Designing Train Mounted Friction Control for Global Transit Systems: The Delhi Metro Experience

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Overview

Part 1:

Solid Stick Friction Control Systems

- Products
- Typical Installations
- Performance
- Designing Solid Stick Systems

Part 2:

Experience with Solid Stick Lubrication at DMRC

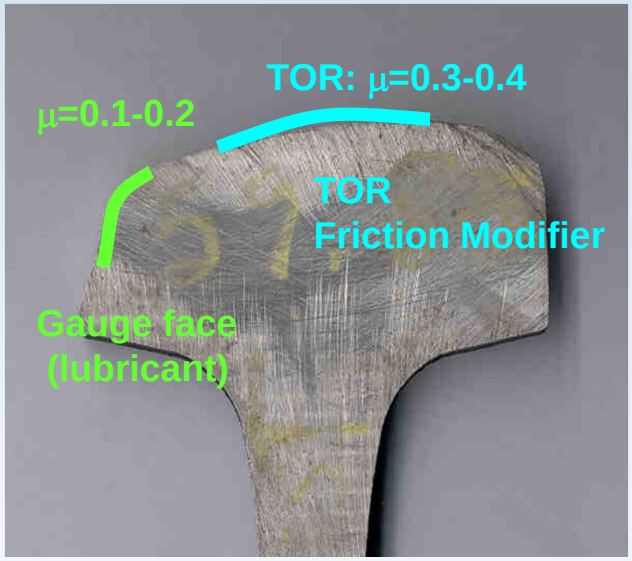
- Network
- Solid Stick Flange Lubrication Deployment
- Performance

Solid Stick Products

Friction Management

Recommended Friction Targets

Low Rail



High Rail

- Gauge face lubrication and TOR friction control operate in tandem to reduce rail wear – one does not take the place of the other

Solid Stick Products

Solid Stick Lubricant (SSL)

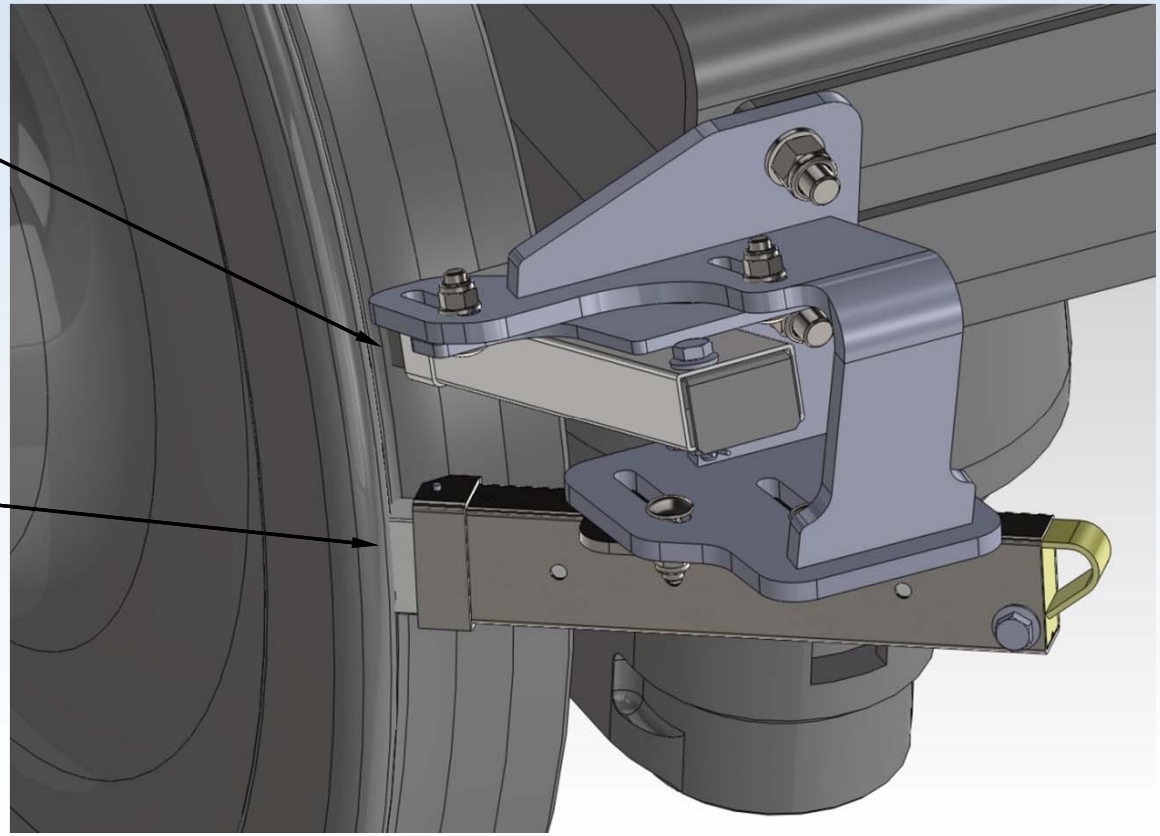
Solid Stick Friction Modifier (SSFM)

