Testing Program and Safety Analysis
EPRI International

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Safety and Hazard Analysis

Definition and Objective

A Safety and Hazard Analysis (SHA) is a systematic, comprehensive, and high-level examination of a proposed system's impending hazards. It will identify and classify potential hazards which can occur or contribute to unsafe conditions for the vehicle, environment, or people; both during failure or malfunction situations and during normal operation.

The Safety and Hazard Analysis process is intended as an engineering tool to set system safety design criteria and to help determine the acceptability of a design concept.

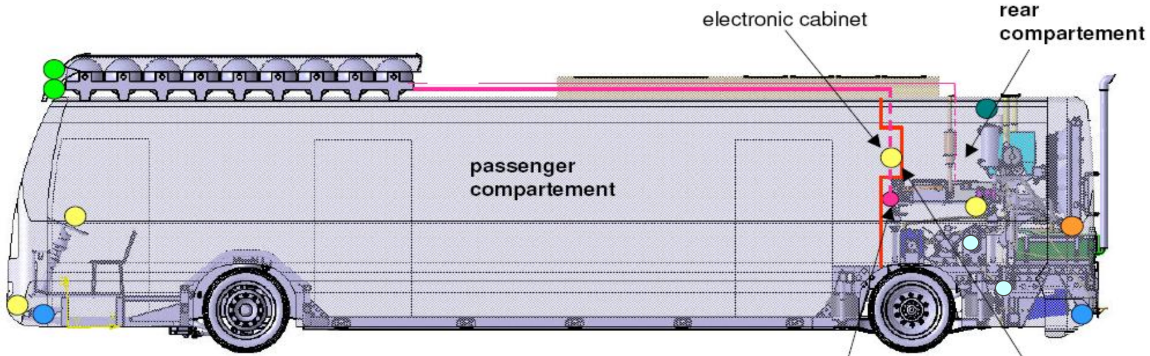
SCOPE

The SHA analyzes the following generic potential hazards as derived from the "Basic Guide to System Safety" which was develop and used in the European CUTE (Clean Urban Transportation in Europe) program.

- Accident / Crash / Collision / Rollover
- Fire & Explosion
- Heat Burns, Steam Burns, and Chemical Burns
- High Pressure Hit
- Electrical shock

- Rotating Equipment, Moving Equipment, and Falling Parts
- Fuelling Hazards
- De-Fuelling Hazards
- Noise
- Environment

Safety Chain Emergency Shut Downs



- Emergency buttons
- Inertia switch
- Collision switch
- Battery temperature switch
- Smoke sensor (directly connected to the VCU)
- HV box and engine bay safety switch

Definition of red and yellow warning lights for the driver

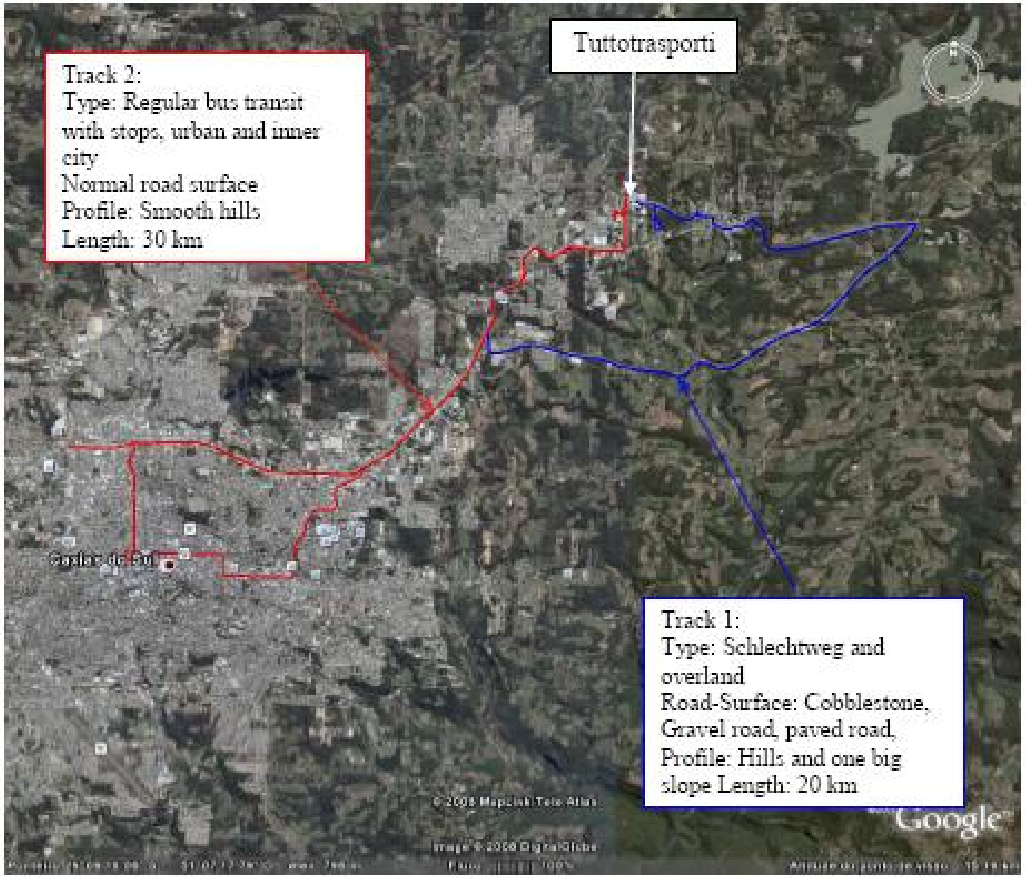
In the software situations for red and yellow warning lights are defined

