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How Communications-Based Train Control (CBTC) is Affecting Transit Agency Rail Maintenance

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Agenda

- CBTC Technology
- Recent Trends in CBTC Projects
- Comparison between Track Circuits and Axle Counters
- The Broken Rail Issue
- Axle Counter Improvements
- Rail Maintenance Evolutions
- Conclusion

Communications Based Train Control (CBTC)

Applications – Main Benefits

- Applications:
  - Urban Mass Transit Systems
  - More than 200 mass transit systems in the world
  - Examples: New York City Transit (NYCT), Hong Kong Mass Transit Railway (MTR), Paris Regie Autonome des Transport Parisiens (RATP)
  - Became the norm for both greenfield and brownfield projects
- Main Benefits:
  - High capacity thanks to reduced headways
  - Continuous speed enforcement
  - Minimum number of equipment on the trackside
  - Operational flexibility
  - Optimal run times
  - Several others

Communications Based Train Control (CBTC)

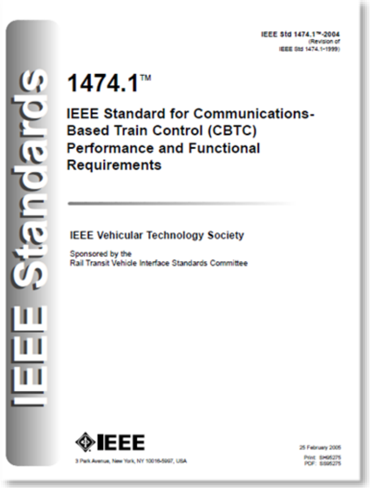
Examples of Projects in the USA

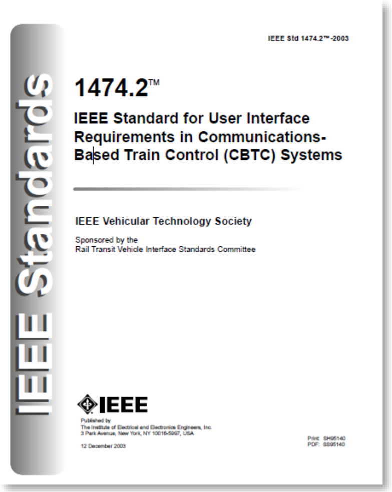
- Examples of Projects in the USA:
  - SFMTA (San Francisco, CA) – Started operation in 1998 (Not radio based)
  - JFK Airtrain (New York, NY) – Started operation in 2003 (Not radio based)
  - NYCT Canarsie Line (New York, NY) – Started operation in 2006
  - SEPTA Green Line (Philadelphia, PA) – Started operation in 2010
  - NYCT Flushing Line (New York, NY) – Started operation in 2017
  - PATH (Jersey City, NJ) – Started operation in 2018
  - SEPTA Sharon Hill Lines (Philadelphia, PA)– On-going
  - NYCT Queens Boulevard Line (New York, NY) – on-going
  - MTA (Baltimore, MD) – on-going
  - BART (San Francisco, CA) – on-going

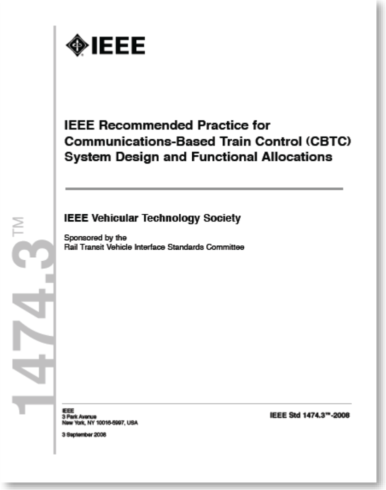
Communications Based Train Control (CBTC)

