New York City Transit Car-Borne Maintenance: Present & Future

John Santamaria, P.E.
Vice President & Chief Mechanical Officer
New York City Transit
Car Equipment - Department of Subways

AGENDA

- Introduction to New York City Transit (NYCT)
- NYCT Current Maintenance Practices
  - *Scheduled Inspections*
  - *Corrective Maintenance*
  - *Scheduled Maintenance System (SMS) Program*
- Condition Based Maintenance (CBM) Principles
- NYCT Future Maintenance Practices with CBM
- NYCT CBM Efforts Under Way

NYCT – Division of Car Equipment (DCE)

Responsible for:

- Car Inspections, Repairs and Maintenance
- Scheduled Maintenance System Program
- Purchase and support of all revenue and non-revenue vehicles
- Engineering
- Emergency Response
- Quality Assurance
- Customer Accidents & Investigations
- Facility Maintenance

NYCT – Division of Car Equipment (DCE)

- 4,800+ Employees

Managers	~ 3%
Professional/Technical	~ 4%
Supervisory	~ 10%
Hourly	~ 83%

- 24-hour / 7-day Operation
- Fleet Size:
  - > 6,500 Revenue Railcars
  - > 550 Non-Revenue (Work) Equipment

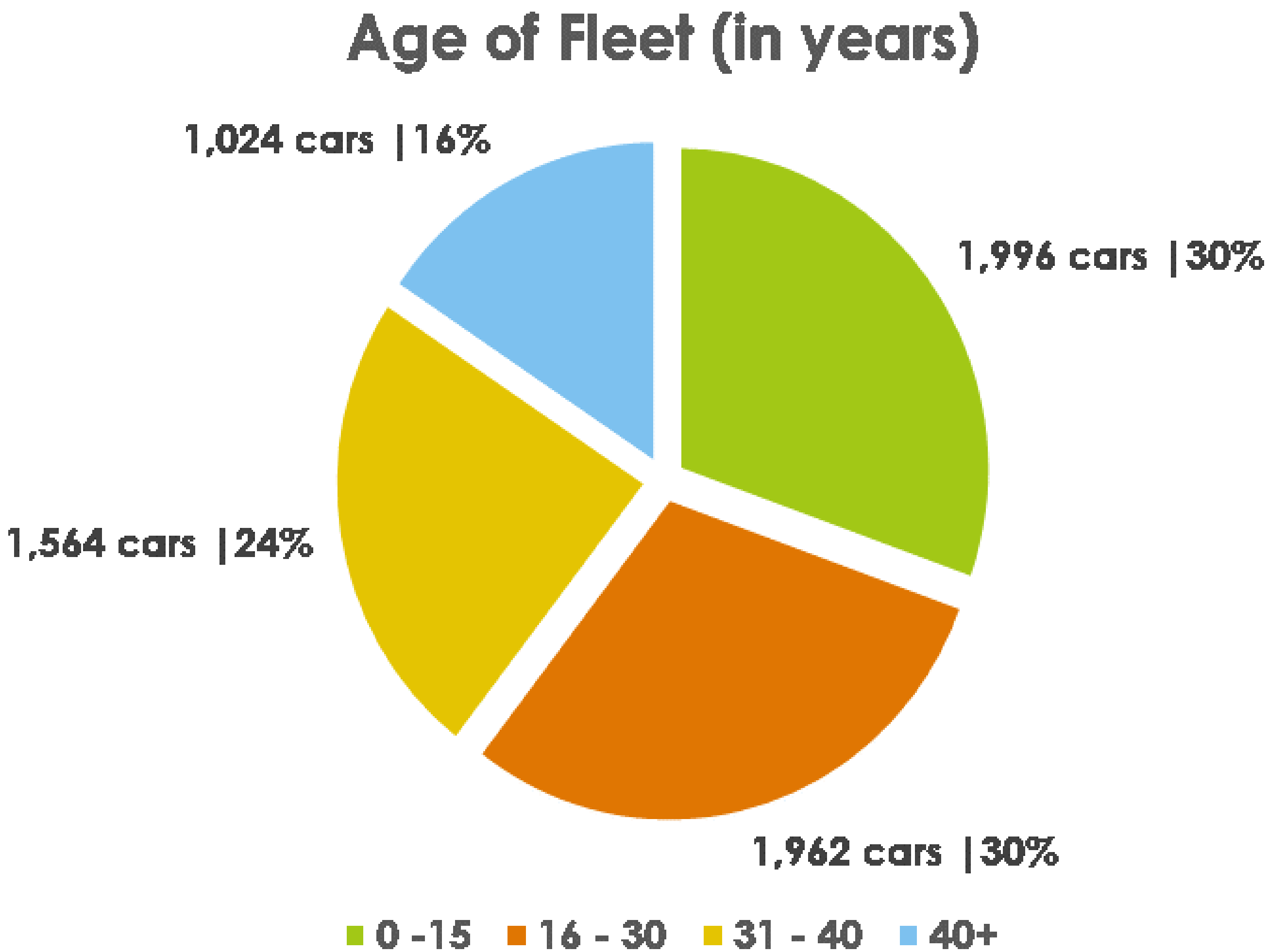
NYCT – Division of Car Equipment (DCE)

- Support Facilities:
  - 13 Fleet Maintenance Facilities
    - ✓ Performing scheduled maintenance and repairs, lay-ups during off-hours
  - 2 Major Overhaul Facilities
    - ✓ Performing scheduled overhauls in addition to car body and truck repairs
    - ✓ Dedicated Component Shops:
  - 2 Work Vehicle Maintenance Facilities
    - ✓ Performing scheduled maintenance and repairs

