Using vehicle dynamic response to challenge set track standards

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Introduction

- Derailment risk has traditionally been managed by identifying local track defects that exceed certain limits
  - Such limits have to be conservative
  - Usually consider track in isolation
  - Do not account for dynamic interaction between track and train
- Using dynamic simulation tools allows maintenance to be targeted by considering vehicle/track interaction
  - Optimised maintenance to minimise derailment risk
  - Reduce costs due to reduction in unnecessary maintenance
  - Improvement in overall ride quality
- This paper describes such an innovative approach and provides an example of its use. Work includes:
  - development of tram vehicle model
  - Validation against actual test results
  - Definition of limits based on dynamic simulations

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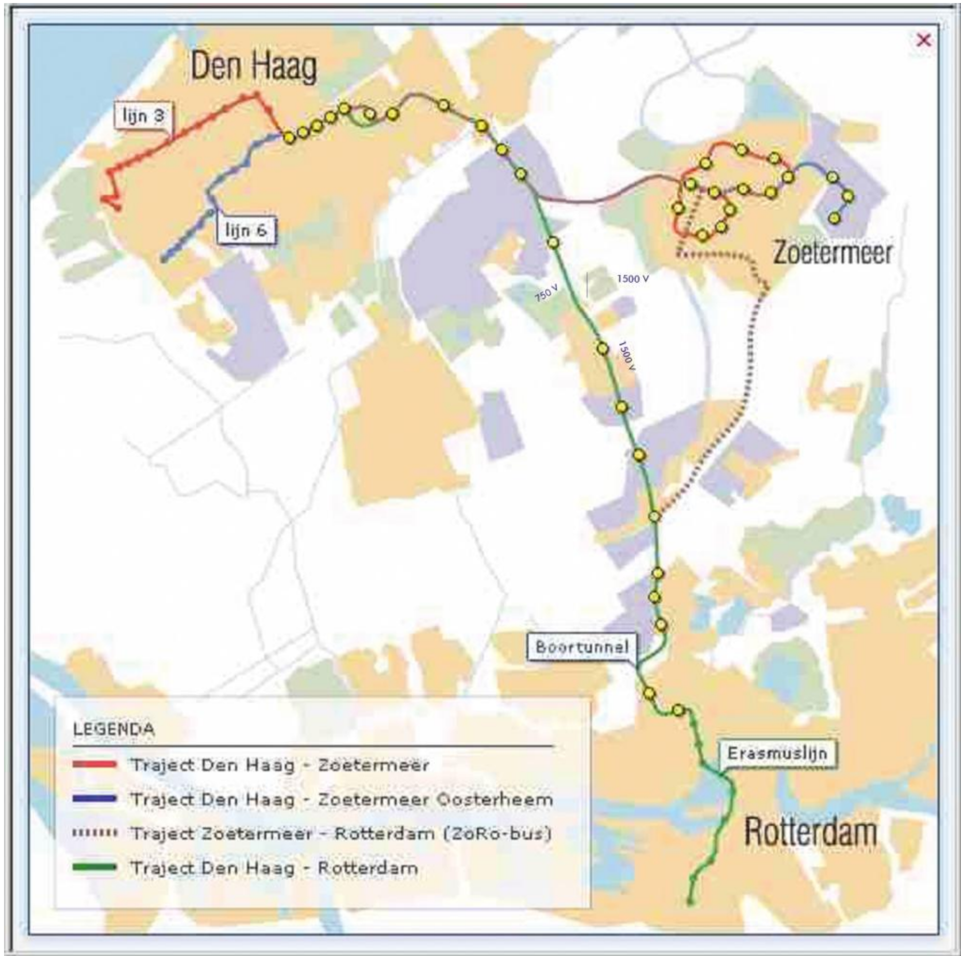
Randstad Rail

- Light rail system connecting Den Haag, Zoetermeer and Rotterdam
- Includes lines converted from heavy rail use
- Operated
  - by Metro vehicles - RET (Rotterdam)
  - By Tram-Trains – HTM (Den Haag)



HTM Trams

Alstom "Regio CITADIS" Tram-Train vehicles used on Randstad Rail

- 75% low floor tram
- Three articulated sections
- Designed for routes that combine light rail and heavy rail type sections
- Conventional power bogies, low floor trailer bogies

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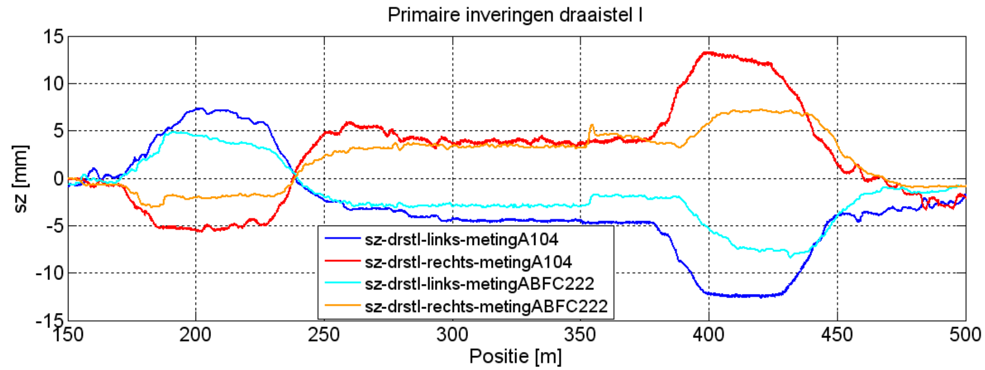
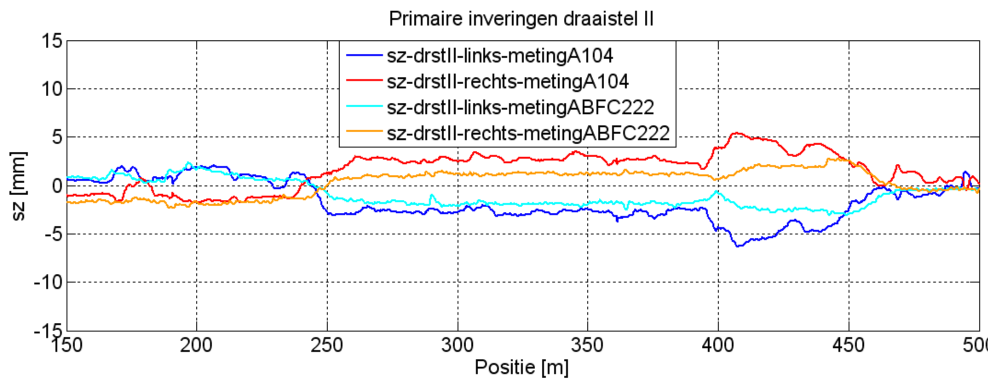
Problems on Randstad Rail

