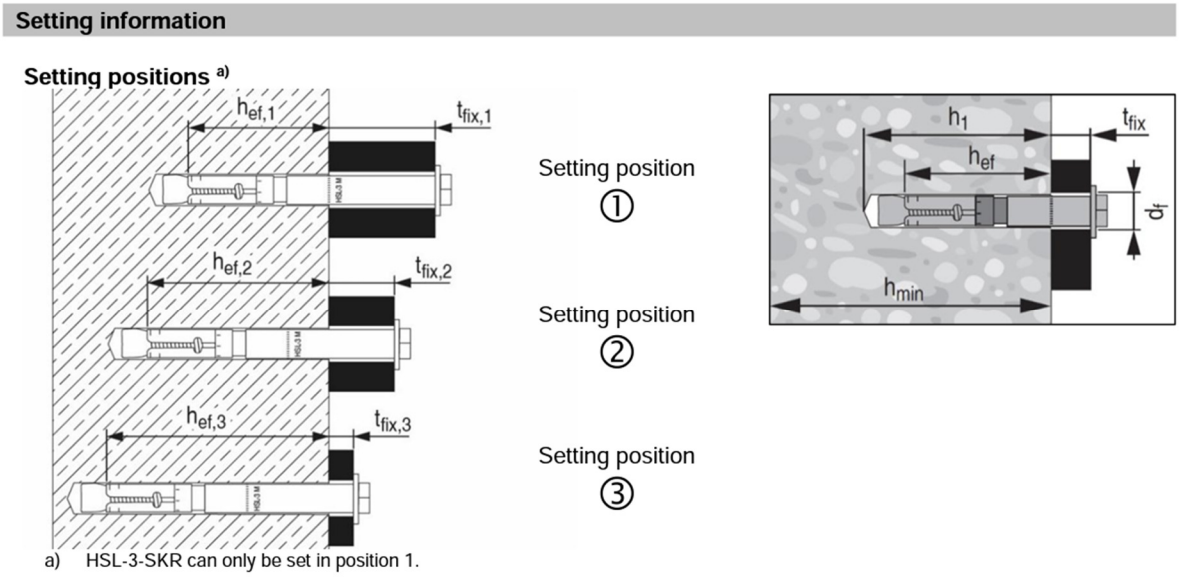

Figure 9: Setting information from Hilti technical documentation.

Using the Hilti HSL-GR with a long threaded stainless-steel rod to support the reaction rail of the SRT Line 3 can explain why several were found by Gannett Fleming to be fractured, see section 7.3. These anchors are not intended to be used in bending load as it is the case on the SRT Line 3. The metallurgical analysis confirmed that this fracture was due to cyclic loading, hence failed in fatigue probably over a long period. Combining this with the inspection process of the track patroller of walking over the reaction rail during revenue service hours suggest that this failure was not systematically reported due to its difficulty to detect. It is possible that the condition of these new anchor bolts became worse over the last few years and was not detected by the track patroller given their inspection method. It is important to note that this new anchor design was progressively replacing the original anchor design over the last 7 years.

14. SYSTRA'S OBSERVATIONS

14.1 POSITIVE OUTCOMES

During site visits, regarding the track, safety and organizational aspects, the positive points are as follows:

- Track:
  - The general quality of the track condition and other installed equipment can be considered as fairly good throughout the inspected area.
  - Best practices were observed and accomplished during the track work.
- Safety: In all inspections and facilities visited, we can confirm the compliance of track maintenance works with TTC safety rules and standards (manpower and equipment).
- Organization: throughout all inspections and interviews SYSTRA has observed that the TTC staff are fully aware of their roles, tasks and commitments to the company within their respective department & units.

14.2 POINTS TO IMPROVE

The track maintenance practices might have required the following improvements:

14.2.1 Reaction rail height controls

Certain elements in the technical procedure should be improved, it is appropriate that the readings carried out by the SRT Laser Inspection Train have an accurate & strict periodicity, aligned with the checks of the rolling stock (every month).

However, it is not clear whether this test is capable of detecting movement of the reaction rail when the electromagnetic force pulls the reaction rail upwards (see section 11.2). Hence, it would have been advisable to document more formally the inspection of loose or broken anchors as an ad hoc procedure.

14.2.2 Prioritization of defects

It is crucial to have a well-defined Priority Level for each potential defects and/or combinations of defects. By doing so, all maintenance stakeholders will have a common framework of references and understanding, starting with the track patrol team. Currently, part of this task seems to be left to subjective assessments, as illustrated by the fact that over the past 5 years, there was no report with a priority level 3 or purple for defects on the reaction rail.