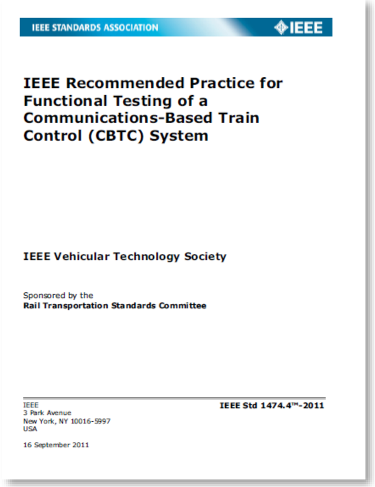
Principles – Main popular Standards

- Principles:
  - Continuous bi-directional communication between trains and wayside equipment
  - On board equipment that determines position, train length and provides it to the wayside equipment
  - Wayside equipment ensures safe train separation by sending Movement Authority Limit to each train in its territory
  - On board equipment enforces this Limit and civil speed protection
- CBTC Standards: IEEE 1474 series









Communications Based Train Control (CBTC)

History

- History:
  - Major evolutions concerned the method of communications
    - 1980s: first systems with principles close to CBTC using inductive loops for communications
      - *Example: Vancouver, BC SkyTrain in 1983 - Greenfield*
    - 1990s: first radio based systems with CBTC
      - *Example: RATP Line 14 in 1998 - Greenfield*
    - 2000s: first systems with CBTC using radio with access points
      - *Example: NYCT Canarsie Line in 2006 - Brownfield*
    - 2010s: first systems with CBTC using IP radio with access points
      - *Example: Milan Line 2 in 2011 - Brownfield*
    - Future: first systems with CBTC using LTE

Starting mid 2000: the number of CBTC projects dramatically increased around the world

Recent Trends in CBTC projects

Secondary Signaling Systems Evolution

- Secondary Signaling Systems in CBTC projects:

First CBTC projects	Today's projects
Very few projects with no Secondary Systems	Still very few projects with no Secondary Systems
Many agencies required a full Secondary Train Control for back-up of the CBTC / to operate without CBTC	Few projects continue to require a Secondary Train Control for back-up of the CBTC
	Most agencies require a Secondary Train Detection system able to track the trains in addition to CBTC
Most systems used Track Circuits	Among the systems using Secondary Train Detection: recent trend is to use axle counters instead of track circuits

Recent Trends in CBTC projects

Secondary Signaling Systems evolution

- Why such evolutions regarding the Secondary Signaling System ?
  1. Secondary Train Control / Full Back-up system is expensive to deploy and maintain
  2. Secondary Train Control has a negative impact on the overall system availability
  3. Availability of CBTC system itself is very good on most projects

→ Conclusion: CBTC projects should work to reduce reliance on Secondary Signaling System

- The minimum Secondary Signaling System is defined by the need to track non-CBTC trains:
  - Maintenance trains
  - Single failed CBTC trains
  - Trains from other non CBTC lines if applicable

→ Conclusion: deploy a Secondary Train Detection with few devices / large tracking blocks

→ Large tracking blocks easier to implement with axle counters than track circuits

Comparison between Track Circuits and Axle Counters

Secondary Train Detection Device evolution

- Secondary Train Detection devices:
  - Track Circuits
  - Axle Counters / Wheel Sensors

- From TCRP Project D-18 about Secondary Signaling System in CBTC projects:
  - Before 2005, among projects with STD/PS:
    - 91% of projects use track circuits
    - 9% of projects use axle counters
  - After 2005, among projects with STD/PS:
    - 29% of projects use track circuits
    - 71% of projects use axle counters

What happened ?

Comparison between Track Circuits and Axle Counters

Criteria	Track Circuits	Axle Counters	Relative advantage to
Functional scope	Detection, direction (by following sequence with adjacent track circuits), average speed through entire section (by also measuring time)	Detection, direction, car counting, train length, average speed between detectors (by also measuring time)	Axle counters (car counting and train length are determined non-vitally)
Installation	More complex	Quicker, no modification to track. May be overlaid over existing track circuits.	Axle counters
Modification of layout	Complex, involves insulated joint and impedance bond changes, new holes in the rail	Simple due to wheel sensors being clamped to the rail (depends on manufacturer). Third rail modification might be required to facilitate maintenance.	Axle counters
Maintenance	Periodic readjustment required due to changes in ballast resistance.	Highly reliable. Minimum maintenance.	Axle counters
Vital Operation	Yes	Yes (CENELEC/EN 5012X, SIL 4)	Equal