SSFM

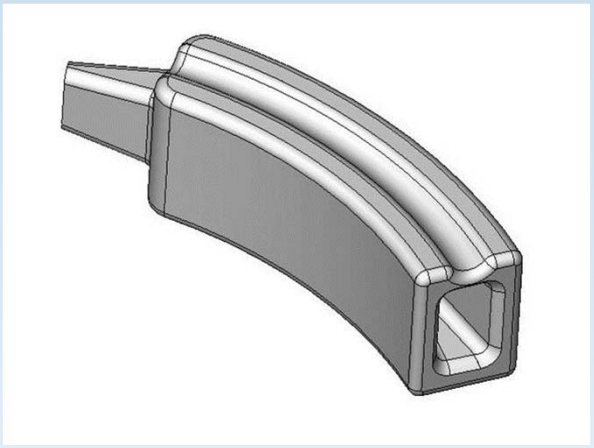
- Tread Wear
- Corrugations

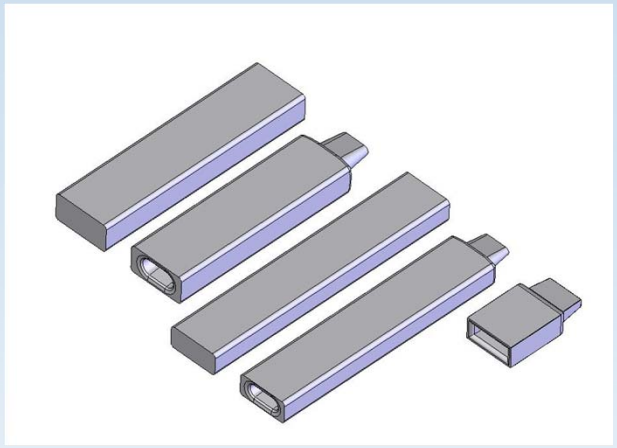
SSL

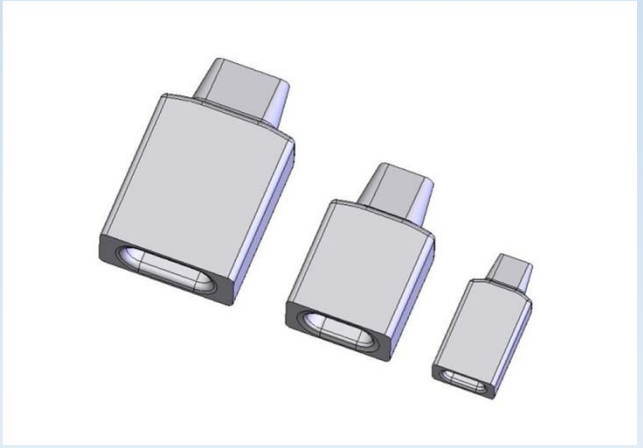
- Flange wear
- Wheel Climb

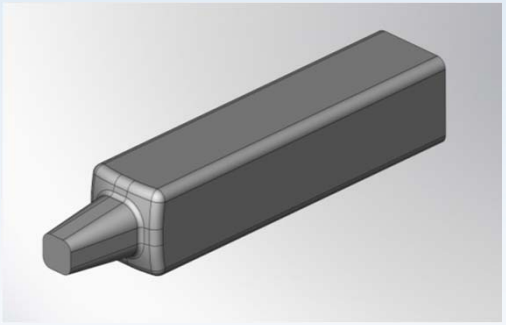


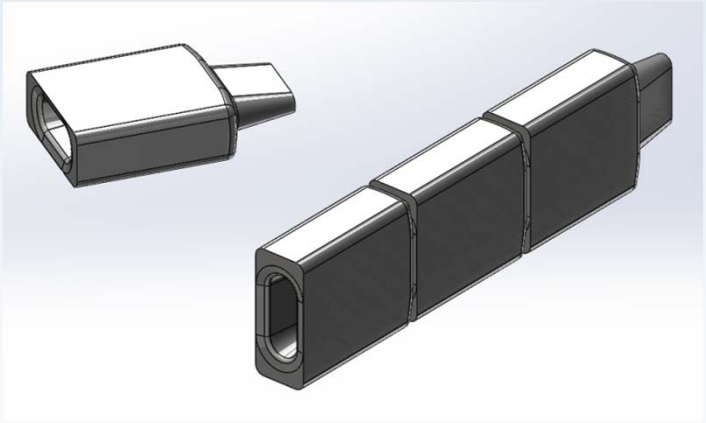
SSL Properties





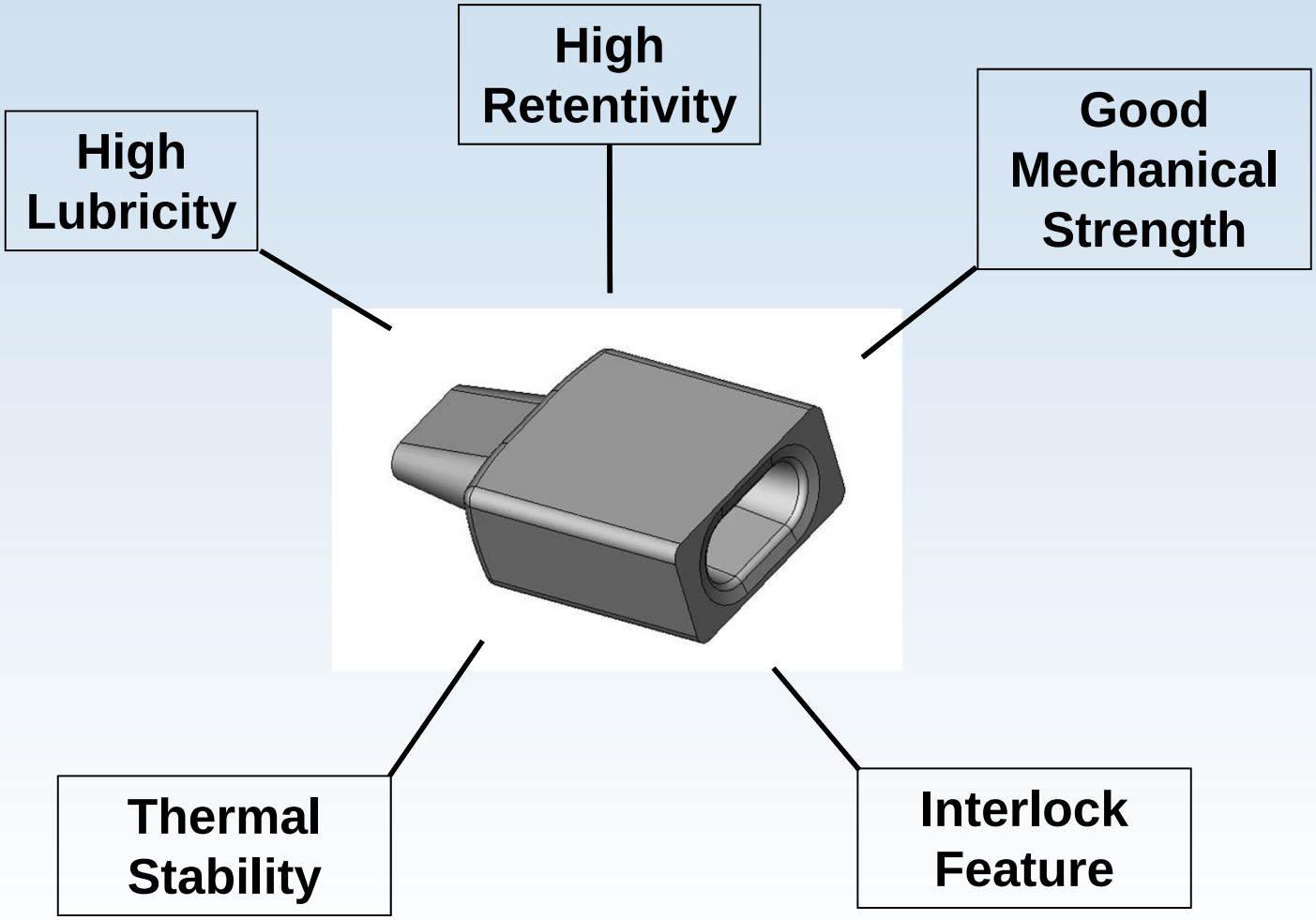






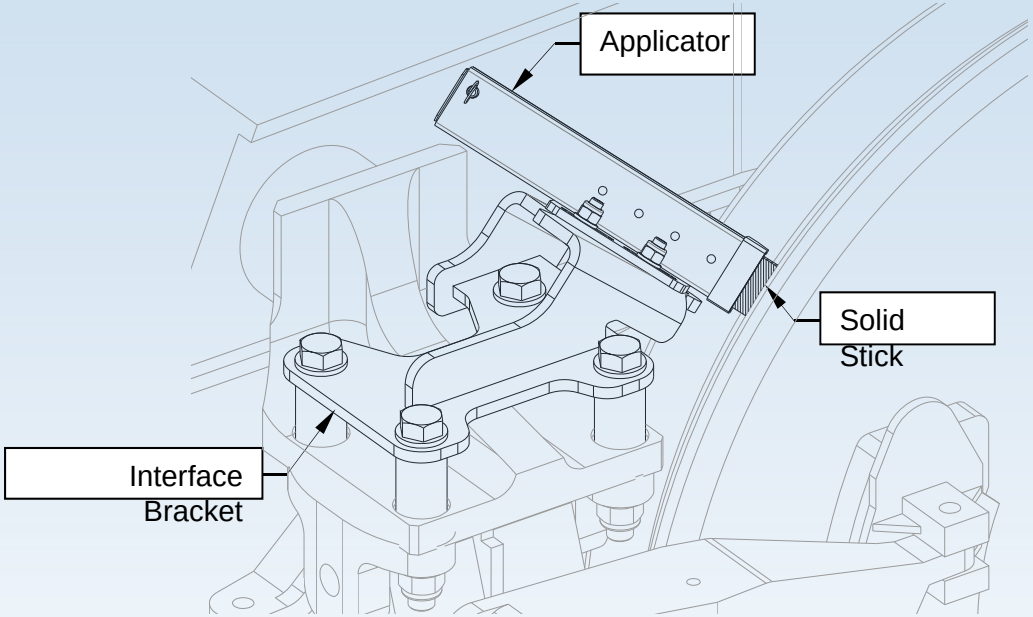
- Sticks come in many shapes and sizes
- Interlock feature

SSL Key Properties



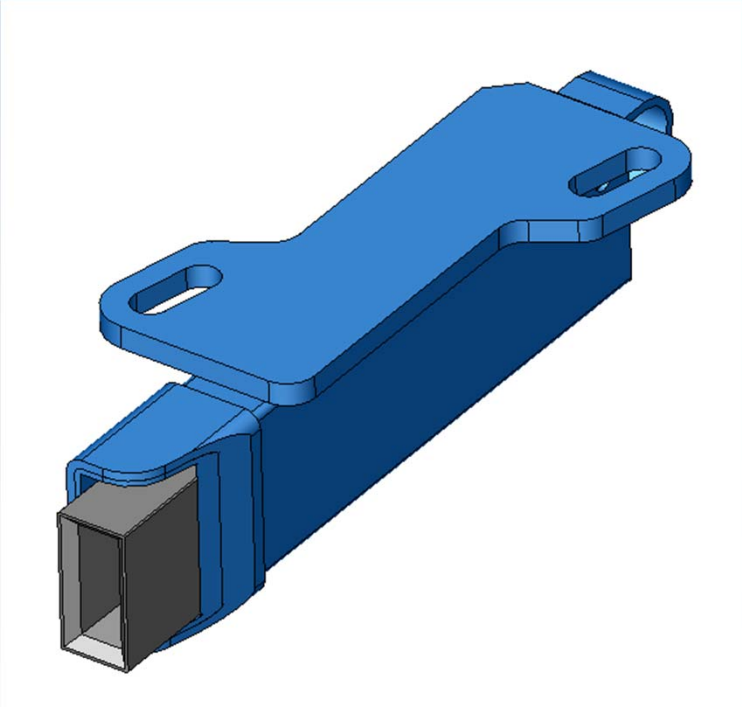
Typical Solid Stick Installations

SS Installations



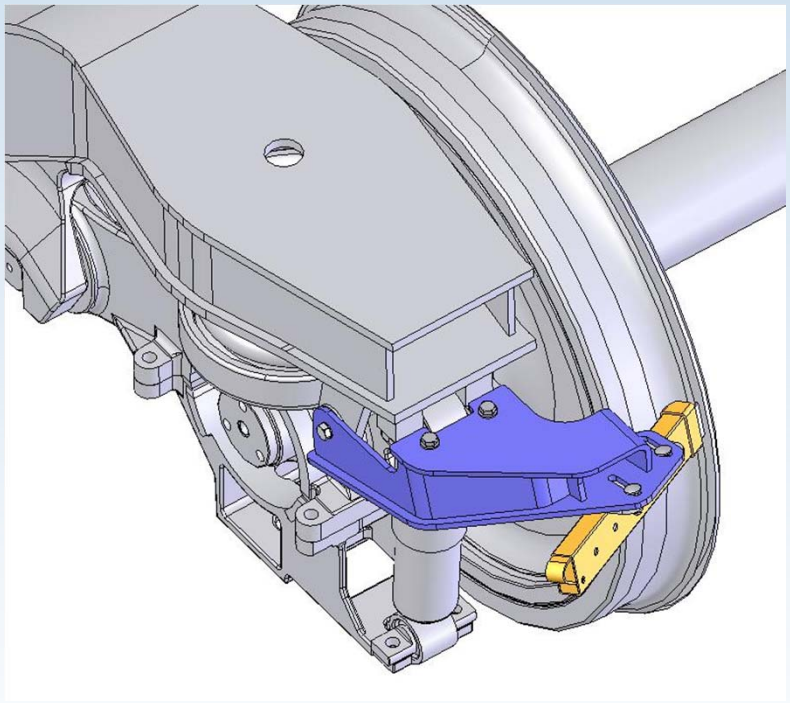
- Stick is applied continuously to the wheel by a constant force spring.
- No electrical or pneumatic connections required.
- No active control system required.