Driver instructions:

Yellow - The tour can be finished but the bus has to be checked in the station and once it was shut down it can’t be started again without having been checked

Red - the driver has to bring the bus into the next safe spot All safety relevant systems will be shut down automatically

Accelerated Initial Reliability Tests in Caxias



Functional Test Program

Verification Tests I

Verification Tests II

Functional Tests Objectives

⇨ **Ensure that the bus is fulfilling all legal and safety requirements necessary for the operation in the EMTU-corridor;**

⇨ **Ensure that the bus meets the performance specifications and requirements.**

Project Challenges

- Features:
  - Only one vehicle available;
  - Available time to perform the tests;
  - Single route application;
- High complexity project;
- Several technical competencies involved;
- Know-how generation to other vehicles;
- Completely new vehicle:
  - Propulsion system;
  - Further vehicle systems, entirely or partially connected to it;
  - Unconventional axles loads distribution;
- Some vehicular systems are either new or have never been largely applied or have no evaluationn in real field application;
- Need for vehicle and systems homologation.

Test Program

- **Tests definition:**
  - **Based on a list normally applied to new conventional vehicles**
  - **Criticaly conditions**
  - **Available conditions**
- **Test Schedule and Meassurements definition:**
  - **Deadlines**
  - **Capacity**
  - **Fuel Logistic**
  - **Resources**