Comparison between Track Circuits and Axle Counters

Criteria	Track Circuits	Axle Counters	Relative advantage to
Track requirements	Isolated rails, insulated joints, impedance bonds, wire connections	None	Axle counters
Length of track section	Limited by feed power, ballast leakage	Unlimited	Axle counters
Traction current return interference	Yes	No	Axle counters
Broken-rail detection	Yes (only certain kinds)	No	Track circuits
Dependence on wheel-rail electrical interface (shunt)	Yes	No	Axle counters
Detects vehicles entering upon track in middle of section	Yes	No	Track circuits
Initialization and reset procedures	No	Yes	Track circuits

The Broken Rail issue

- Broken Rail may cause train derailment:
  - Recent example: Washington Metropolitan Area Transit Authority Red Line Train in January 2018

- Track Circuits are not able to catch 100% of broken rails:
  - American Public Transportation Association (APTA) standard RT-FS-S-002-02, Rail Transit Track Inspection and Maintenance from April 2017: *"signal circuits do not provide 100 percent reliability for pull-apart detection."*

- For years the Broken Rail issue was the reason transit agencies were not considering using a signaling system without track circuits.

- Things have changed ! With rail defect prevention and detection techniques, broken rail protection does not always imply track circuits

The Broken Rail issue

- Why the evolution towards axle counters even though they do not provide broken rail detection?

  1) The need from CBTC project changed:

  - Secondary Train Detection systems need only long blocks: in favor of axle counters
  - More brownfield projects: axle counters can be installed in parallel of existing system

  2) Axle Counters became an alternative viable solution with the following changes in the 2000s:

  - More reliable
  - Ability to detect any type of vehicles including maintenance vehicles
  - Ability to clamp them on the rail

  3) Broken rail prevention / Rail Maintenance became more efficient in the 2000s:

  - Track Geometry Car benefited from new technologies
  - Asset Management Systems was deployed and able to include rail status
  - Ultrasonic testing became widely used with good performance at higher speeds

Axle Counters Improvements

- Popular vendors in the USA: Frauscher Sensor Technology, Siemens, Thales, Tiefenbach.

- Ability to clamp them on the rail:
  - Available since the 2000s
  - Still not proposed by all vendors

- More reliable in the capacity to detect wheels:
  - Vendor claim: "*For example, for each track section, this may be one error (a) every 10 years or (b) during traversing of 10 million axles*."

- Ability to detect any type of vehicles including maintenance vehicles:
  - Performance improvements now allow to detect even hi-rail vehicles
  - Detection depends on wheel size and wheel flange

Rail Maintenance changes

Track Geometry Car

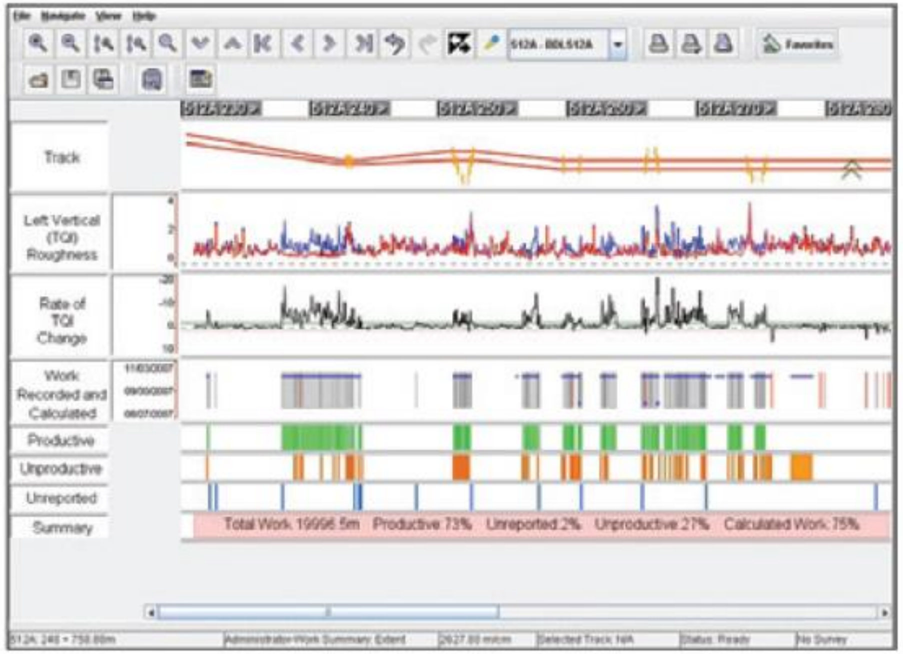
- Track Geometry Car now benefits from new technologies
- Example of state of the art capabilities:
    - Track Geometry measurement
    - Rail Profile / Surface measurement
    - Track View Video Tunnel Inspection
    - Third rail measurement
    - Under car video machine vision for track inspection
    - Rail corrugation
    - Light Detection And Ranging (LIDAR) scanner for inspection of tunnels and clearance profile