Typical SS Installations



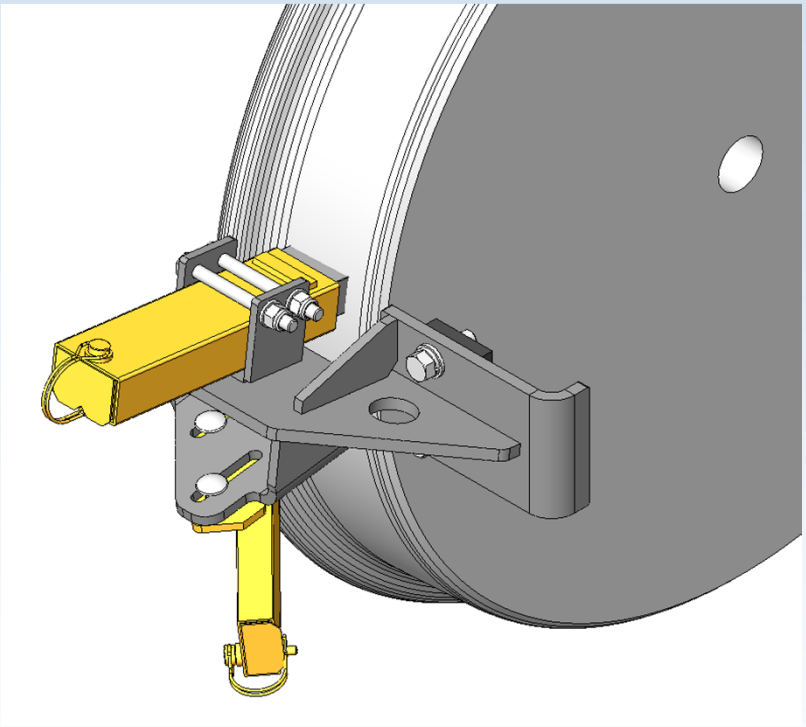
High Speed Train

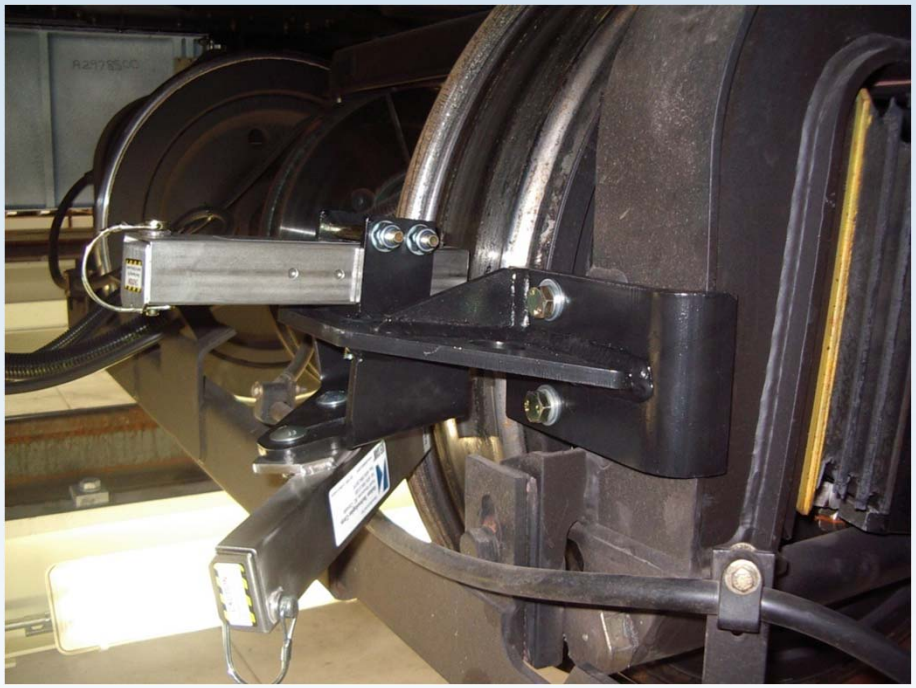
Typical SS Installations



Metro System

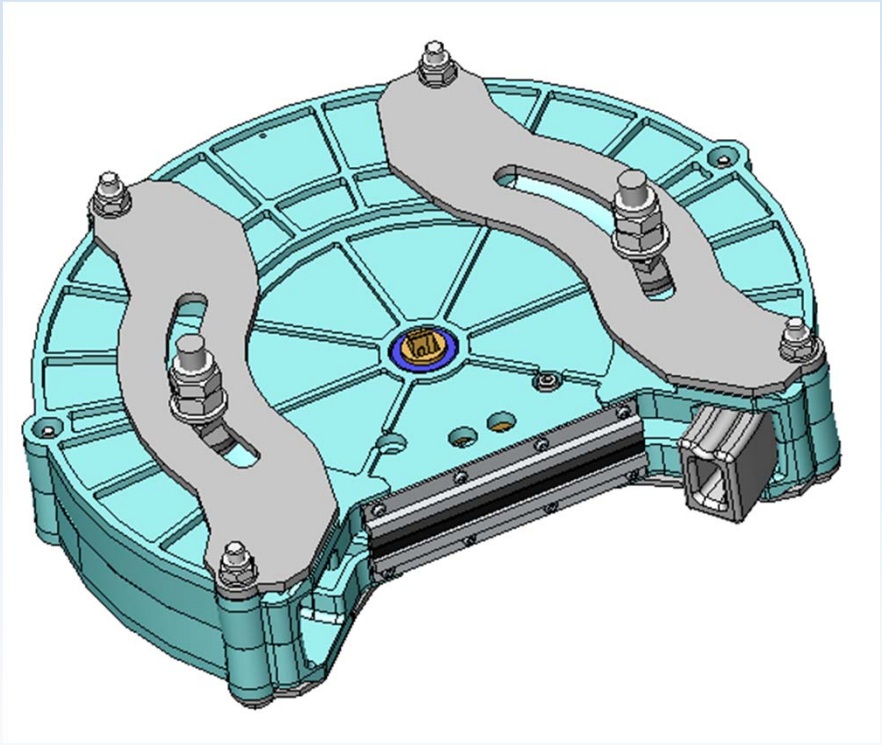
Typical SS Installations



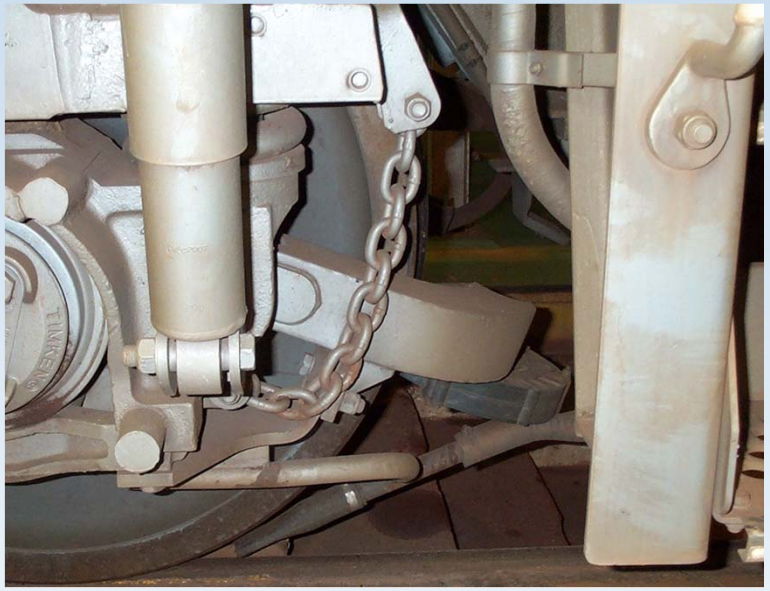


LRV System

Typical SS Installations

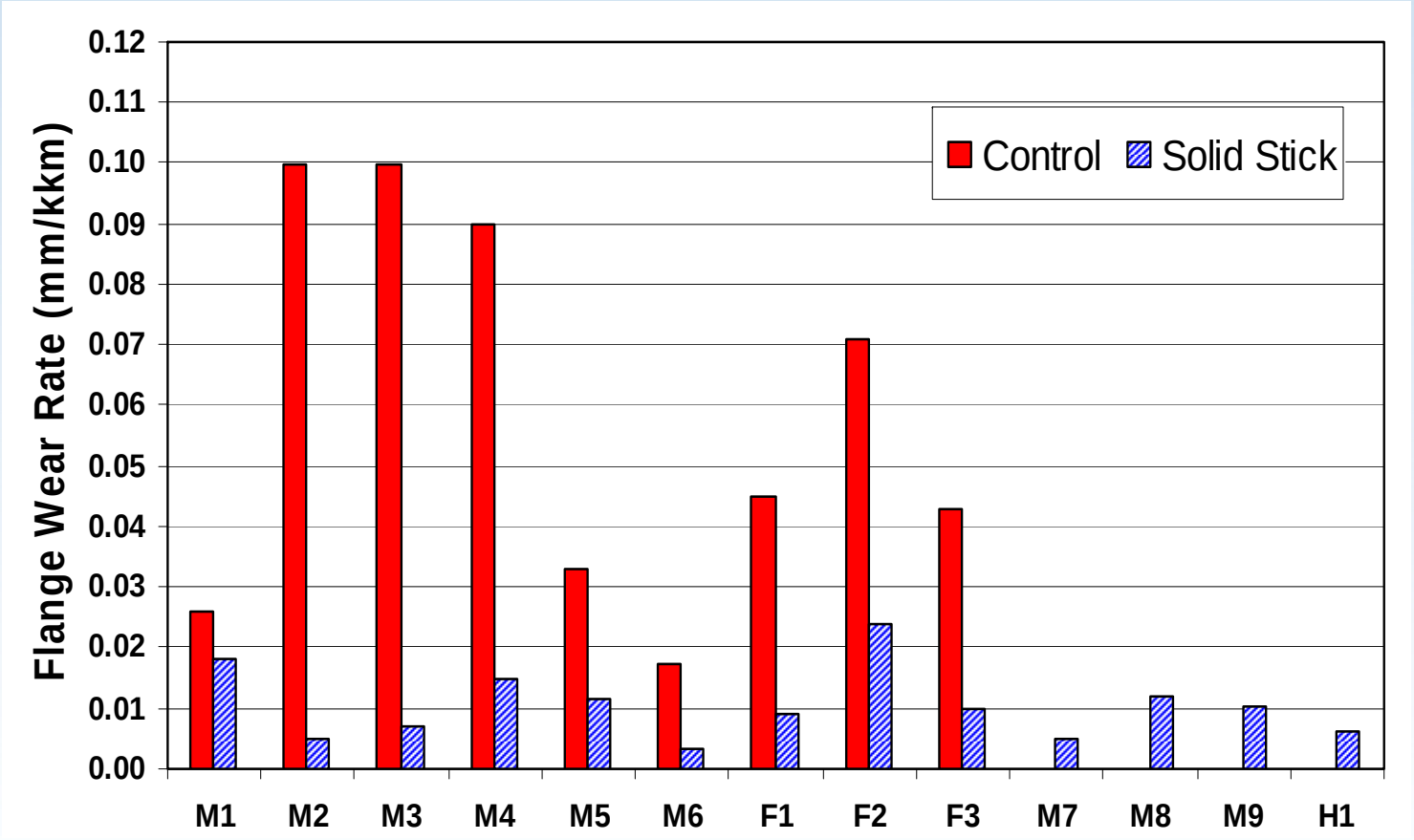


Circular Applicator on Freight Locomotives



Performance

SSL Flange Wear Rate Control



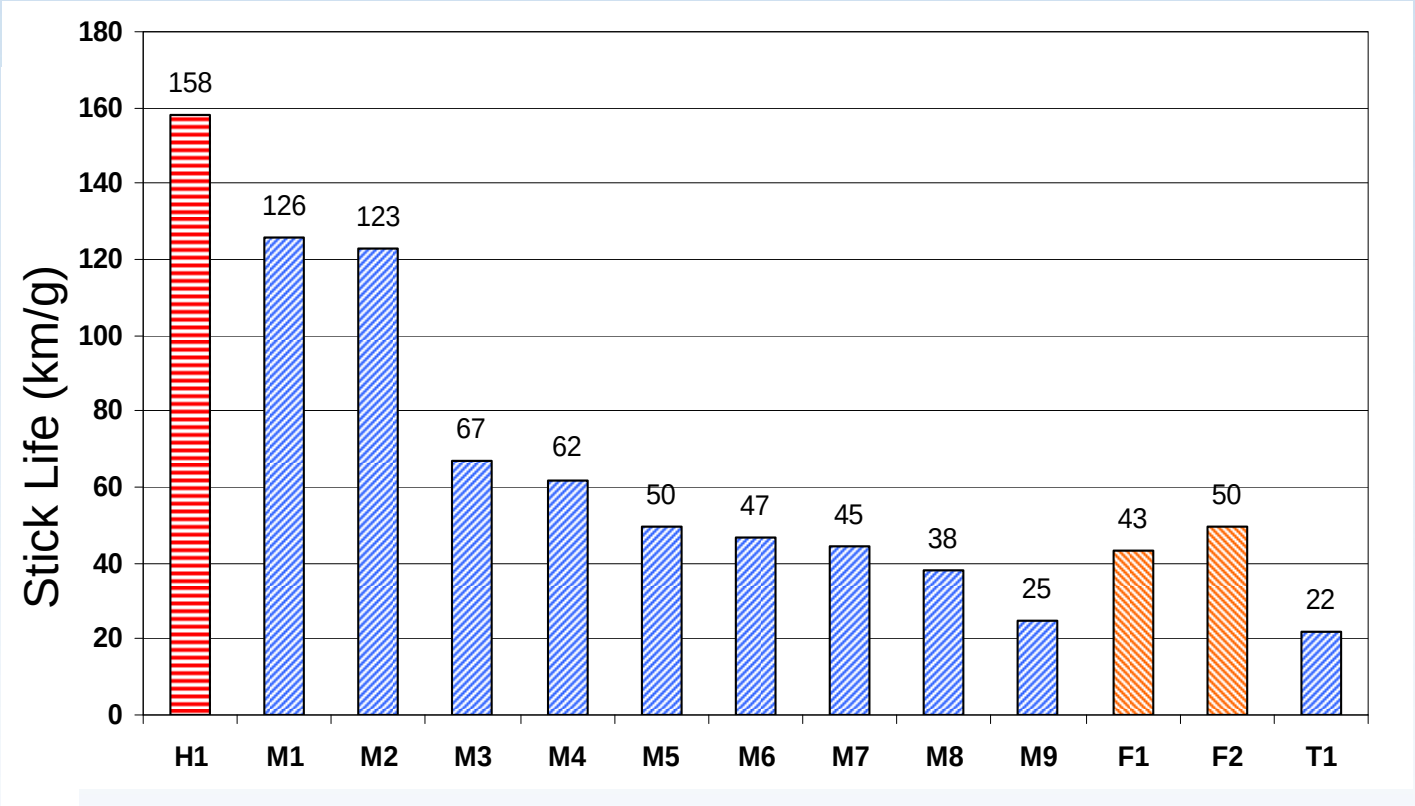
Flange Wear Rates With Solid Stick Lubrication: M = Metros, F = Freight, H = High Speed Trains

SSL Flange Wear Rate Control

	Wear Rate (mm/kkm) (Trials with Control Vehicles)		Wear Rate (mm/kkm) (Trials without Controls)
	Metros	Freight	Metros/High Speed Trains
Control Vehicles	0.017 – 0.100	0.043 – 0.071	N/A
Test Vehicles	0.004 – 0.018	0.009 – 0.024	0.005 – 0.012

- Typical Flange Wear Target: 0.01 – 0.02 mm/kkm (0.0006 – 0.0012 inches/1000 miles)

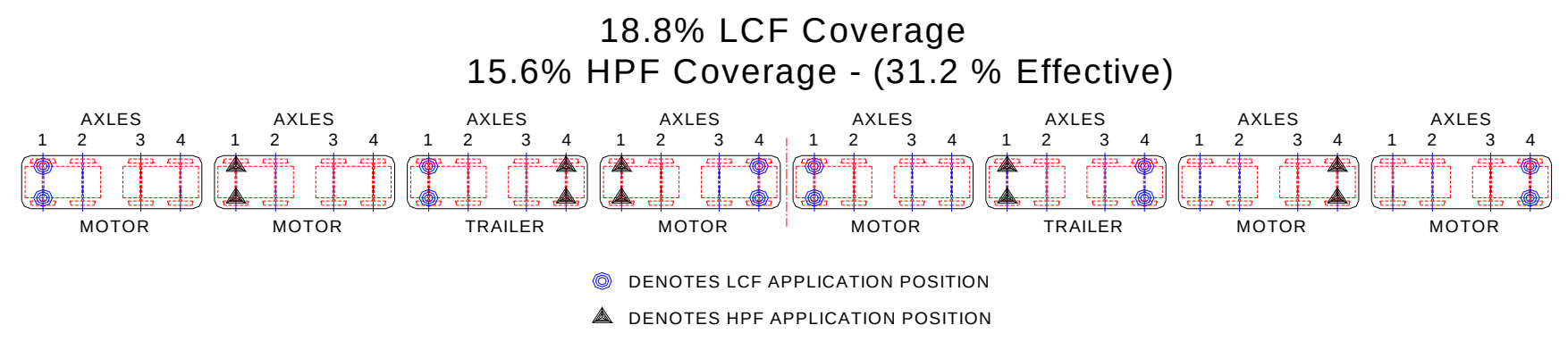
SSL Stick Life Varies by System Type



Specific Consumption Rates: M = Metros, F = Freight, T = Trams, H = High Speed Trains

