IHHA RIO 2023

12th INTERNATIONAL HEAVY HAUL ASSOCIATION CONFERENCE

27 – 31 August 2023
Rio de Janeiro, Brazil
Windsor Convention & Expo Centre

Application of Heavy Haul Innovations for a Sustainable World

Theme: Application of Heavy Haul Innovations for a Sustainable World

INTERNATIONAL HEAVY HAUL ASSOCIATION

Presentation Title: MONITORING RAILWAY TRACK QUALITY AND SAFETY USING DYNAMIC INERTIAL RESPONSE OF THE CARBODY AND TRUCKS

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INTRODUCTION

BASIC FUNDAMENTAL QUESTIONS:

What is railway track **QUALITY**? How to measure track **QUALITY**?

When a railway track is **SAFE**? How to measure track **SAFETY**?

When a track **MAINTENANCE** is effective? How to measure **MAINTENANCE** effectiveness?

DEFINITIONS

ASSUMED DEFINITIONS:

TRACK QUALITY is the ability of the track to keep its own original design geometry to allow a good, smooth and satisfactory journey for the trains and passengers.

TRACK SAFETY is the ability of the track to keep its own structural integrity while train pass on, and do not promote any unsafe conditions for the rolling stock travelling respecting allowed speed.

EFFECTIVE MAINTENANCE is the ability to keep the track as good and safe as possible, with the lower cost.

REQUIREMENTS

ACHIEVEMENT OF PROPERTIES

TRACK QUALITY: is to keep track as close as possible to the structural (strength) and geometric requirements (**TQI** - Geometric Index).

TRAFFIC SAFETY: is to keep vehicle and train travelling over the track within safe conditions.

EFFECTIVE MAINTENANCE: is to invest less effort and resources to get the best ration between cost and good properties.

PARADOX

SAFETY PARADOX:

- Some derailments occurs in a very **GOOD QUALITY** track that respects all the standardized geometric limits and tolerances.
- Instead, there are several track of **POOR QUALITY** that does not promote any derailment or unsafety condition.
- **WHY this PARADOX**?

MOTIVATION

MOTIVATION FOR THIS DEVELOPMENT:

To address efficient and easy ways to measure track **QUALITY** and **SAFETY**, to get the substance that direct the effective **MAINTENANCE**.

FUNDAMENTALS: seek to create the right environment for proper monitoring of systems behaviour. Railway systems are composed by the **track** geometry, **vehicle** and **train** operations. Therefore, monitoring process must necessarily involve and simultaneously contemplate the contribution of each subsystem involved.

EXPECTATION

MODERN RAILWAY SYSTEM MUST BE:

SUSTAINABLE, AFFORDABLE and RELIABLE

TRADITIONAL METODOLOGY

MAINTENANCE TRADITIONAL METHODOLOGY

Track Roughness ⇒ *Measuring Car* ⇒ *Geometric Limits*

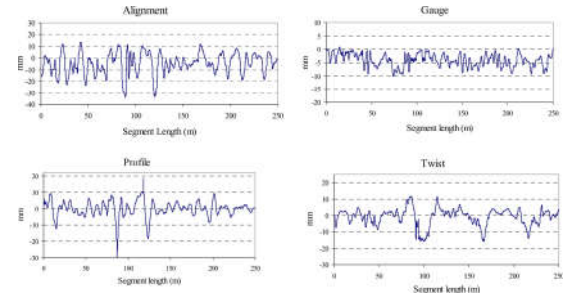
Vehicle Dynamic ⇒ *Monitoring Process* ⇒ *Dynamic Limits*

TWO INDEPENDENT METHODS

TRADITIONAL METODOLOGY

TRACK GEOMETRIC QUALIFICATION

Track Roughness ⇒ *Measuring Car* ⇒ *Geometric Limits*



U.S. Department of Transportation
Federal Railroad Administration

Tabela 1 - Empenamento da Via (FRA)

Classe	1	2	3	4	5	6
Velocidade Vagão Velocidade Pass.	16 km/h 24 km/h	40 km/h 48 km/h	64 km/h 96 km/h	96 km/h 128 km/h	128 km/h 144 km/h	176 km/h 176 km/h
Empeno[A] (pol)	3.5"	3.0"	2.0"	1.5"	1.0"	0.5"
Empeno[A] mm	88,9 mm	76,2 mm	50,8 mm	38,1 mm	25,4 mm	12,7 mm
Grandeza Absoluta em mrad/metro.[B]	6,55	5,62	3,75	2,81	1,87	0,94
Métrica[C] (10 m)	65,5	56,2	37,5	28,1	18,7	09,4
Larga[C] (10 m)	105 mm	90 mm	60 mm	45 mm	30 mm	15 mm

Obs.: [A] para bitola standard (1435 mm) e base de 31 pés (9,448 metros), Obs.: [B] Torção absoluta em mrad/metro, conforme Track Safety Standards (Federal Railroad Administration, 1971). Obs.: [C] bitola estrita e larga em base de 10 metros