Test Program

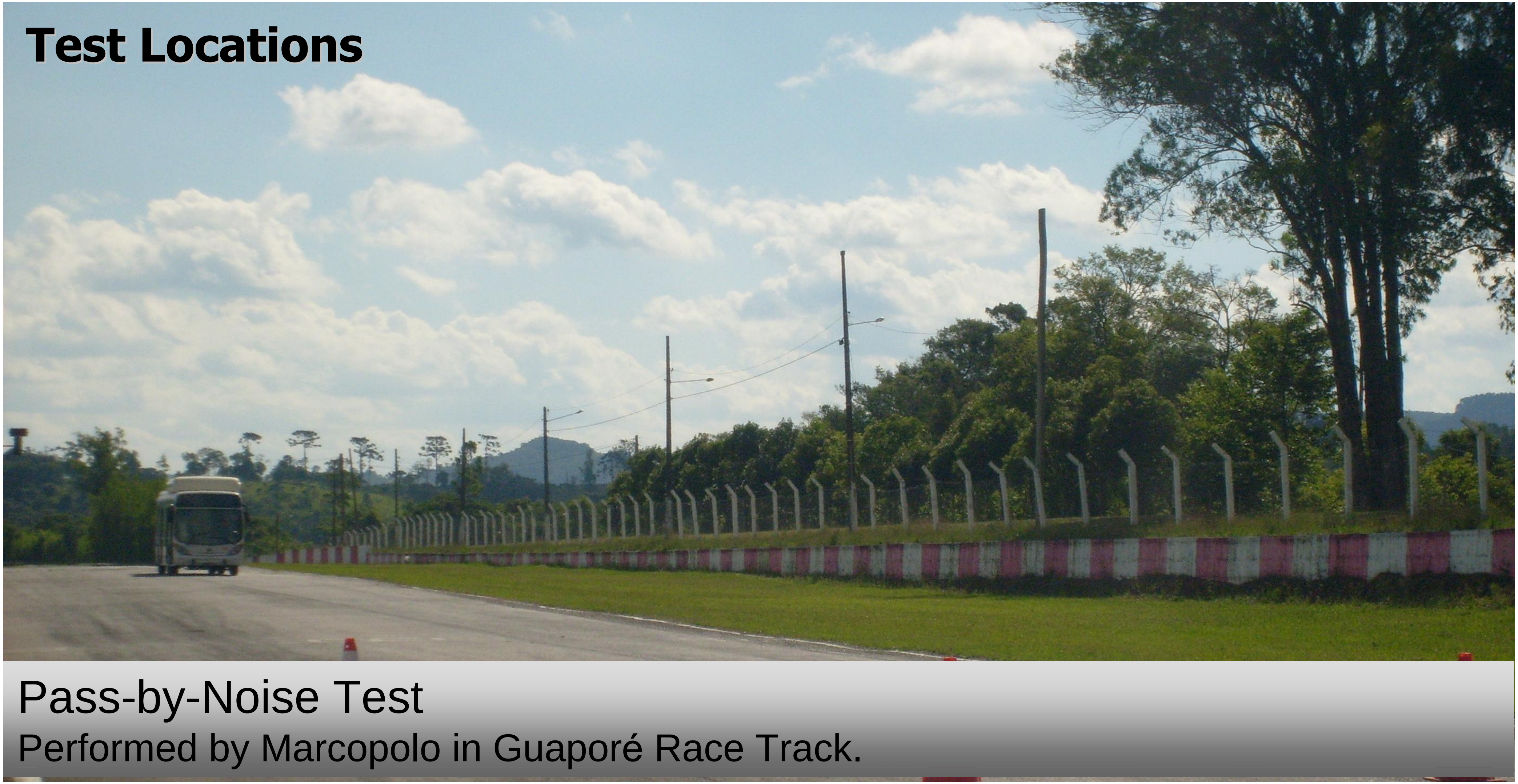
TEST CATEGORY	Specificatio n	Technolog y	Homologation
Overall Capability			
Fuel consumption			
Noise			
Acceleration			
Speed recovery			
Maximum Speed			
Startability			
Gradebility			
Hill holding			
Service Brake			
Emergency Brake			
Parking Brake			
Brake Fading			
Regenerative Brake			
Steering force			

Test Location

Fueling

Performed at Caxias do Sul

Test Locations



Pass-by-Noise Test
Performed by Marcopolo in Guaporé Race Track.

Tests Locations

Caxias do Sul

São Bernardo do Campo

Caxias do Sul

EMTU Track

Data Logging and Instrumentation

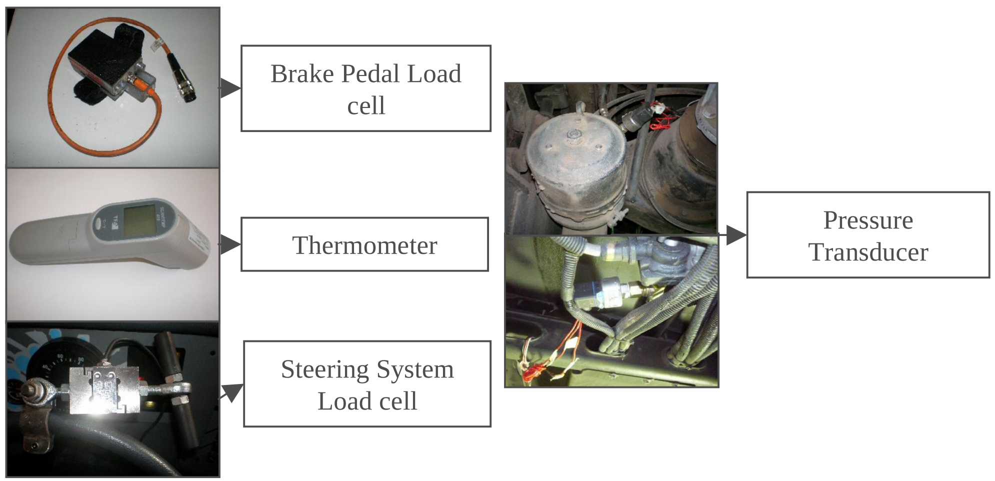
The great amount of information that flows through the vehicle electronic control systems made the performance data collection possible without the need to use complex measuring