- Typical Applicator: 20 – 34 kkm (12k – 21k miles)

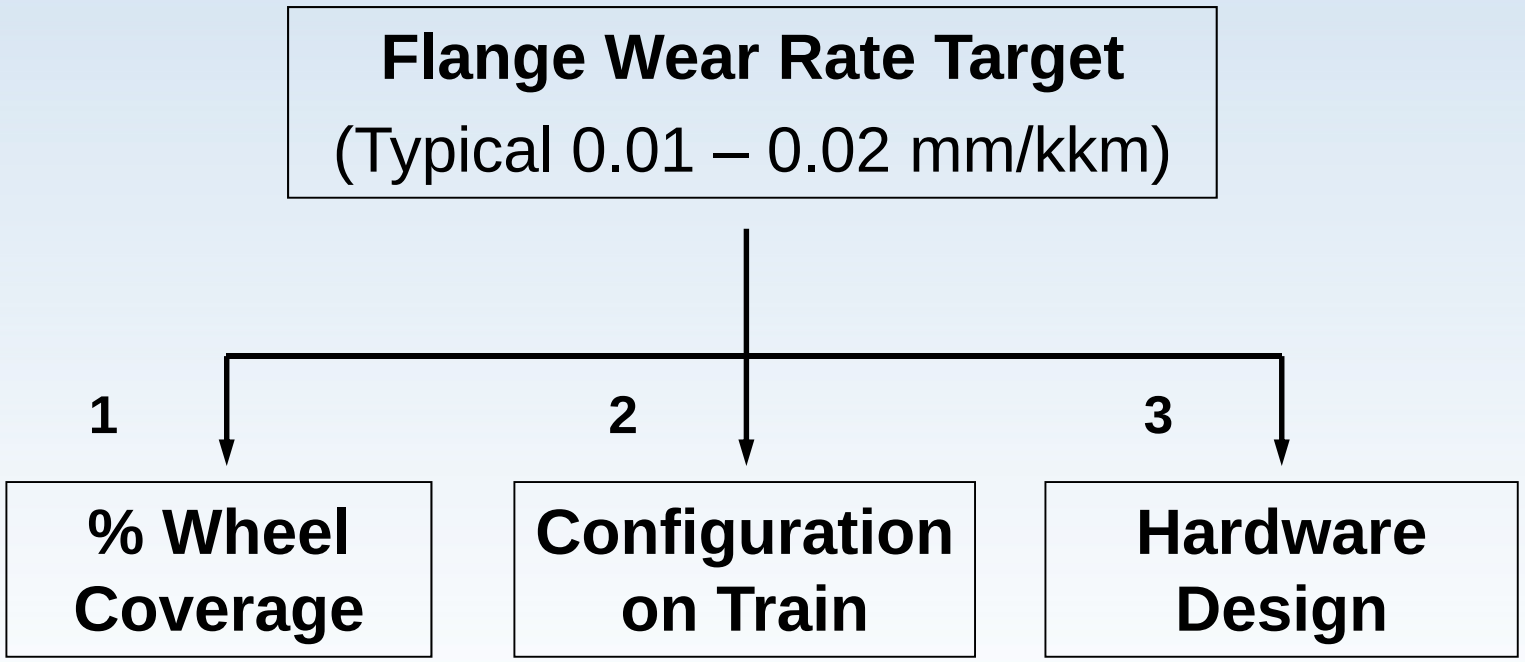
SSFM – Corrugation Growth Reduction



- Noise mitigation through reduced corrugation growth
- Extended grinding interval from 3-4 months to 6-9 months

Designing a SSL System

Designing a SSL System



Designing a SSL System
% Coverage

Designing a SSL System

- Protection of multiple wheels with application to only a proportion of the wheels.
- LCF wheel coverage ranges from 8% and up. Typical transit value is 25 - 33%, but lower values can be effective…depends on system characteristics.
- Main factors:
  - Track curvature
  - Open/closed system
  - Environmental conditions

Designing a SSL System

% Wheel Coverage Based on Flange Wear Index (FWI)

- High level wear model based solely on track curvature
- Index based on track wear data and Vampire Vehicle Dynamic simulations
- Curve radius
- Curve, spiral & tangent distances are tracked
- Separates LH & RH curves

Designing a SSL System

% Wheel Coverage Based on Flange Wear Index (FWI)

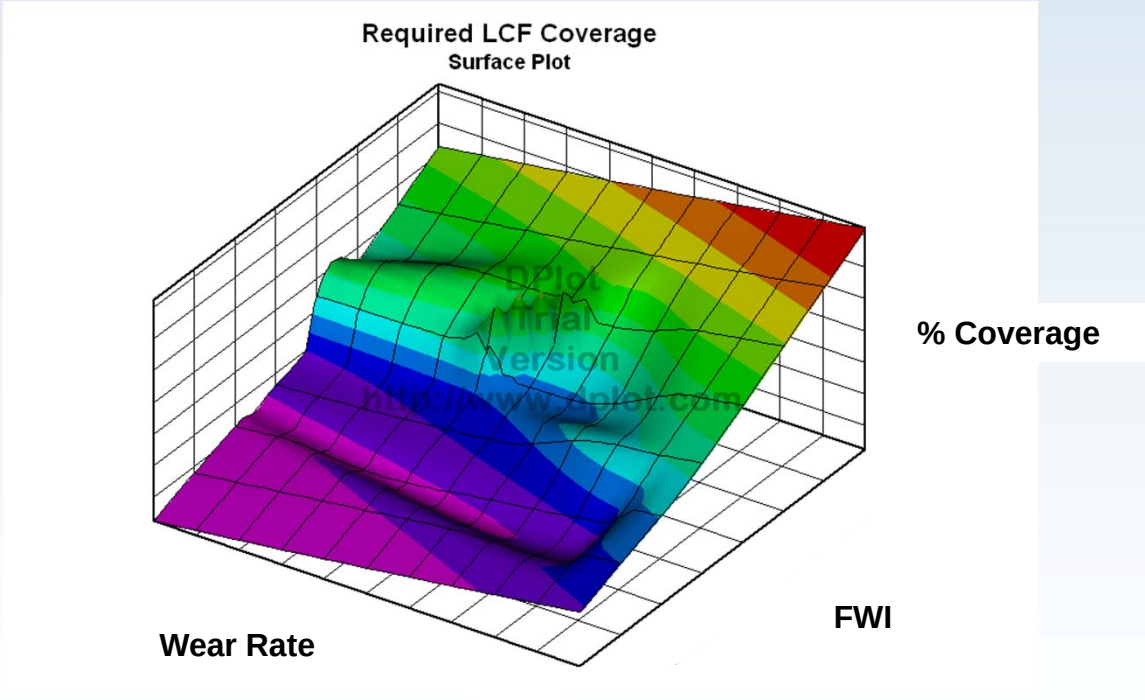
System	No. of Curves				FWI
	0 – 300 m	301 – 500 m	501 – 1000 m	≥ 1001 m	
A	1	1	24	25	0.22
B	1	17	29	8	0.35
C	5	12	4	7	2.04
D	25	24	38	28	3.16

A Comparison of Flange Wear Indexes

Designing a SSL System

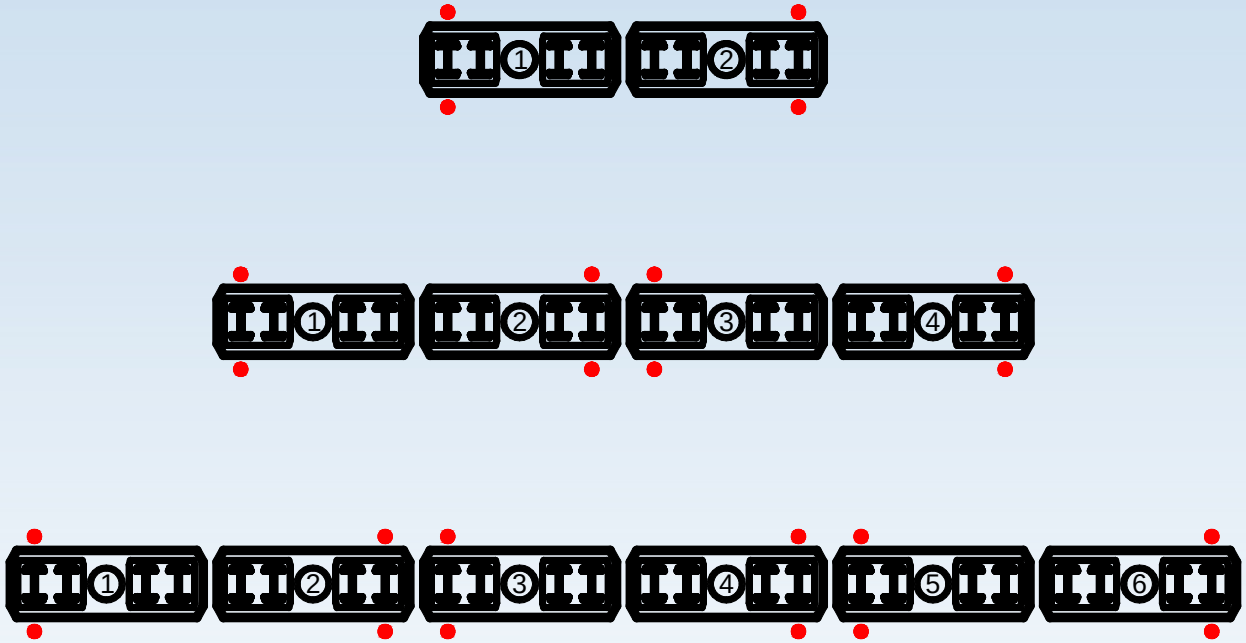
% Wheel Coverage Based on Flange Wear Index (FWI)

- Integrated FWI with SSL trial information (wear rate & coverage) to get relationship between the 3 variables