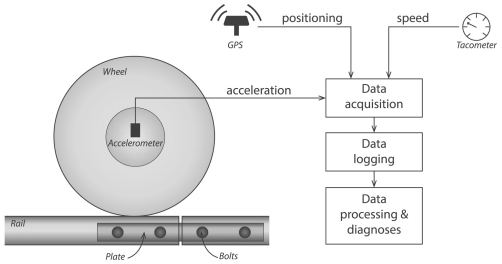
IMAGES FROM INTERNET

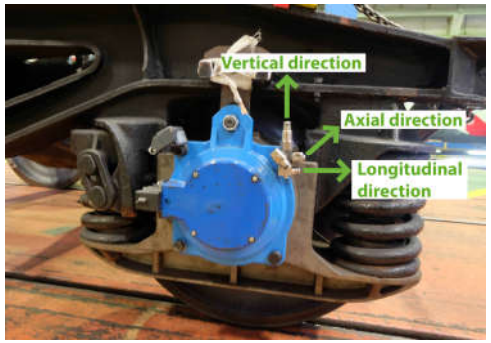
TRADITIONAL METODOLOGY

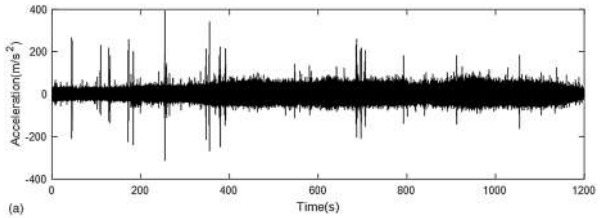
TRACK RESPONSE QUALIFICATION

Vehicle Dynamic ⇒ *Monitoring Process* ⇒ *Dynamic Limits*

INSTRUMENTED WHEELSET
AXLE BOX ACCELEROMETERS







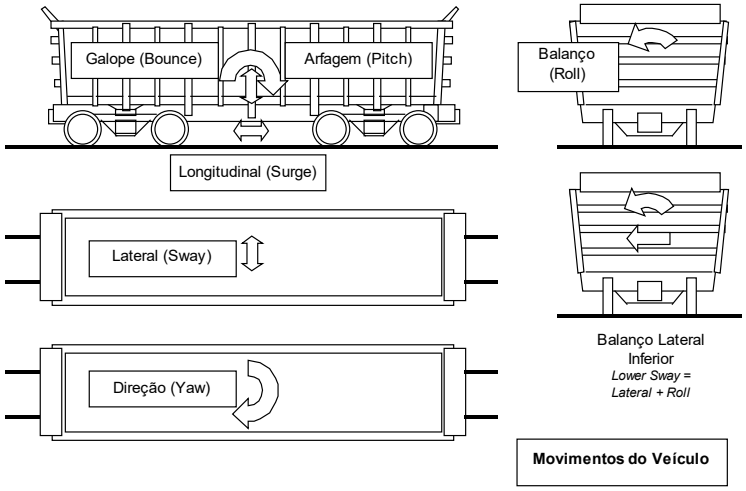
EUROPEAN STANDARDS

Safety and Ride comfort
for passengers.
EN-12299 & EN-14363

IMAGES FROM INTERNET

MODERN METHODS

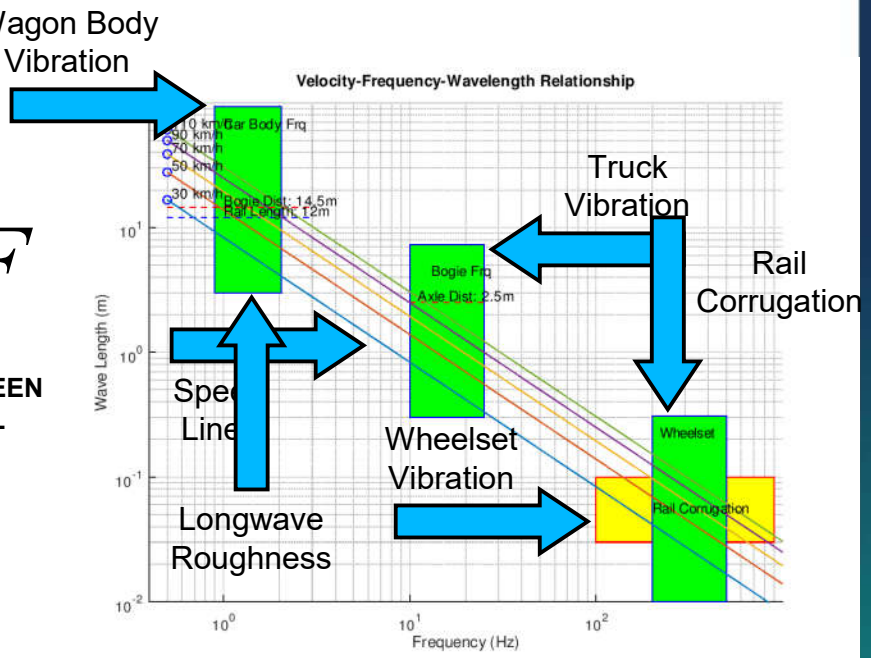
VEHICLE × TRACK CORRELATION



MODAL PROPERTIES

$$V = \lambda F$$

CORRELATION BETWEEN SPEED AND MODAL FREQUENCIES

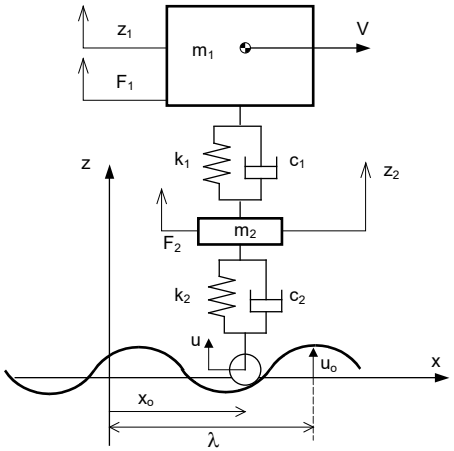


SPEED AND SPECTRAL BANDS

MODERN METHODS

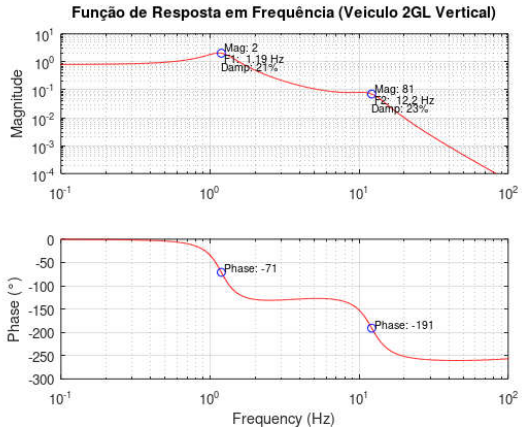
VEHICLE QUALIFICATION

Vehicle Dynamic → *Monitoring Process* → *Dynamic Response*



MODEL SIMULATION

COMPLEX VEHICLE INSTRUMENTATION



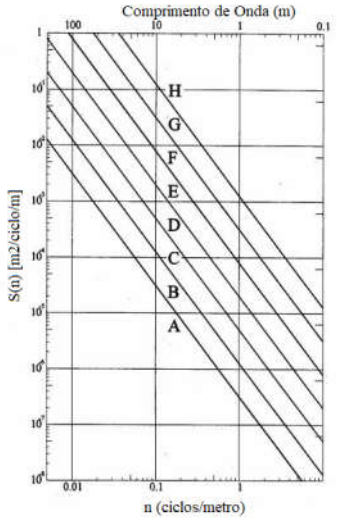
SPECTRAL ANALISYS

IMAGES FROM INTERNET

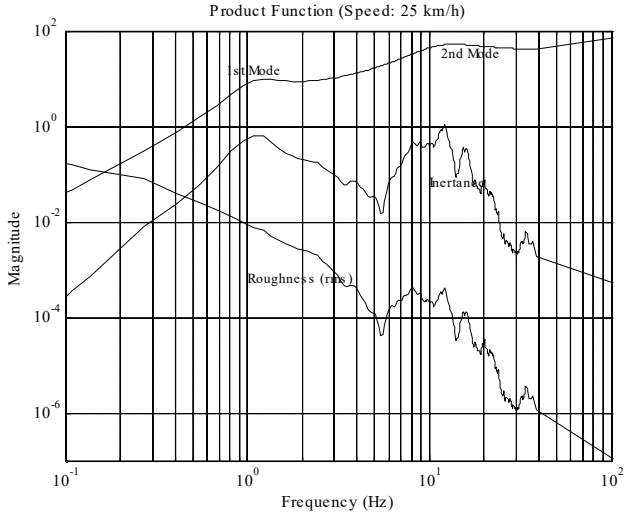
MODERN METHODS

MODAL ANALYSIS

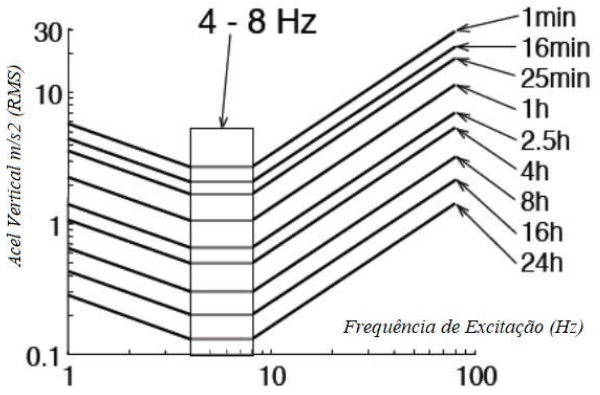
Roughness ⇒ *Spectral Response* ⇒ *Comfort Tolerance*



Spectral Irregularities Content ISO-8608



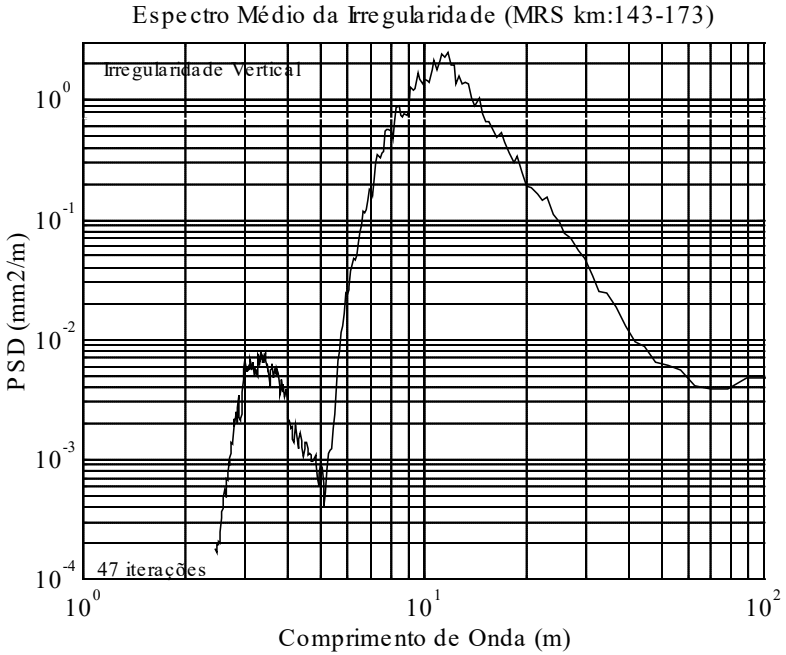
Vehicle Spectral Response and Track Irregularities Content