- Nine derailments in first month of operation
  - Approval to operate withdrawn
- Intensive research into problems
  - Onderzoeksraad Voor Veilegheid report
- Derailments from various causes
  - Included low speed derailment in exit transition from canted curve (200m radius, 1:300 transition)
  - Derailment at this location (Ternoot) studied before service resumed
  - Minimum speed recommended until cant and twist could be reduced
- DeltaRail asked to evaluate track geometry and develop new standard
  - to be based on response of rolling stock to track

Investigation of Ternoot Derailment (1)

- Test runs with instrumented tram
  - Video and suspension displacements
- Tests repeated after cant and twist reduced





Investigation of Ternoot Derailment (2)

- Trailer wheelset derailed, but motor showed greater wheel unloading (36% versus 21%)
- Therefore lateral force key factor
- Trailer bogie factors:
  - Independent wheels – no self steering
  - No traction forces, which on driven wheelsets may have led to reduced lateral forces
  - Bogie rotational resistance may be higher than motor bogie
- Simulations recommended but development of track standards and validation of measuring tram was given priority

Provisional Track Limits for Randstad Rail

- **HTM initial standards based on ProRail limits**
  - **Heavy rail limits, based on individual parameters**
  - **Do not consider combined influence of track parameters or repeated faults**
  - **Limits expressed as mid-chord versines**
  - **Safety (VW) and maintenance (BW) limits – BW= 75% of VW**
- **HTM initial safety limits set to 75% of ProRail maintenance limits**

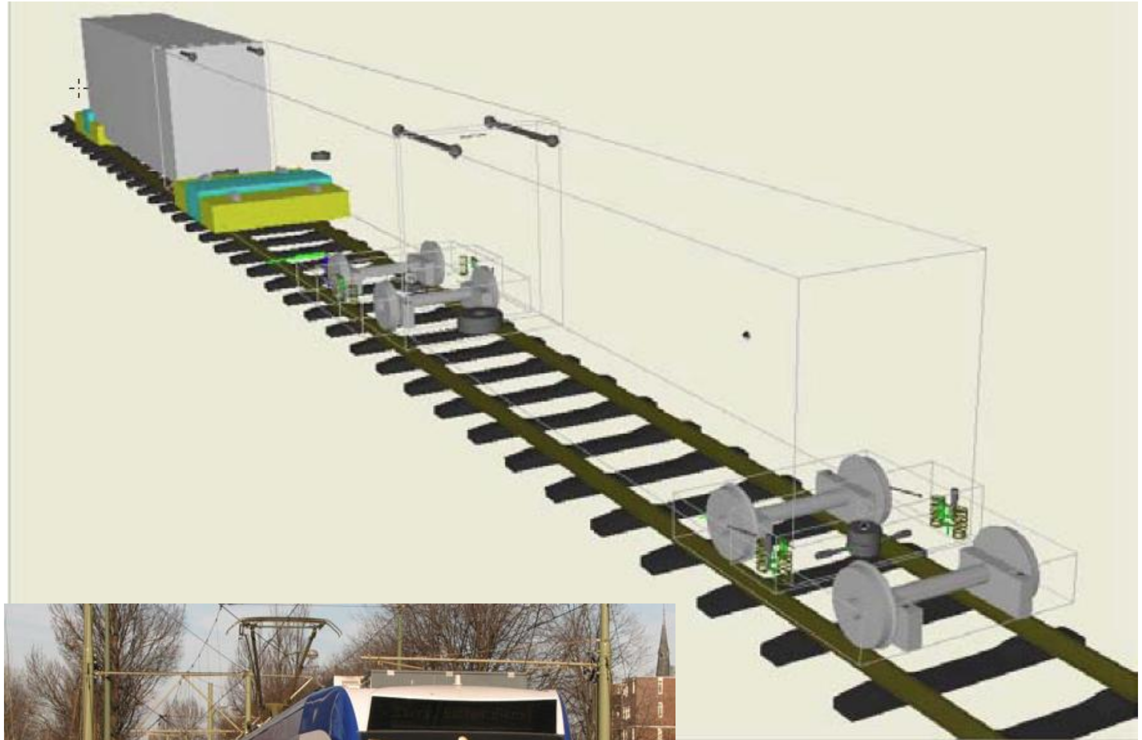
Parameter		**ProRail (safety)**		**EN13848**	**HTM Provisional**		**HTM New Concept**		**HTM New Final**	
	Chord length	VW mm	BW mm	VW mm	VW mm	BW mm	VW mm	% lim response	VW mm	% lim response
Level mid chord	1 m	3	2,2		1,5	1,1				
	2 m						**3**	98	**6.5**	100□±□2
	6 m						**20**	98	**24**	100□±□2
	10m	24	18				**28**	98	**2**[illegible]	[illegible]
	15m	30	22							