MTA NYCT: Quick Facts

- Ridership:
  - Average weekday subway ridership: 5.6 million
  - Annual ridership: > 1.7 billion
- **Number of Stations:** 472 (The largest number of public transit subway stations of any system in the world).
- Number of Lines: 24
- **Miles of Track:** 665 mainline track miles / 840 miles including non-revenue (4’8.5” gauge)
- Number of Weekday Train Trips: 8,200
- Subway Annual Car mileage: Fleet traveled 358 million miles
- Miles traveled by an average subway car between repairs: > 120,000

Fleet Age



Overall Fleet Age (As of 2nd Quarter 2019): 23 Years

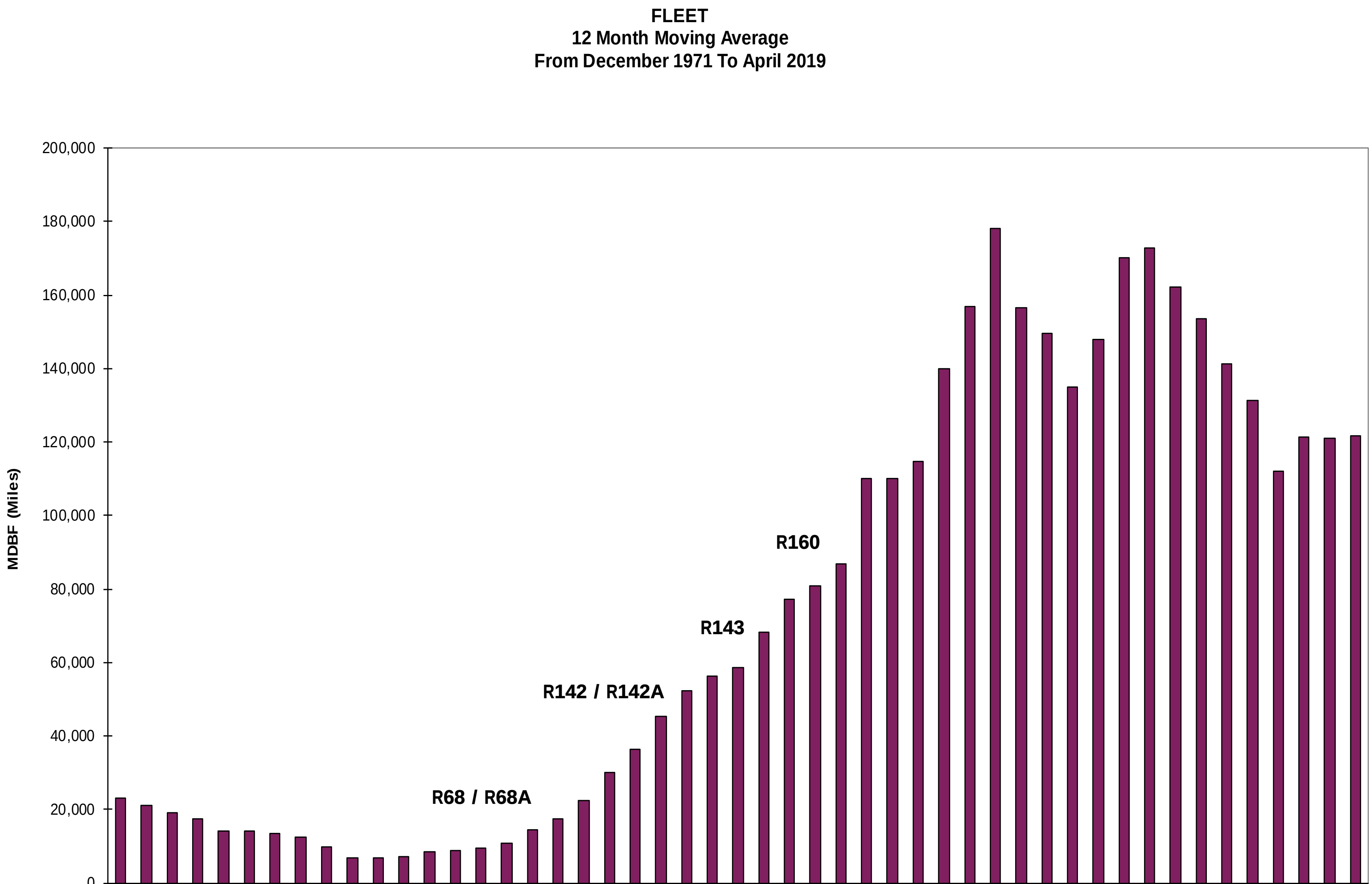
KPI: Mean Distance Between Failure (MDBF)

- Key indicator for fleet performance.
- Measures car reliability as it relates to its on-time performance.

$$\text{MDBF} = \frac{\text{TOTAL MILES OPERATED}}{\text{TOTAL NUMBER OF MECHANICAL FAILURES}}$$

Total Miles Operated:	Actual number miles traveled in revenue service (excluding deadhead, training and maintenance)
Mechanical Failures :	Service delays greater than five minutes, including cancelations and terminations

NYCT MDBF History: 1972 to Present



	Dec-71	Dec-72	Dec-73	Dec-74	Dec-75	Dec-76	Dec-77	Dec-78	Dec-79	Dec-80	Dec-81	Dec-82	Dec-83	Dec-84	Dec-85	Dec-86
12- Mo Moving Avg	23,136	21,125	19,006	17,546	14,156	14,021	13,488	12,393	9,736	6,823	6,994	7,145	8,620	8,781	9,490	10,826