- Many new tools relies on machine vision which started to become efficient and widely used in the 2000s
- LIDAR technology available in the railway only since the 2010s

Rail Maintenance changes

Asset Management System - Technology

- Asset Management systems able to better managed wayside asset including rail status
- Big data management allows to collect and analyze data from Track Geometry Cars and link it to other Asset Management Systems
- Example of vendors for management Track Geometry car data: Bentley/OPTRAM, Protran/MOWIS

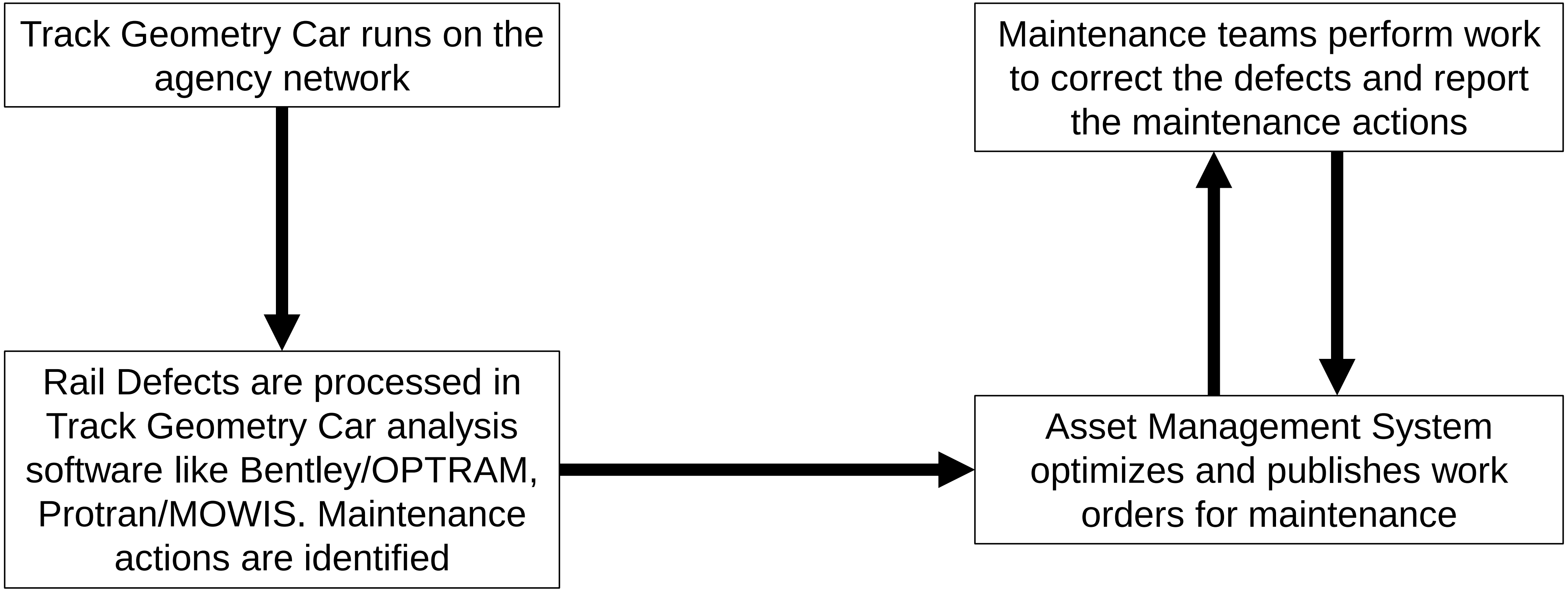


Example of Aggregation of track geometry before and after work, to assess work productivity