Development of new track standard

- Development and validation of VAMPIRE® model of Regio-CITADIS tram
- Track input from measured data
- Simulations performed with increasing track irregularities until limit reached
  - Applied by scaling amplitude
- Review track irregularities to set safety limits

VAMPIRE® Vehicle model

- Model composed of masses and wheelsets connected by mass-less suspension elements
- Independent wheels modelled



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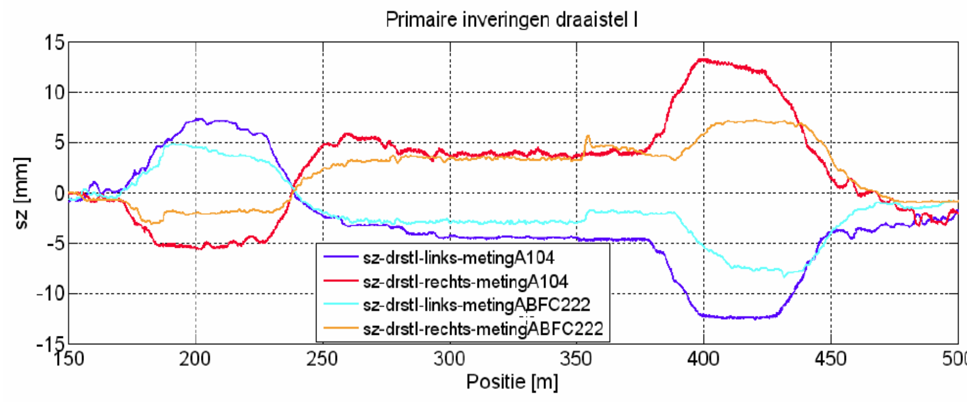
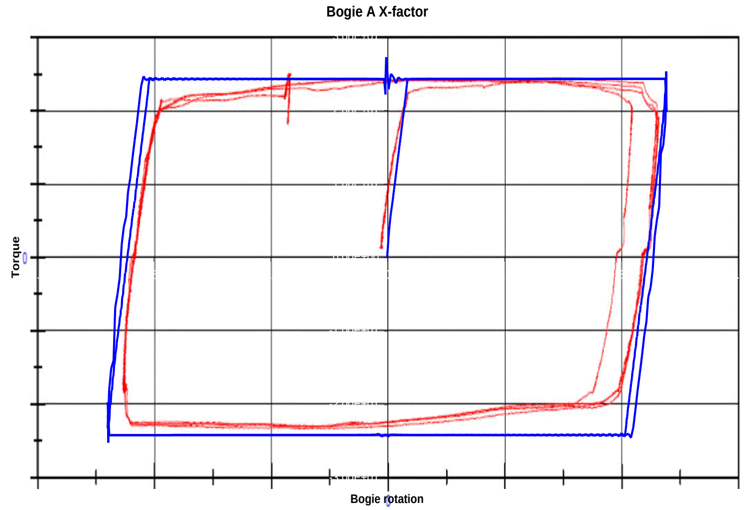
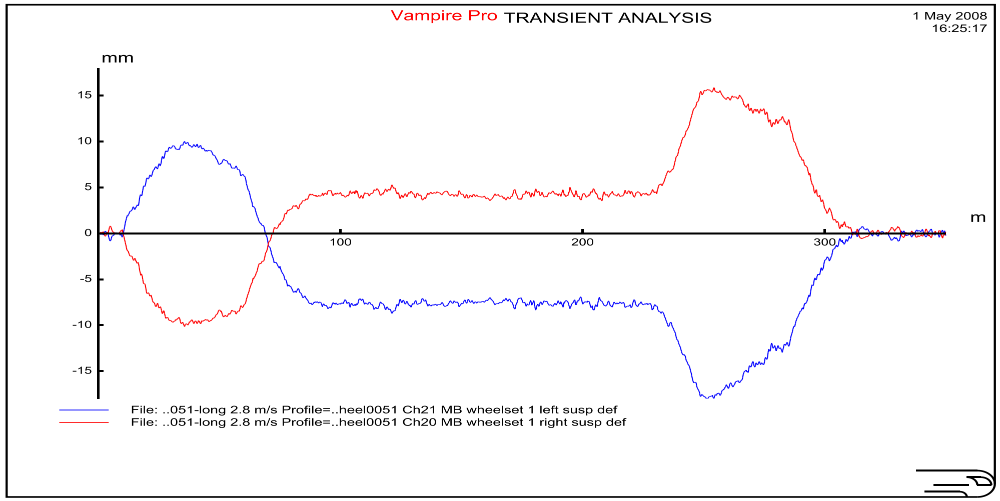
Model validation

- **Comparison with**
  - UIC518 test results
  - Measured displacements of primary suspension
  - Bogie rotation