	Dec-87	Dec-88	Dec-89	Dec-90	Dec-91	Dec-92	Dec-93	Dec-94	Dec-95	Dec-96	Dec-97	Dec-98	Dec-99	Dec-00	Dec-01	Dec-02
12- Mo Moving Avg	14,547	17,451	22,358	29,948	36,413	45,253	52,403	56,270	58,622	68,238	77,161	80,990	86,884	110,180	109,914	114,619

	Dec-03	Dec-04	Dec-05	Dec-06	Dec-07	Dec-08	Dec-09	Dec-10	Dec-11	Dec-12	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-18	Apr-19
12- Mo Moving Avg	139,960	156,815	178,085	156,624	149,646	134,795	148,002	170,217	172,700	162,138	153,382	141,202	131,325	112,208	121,220	121,116	121,704

NYCT Maintenance Practices

Scheduled Maintenance Inspection

- The Scheduled Maintenance Inspection (SMI) Program verifies that cars are mechanically and electrically reliable, ensuring safe operation with adequate number of trains available for daily service.

Scheduled Maintenance Inspections (SMI)

Scheduled Maintenance Inspection (SMI) Program

- There are four SMI Cycles (SM1 through SM4).
  - Inspection criteria: 68-76 days or 10,000 to 12,000 miles, whichever comes first.
  - All systems are checked in each cycle
  - “Regular” or “Heavy” inspections are performed, based upon the OEM recommendations and lessons learned
  - Components with longer lifetimes are given extended service (“Heavy Inspection”) on a rotating basis over the four cycles.
  - Larger components with longer lifetimes are addressed in the SMS Program.

Scheduled Maintenance Inspections (SMI)

INSPECTION FUNCTION	INSPECTION SCHEDULE			
	SM1	SM2	SM3	SM4
PROPULSION				
CURRENT COLLECTORS	R	R	H	R
TRACTION MOTOR	R	R	R	H
BATTERY AND BATTERY BOX	R	R	R	H
CONTROL ELECTRONICS	R	R	H	R
TRACTION INVERTER	R	R	R	H
MASTER CONTROLLER	R	R	H	R
MISC PROPULSION	R	R	R	H
UNDER CAR				
TRIP VALVES	R	R	H	R
DRAIN VALVES, TANKS	R	R	H	R
CUTOUT VALVES, HOSES, PIPES	R	R	H	R
COUPLER SYSTEM	R	R	H	R
AIR BRAKE SYSTEM	R	R	H	R
AIR SUPPLY UNIT	R	R	H	R
TRUCK BRAKE EQUIP	R	R	H	R
TRUCKS & WHEELS	R	R	H	R
MISC UNDER CAR	R	R	R	R
CAR BODY				
HVAC	H	R	H	R
DOOR CONTROL	R	H	R	R
CAR BODY	R	R	R	R
PANELS	R	R	R	H
LIGHTING SYSTEM	R	H	R	R
COMMUNICATION SYSTEM	R	R	R	H
UNDER CAR CLEANING	H	R	R	R
MISC CAR BODY	R	R	H	R
MONITORING & DIAGNOSTICS				
MDS SYSTEM	R	R	H	R
CBTC	R	R	R	H

TRACTION INVERTER

- Propulsion Self Test
- Inspection, Exterior
- Inspect Inductor Assembly
- Inspection, Interior
- Inspect Line Breaker & Overload Relay
- Inspect Line Charging & Brake Contactor
- Inspect Emergency Relay
- Inspect High-performance Relay
- Inspect Inverter / Dynamic Brake Assembly
- Inspect Logic Assembly
- Inspect High Performance Enabling Relay
- Inspect COMC
- Inspect Rail Gap Detector Assembly
- Cleaning
- Power Self Test

NYCT Maintenance Practices

- Corrective Maintenance
  - Corrective Maintenance is performed upon detection of a failure (either while the car is in service, during the daily pre-trip inspection or at the scheduled inspection interval).

Present Corrective Maintenance Practices

- Repair action is designed to return the subway car to a state of operational readiness as quickly as possible, without compromising safety.

- In the late 1980s, the technical specifications redefined car-borne maintenance philosophy, incorporating the concept of Line Replaceable Unit (LRU) and Lower Level Replaceable Unit (LLRU) into the design approach.

  - <u>Level 1 Operational Level Maintenance: Car-borne level</u>
    - LRU
      - Portable Test Equipment (PTE)

  - <u>Level 2 Intermediate Level Maintenance: Dedicated Repair Shops</u>
    - LLRU
      - Bench Test Equipment (BTE)

  - <u>Level 3 Intermediate Level Maintenance: Dedicated Repair Shops</u>
    - Sub- components
      - Bench Test Equipment (BTE)

Present Level 1 Corrective Maintenance: Car-borne LRU Isolation

Subway Car
Maintenance Shops

Portable Test Equipment (PTE)

FAULTY LRU

GOOD LRU

1. Upon detection of a failure in service (or during inspection), trouble-shooting is performed.
2. Defective LRU is identified and removed from the car.
3. Functional LRU is removed from inventory stock and installed on the vehicle.
4. Train placed back into service

Electronics Repair Shop
Pneumatics Shop
Electro-Mechanical Shop

Bench Test Equipment (BTE)

FAULTY LRU

GOOD LRU

1. **Faulty LRU is sent to a dedicated repair shop.**
2. **Repaired LRU is returned to inventory stock.**

Level 2 Corrective Maintenance: LRU Testing to LLRU Isolation

LRU

Bench Test Equipment

END OF PROGRAM.