Rail Maintenance changes

Asset Management System - Technology

- Taking advantage of Track Geometry Car and Asset Management System:



Rail Maintenance changes

Asset Management System - Regulation

- Federal Transit Administration (FTA) recent regulation in favor of Asset Management Systems

- 49 CFR Parts 625 and 630 – July 26, 2016 about Transit Asset Management:

    - *The Federal Transit Administration is publishing a final rule to define the term **state of good repair** and to establish minimum Federal requirements for **transit asset management** that will apply to all recipients and subrecipients of chapter 53 funds that own, operate, or manage public transportation capital assets.*

    - *This final rule requires public transportation providers to develop and implement out Transit Asset Management (TAM) plans.*

Rail Maintenance changes

Ultrasonic Testing

- Most transit agencies are adopting Ultrasonic Testing independently of signaling system upgrade

- Determining the number of Ultrasonic Testing per year – FRA changes:
  - Majority of potential CBTC users are not under FRA but maintenance remains influenced by FRA
  - FRA Standards 49 CFR Part 213 Track Safety Standards from 2011 :
    - Discussed about internal rail defects but does not mention the words ultrasonic testing
    - Required to be tested for internal rail defects at least once every accumulation of 40 million gross tons (mgt) or once a year
  - 79 FR 4233 Track Safety Standards; Improving Rail Integrity; Final Rule from 2014:
    - Introduce the words Ultrasonic testing
    - Introduce the concept of a **performance-based risk management** for determination of rail inspection frequency

Broken Rail Protection / Rail Maintenance Evolutions

Ultrasonic Testing

- Performance-based risk management for determination of rail inspection frequency:
  - Targeted number of **Service Failure per Mile per Year.** Also called **Risk Value.**
  - Service failure is a failure that:
    - happens during revenue service
    - was not catch before it became a broken rail
  - In systems with track circuits, there is still a chance that the track circuits will detect the broken rail

Broken Rail Protection / Rail Maintenance Evolutions

Ultrasonic Testing - Regulation

- Determining the targeted Risk Value:
  - 79 FR 4233 Track Safety Standards; Improving Rail Integrity; Final Rule:
    - No more than 0.1 service failures per track mile per year for all Class 4 and 5 track;
    - No more than 0.09 service failures per track mile per year for all Class 3, 4 and 5 track that carries regularly-scheduled passenger trains or is a hazardous material route; and
    - No more than 0.08 service failures per track mile per year for all Class 3, 4, and 5 track that carries regularly-scheduled passenger trains and is a hazardous material route.
    - Class 3, 4 and 5 track with regularly-scheduled passenger trains : 370 days between inspections or a tonnage interval of 40 mgt between inspections, whichever is shorter.

Broken Rail Protection / Rail Maintenance Evolutions

Ultrasonic Testing - Regulation

- Deriving the Ultrasonic Test (UT) inspection frequency based on the targeted Risk Value:

  - 79 FR 4233 Track Safety Standards; Improving Rail Integrity; Final Rule:

For track owners without access to a sophisticated self-scheduling algorithm to determine testing frequencies, FRA has posted an algorithm program. The algorithm requires five inputs:

(1) Service failures per mile in the previous year;

(2) Detected defects per mile in the previous year; ← UT detected defect

(3) Annual tonnage;

(4) Number of rail tests conducted in the previous year; and

(5) The targeted number of service failures per mile

Broken Rail Protection / Rail Maintenance Evolutions

Ultrasonic Testing - Regulation

- Determining the number of Ultrasonic Testing per year:

SELF-ADAPTIVE SCHEDULING ALGORITHM

INPUT: *Enter your data in yellow cells. Click button to calculate. Output appears in green cells below.*