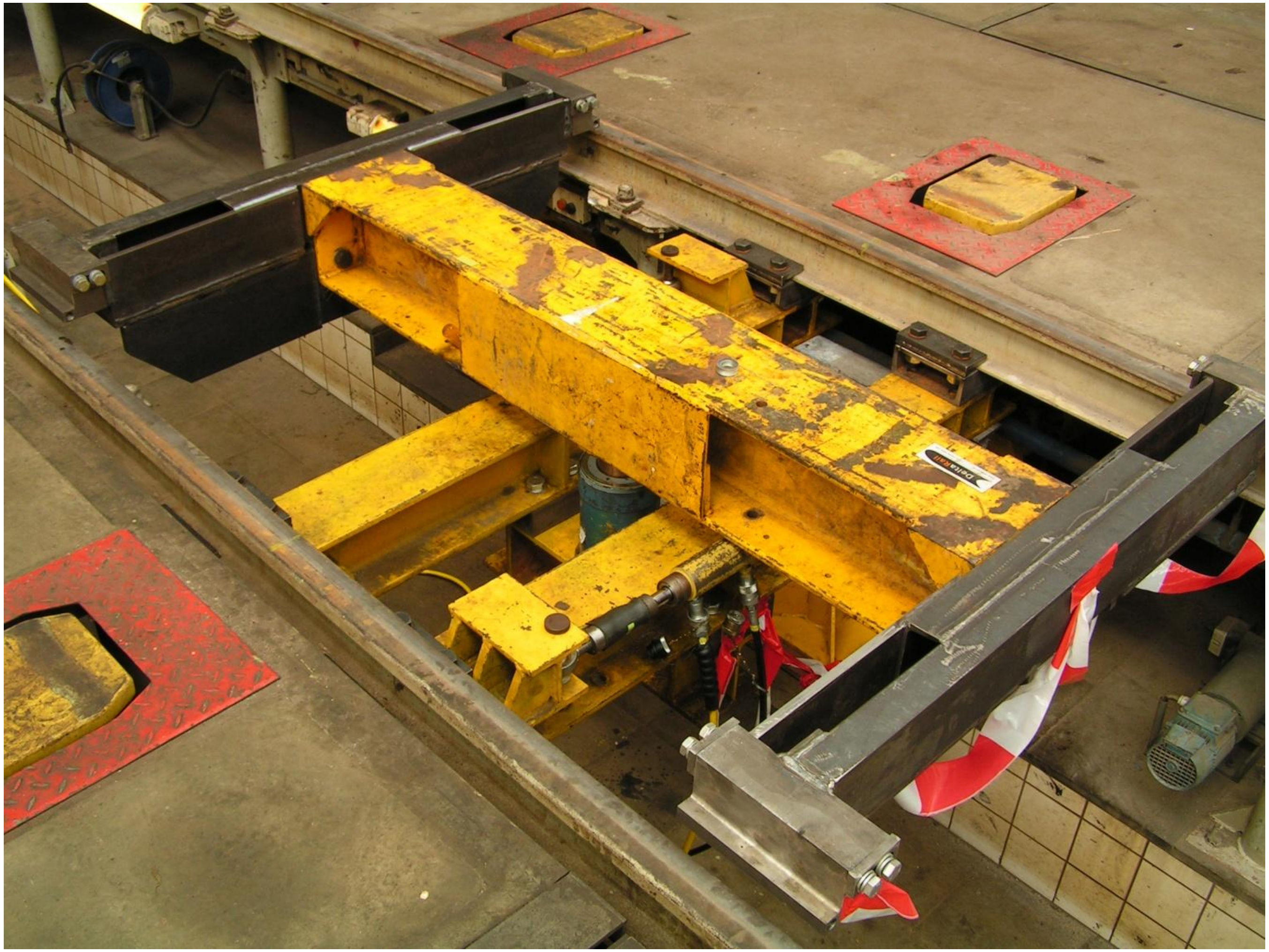






VAMPIRE Plot

Bogie Rotation Rig



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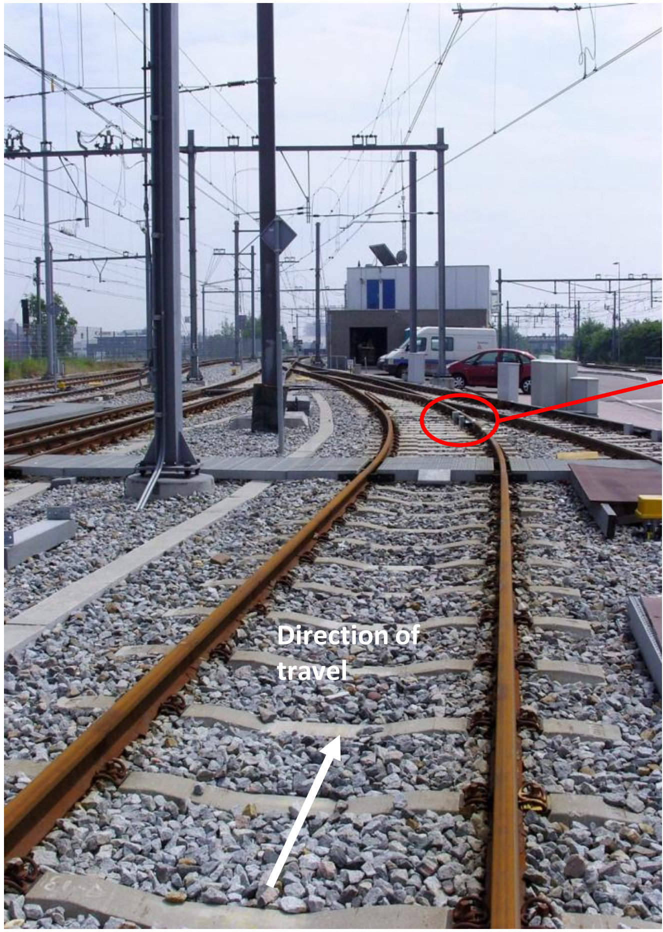
Leidschendam derailment study



- Derailment April 2008 (photos taken June)
  - 55m radius curve
  - Lubrication equipment installed after derailment
  - Flange climbing still visible
  - Rail not worn