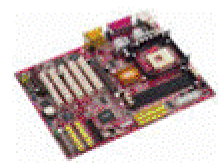
LRU IS GOOD.

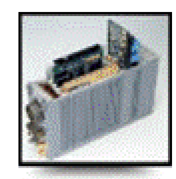
OR

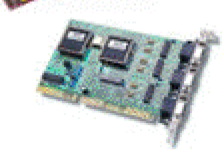
END OF PROGRAM

LRU IS FAULTY.

SUSPECTED PCBS:
1. PCB “A”
2. PCB “B”
3. PCB “C”



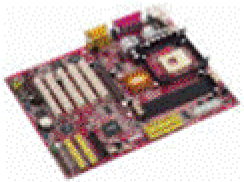


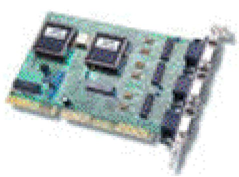


LLRU

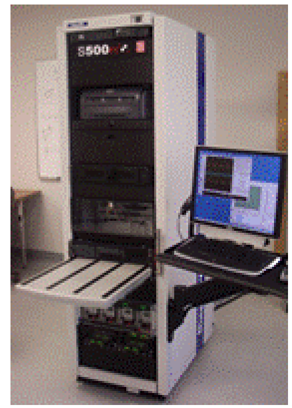
Level 3 Corrective Maintenance - LLRU testing to Component Isolation

LLRU





Test Equipment Platforms



END OF PROGRAM.

PCB IS GOOD.

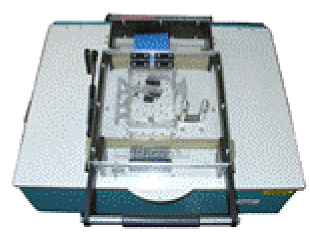
OR

END OF PROGRAM

PCB IS FAULTY.

SUSPECTED COMPONENTS:

1. IC1
2. IC2
3. IC3
4. C1
5. R1



Manual Fixtures

NYCT Maintenance Practices

Scheduled Maintenance System (SMS)

- Compliments the Scheduled Inspection program and is the cornerstone of NYCT's fleet maintenance program.

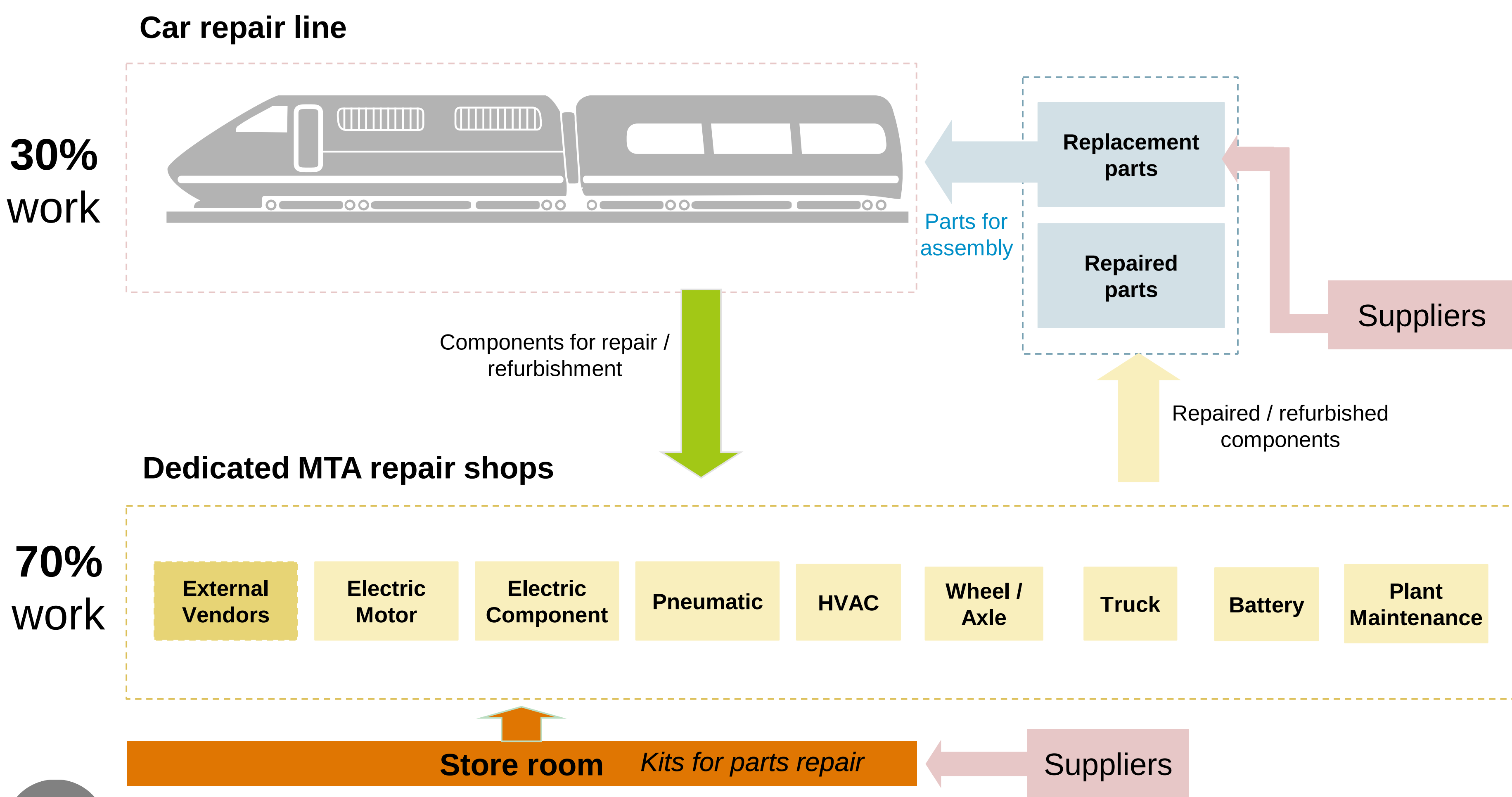
- SMS is a preventative maintenance program based on the planned replacement of key components and systems to sustain a state of good repair (SOGR) and optimize performance through the vehicle's lifecycle.