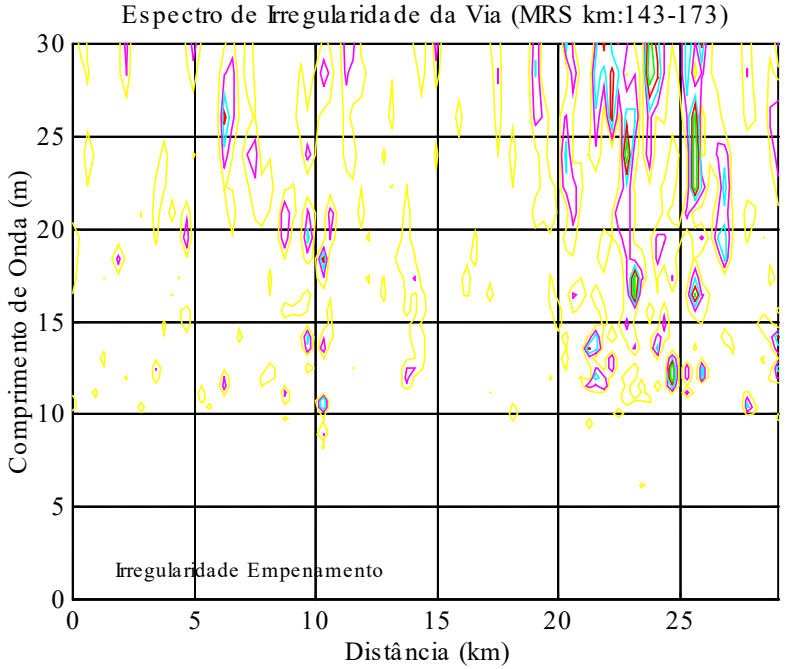
Passenger Confort Performance

MODERN METHODS

SPECTRAL TRACK ANALYSIS



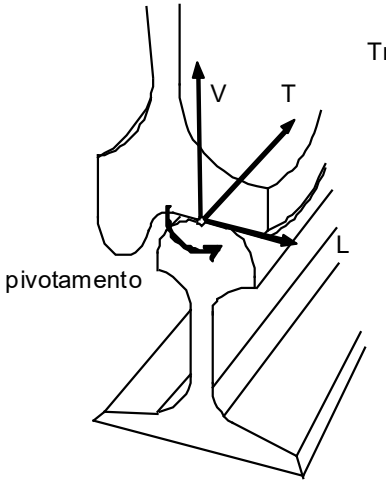
VERTICAL POWER SPECTRAL DENSITY



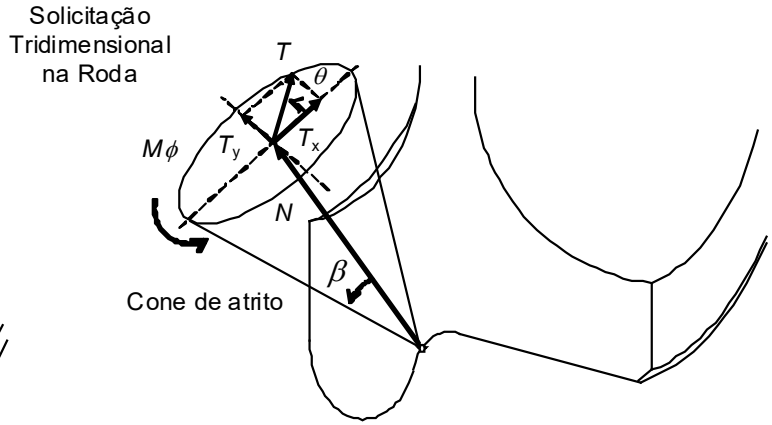
TWIST SPECTROGRAM ALONG TRACK LENGTH

SAFETY LIMITS

TRADITIONAL NADAL's SAFETY FORMULA



CONTACT FORCES



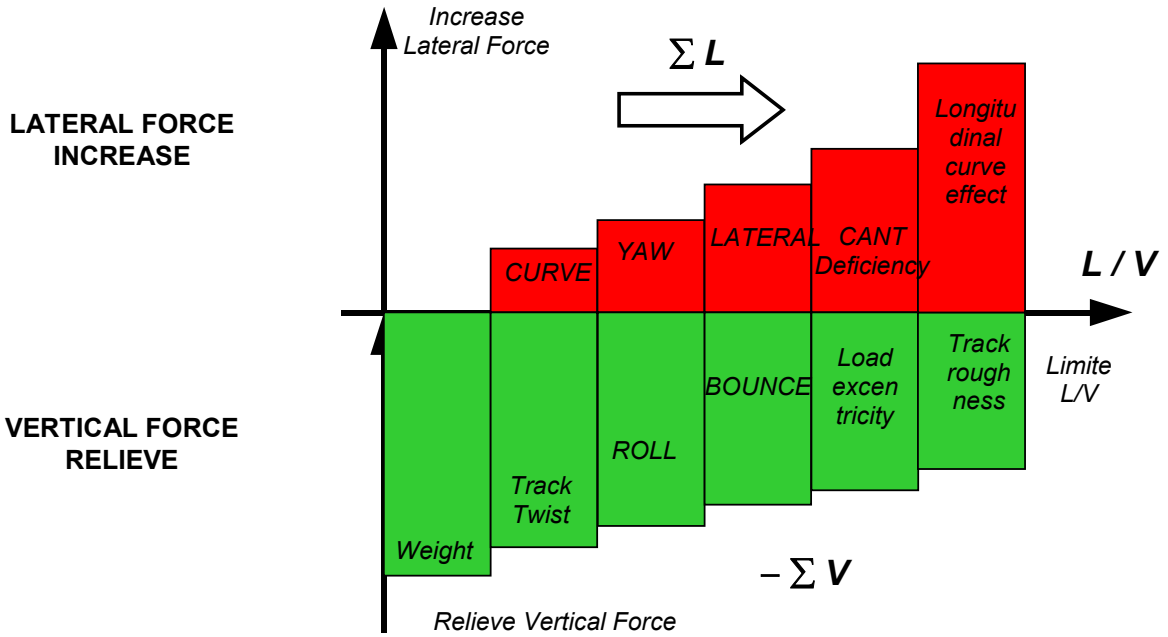
FRICTION CONE

$$\frac{L}{V} \geq \frac{\tan\alpha - \mu}{1 + \mu \tan\alpha}$$

NADAL'S FORMULA

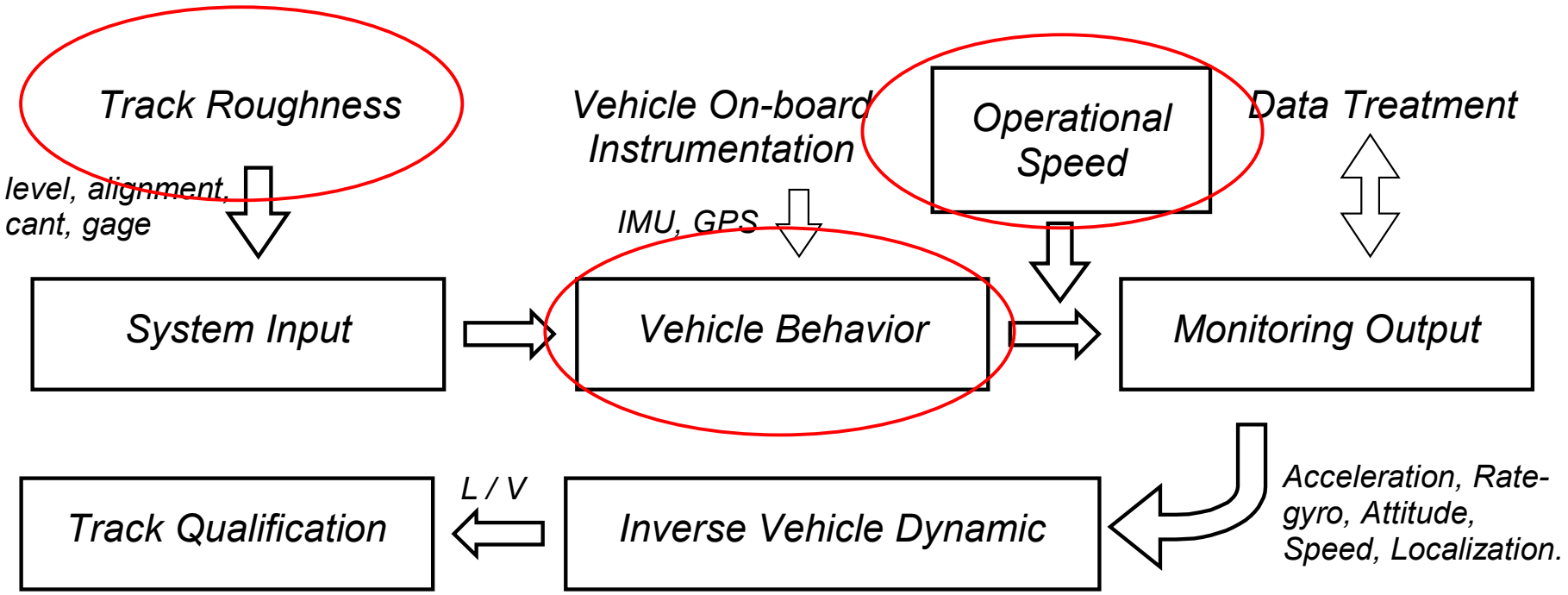
SAFETY COMPOSITION

COMPOSITION EFFECTS ON SAFETY FORMULA



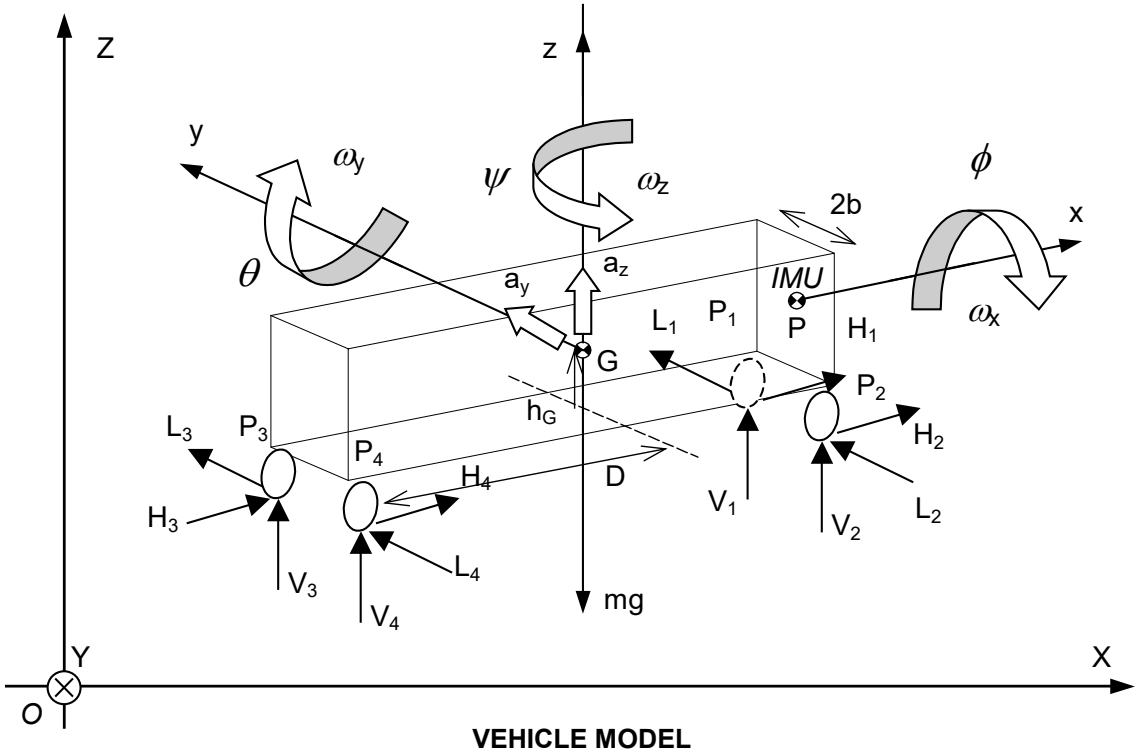
SAFETY VALUE
NADAL'S FORMULA

NEW METODOLOGY



THREE CONCATENATED CONTRIBUTION

VEHICLE MODEL



VEHICLE MODEL

$$m\ {}^{N}\vec{a}_G = \sum \vec{F}_{wheels} - m\ {}^{N}\vec{g}$$

$$[J]_G\{\dot{\omega}\} + [\tilde{\omega}]\cdot[J]_G\{\omega\} = \{M_G^{ext}\}$$

$$\vec{a}_G = \vec{a}_P + \dot{\vec{\omega}} \wedge (G-P) + \vec{\omega} \wedge [\vec{\omega} \wedge (G-P)]$$

DYNAMIC EQUATIONS

DATA TREATMENT

INERTIAL MEASUREMENTS ⇒ INVERSE DYNAMICS ⇒ EVALUATE SAFETY – L/V

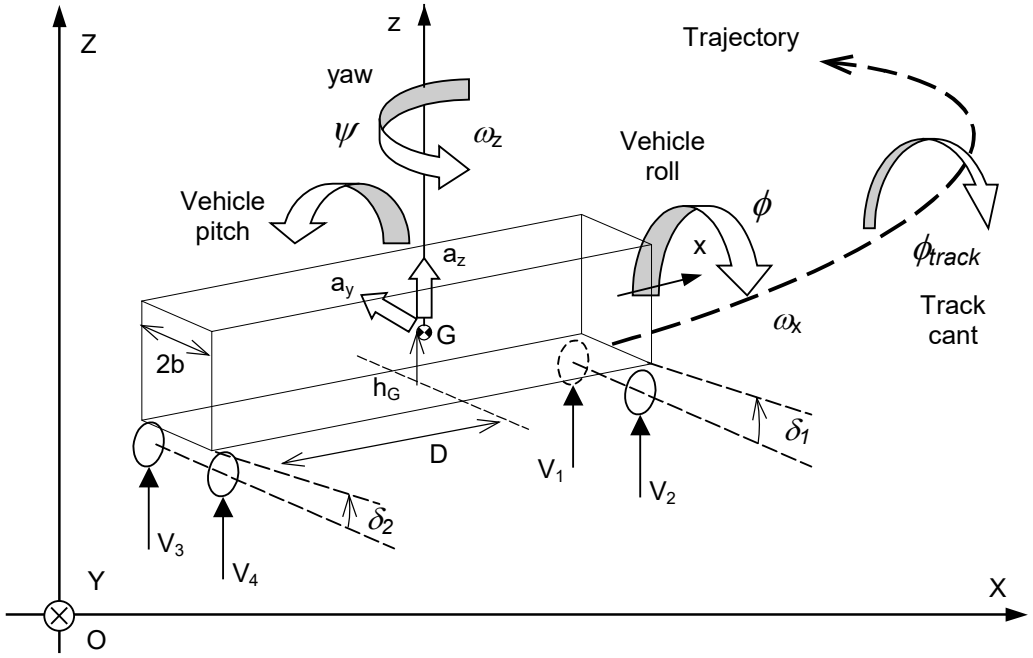
$$\vec{F}_{wheel} = -m \cdot \left({}^{N}\vec{a}_{G} + {}^{N}\vec{g} \right)$$

$$\left\{ M_{G}^{ext} \right\} = \left[J \right]_{G} \left\{ \dot{\omega} \right\} + \left[\tilde{\omega} \right] \cdot \left[J \right]_{G} \left\{ \omega \right\}$$

SOLVE THE INVERSE DYNAMIC EQUATIONS

VEHICLE TRAJECTORY

VEHICLE MOVEMENT DUE TO CURVE INSCRIPTION



CURVE INSCRIPTION

HOW DOES IT WORKS?