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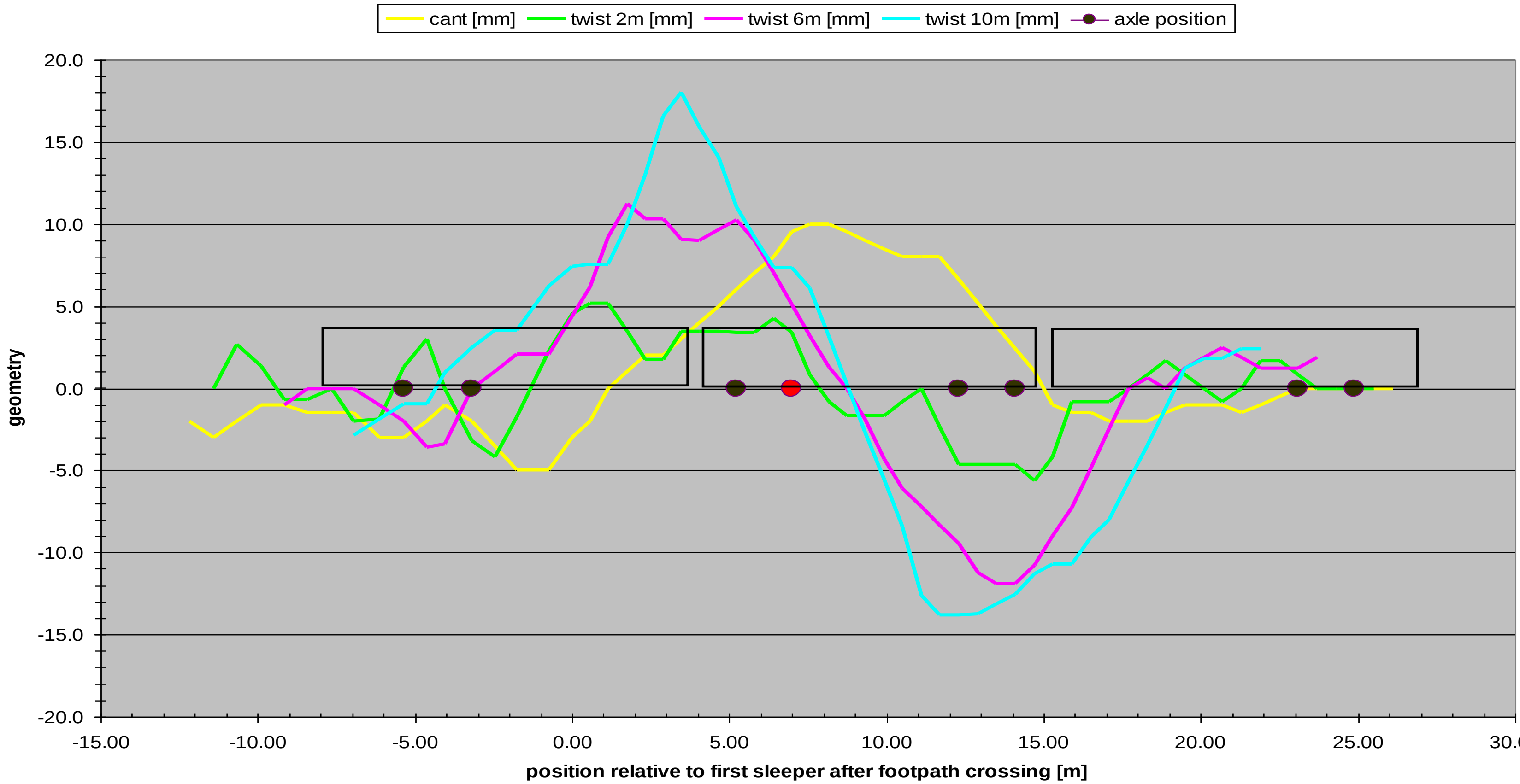
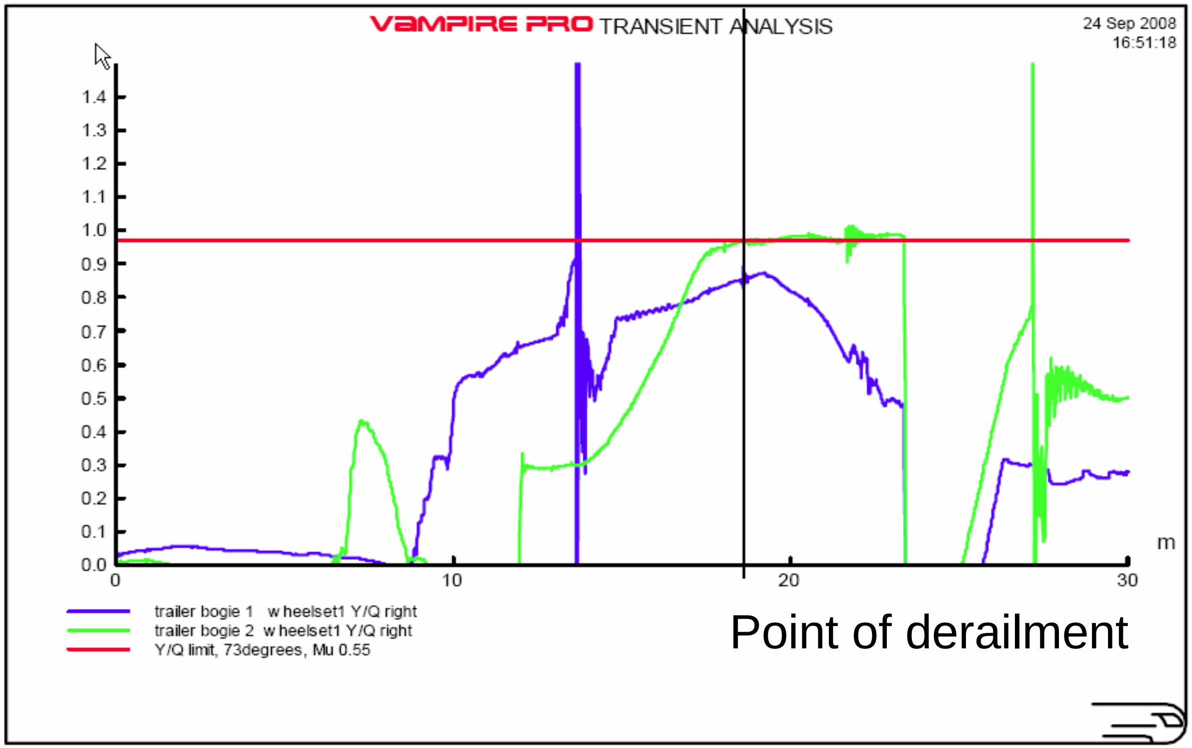
Derailment site cant and twist