Designing a SSL System Configuration

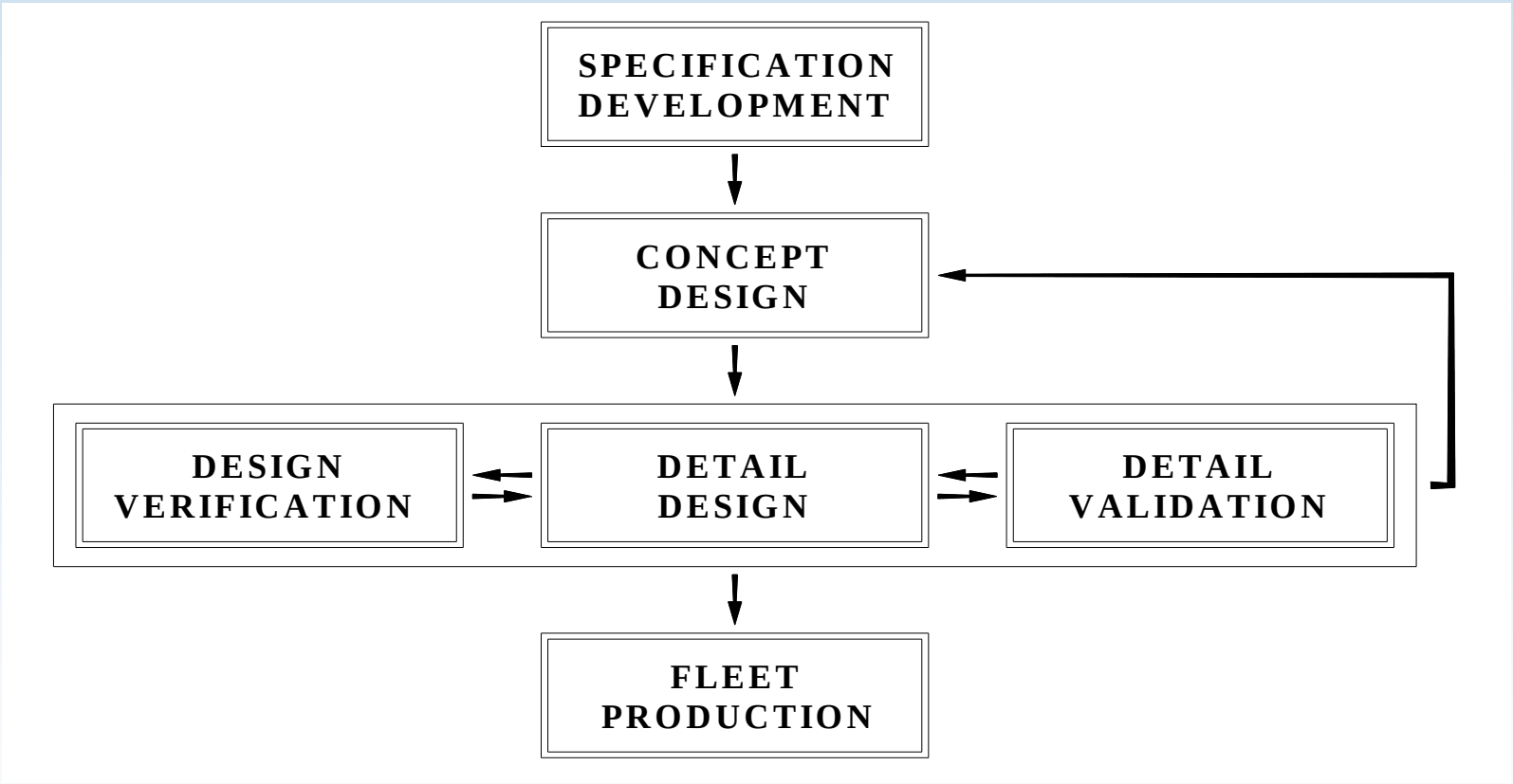
SSL – Ideal Configurations for 25% Coverage



- Space constraints
- Mounting location availability
- Distribute the applicators strategically

Designing a SSL System Hardware Design

Solid Stick Hardware Design



Typical SS Hardware Design Process

SS Hardware Specifications

Loads – Vibration/Shock

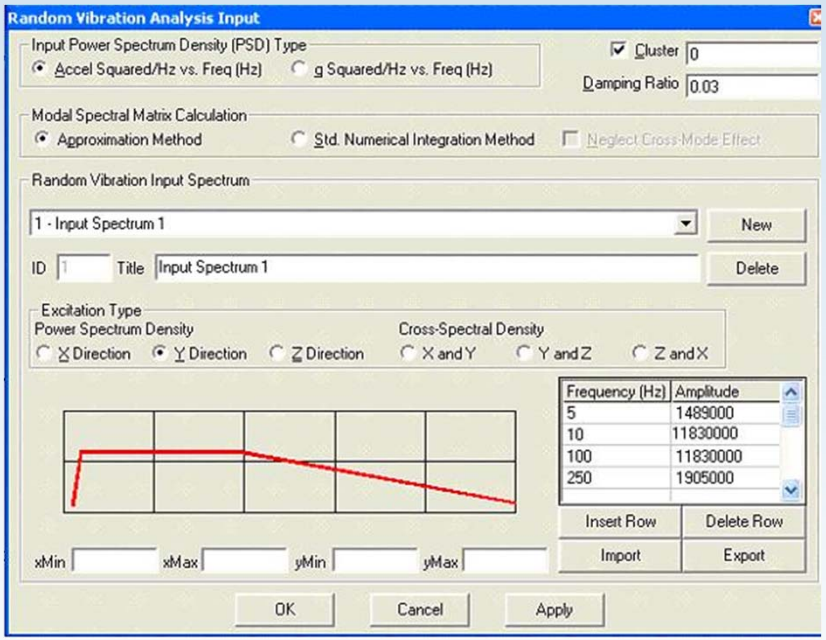
- IEC 61373
- GM/RT 2100
- BS EN 13749
- RIA 20
- Train OEM Specifications

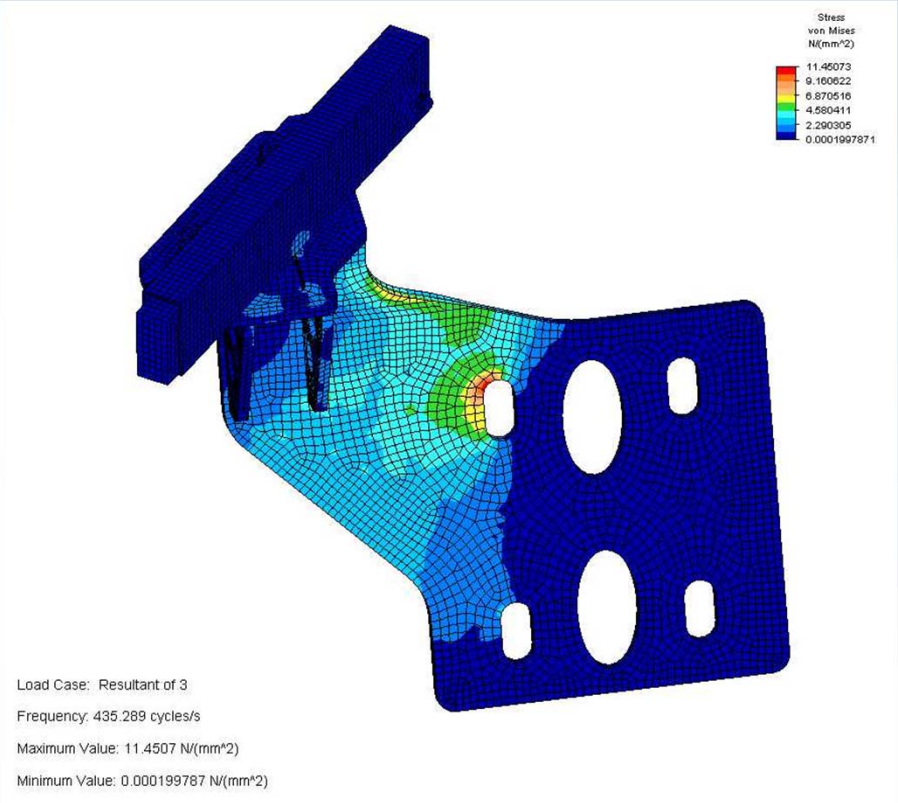
Fatigue

- BS 7608
- BS EN 1993 (Eurocode 3)