14.2.3 Track patrol inspection

The on-foot inspections (track patrol) should not only carry out visual observations on line 3 SRT but they should have been performed with some light tools to do measurements when there is doubt about a "polished top cap", or about the height of the reaction rail. Furthermore, it should have been advisable to plan more track inspections led by a foreperson, particularly after the passage of the SRT Laser Inspection Train.

It is essential that all people responsible for track maintenance also carry out regular inspections of the track with a frequency commensurate to each level of responsibility (monthly for the foreperson, quarterly for roadmasters, semesterly for the track department head, annually for the head of relevant departments). These manager inspections with the track patrol could enhance the communication between the different teams and promote knowledge sharing.

14.2.4 Preventive & corrective maintenance

Probably caused by the very short effective work time on site during the night, between 1h30 and 2h of effective work once the safety measures have been carried out and following the arrival of the working trains in the work areas, the priority is given to corrective maintenance. The corrective maintenance is efficient and carried out on time. However, the Preventive maintenance appears to be weak or even non-existent. The preventive maintenance is focused on turnouts and is performed once a year by a roadmasters unit with measurement tools. There is also an inspection of turnouts, every two months, performed by Track and Structure and Signal Maintenance (joint inspection), these inspections appear to be recorded on hard copy only.

14.2.5 Organization of maintenance.

The transversal communication between within Track and Structure should be improved, particularly on low-level staff (inspectors, supervisors, etc.). As illustrated by the fact that the track patrol unit communicates with the planners & the track works team via comments in MAXIMO and the planners communicate with track works teams via WO (work order).

The first step to improve transversal communication could be achieved with a joint inspection of the track by a mix of members from various teams 0.

In addition, several maintenance documents are outdated and are still referring to the old data management software “MOWIS” instead of “MAXIMO” e.g., documents SI-T-0089, RI-WI-736-0301/0, RI-SOP-736-01/0.

15. CONCLUSION

The root causes of the derailment of July 24, 2023, are known and come from a failure of the reaction rail anchors which caused the reaction rail to lift and then collide with the rolling stock LIM. However, further upstream, this derailment can also be explained by several contributing factors that explain why there was a reduction of defects being reported on the reaction rail over the last 2 years .

Data Migration from MOWIS to MAXIMO: From the on-site interviews held with different stakeholders, the defects data has dropped off significantly following the migration to MAXIMO, possibly due to the erasing of duplicated defects already present in MOWIS which may have artificially increased the number of defects prior to 2022. Overall, the migration process is not clear and should be reviewed and better documented. A detailed forensic investigation of this data migration was not possible as we did not witness this process.

New anchor bolt design: Several aspects of the new anchor bolt design are questionable and could have led to the fatigue failure in the threaded portion which is very difficult to detect by track patroller. Furthermore, the lack of supporting engineering documentation raises concern over the design review process.

Reduction of preventive maintenance: Some actions linked to preventive maintenance were no longer carried out once the line was announced to be closing. Furthermore, the anchor bolts were never subjected to preventive maintenance.

Top cap painting: The top cap was no longer re-painted making it more difficult for track patrollers to detect new areas of ‘’Polished Top Cap’’.

Training and experience of track patrollers: As reported in the NRC report, the track patroller's training needs to be updated. TTC is currently working on updated modules, the previous ones were running on a defunct computer software. It was reported that there is minimal exchange between the track patrollers and the other unit personnel responsible for maintenance. The NRC report also shows that the experience of the track patrollers is low where 11 out of 36 received their certification in 2021 and 17 are in the process of obtaining theirs. Track patrollers without their certification are required to patrol with a certified track patroller.

Beyond the training of track patrollers, it is necessary, as a prerequisite, that the track patrollers have already worked on the track. Their curriculum should include integration into a track works team.

Furthermore, it is not uncommon on other rail networks to have the track patrollers included in track maintenance work. This practice adds polyvalent and flexibility to the track patrol team while improving their knowledge of track components.

Priority level: The priority level assignments to each defect is problematic as it depends on the interpretation of the track patroller and his perception of the urgency of such defect and not with uniform criteria for all inspectors. Also, each defect is evaluated individually, and the combination of defects is not considered in assigning a priority level.

Reaction Rail height measurement: RC&S explains that the SRT Laser Inspection Train test was implemented approximately ten years ago, and the intent was to supplement proper reaction rail height inspections performed by Track and Structure, and not to supersede them. In our opinion, the periodicity is too long, it should be aligned with the inspection carried out on the rolling stock for the height of the LIM.

SYSTRA has not found a definitive cause for the reduction in the reporting of reaction rail defects in the last two years but a series of contributing factors. Knowing that the SRT Line 3 is definitely closed and scheduled for decommissioning, some contributing factors may apply only to the SRT Line thus not requiring intervention, whereas other apply to the entire network and should be reviewed and corrected to avoid future incidents. Below, are SYSTRA's recommendations.