- Track geometry and rail profiles measured



VAMPIRE® simulation of derailment

- **Simulation of Y/Q**
  - **High derailment risk for trailer bogie 2 coincides with the actual point of derailment**



VAMPIRE Plot

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Track standard development (1)

- **Initially based on simulations with track measured by a tamping machine**

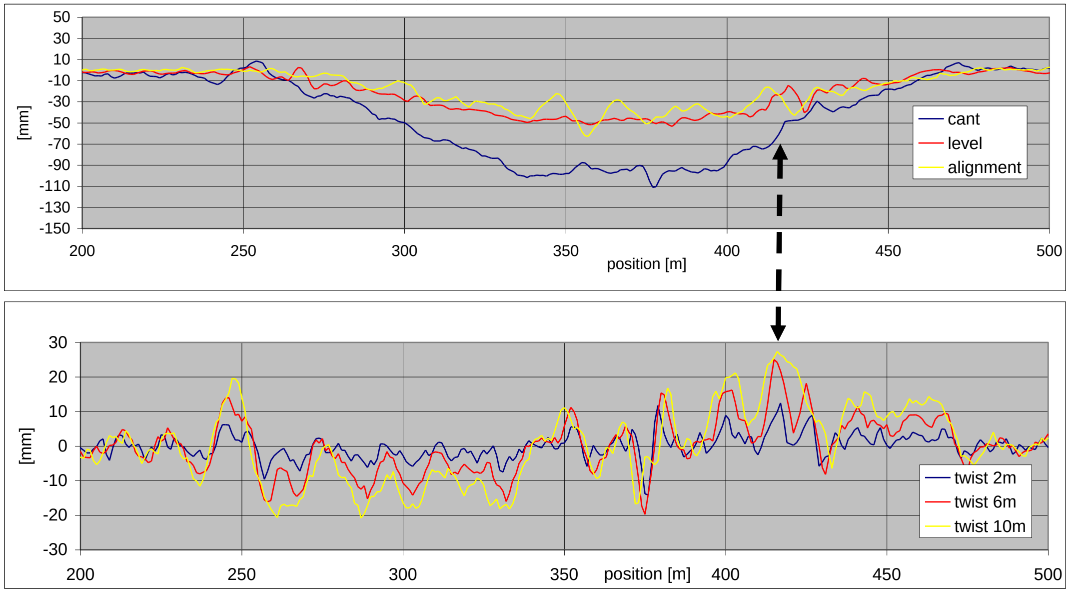
- **The following input parameters were varied:**
  - **Vehicle load: Fully loaded and an empty vehicle**
  - **Wheel profile: New and worn (measured) wheel profile**
  - **Speed: 10, 60, 80 and 90 km/h.**
  - **Track: Three track sections of 1 km length.**
  - **Scaling factor for track irregularities: 0, 100, 150, 200, 250 and 300% (equal for all track geometry parameters).**

Track standard development (2)

Parameter	EN 14363	CITADIS empty		CITADIS laden		unit
		Motor bogie	Trailer bogie	Motor bogie	Trailer bogie	
ΣY_{max}	$\leq (10 + 2Q_0 / 3)$	35.3	30.5	41.9	41.0	kN
Y / Q	$\leq$ 0.8	0.8				-
dQ / Q	$\leq$ 0.6	0.6				-
$\ddot{y}_{qst}$	$\leq$ 1.5	1.5				m/s^2
$\ddot{y}$	$\leq$ 2.5 – 3.0 *)	2.5 – 3.0				m/s^2
$\ddot{z}$	$\leq$ 2.5 – 3.0 *)	2.5 – 3.0				m/s^2