Design Verification

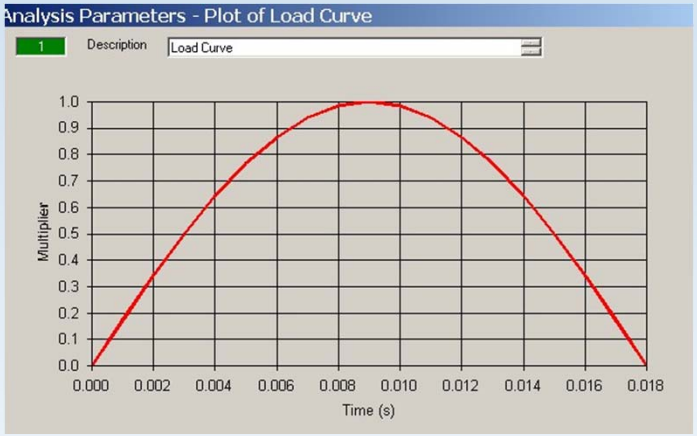
FEA Analysis – Random Vibrations

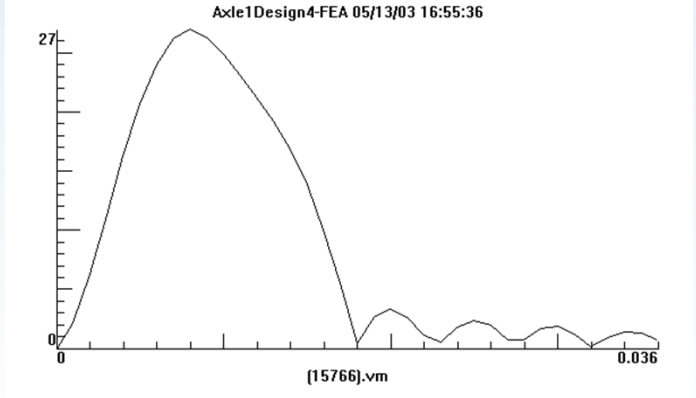


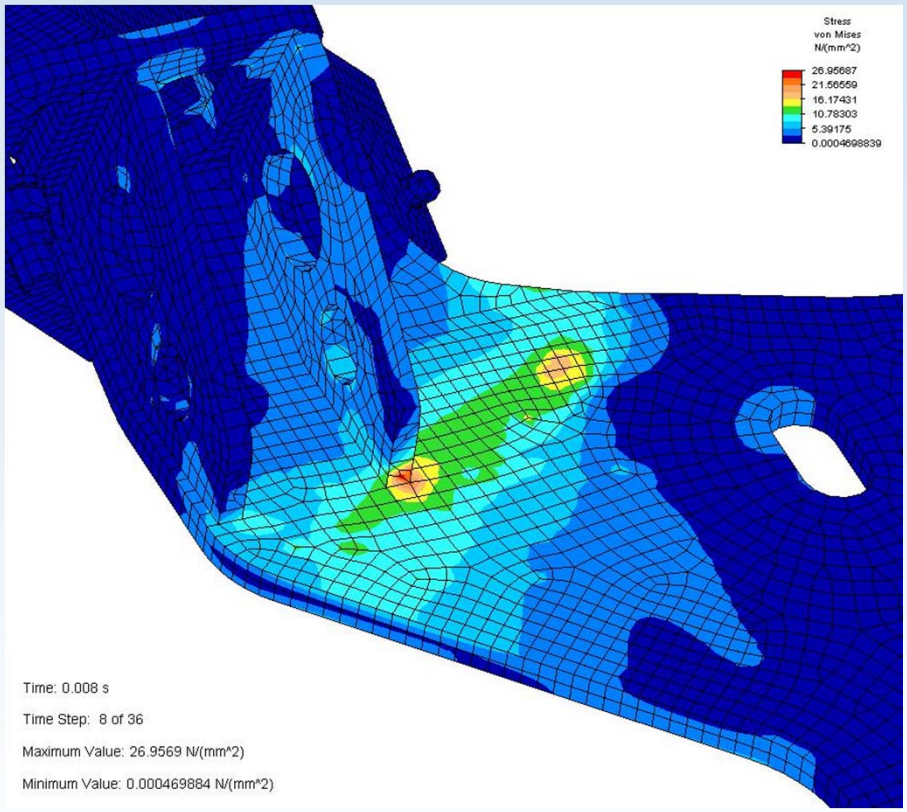


Design Verification

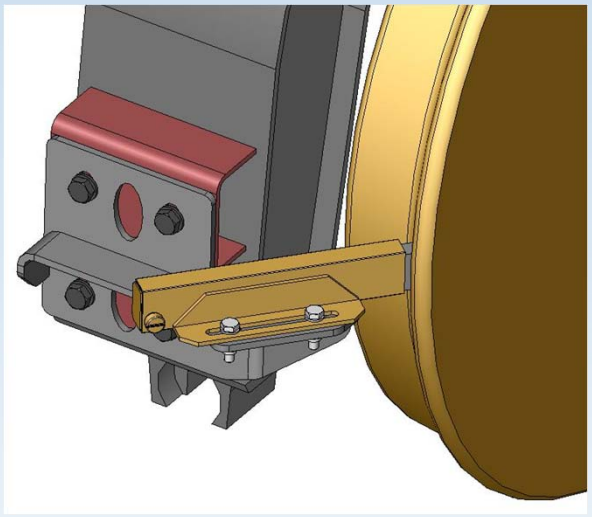
FEA Analysis – Shock

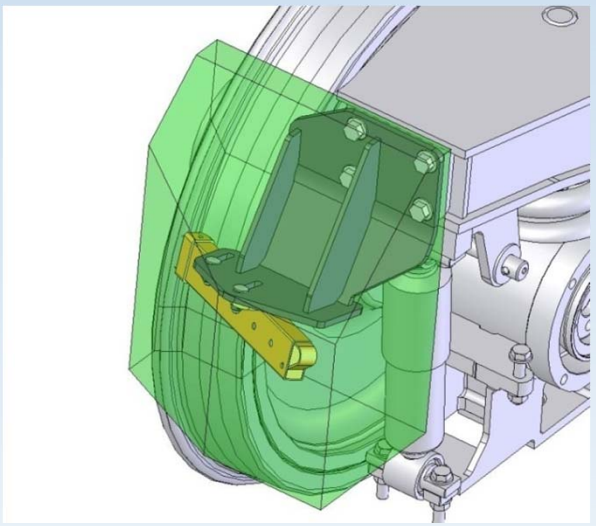


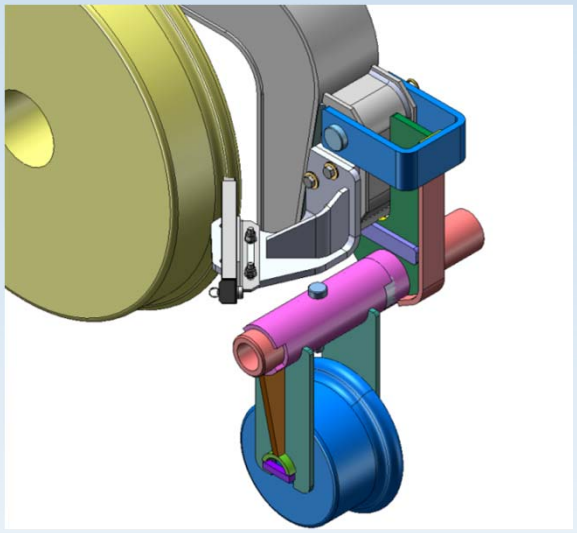


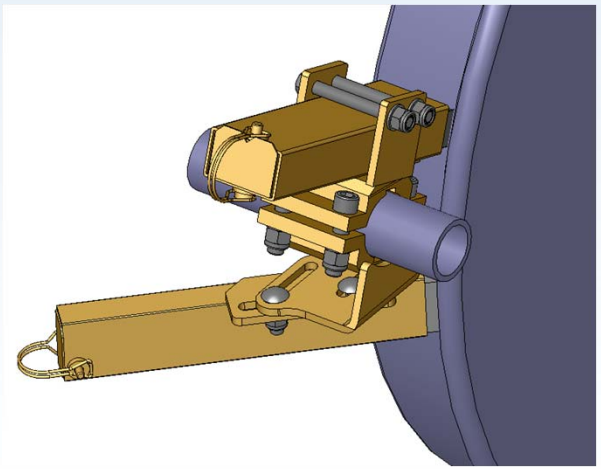


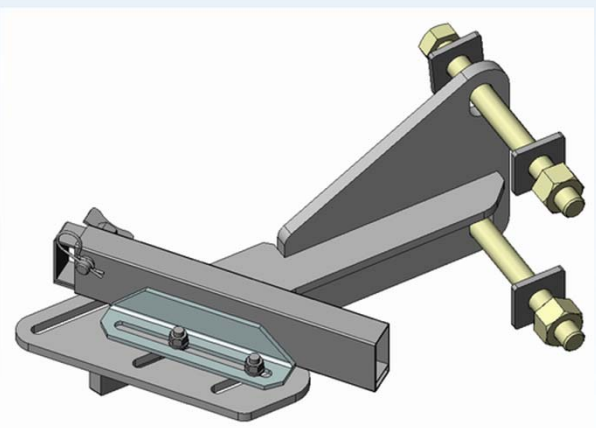
Custom Designs

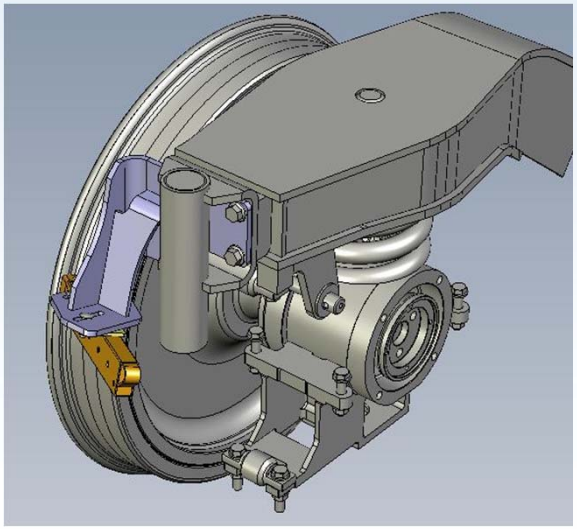












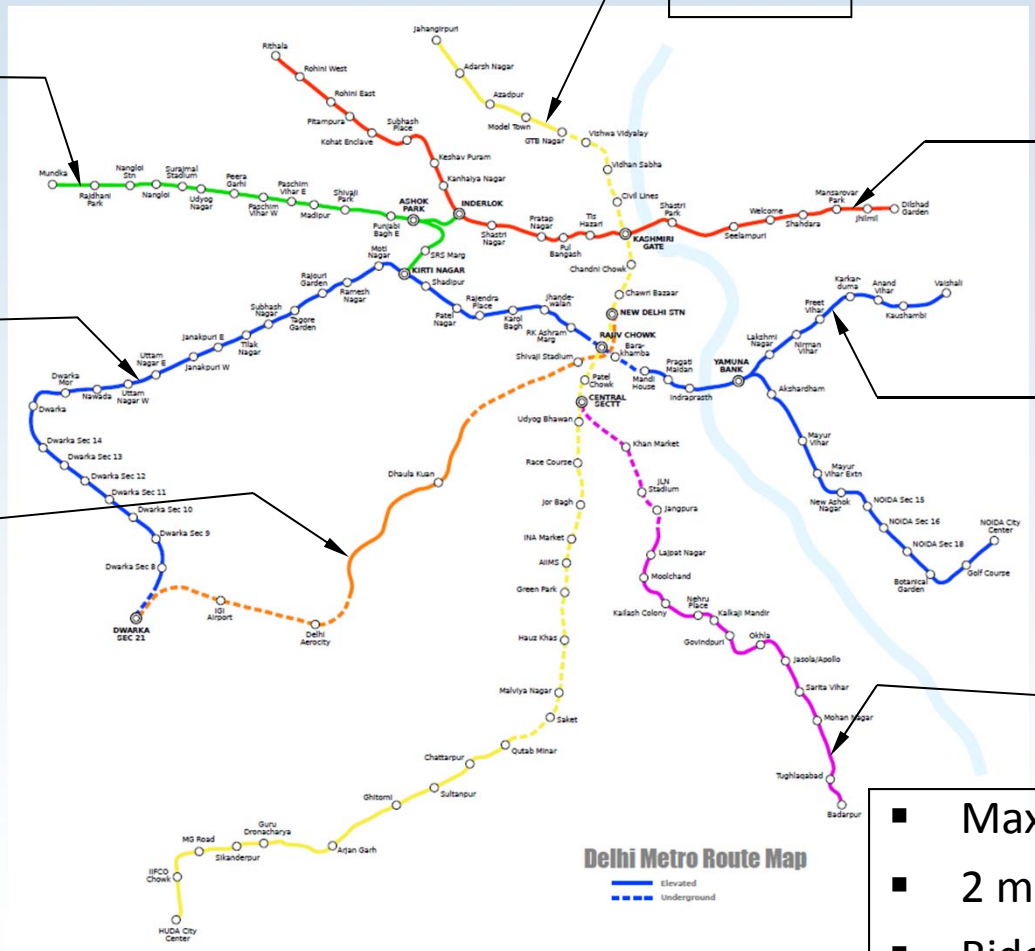
Delhi Metro (DMRC) Network Experience with Solid Stick Flange Lubrication

DMRC Network - Current

DMRC Network - Current

Delhi Population: 22 million

DMRC Network - Current



Line 2

Line 5

Line 1

Line 3

Line 4

Airport Express

Line 6

- Max. speed: 80 km/hr
- 2 min 40 sec head way
- Ridership: 2.6 million/day

DMRC Network - Current

Line Information

Line	Opening Year	Gauge	Length (km)	Stations
1 - Red	2002	1676 mm	25.09	21
2 - Yellow	2004	1676 mm	44.65	35
3 - Blue	2005	1676 mm	49.93	43
4 - Blue	2010	1676 mm	8.74	7
5 - Green	2010	1435 mm	18.46	14
6 - Violet	2010	1435 mm	20.04	15
Airport Express	2011	1435 mm	22.70	6
Total			189.61	141