SYSTEM PERCEIVE VEHICLE OSCILATIONS DUE TO TRACK ROUGHNESS AND TRAIN SPEED

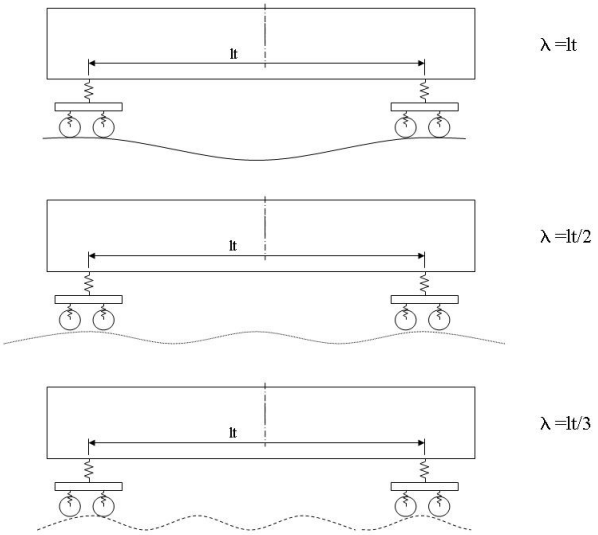
VIBRATION MONITORED IS CONVERTED INTO FORCE INPUT FOR THE VEHICLE (INVERSE DYNAMIC MODEL)