*) 2.5 – comfort limit ; 3.0 – safety limit

Zoetermeer, spoor R10: Design + 300% Irregularity

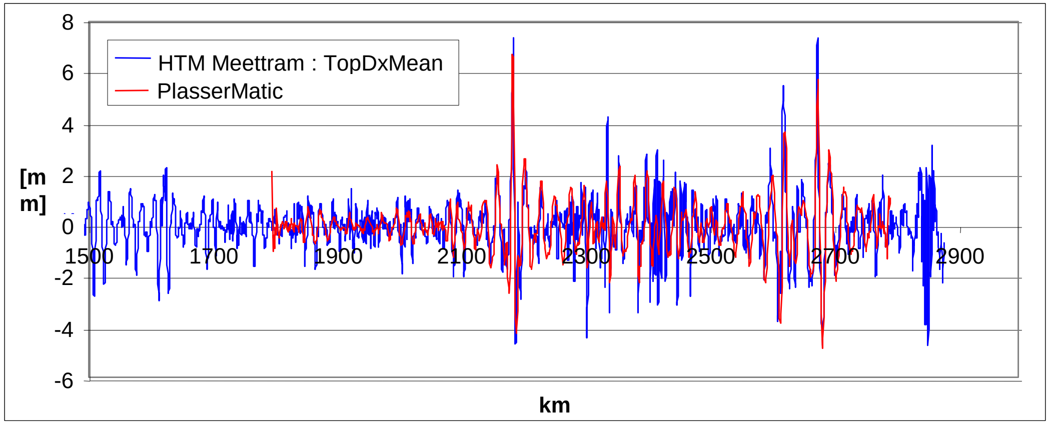


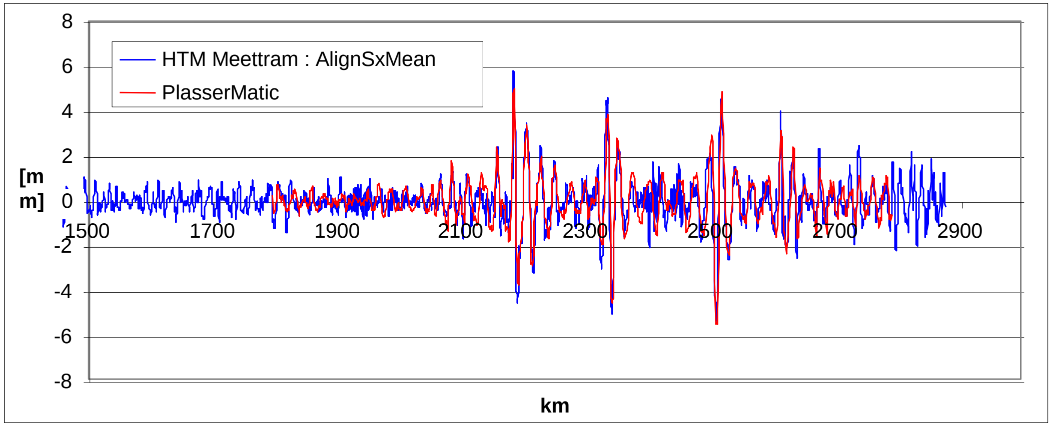
– Applied Safety limits

– Example of analysis of track location giving exceedence

HTM Track recording tram

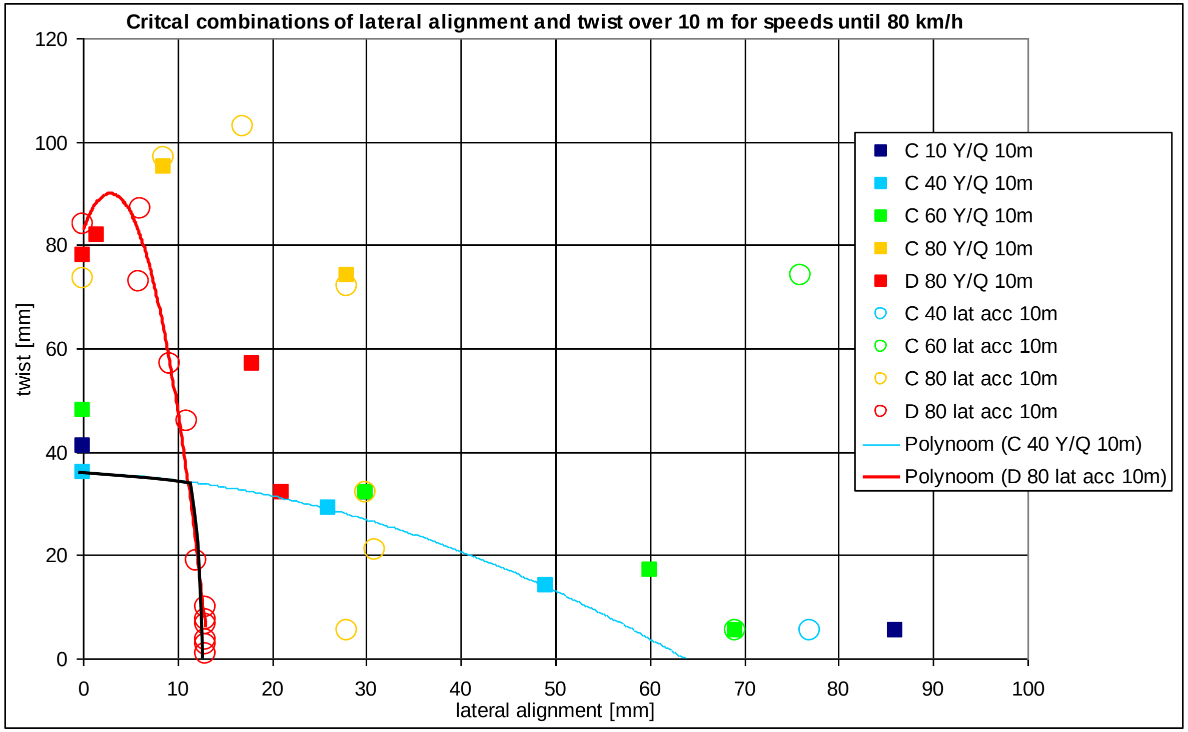
- **Service tram**
  - **Advanced optical measuring system**
  - **Laser scanning of rail profiles**