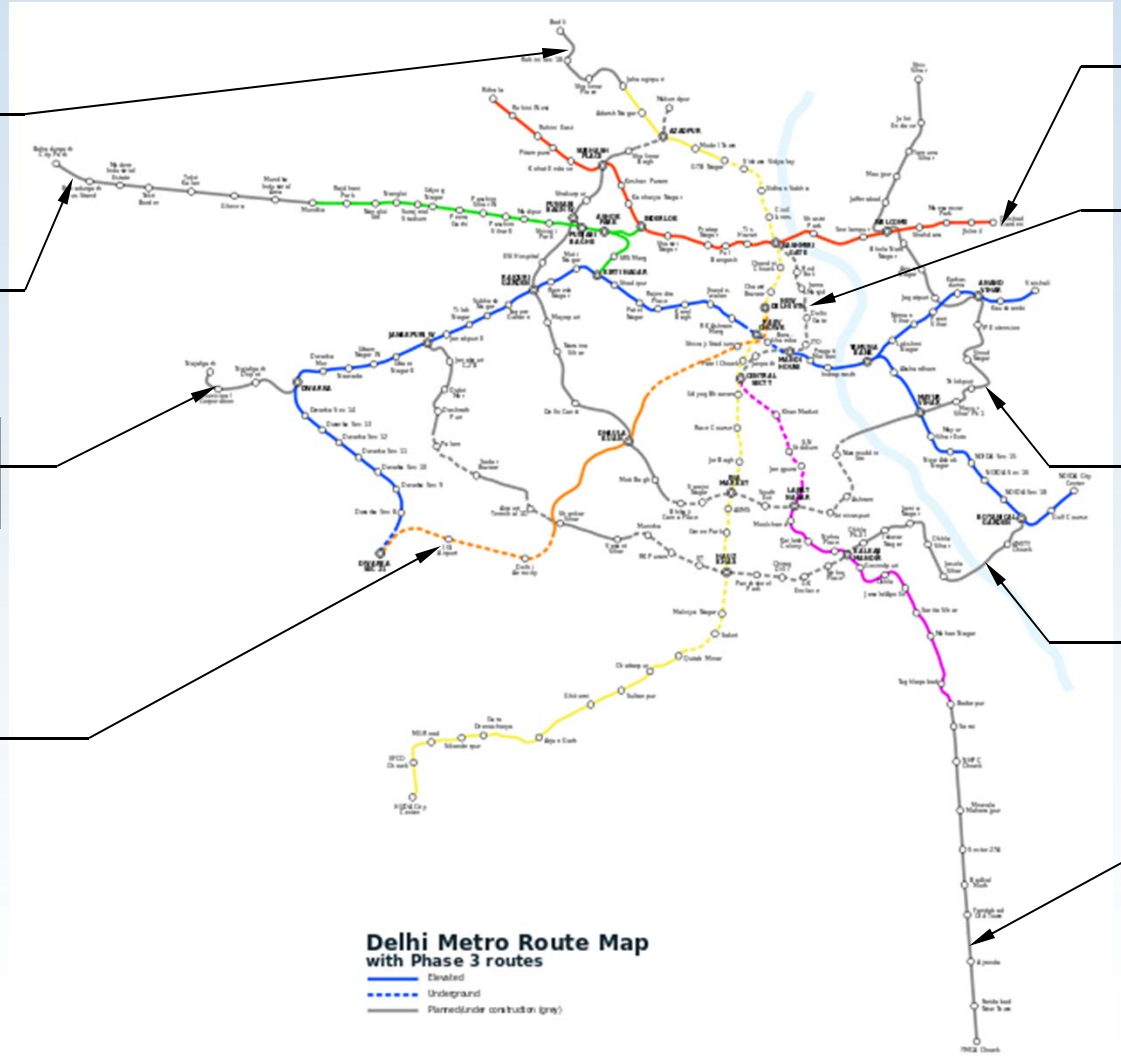
DMRC Network - Current

Rolling Stock Information

Line	OEM	No. Trains	Cars/Train	Cars Total
1 - Red	Rotem/BEML (BG)	29	4	116
2 - Yellow	Rotem/BEML (BG)	10	6	60
	BT (BG)	12	6	72
	BT (BG)	38	8	304
3 & 4 - Blue	Rotem/BEML (BG)	31	8	248
	BT (BG)	40	6	240
5 - Green	Rotem/BEML (SG)	17	4	68
	Rotem/BEML (SG)	1	6	6
6 - Violet	Rotem/BEML (SG)	29	4	116
	Rotem/BEML (SG)	1	6	6
Airport Express	CAF	8	6	48
Total (RS1 to RS7 + CAF)				1284

DMRC Network - Future
Phase III

DMRC Network – Future (Phase III)



Line 2
N. Extension

Line 5
W. Extension

Line 3
W. Branch

Airport Express
W. Extension

Line 1
Extension

Line 6
N. Extension

Line 7
Inner Ring Rd. Line

Line 8
Outer Ring Rd. Line

Line 6
S. Extension

DMRC Network – Future (Phase III)

Phase III - Line Information

Line		Length (km)	Stations
1 - Red	Extension	9.60	6
2 - Yellow	N. Extension	4.48	3
3 - Blue	W. Branch	5.5	4
5 - Green	W. Extension	11.18	6
6 - Violet	N. Extension	9.36	7
	S. Extension	13.88	11
Airport Express	W. Extension	11.63	5
7 - Brown	Inner Ring Road Line	58.40	37
8 - Magenta	Outer Ring Road Line	37.25	26
Total		161.28	98 (New)

DMRC Network – Future (Phase III)

Additional Rolling Stock Requirements

- Rotem / BEML Broad Gauge - 136 Cars
- Rotem / BEML Standard Gauge (RS9) - 92 Cars
- Rotem / BEML Standard Gauge (RS10) - 486 Cars

Total: 714

LCF Flange Lubrication on DMRC Network

LCF on DMRC Network

DMRC Goals for Friction Management

- Reduce Wheel Flange Wear Rate
  - Optimize Wheel Reprofiling Period
  - Reduce Life Cycle Cost of Wheel set
- Reduce Rail Gauge Face Wear Rate
- Reduce Wheel Flanging Noise (by product)

LCF on DMRC Network

Lubrication Systems at DMRC

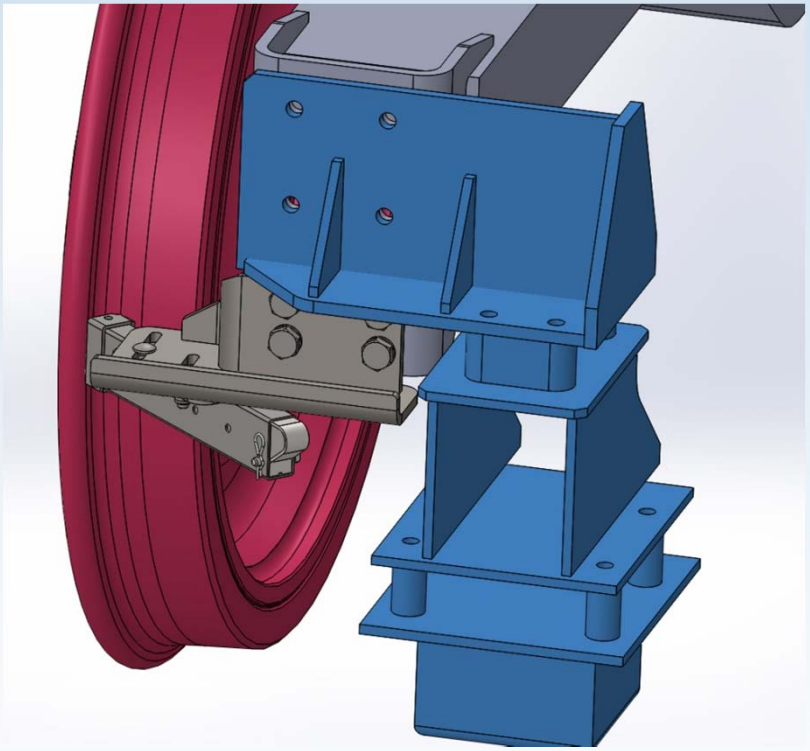
Line	FWI	OEM	Lubrication Type	LCF Coverage (%)	LCF Effective Coverage (%)
1 - Red	0.530	Rotem/BEML (BG)	On Board Oil	n/a	n/a
2 - Yellow	0.686	Rotem/BEML (BG)	None	0 (25 Planned)	21.6
		BT (BG)	LCF	25	
3 & 4 - Blue	0.540	Rotem/BEML (BG)	None	0 (25 Planned)	12.3
		BT (BG)	LCF	25	
5 - Green	0.552	Rotem/BEML (SG)	LCF	25	25
6 - Violet	1.634	Rotem/BEML (SG)	LCF	25 (50 Planned)	25
Airport Express	-	CAF	On Board Oil	n/a	n/a

- Line 3 has GF protectors between Patel Nagar and Rajender Place and between Kirti Nagar and Moti Nagar.

DMRC Network - Current

Rotem / BEML - Broad Gauge - Rolling Stock
RS1, 2002, No LCF
Lines 1, 2, 3 & 4

LCF on DMRC Network



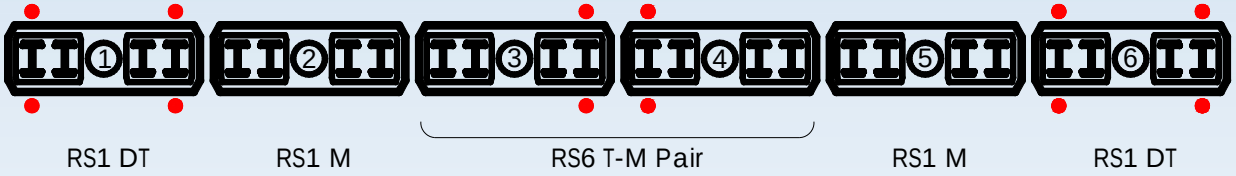
Design for Rotem / BEML Broad Gauge Rolling Stock
(To Be Implemented with LCF)

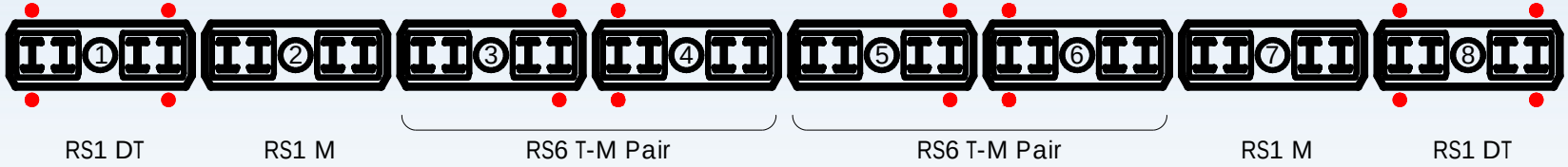
LCF on DMRC Network

ROTEM / BEML - Broad Gauge - (RS1, RS4 & RS6)

CONFIGURATION FOR 25% COVERAGE (Lines 2, 3 & 4)

Outer Axle Availabilty Only (RS1 DT & all RS6 Cars)





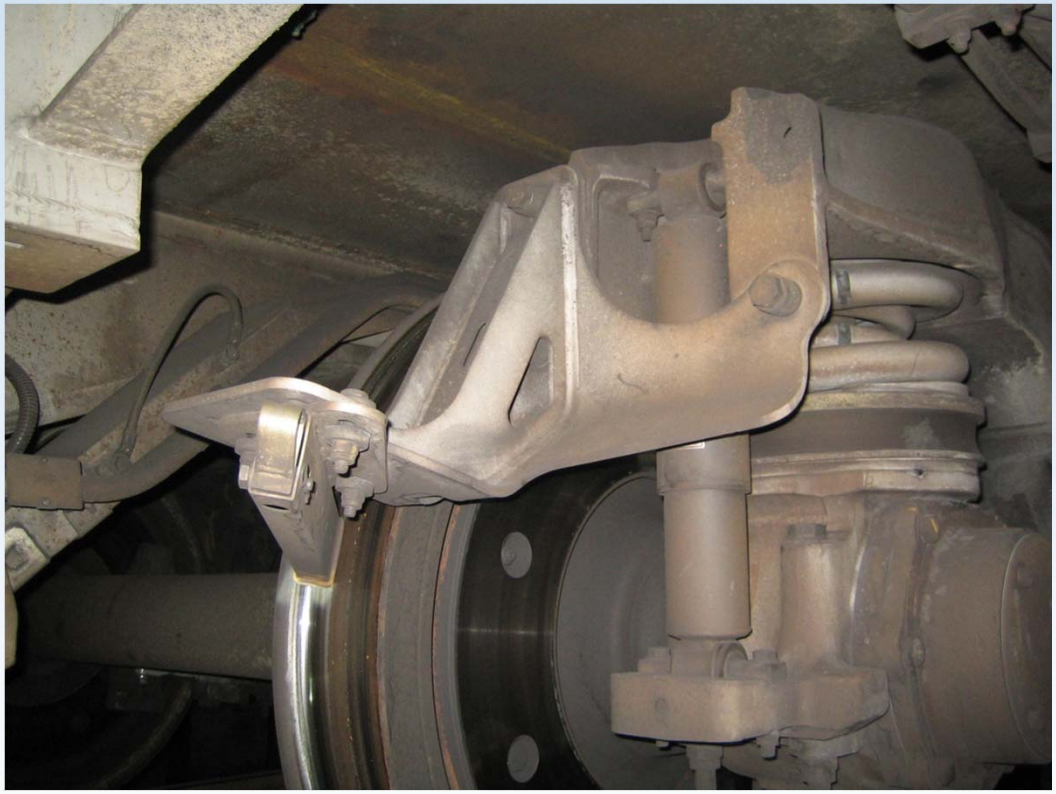
● DENOTES LCF APPLICATION

6 & 8 Car Train Configurations for Rotem / BEML Broad Gauge Rolling Stock

DMRC Network - Current

BT - Broad Gauge - Rolling Stock
RS2, 2009, With LCF
Lines 2, 3 & 4

LCF on DMRC Network



Design on BT Broad Gauge Rolling Stock

LCF on DMRC Network

BOMBARDIER - Broad Gauge - (RS2, RS5 & RS7)

CONFIGURATION FOR 25% COVERAGE (Lines 2, 3 & 4)