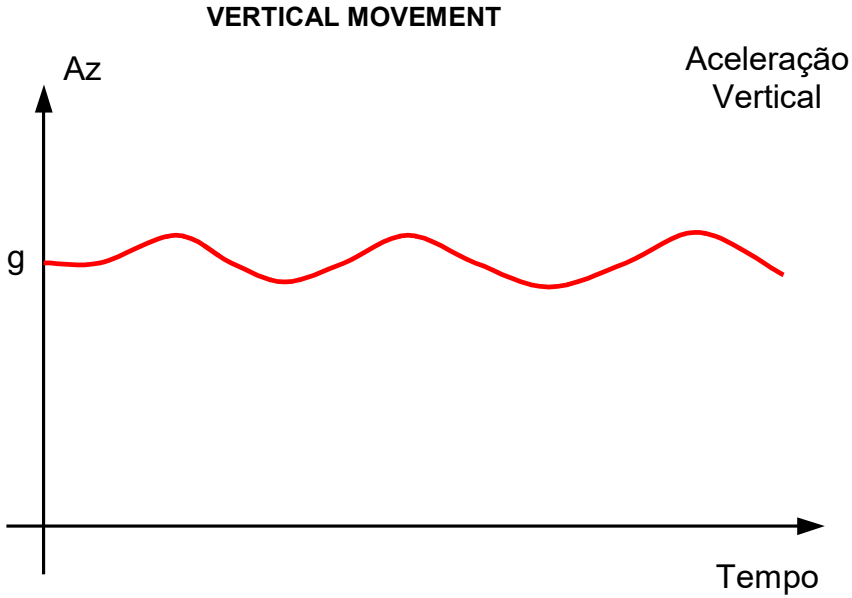
VEHICLE SAFETY IS ASSOCIATED WITH LOCATION OF POOR TRACK QUALITY

PRIORITY LOCATIONS FOR EFFECTIVE MAINTENANCE IS ELECTED

VEHICLE OSCILATION

VERTICAL OSCILATION DUE TO TRACK ROUGHNESS

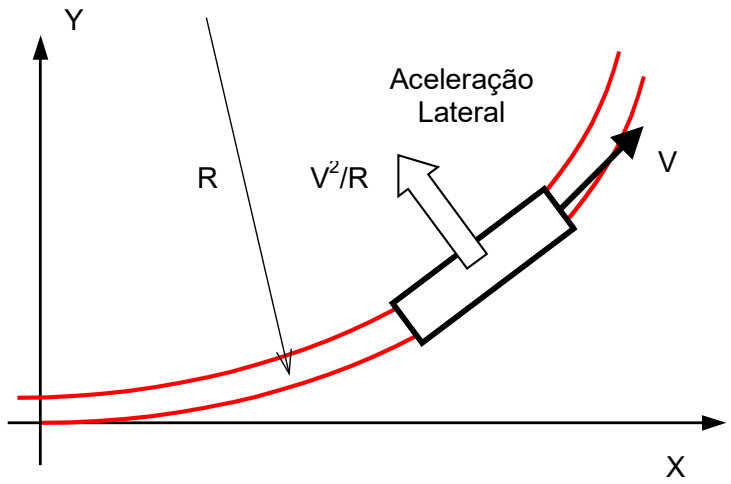




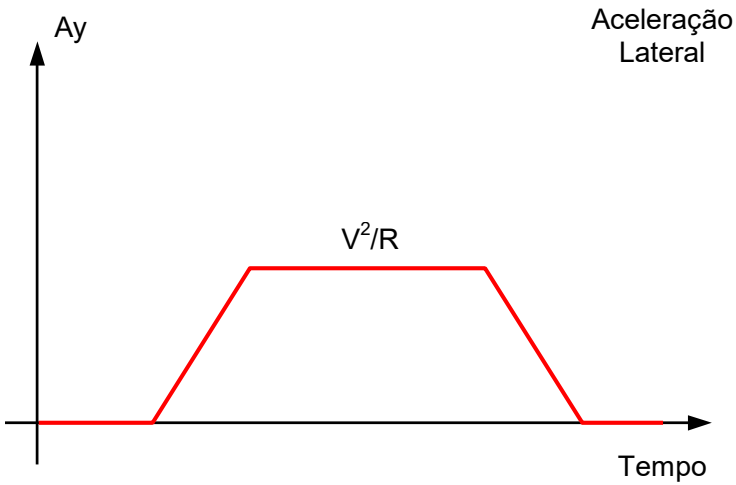
VEHICLE INSCRIPTION

LATERAL LOAD DUE TO CURVE INSCRIPTION

CIRCULAR TRAJECTRY

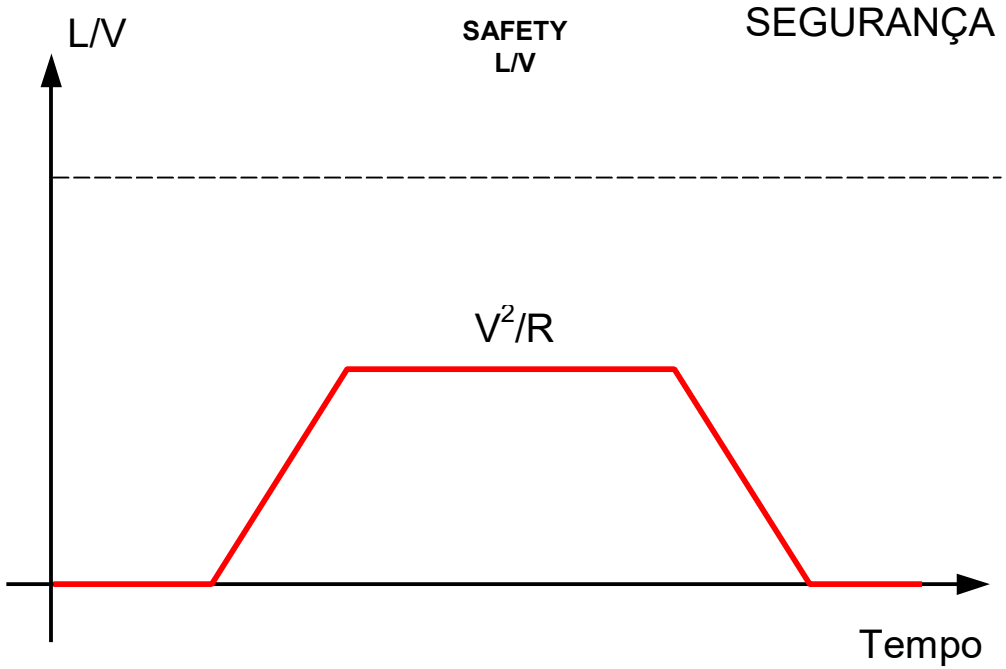


LATERAL ACCELERATION



VEHICLE SAFETY

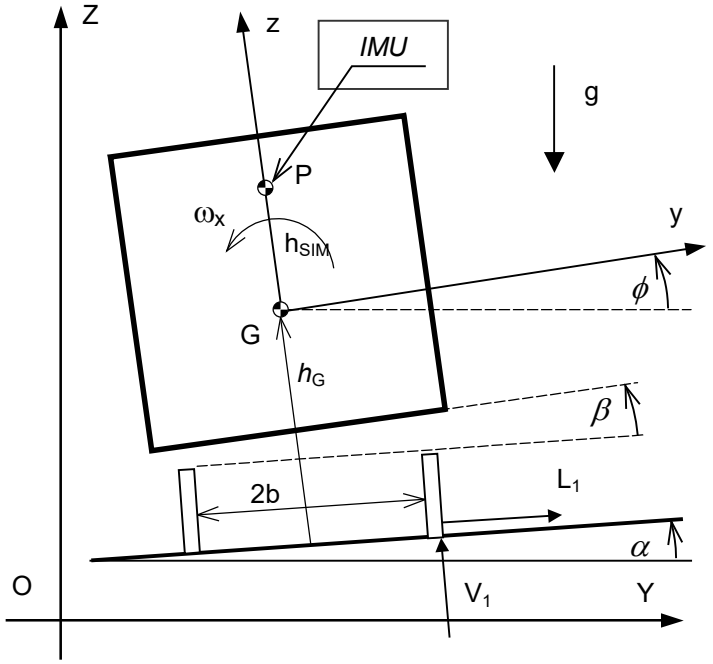
SAFETY DUE TO TRACK GEOMETRY



$$\frac{L}{V} = \frac{mV^2 / R}{m\,A_z}$$

SUSPENSION TORSION

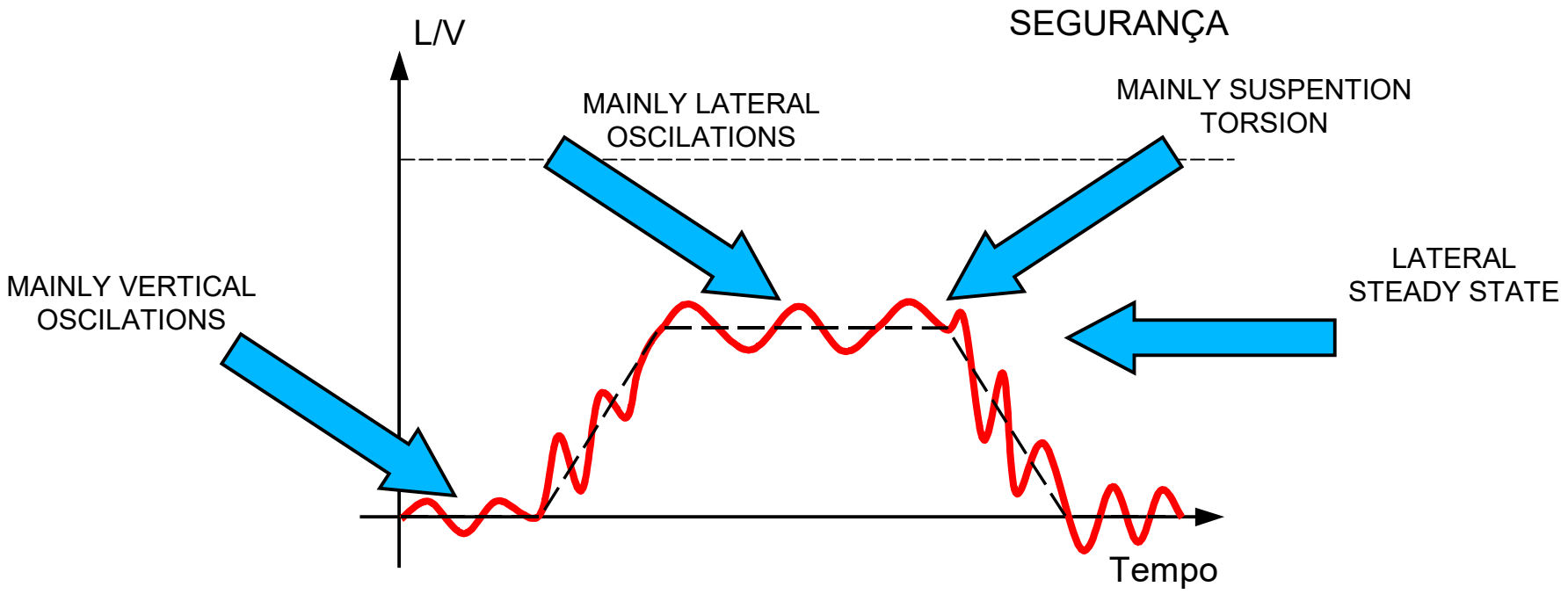
BODY ROLL AND SUSPENSION TORSION DUE TO TRACK TWIST



$$\Delta V = -k_{\varphi} \frac{D}{2b} \delta$$

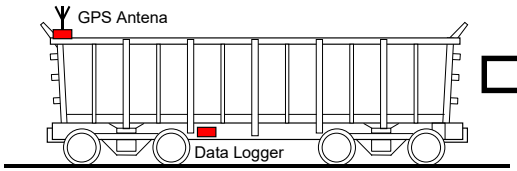
GLOBAL VEHICLE SAFETY

ALL EFFECT COMBINATION

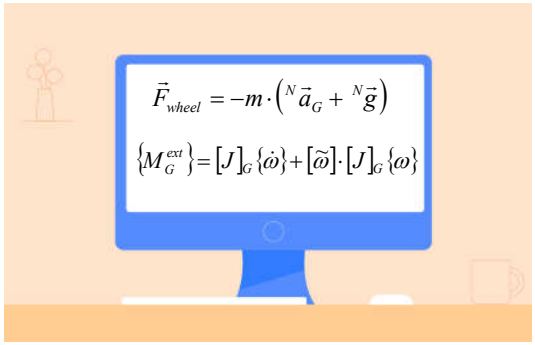


NEW SYSTEM CONFIGURATION

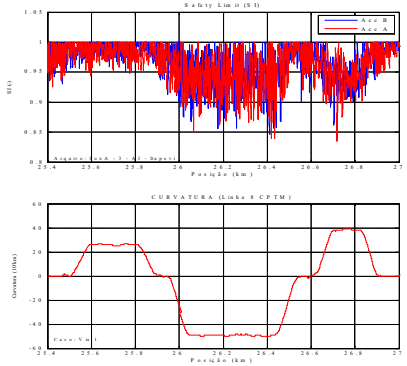
Vehicle Instrumentation → *Data Treatment* → *Poor Safety Location*