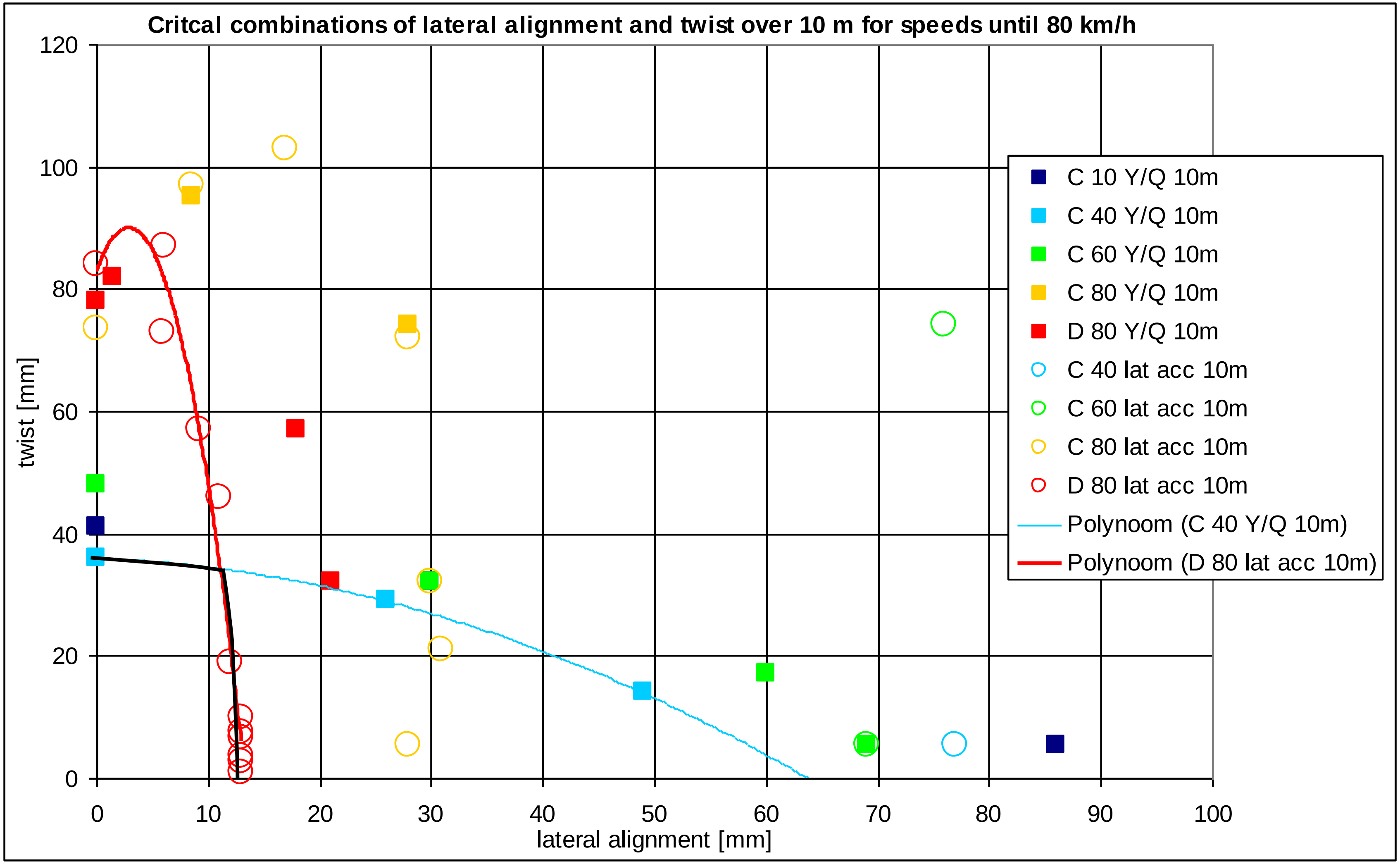


Track standard development (3)

- Using vehicle dynamic response allows determination of limits based on combinations of track inputs (twist and alignment)



Track standard development (3)



Limiting combinations of alignment and twist

- **Combinations of lateral alignment and track twist at different chord lengths**

Critical combinations of lateral alignment and track twist in [mm] for speeds up to 40 km/h							
chord length 2 m		chord length 6 m		chord length 10 m		determining response	
alignment	twist	alignment	twist	alignment	twist	Y/Q	lat. acc.
0	23 / 9.1	0	37 / 16	0	36 / 17	x	
3.7 / 1.6	16 / 8.6	16	29 / 15	26 / 12	29 / 16	x	
8.2 / 7.7	0	48 / 37	0	64 / 58	0	x	

Critical combinations of lateral alignment and track twist in [mm] for speeds up to 60 km/h							
chord length 2 m		chord length 6 m		chord length 10 m		determining response	
alignment	twist	alignment	twist	alignment	twist	Y/Q	lat. acc.
0	23 / 9.1	0	37 / 16	0	36 / 17	x	
3.7 / 1.6	16 / 8.6	16	29 / 15	26 / 12	29 / 16	x	
8.2 / 7.7	0	48 / 37	0	64 / 58	0	x	

Critical combinations of lateral alignment and track twist in [mm] for speeds up to 80 km/h							
chord length 2 m		chord length 6 m		chord length 10 m		determining response	
alignment	twist	alignment	twist	alignment	twist	Y/Q	lat.acc./sumY
0	23 / 9	0	37 / 16	0	36 / 17	x	
3.7 / 2.8	16 / 7	7.7 / 9.5	34 / 15	12 / 12	34 / 16	x	x
3.8 / 2.9	0	9.8	0	13 / 13	0		x

Conclusions

The use of dynamic simulation tools such as VAMPIRE®

- Allows the track engineer to target maintenance where it is most needed
- Identifies sites with a high risk of derailment, due to interaction with vehicle response, despite track being within standard
- Could drive step change in maintenance:
  - Optimised track maintenance to reduce derailment risk
  - Reduce cost with reduction in unnecessary maintenance
  - An improvement in overall ride quality
- This paper shows this approach can be applied successfully in practice
- HTM are now using this approach (with safety limits based on simulation of vehicle/track interaction)

Questions

Using vehicle dynamic response to challenge set track standards

- **Questions…**