Present: Scheduled Maintenance System (SMS)

Three distinct SMS Overhaul (O/H) cycles, based upon anticipated breakdown date:

- 4 Year O/H - air brake operating unit valves, load sensor valve, cab emergency magnet valve, battery reconditioning
- 6 Year O/H – truck, brake valve, coupler/electric, HVAC, propulsion cards, magnet valves, Air Compressors
- 12 Year O/H – all 4 and 6 year work plus car body, draft gear, flooring, door operators/control, master controller, propulsion, electronic signs, auxiliary electric/electronic units

SMS Functional Breakdown



Present: Scheduled Maintenance System (SMS)

System	4 Year	6 Year	12 Year
Air Brake valves	X		X
Load sensor valves	X		X
Emergency Magnet Valve	X		X
Battery Conditioning	X		X
Truck Brake Valve		X	X
Electric Coupler		X	X
HVAC		X	X
Propulson Controls		X	X
Air Compressor		X	X
Car Body			X
Draft Gear			X
Flooring			X
Door Operators / Controls			X
Master Controller			X
Propulson System			X
Auxiliary Electric			X

Challenges: Scheduled Maintenance System (SMS)

- Existing Scheduled Maintenance Intervals and SMS Programs are based upon ridership history and current car technologies.
- Fleet Mileage is increasing faster than originally anticipated when SMS Program was derived.
- Increases in electronic systems impacting scope of work for inspections being performed at scheduled maintenance intervals

Where do we go from here ?

Condition-based Maintenance (CBM)

Future: Condition-Based Maintenance (CBM)

- CBM is based on using real-time data to monitor and determine the overall health of the system.
- CBM recommends a maintenance action based upon decisions from the information collected through condition monitoring.
- The CBM process can be divided into three steps:
  - Data Capture
  - Data Processing
  - Recommended Maintenance Action

.

Future: Condition-Based Maintenance (CBM)

- Data Capture

  On board data from subsystem health and diagnsotics is transmitted at key locations (terminal stations, layup locations, etc.) to a central work station

- Data Processing

  Data and analyzed to determine next course of action.

- Recommended Maintenance Action

  When an established "Impending Failure" go/no-go criteria has been reached, vehicle is sent to the maintenance shop after completion of scheduled service.

  - Level 1 actions (troubleshooting & repair)
    - Level 2 (LRU) and Level 3 (LLRU) maintenance remains unchanged.

Future: Condition-Based Maintenance (CBM)

- Types of systems that are candidates for CBM:

  - DOORS
    - Motor Current
    - Door opening / closing times

  - PROPULSION
    - Traction Motor Current
    - Vibration

  - BRAKING
    - Cylinder Pressure Status
    - Valve Status

  - HVAC
    - Inlet Air Temperature vs. Car Temperature
    - Inverter Status

Future: Level 1 Maintenance; Car-borne LRU Isolation with CBM

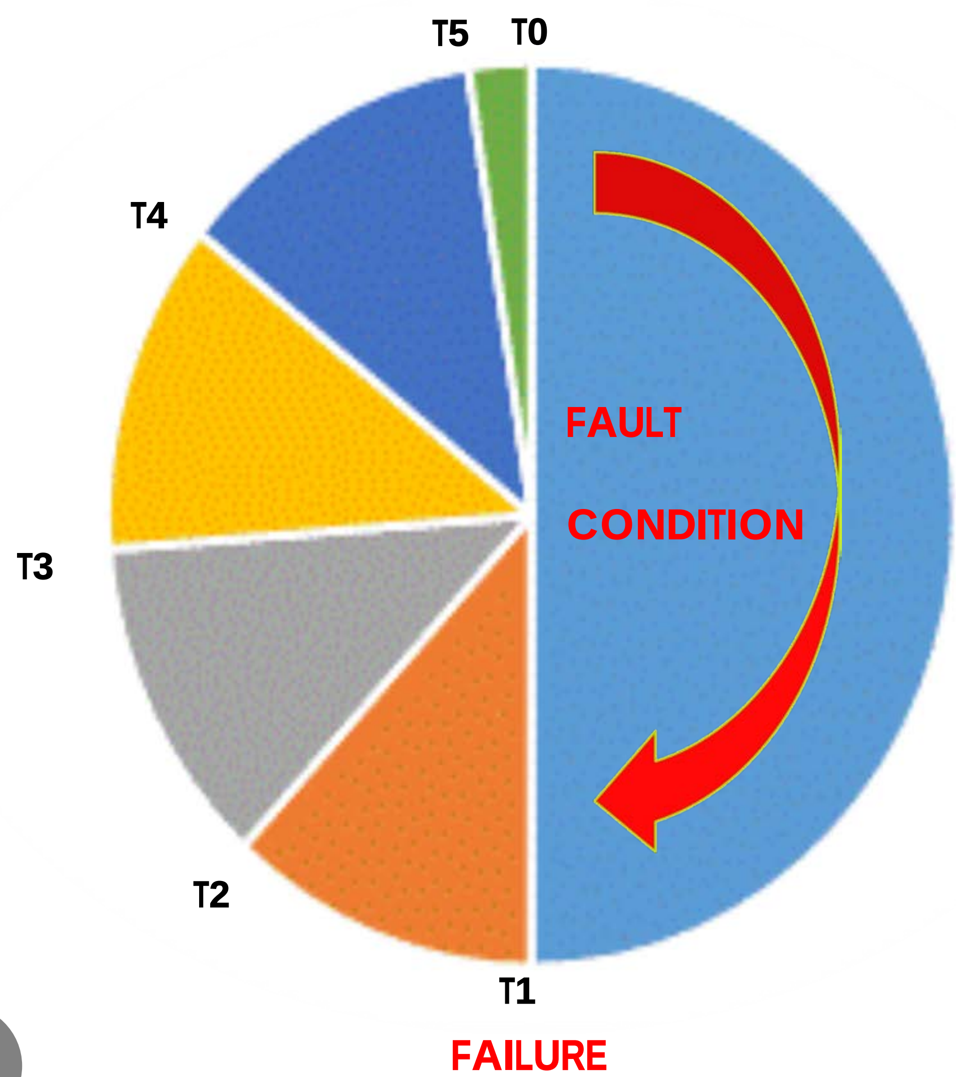
Subway Car in Terminal Station

1. **Real-time data transmitted to Car Maintenance Facility prior to failure.**
2. **CBM download identifies potential faulty LRU(s).**
3. **Maintenance action request to be performed post-service.**

1. **Spare LRUs removed from stock, awaiting train arrival into the shop.**

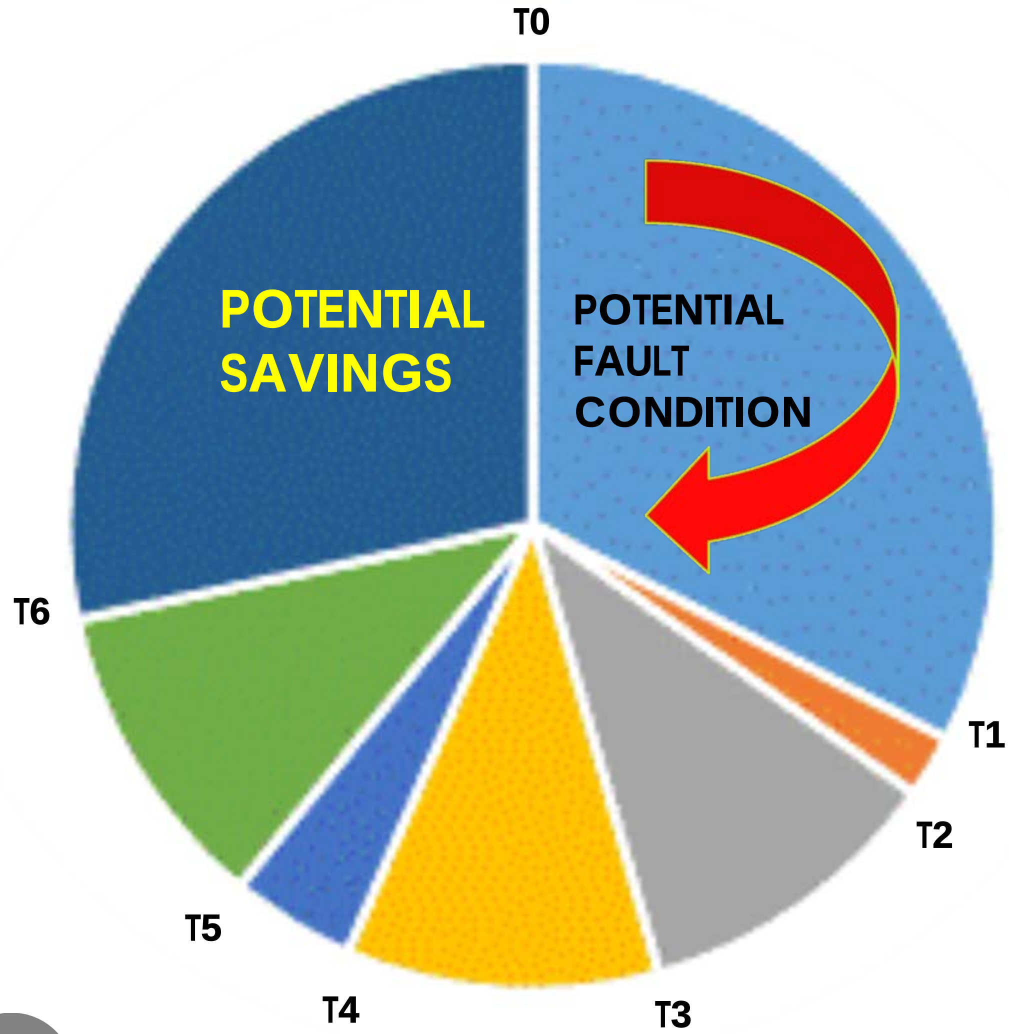
1. **After completing service, train is sent to maintenance shop to perform follow-up predictive maintenance actions.**
2. **Isolation and removal of LRUs that are identified as approaching "failure" condition.**
3. **Minimized turnaround time in trouble-shooting results in faster train availability.**