Service failures per mile performance target:	0.10	SF/mile for this segment
Annual tonnage for this segment:	100	MGT
Number of inspections in previous year:	4	
Detected defects per mile in previous year:	0.500	
Service failures per mile in previous year:	0.180	

CLICK HERE TO CALCULATE

OUTPUT

Number of rail tests for this segment next year:	5

Extract from FRA document presenting the tool to determine the number of rail tests per year

Rail Maintenance Evolutions

Ultrasonic Testing

- Determining the number of Ultrasonic Testing per year:
  - Instead of the FRA developed tool, agencies may used private sector service provider
  - Example of service provider: PROTRAN Technology proposes a tool named RailTest
  - Data needed:
    - Track Definitions
    - Current Ultrasonic Test Plan
    - Annual tonnage
    - Defect Records – Defected Defects
    - Defect records – Service Defects
    - Passenger/Non-passenger carrying track locations
    - Track Speed
    - Signal Track Locations
    - Reliability of Test Equipment
    - Traffic Makeup

Additional possible parameters in comparison to the FRA tool

Rail Maintenance Evolutions

Ultrasonic Testing

- Determining the number of Ultrasonic Testing per year:
  - Selection of Risk Value: Service failures / mile / year
  - Typical industry Risk Value:

Typical Target Risk Values		
Track Description	Risk Value	Max Speed (mph)
US Freight Average	0.1	N/A
US Freight with Limited Passenger Service	0.06	N/A
Low Speed Passenger Service	0.03	59
Moderate Speed Passenger Service (US, Europe)	0.01	100
High Speed Passenger Service (US, Europe)	0.001	160

Rail Maintenance Evolutions

Ultrasonic Testing

- Selecting the Risk Value when switching from track circuit signaling to CBTC with axle counters:
    1. Collect data about service failures in previous years
    2. Filter out the service failures which were detected by track circuits
    3. Use this value of service failure not detected by track circuits to calculate the target risk value
- Examples:

Agency	Miles of Track(mph)	Risk Value : Service failures / mile / year			
		R=0.1	R=0.01	R=0.005	R=0.001
WMATA	117	11.7	1.17	0.59	0.18
Baltimore MTA	31	3.1	0.31	0.16	0.03
BART	250	25	2.5	1.25	0.25
		Not acceptable	May be acceptable in existing system with track circuits	Possible new targeted risk value if R=0.01 in current system and track circuits detect 50% of service failures	Possible new targeted risk value

Rail Maintenance Evolutions

Ultrasonic Testing

- Example of number of Ultrasonic Testing per year for agencies with track circuits:
  - Typically two (2) to three (3) times a year (more than FRA recommendation)
  - Up to five (5) times a year

- No feedback on experience yet:
  - CBTC heavy rail mass transit projects completed in the USA all had track circuits
    - New York City Transit
    - Port Authority Trans-Hudson

  - Several on-going projects very likely to use axle counters only:
    - Baltimore Maryland Transit Administration (MTA)
    - Bay Area Rapid Transit (BART)
    - Canada: Toronto Transit Commission (TTC) already in revenue service on part of the network

Summary

Before

Broken Rail Protection

Need to keep track circuits

Changes

- CBTC has become the norm. No need for track circuits
- CBTC still uses Secondary Detection systems
- Most CBTC are brownfield projects

- Axle Counters became an optimal solution for CBTC projects

- Rail Maintenance benefited from technology advances:
  - Track Geometry Car
  - Asset Management Software
  - Ultrasonic Testing

Now

Most CBTC projects with axle counters

Rail Maintenance need to be adapted. Ultrasonic Testing frequency to be updated

2000 2005 2010 2018

Conclusion

- **Most CBTC Systems today use minimal Secondary Train Detection systems, now more often with axle counters**
  - Axle counters based secondary train detection systems need less capital cost and have lower maintenance cost than previous signaling systems and earlier CBTC systems using track circuits as Secondary Train Detection

- **New and improved technologies allow for a more efficient Rail Maintenance Program while enhancing safety**
  - Safety issues related to track condition can be maintained and enhanced even when the new CBTC system does not include track circuits

Thank you for your attention

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