16. RECOMMENDATIONS

Improve communication and training between maintenance personnel: As stated above, by introducing track patrol with various levels of leadership and contributors, it allows the track patrollers to improve their knowledge and communicate directly to the various stakeholders. SYSTRA proposes the following periodicity:

- Monthly for forepersons
- Quarterly for roadmasters
- Semi-annually for the track department head
- Annually for maintenance engineering

Improve the priority level definition: Track patroller should refer to a clear document stating which priority level to assign to which defect or combination of defects. This is to avoid issues with interpretation of severity and assign an appropriate priority level to a combination of defects within the same chainage such as multiple failed anchor bolts.

Define a clear inspection program for track survey: Specific to the SRT Line 3, the height of the reaction rail was only surveyed every 2-3 months, but no specific requirement existed to enforce this measurement and the SRT Laser Inspection Train measurements were not sufficient to properly monitor the movement of reaction rail, whereas the rolling stock was checked every 32-36 days. As it was not within the scope of this investigation to evaluate the processes used on the other line, it is important to have a clear inspection program to monitor key infrastructure elements and be able to detect all of their potential failure modes.

Improve maintenance organization: The roles and responsibilities of the various departments in charge of maintenance should be clarified. As stated in section 8.28.2, the responsibility of measuring the height of the reaction rail was not clearly defined between Track and Structure and RC&S. A clear role and responsibility matrix would ensure a more efficient modus operandi.

Audit the engineering review process: The engineering review process should be audited to make sure design change such as the new anchor bolt design is reviewed diligently before being released. When SYSTRA requested an engineering validation for the new anchor bolt design, TTC was not able to provide such supporting documentation.

Update maintenance procedure documentation: On top of the update to the priority level definition and track survey procedures, several other maintenance documents are outdated and still refer to the old data management software “MOWIS” instead of “MAXIMO” e.g., documents SI-T-0089, RI-WI-736-0301/0, RI-SOP-736-01/0.

Report SRT Line 3
Incident

APPENDICES

SYSTRA CANADA

APPENDIX A

TTC - 13.09.2023 Inspection report

SYSTRA CANADA

SITE INSPECTION REPORT

Project: TTC - Subway Track Maintenance Oversight Analysis Services	
Inspectors: **GUERRA, Jorge**	Inspection Date: **13.SEP.2023**
Staff on site:	Weather:
Location: **LINE 3 SRT - KENNEDY Station & Mc COWAN yard**	

ACTIVITIES

SCOPE: SRT track and facilities visit

Attendees:

TTC - James Way, Senior Safety Assurance Officer

SYSTRA – Jorge Guerra, Senior Track Expert

Observations:

1. Kennedy Station

- Track visual observation of the installed track components (rails, fasteners, platform, etc)
- Special focus on the reaction rail alignment and its fastening condition



2. Mc Cowan Yard

- Tour on the rolling stock facilities

- Yard visual observation of the installed track components (turnouts, rails, fasteners, platform, etc)


- Brief contact with the derailed car (including some damaged components and damaged reaction rail)
- Demonstration of the measurement gap car lime/reaction rail



Prepared by: **GUERRA, Jorge**	Project: **TTC - Subway Track Maintenance**
Signature:	Date: **13.SEP.2023**

APPENDIX B

TTC - 25.09.2023 Inspection report

SYSTRA CANADA

SITE INSPECTION REPORT

Project: **TTC - Subway Track Maintenance Oversight Analysis Services**	
Inspectors: **LEGUET, Christian**	Inspection Date: **25.SEP.2023**
Staff on site:	Weather:
Location: **LINE 3 – SRT line at Mc Cowan station and Mc Cowan yard**	

ACTIVITIES

SCOPE: Safety/Track quality walking inspection

Attendees:

TTC – James Way, Senior Safety Assurance Officer

TTC – Villiam , Safety

SYSTRA – Christian Leguet, Senior Track Expert

Decription:

Safety/Track quality walking inspection on LINE 3 at Mc Cowan station and Mc Cowan yard
Started at 9am 25.Sep.23 and ended at 13.30pm 25.Sep.23

Observations/tasks:

1. Track & reaction rail

- There are many areas where the train rubs on the reaction rail (photo n°1) and a few areas where the nuts are not tightened or missing (Photo n°2)

Photo n°1

Photo n°2

- The control and adjustment for the rolling stock is done with a ruler and a measuring wedge (photo n°3) and the control and adjustment at track level is done with a rolling stock equipped with laser sighting at the front (running every 2 to 3 months), then the control and adjustment is done with a composite ruler (photo n°4)

Photo n°3

Photo n°4

- derailment of July 24, 2023: reaction rail  and rolling stock 

Prepared by: **LEGUET, Christian**	Project: **TTC - Subway Track Maintenance**
Signature:	Date: **25.Sep.2023**

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