MONITORING



INVERSE DYNAMICS



EFFECTIVE MAINTENANCE

SYSTEM EVALUATION

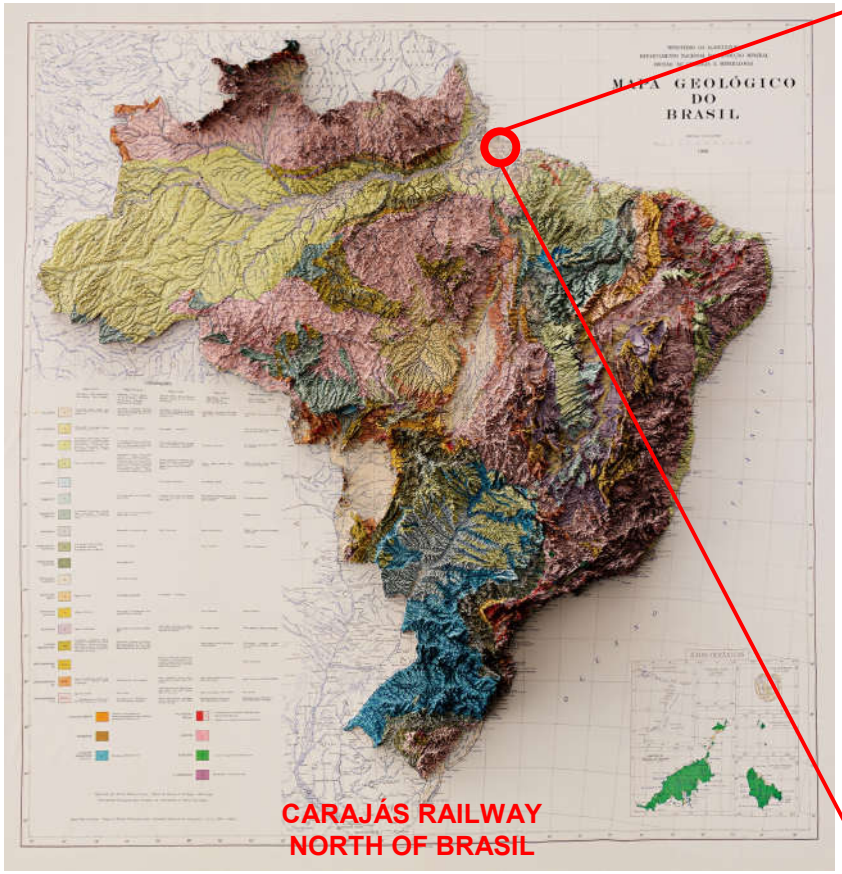
TWO PERFORMANCE TEST

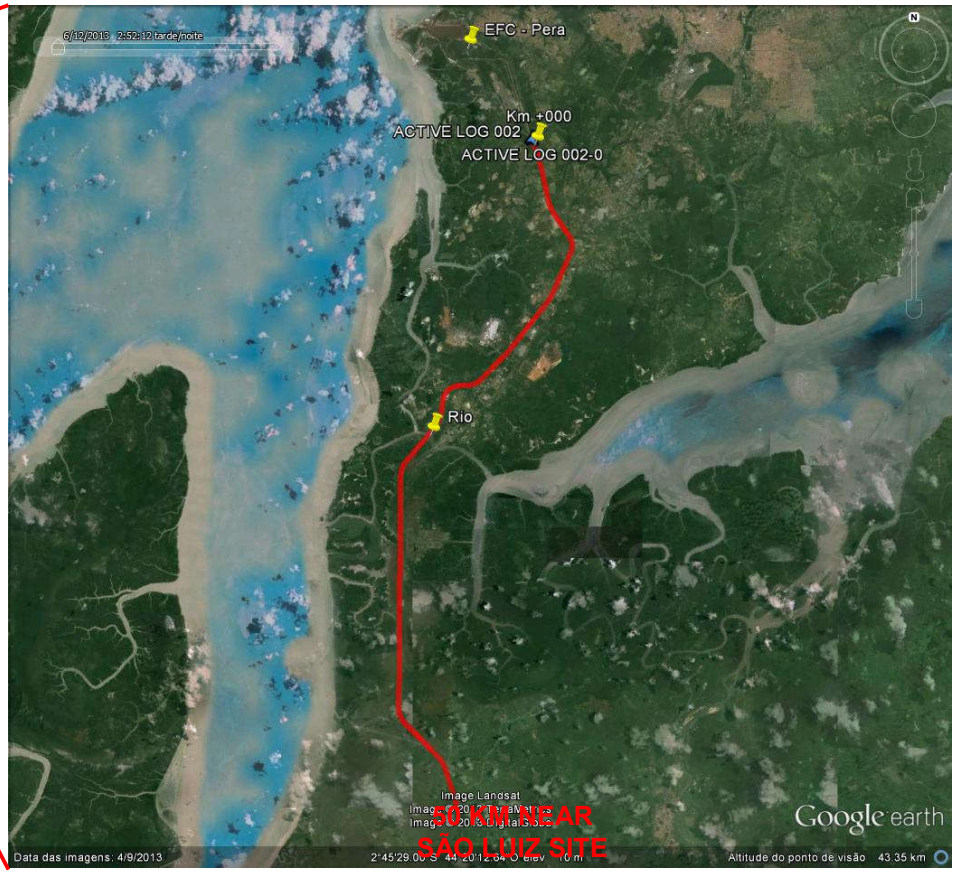
A) IRON ORE WAGON - HEAVY HALL TRAIN

B) PASSENGER CAR - URBAN COMMUTER TRAIN

WAGON PERFORMANCE TEST

TEST SITE – CARAJÁS RAILWAY



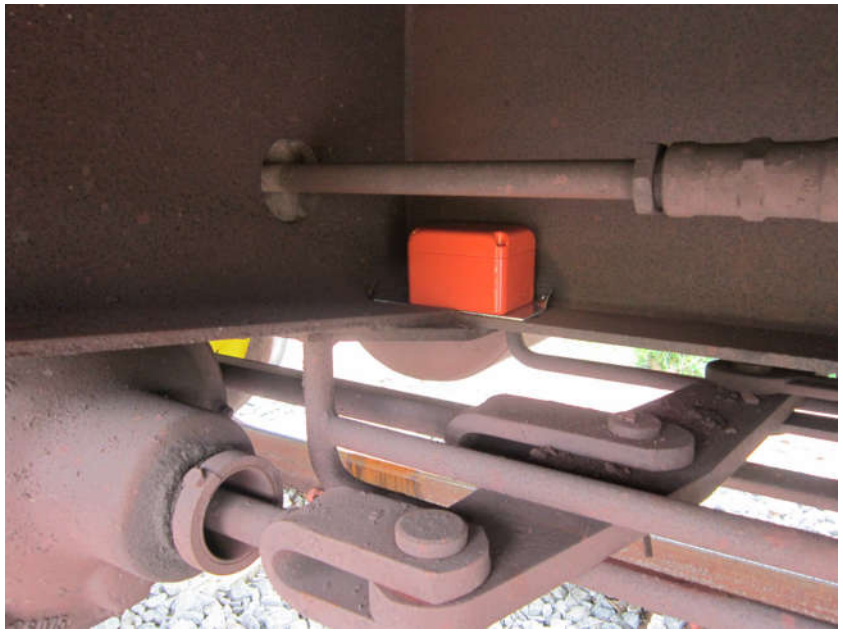


500 KM NEAR
SÃO LUIZ SITE

IMAGES FROM INTERNET

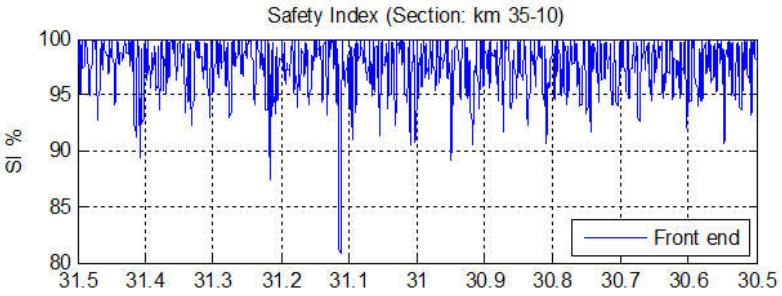
WAGON INSTRUMENTATION

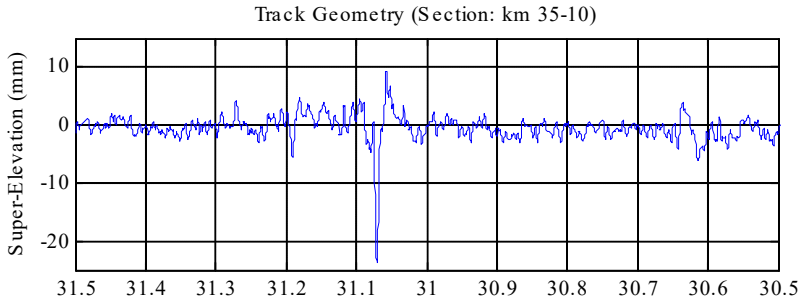
120 TON GDT IRON ORE WAGON - VALE

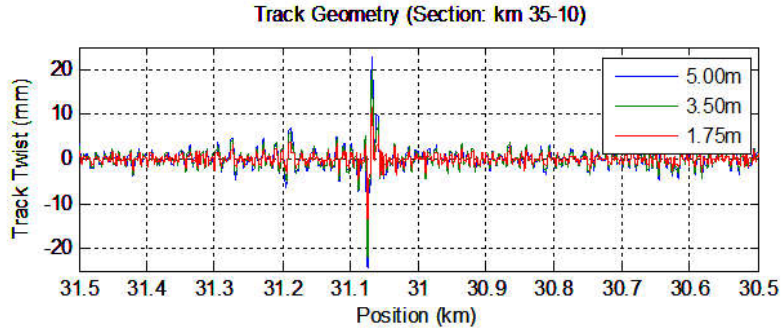


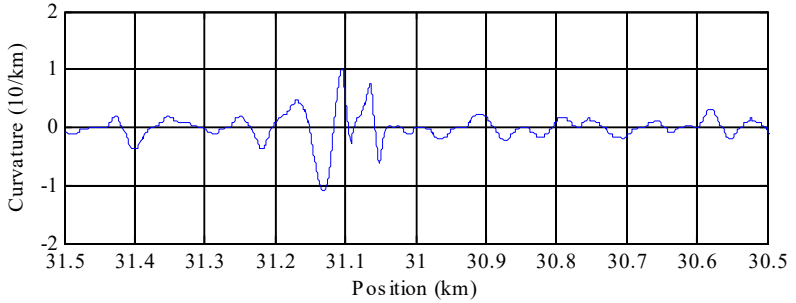
TEST RESULTS WAGON

SAFETY × MEASURED TRACK GEOMETRY



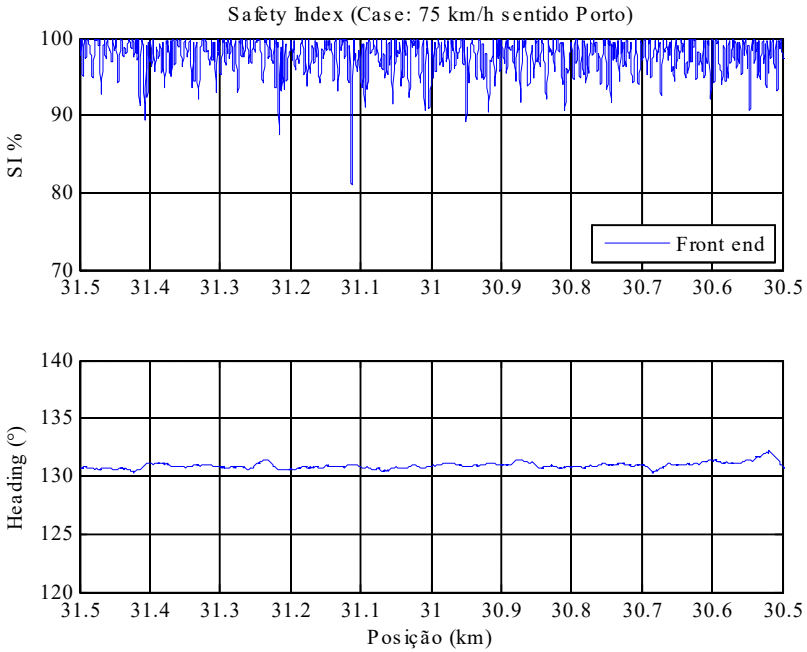


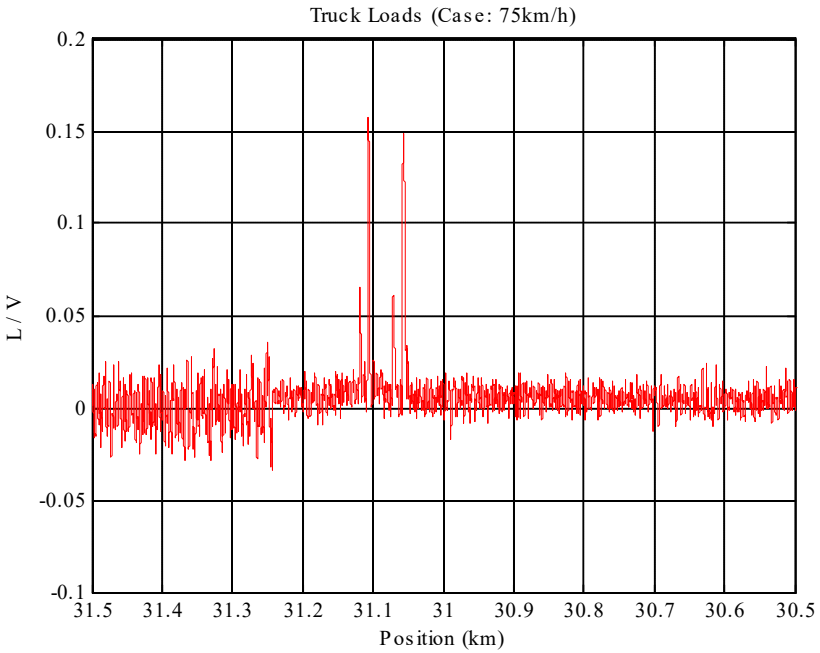




TEST RESULTS WAGON

SAFETY × MEASURED L/V (IWS)

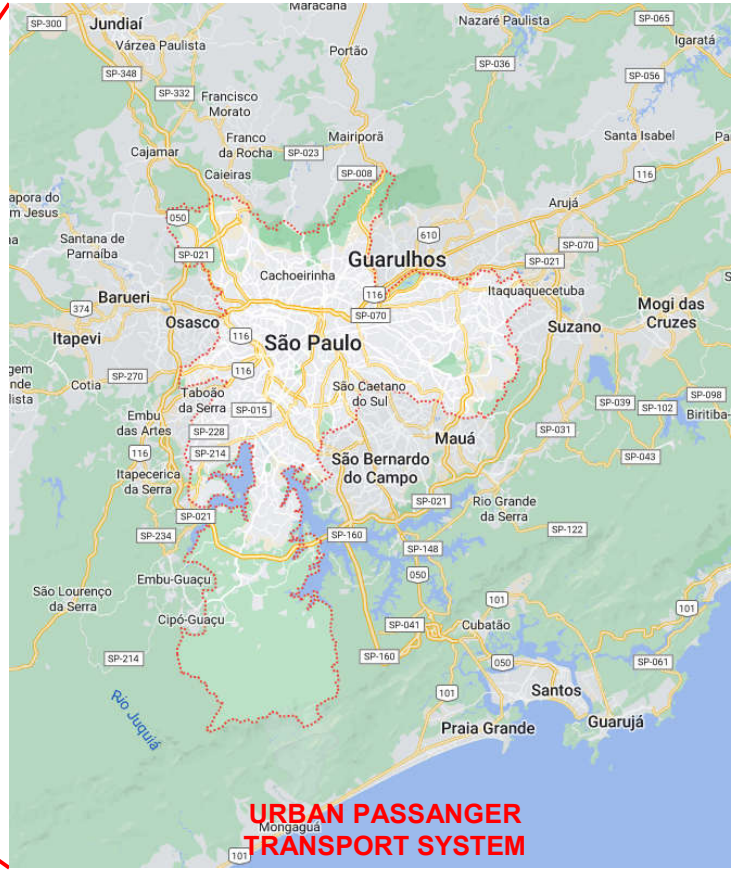




PASSENGER CAR PERFORMANCE TEST

TEST SITE – SÃO PAULO

SÃO PAULO CITY
SOUTH-EAST BRAZIL

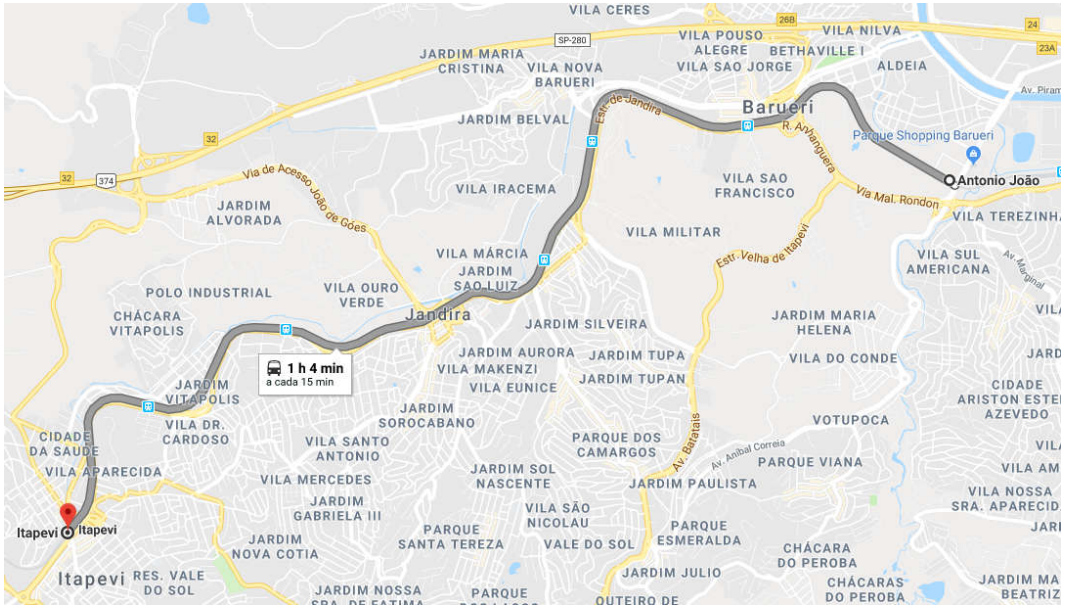


URBAN PASSANGER
TRANSPORT SYSTEM

IMAGES FROM INTERNET

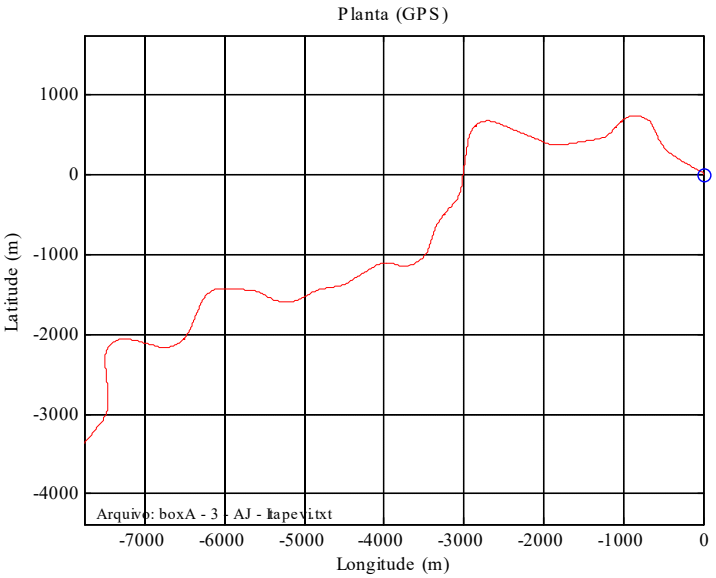
TEST SITE - CPTM

TRACE LINE & GPS SIGNAL (PASSENGER CAR - CPTM)