Present: Corrective Maintenance Timeline



T0 – T1:	DEVELOPMENT OF FAULT CONDITION
T1:	FAILURE OCCURS
T1-T2:	SERVICE DISRUPTION; TRAIN REMOVED FROM SERVICE & TRAVELS TO SHOP
T2-T3:	LEVEL 1 TROUBLE-SHOOTING
T3-T4:	SPARE PART(S) RETRIEVAL
T4-T5:	REPAIR ACTION: - REMOVE/REPLACE PART - TEST
T5 + :	TRAIN RETURNS TO SERVICE

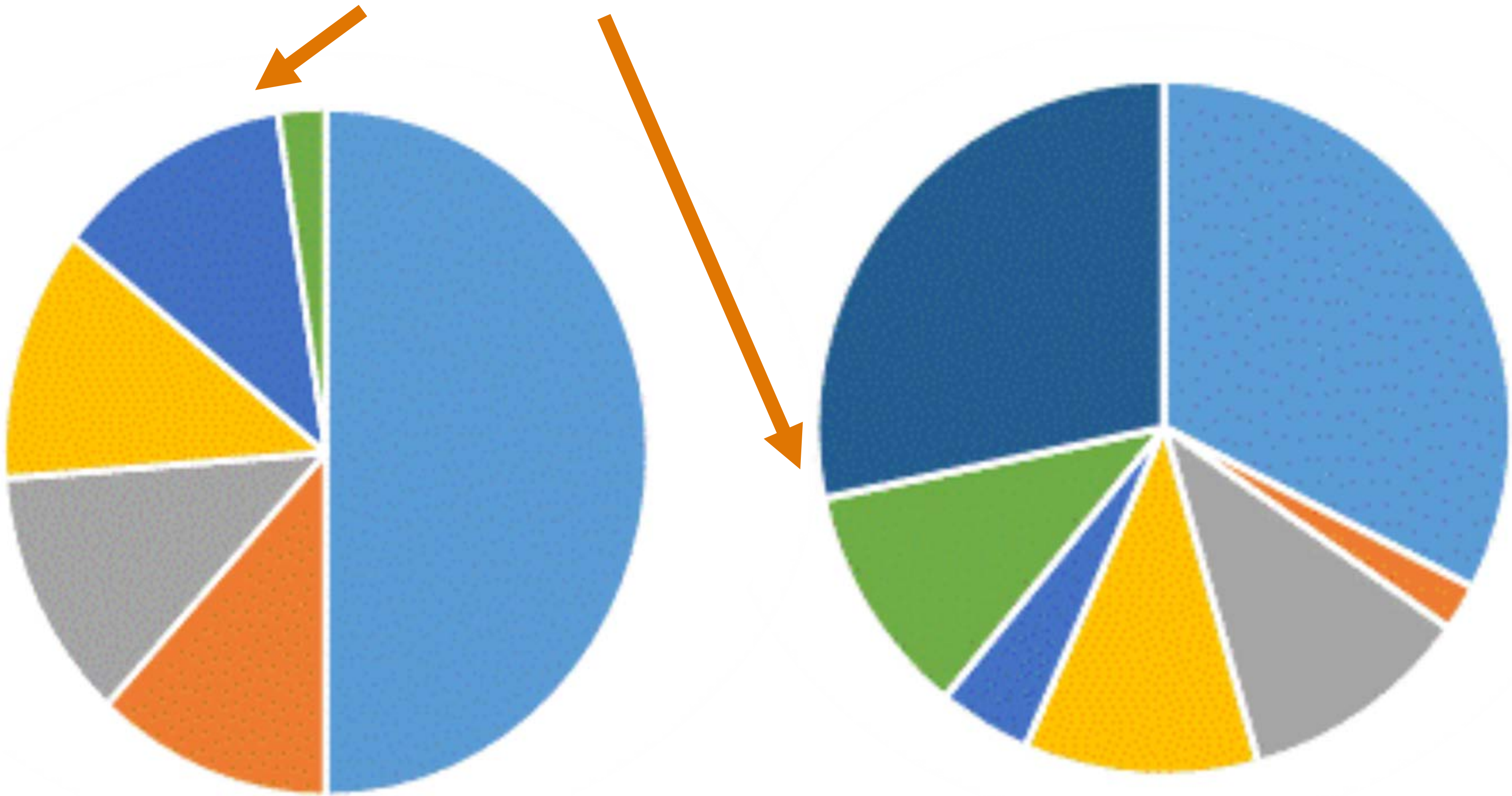
Future: Condition-Based Maintenance Timeline



T0 – T1:	DEVELOPMENT OF FAULT CONDITION
T1:	CBM DIAGNOSTICS TRANSFER
T1-T2:	TRAIN COMPLETES SERVICE
T2-T3:	DATA ASSESSMENT - SPARE PARTS RETRIEVED
T3-T4:	TRAIN TRAVELS TO SHOP
T4-T5:	TROUBLE-SHOOTING
T5-T6:	REPAIR ACTION - REMOVE/REPLACE PART - TEST
T6 + :	TRAIN RETURNS TO SERVICE
	SAVINGS ! ! !

Improved Vehicle Availability with CBM

TRAIN RETURNED TO SERVICE



PRESENT

FUTURE

Future: Condition-Based Maintenance (CBM)

- Advantages
  - Improved system reliability and overall performance
  - Decreased maintenance costs
  - Increased inspection intervals
  - Reduced number of unplanned failures and maintenance operations
  - Reduction of human interaction with carborne system components
  - Increased asset life
  - Increased turnaround vehicle availability
  - Reduced overall maintenance costs
  - Increased efficiency of maintenance management
  - Potential extension of the subsystem overhaul intervals
  - Potential in redefined scheduled overhaul scope of work

Future: Condition-Based Maintenance (CBM)

- Disadvantages:
  - Increase initial investment for monitoring equipment
  - Requires investment for additional training of personnel
  - Increased additional maintenance due to increase in hardware
  - Increased installation costs
  - GO/NOGO critical level and monitoring intervals (sampling rate) often established in a cost prohibitive fashion.