Outer Axle Availabilty Only - Except at Antenna Locations

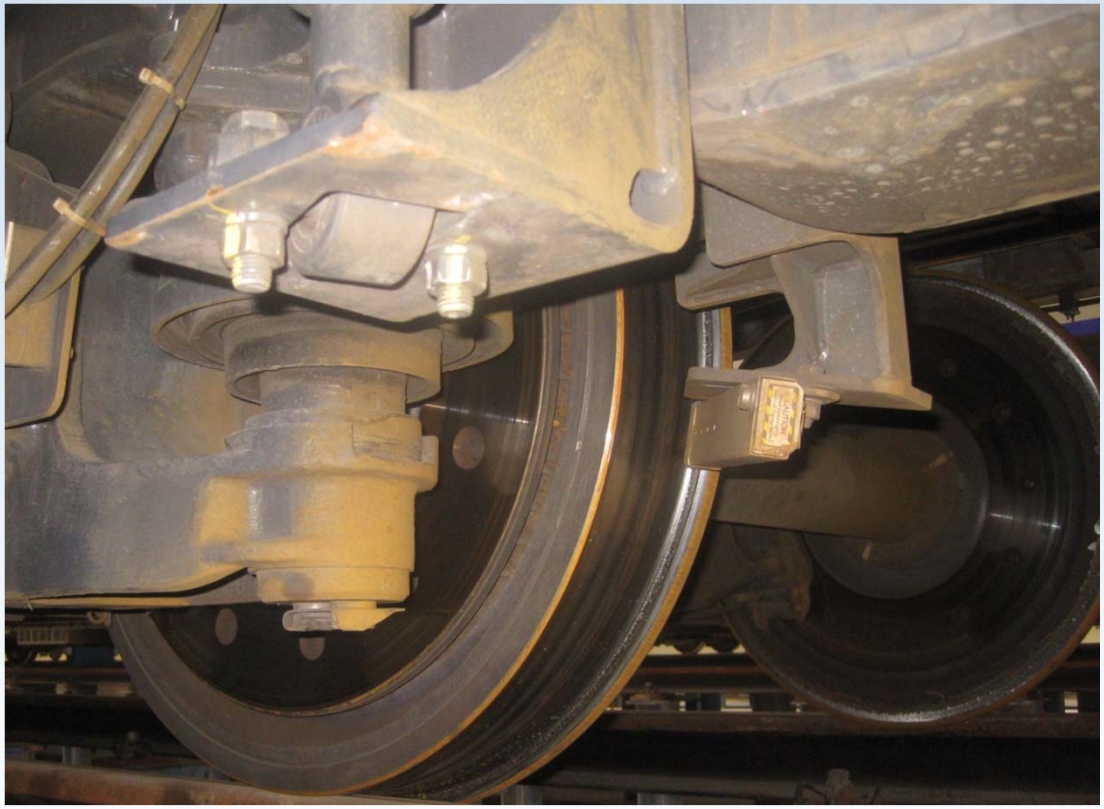
● DENOTES LCF APPLICATION

6 & 8 Car Train Configurations for Bombardier Broad Gauge Rolling Stock

DMRC Network - Current

Rotem / BEML - Standard Gauge - Rolling Stock
RS3, 2010, With LCF
Lines 5 & 6

LCF on DMRC Network



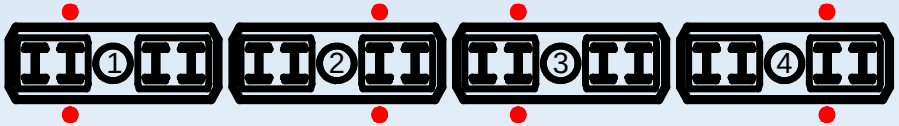
Design on Rotem / BEML Standard Gauge Rolling Stock

LCF on DMRC Network

ROTEM / BEML - Standard Gauge - (RS3)

CONFIGURATION FOR 25% COVERAGE (Lines 5 & 6)

Inner Axle Availabilty Only



● DENOTES LCF APPLICATION

4 & 6 Car Configurations for Rotem / BEML Standard Gauge Rolling Stock

Performance

LCF on DMRC Network

LCF Performance
Broad Gauge Rolling Stock – Lines 2, 3 & 4

2002 – 2009: RS1 (Rotem/BEML)

- Operation on Lines 1, 2, 3 & 4 without LCF.
- Wheels have both Tread and Flange Wear.
  - Motor cars – Reprofiled primarily due to Flange Wear.
  - Trailer cars – Reprofiled due to both Tread and Flange Wear.
  - Motor cars typically had higher Flange wear than Trailer cars.

2009 – Present: RS2 (BT)

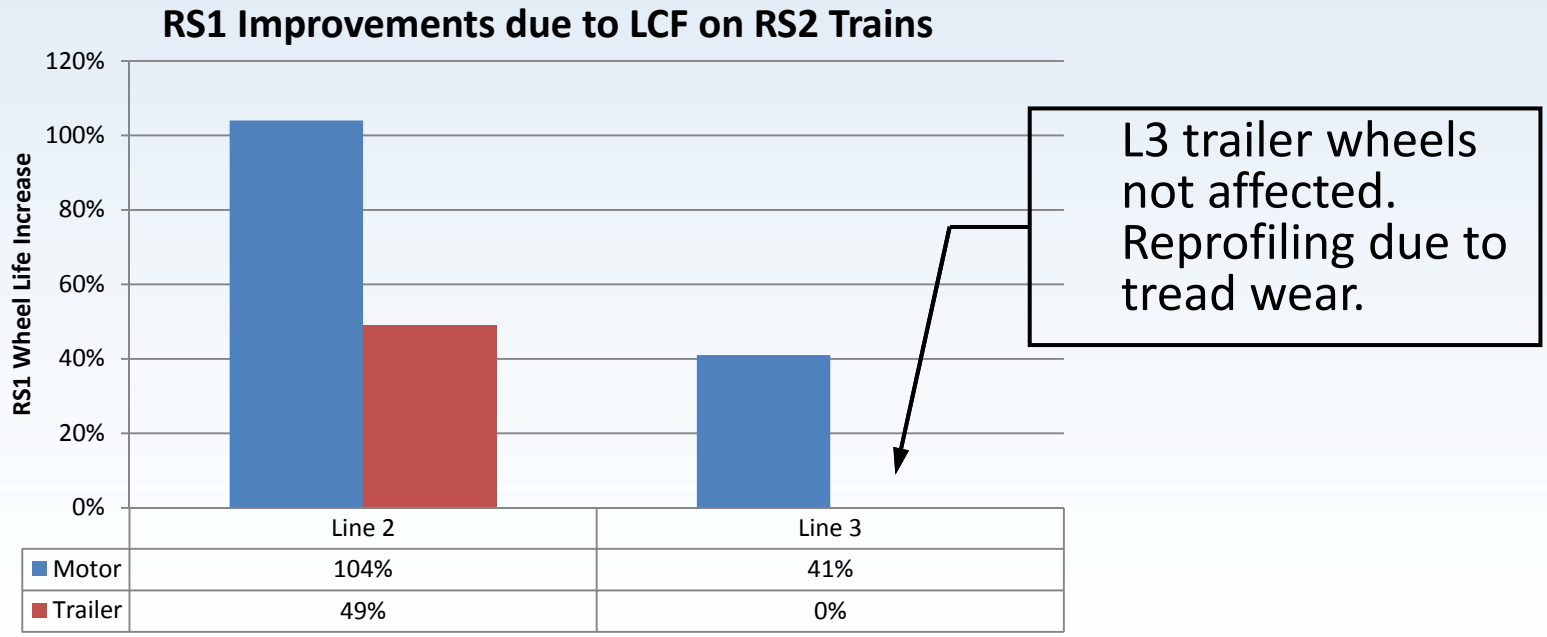
- Operation on Lines 2, 3 & 4 with LCF.
- Negligible Tread and Flange Wear.
  - Wheels reprofiled due to tread RCF only.

LCF on DMRC Network

LCF Performance

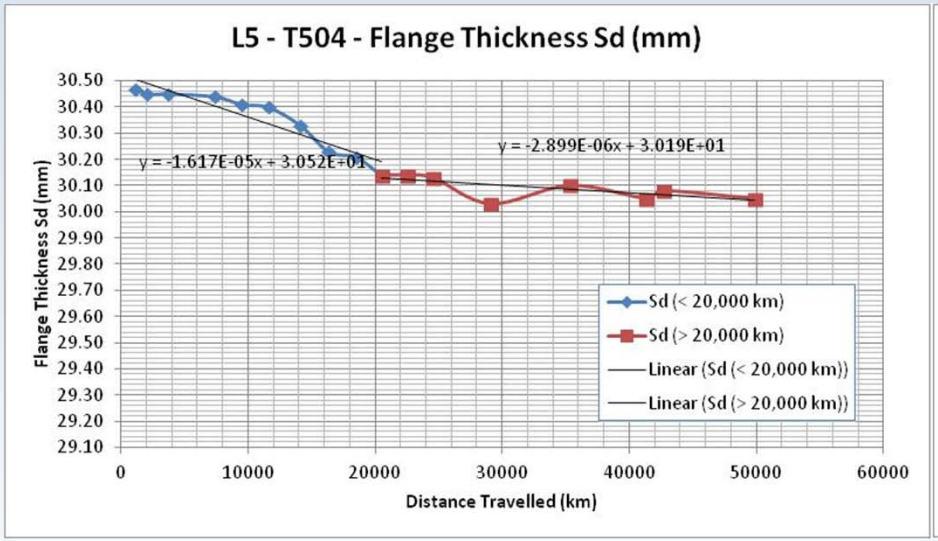
Broad Gauge Rolling Stock – Lines 2, 3 & 4

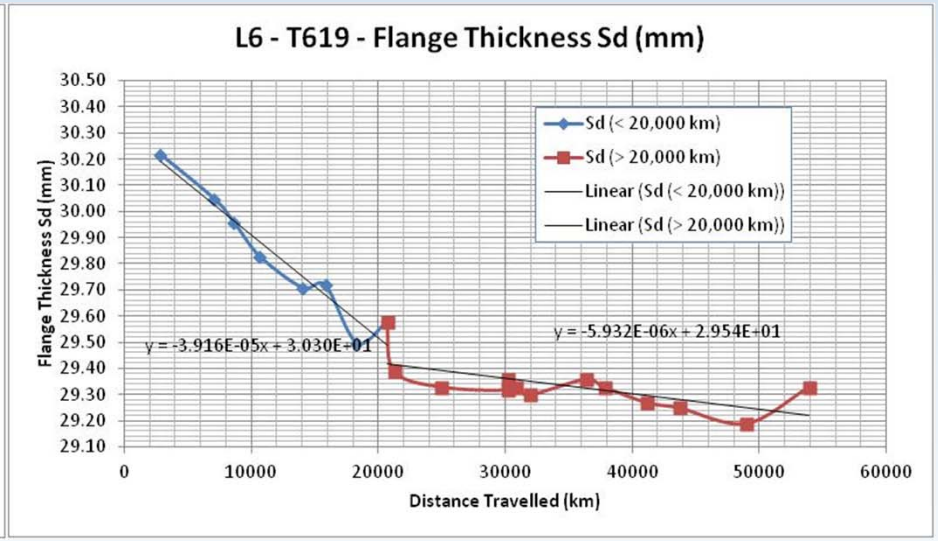
- February 2012 – Evaluation on the effectiveness of LCF.
- Data based on re-profiling records of 2010 and 2011.



LCF on DMRC Network

LCF Performance
Standard Gauge Rolling Stock – Lines 5 & 6





Line 5: FWI = 0.552

Wear Rate = 0.006 mm/kkm

Line 6: FWI = 1.634

Wear Rate = 0.019 mm/kkm

- Both lines use Rotem RS3 rolling stock and currently with 25% LCF coverage
- Wear rates between lines correspond fairly well with FWI model

Future Directions

- Retrofit Rotem/BEML BG rolling stock (RS1) with 25% LCF coverage.
- Increase L6 Rotem/BEML SG rolling stock (RS3) from 25% to 50% coverage.

Conclusions

- Solid Stick Systems are customized for each line.
- Technology has matured in the past 10 years.
- Adopted by many major networks including London, Beijing, Delhi, Hong Kong, Washington and Los Angeles.
- Used on over 100 lines (systems) in over 60 cities world wide.

Thank You