LINE 8 - CPTM

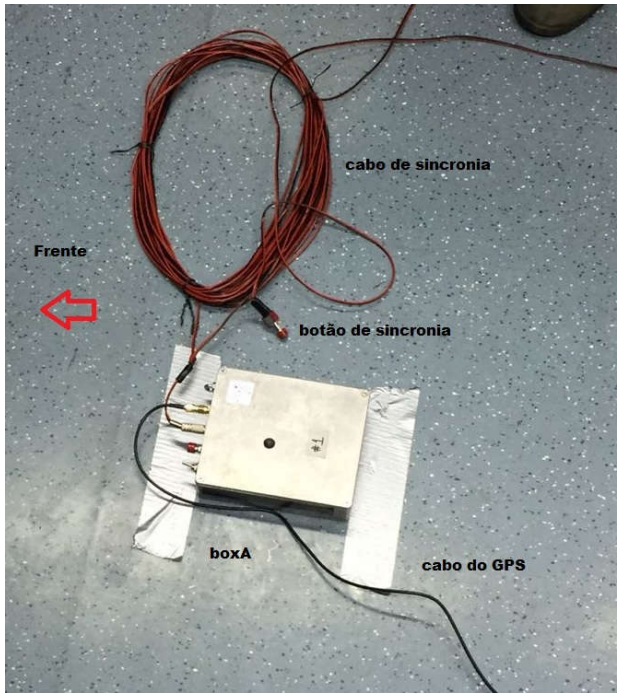
IMAGE FROM INTERNET



GPS SIGNAL

INSTRUMENTATION

DATA LOGGER + GPS PASSENGER CAR - CPTM



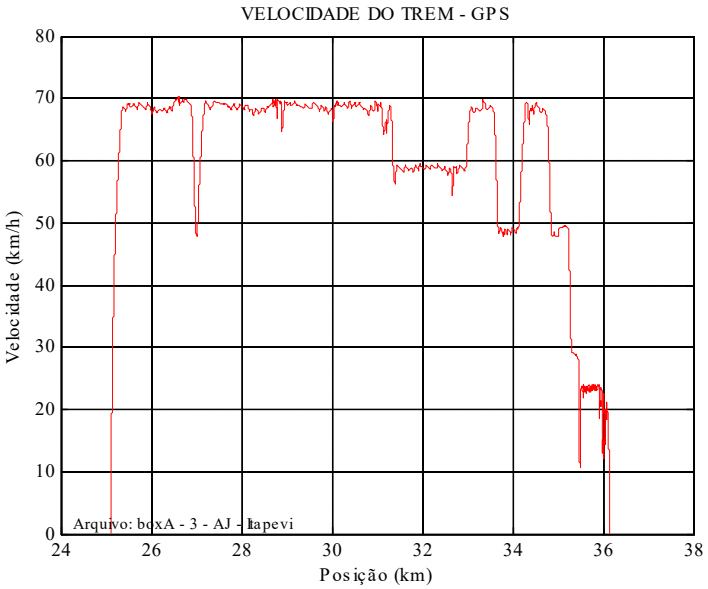
DATA LOGGER + IMU

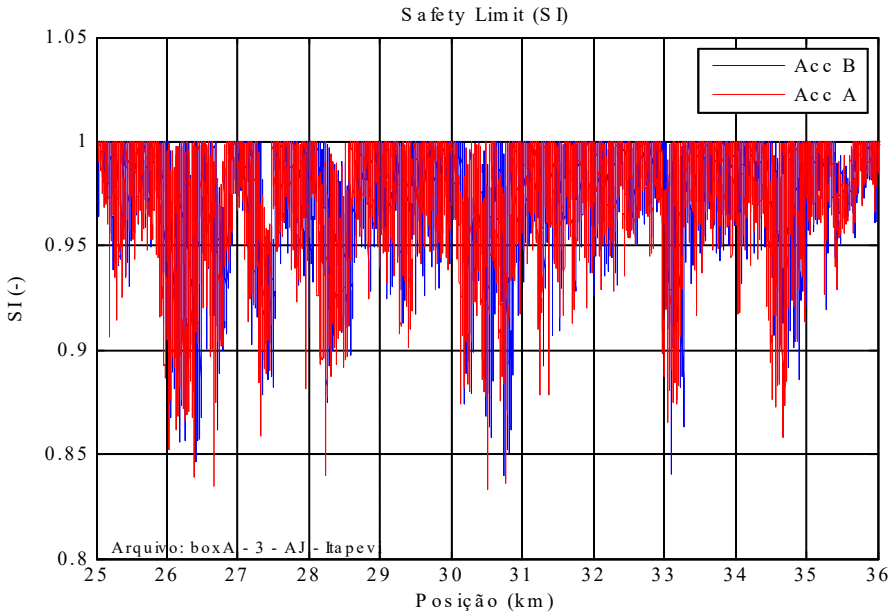
PASSENGER SALOON

TRUCK INSTRUMENTATION

TEST RESULTS

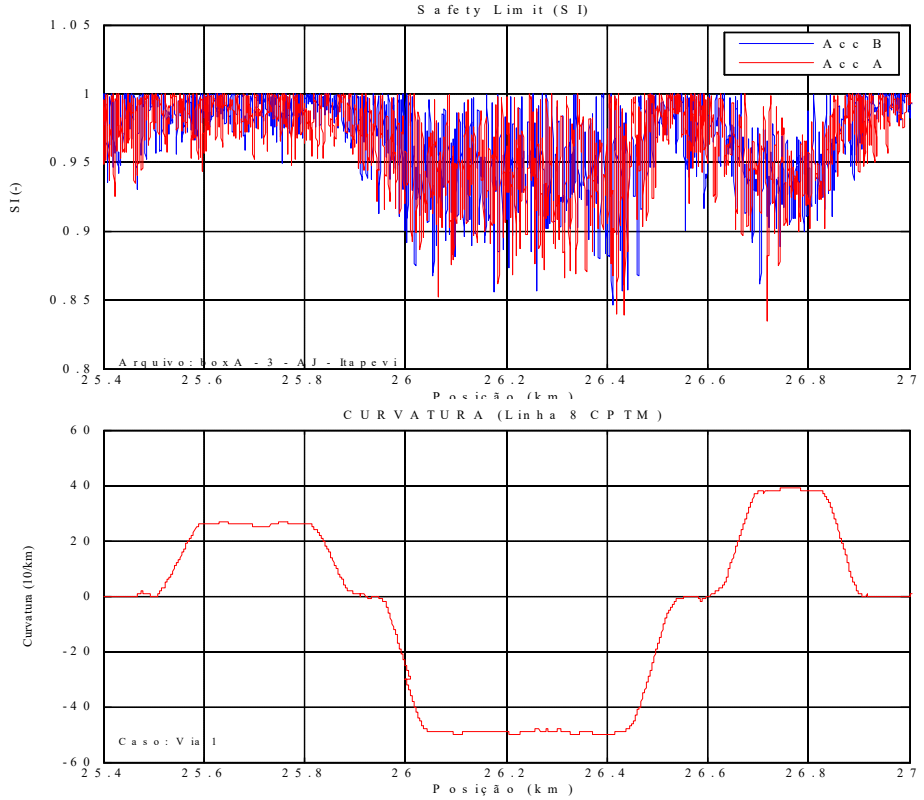
SPEED & SAFETY (PASSENGER CAR - CPTM)





TEST RESULTS

COMPARISON SAFETY & CURVATURE (PASSENGER CAR - CPTM)