Future: Condition-Based Maintenance (CBM)

- Challenges
  - Collection of adequate amount of "near real-time" data in order to establish optimal "GO/NO-GO" threshold
  - Streamlined analysis of collected data and update of carborne monitoring software
  - Quality of sensor data
  - Cyber-security
  - Lack of standard of data communication
  - Assessment of component failure modes
  - Statistics for determining failure root cause
  - Accuracy of historical data.

Future: Scheduled Maintenance Inspections w/CBM

INSPECTION FUNCTION	INSPECTION SCHEDULE			
	SM1	SM2	SM3	SM4
PROPULSION				
CURRENT COLLECTORS	R	R	H	R
TRACTION MOTOR	R	R	R	H
BATTERY AND BATTERY BOX	R	R	R	H
CONTROL ELECTRONICS	R	R	H	R
TRACTION INVERTER	R	R	R	H
MASTER CONTROLLER	R	R	H	R
MISC PROPULSION	R	R	R	H
UNDER CAR				
TRIP VALVES	R	R	H	R
DRAIN VALVES, TANKS	R	R	H	R
CUTOUT VALVES, HOSES, PIPES	R	R	H	R
COUPLER SYSTEM	R	R	H	R
AIR BRAKE SYSTEM	R	R	H	R
AIR SUPPLY UNIT	R	R	H	R
TRUCK BRAKE EQUIP	R	R	H	R
TRUCKS & WHEELS	R	R	H	R
MISC UNDER CAR	R	R	R	R
CAR BODY				
HVAC	H	R	H	R
DOOR CONTROL	R	H	R	R
CAR BODY	R	R	R	R
PANELS	R	R	R	H
LIGHTING SYSTEM	R	H	R	R
COMMUNICATION SYSTEM	R	R	R	H
UNDER CAR CLEANING	H	R	R	R
MISC CAR BODY	R	R	H	R
MONITORING & DIAGNOSTICS				
MDS SYSTEM	R	R	H	R
CBTC	R	R	R	H

- **INSPECTION CYCLES MAY HAVE THE OPPORTUNITY TO BE LENGTHENED**
  - **72 days → 90 days ?**
- **INSPECTION STEPS COULD BE STREAMLINED OR ALTERNATED BETWEEN CYCLES**

Future: Scheduled Maintenance System with CBM

- With the ability to perform condition-based maintenance (CBM) at the maintenance shop level, the next generation SMS Overhaul cycle will be driven by the carborne system that possesses the weakest link (shortest cycle).
  - Time interval may remain the same or potentially increase
  - Scope of Work should be reduced as a result of CBM scheme

Future: Scheduled Maintenance System with CBM

Current

System	4 Year	6 Year	12 Year
Air Brake valves	X		X
Load sensor valves	X		X
Emergency Magnet Valve	X		X
Battery Conditioning	X		X
Truck Brake Valve		X	X
Electric Coupler		X	X
HVAC		X	X
Propulson Controls		X	X
Air Compressor		X	X
Car Body			X
Draft Gear			X
Flooring			X
Door Operators / Controls			X
Master Controller			X
Propulson System			X
Auxiliary Electric			X

Future

System	4 Year	6 Year	12 Year
Air Brake valves		X	X
Load sensor valves		X	X
Emergency Magnet Valve		X	X
Battery Conditioning		X	X
Truck Brake Valve		X	X
Electric Coupler		X	X
HVAC			X
Propulson Controls			X
Air Compressor			X
Car Body			X
Draft Gear			X
Flooring			X
Door Operators / Controls			X
Master Controller			X
Propulson System			X
Auxiliary Electric			X

NYCT CBM Efforts Under Way

Many of the condition-monitoring systems for railway vehicles are focused on the wheel and truck interfaces as these subsystems have the largest impact on the performance and maintenance costs.

- **R188 Fleet: # 7 Line**
  - Wheel Wear Wireless Sensors
  - Traction Motor Vibration Sensors via Energy Harvesters

NYCT CBM Efforts Under Way

- **R211 New Fleet Procurement: Maintenance & Diagnostic System Status**
  - Propulsion
  - Braking
  - Doors
  - HVAC

NYCT CBM Efforts Under Discussion

- Car Borne Monitoring & Diagnostics Interface with Wayside CBTC
  - R188 Fleet MDS Status (CBTC Vendor: Thales)
  - R160 Fleet MDS Status (CBTC Vendor: Siemens)

- R142 Fleet Enhancements: MDS Car Status using VPN Interface
  - Doors
  - HVAC
  - Propulsion / Braking

Examples of Suppliers Offering CBM Solutions

- **Rail / Signals**
  - Alstom - HealthHub
  - Bombardier – INTERFFLO & CITYFLO
  - Knorr Bremse – Intelligent Condition Oriented Maintenance (iCOM)
  - CAF – LeadMind Digital Platform
  - Siemens – Railigent
- **Bus**
  - Allied - SMARTCBM
  - Samasara - Telematics Fleet Management Solution
  - Trapeze – Intelligent Condition Oriented Maintenance (iCOM);Rail
- **General Designers for Corrective / Predictive Maintenance**
  - PERPETUUM
  - TRAPEZE
  - GEOTAB
  - DEEPVIEW

Thank you.