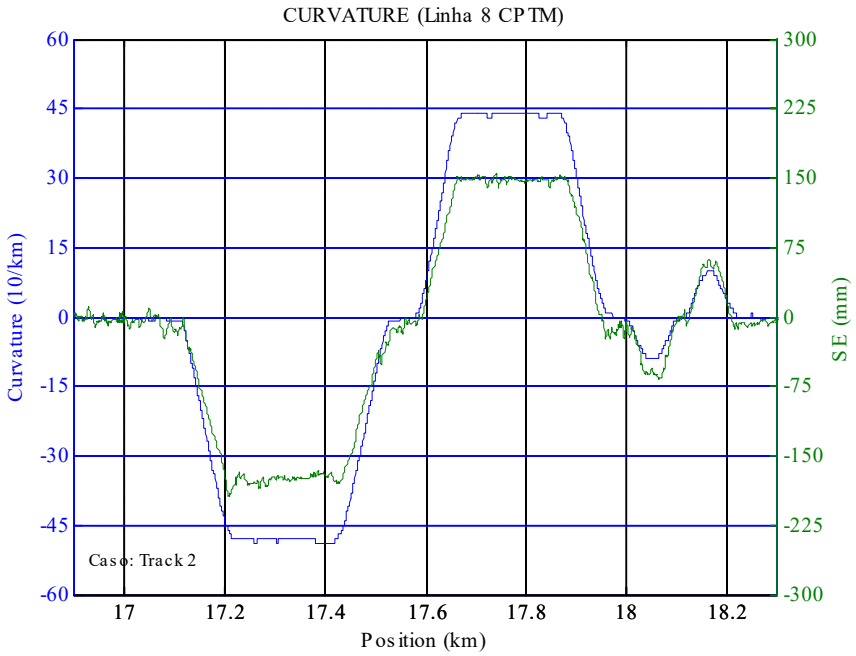


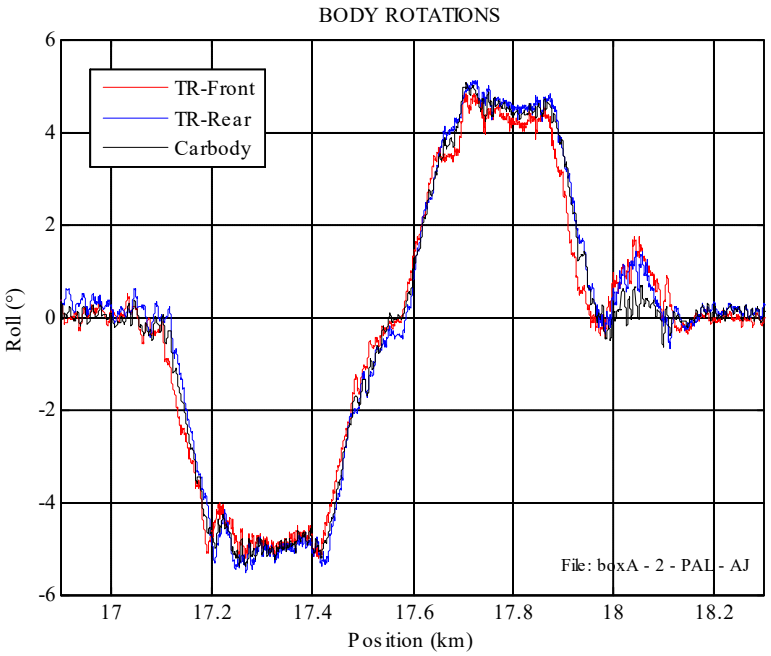
TEST RESULTS

CRITICAL LOCATION

ANALYSIS

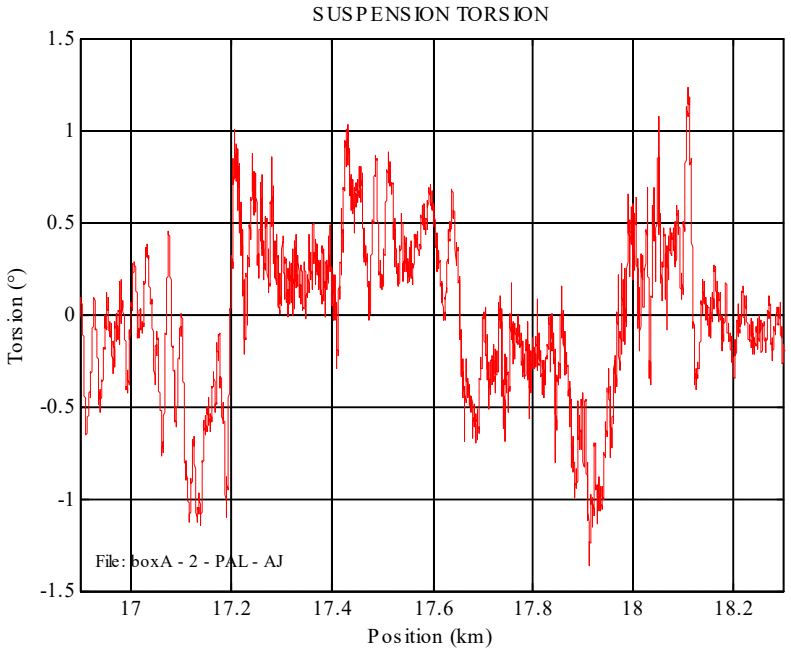
TRACK GEOMETRY × BODY ROLL

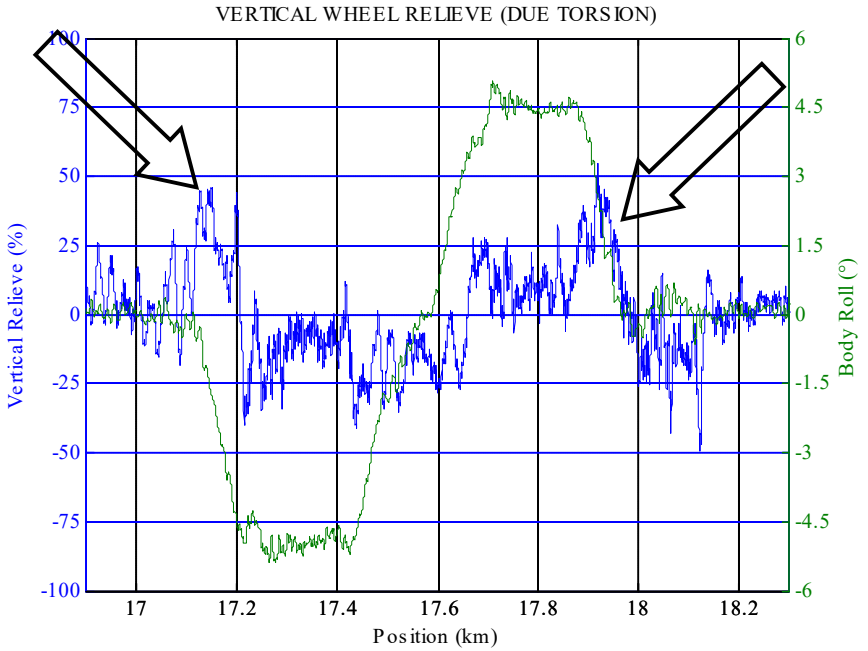




ANALYSIS

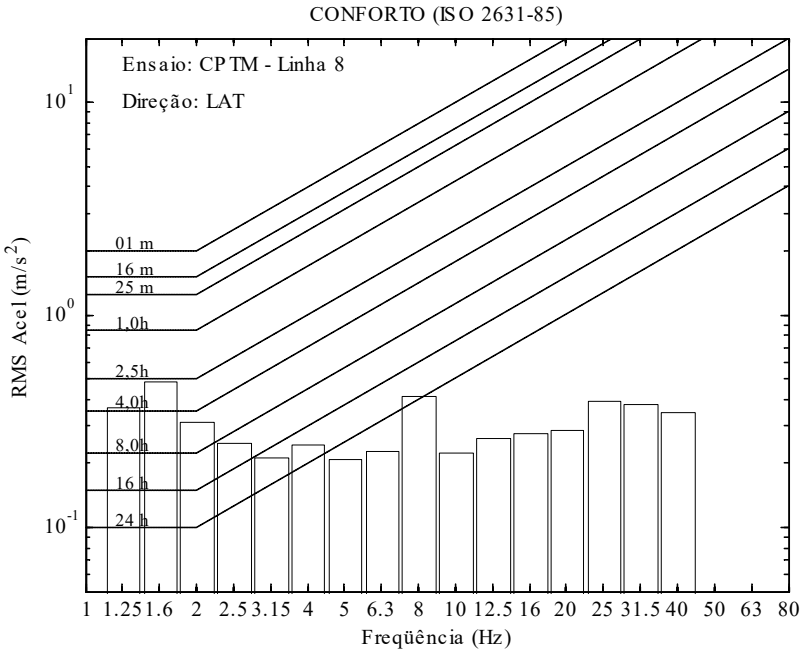
SUSPENSION TORSION × LOAD RELIEVE

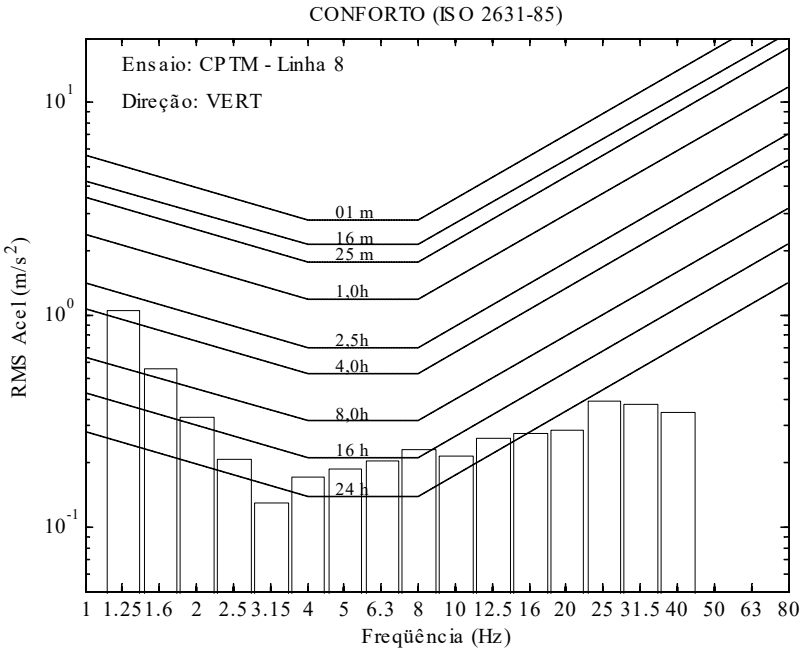




ANALYSIS

CONFORT ANALYSIS – ISO 2631





CONCLUSIONS

- Developed inertial onboard system measures carbody dynamics due to track irregularities and estimate the L/V safety ratio.
- The system records the exact geo-referenced location on the track with poor quality or safety for maintenance purposes.
- The monitoring system is easy to install, can be used with any type of rolling stock at any speed and does not disturb the regular system operation.
- The analyses can be focused to compute different priority criteria (passenger comfort, minimal dynamic vertical load applied to the track, instantaneous safety indicator, etc.) according to the user interests.
- This low-cost measuring method is complementary to the traditional existing ones, been a promising technique.

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The End

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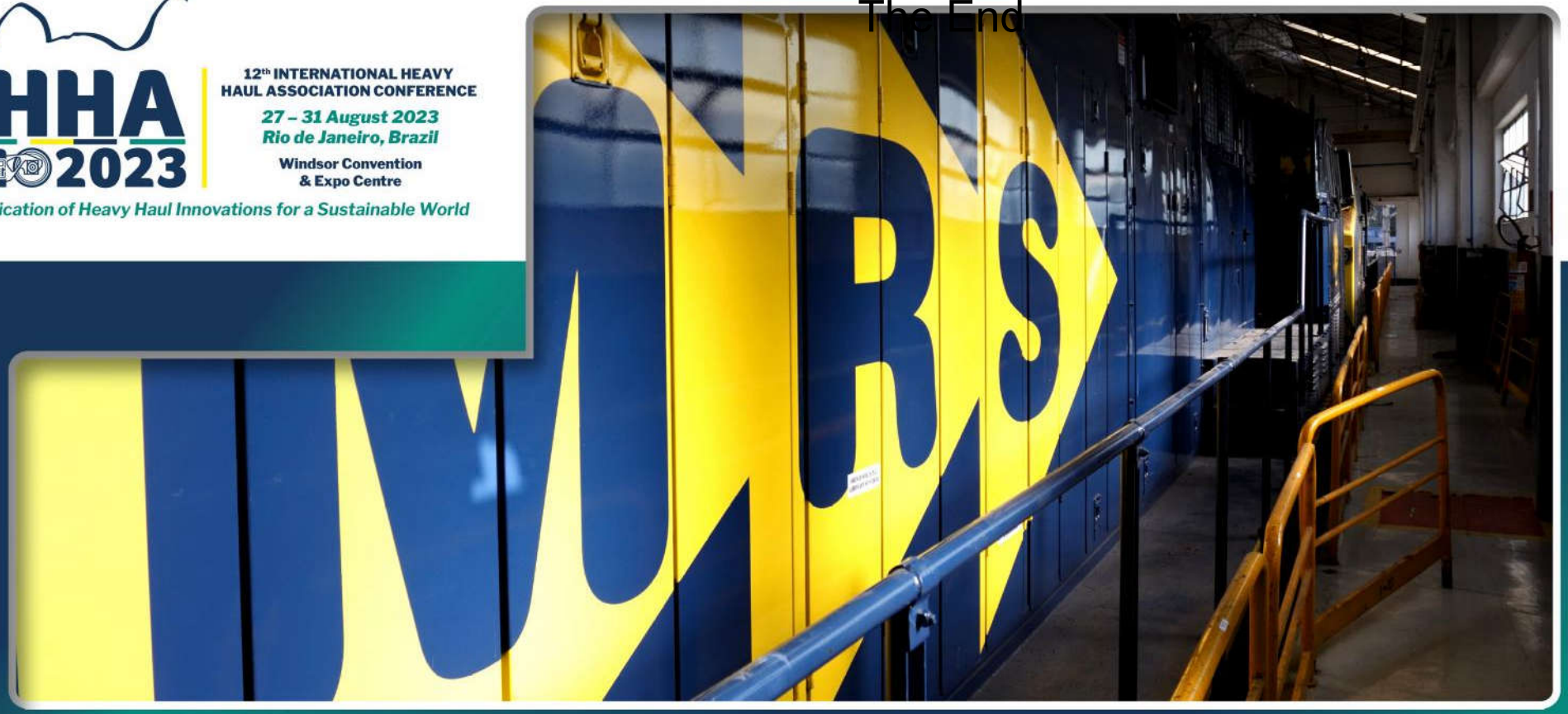

THANK YOU!