- **Logged datas:**
  - **Accelerator pedal position;**
  - **Brake pedal position**
  - **Brake pedal force;**
  - **Front and rear axle air pressure;**
  - Time;
  - **Engine Power;**
  - **Engine rpm;**
  - **Speed.**

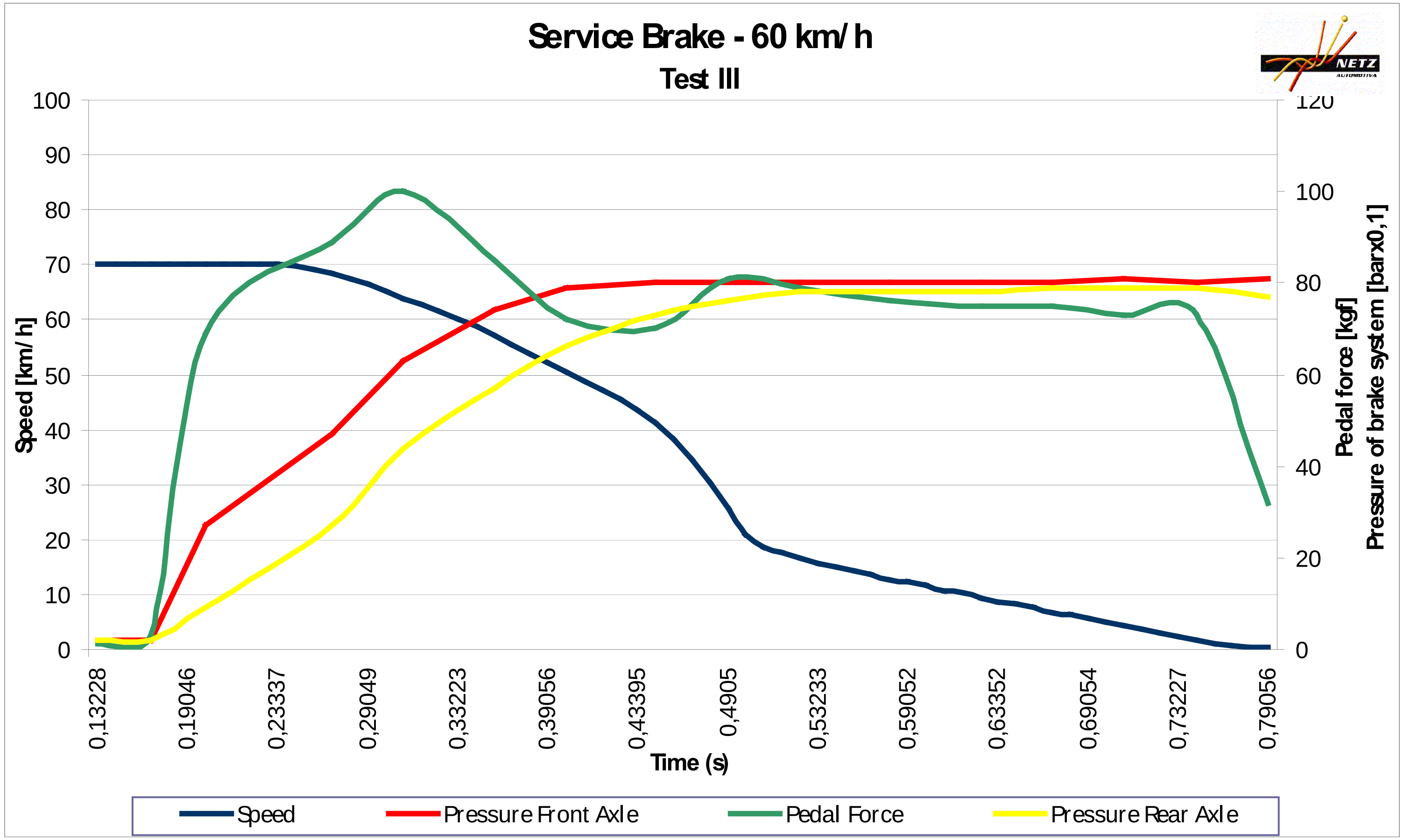
- **The data came from two vehicle CAN lines, a 29bits/250Kbaud and a 11bits/500Kbaud.**

- **Some other necessary data to perform the vehicle analysis were obtained processing the data above.**

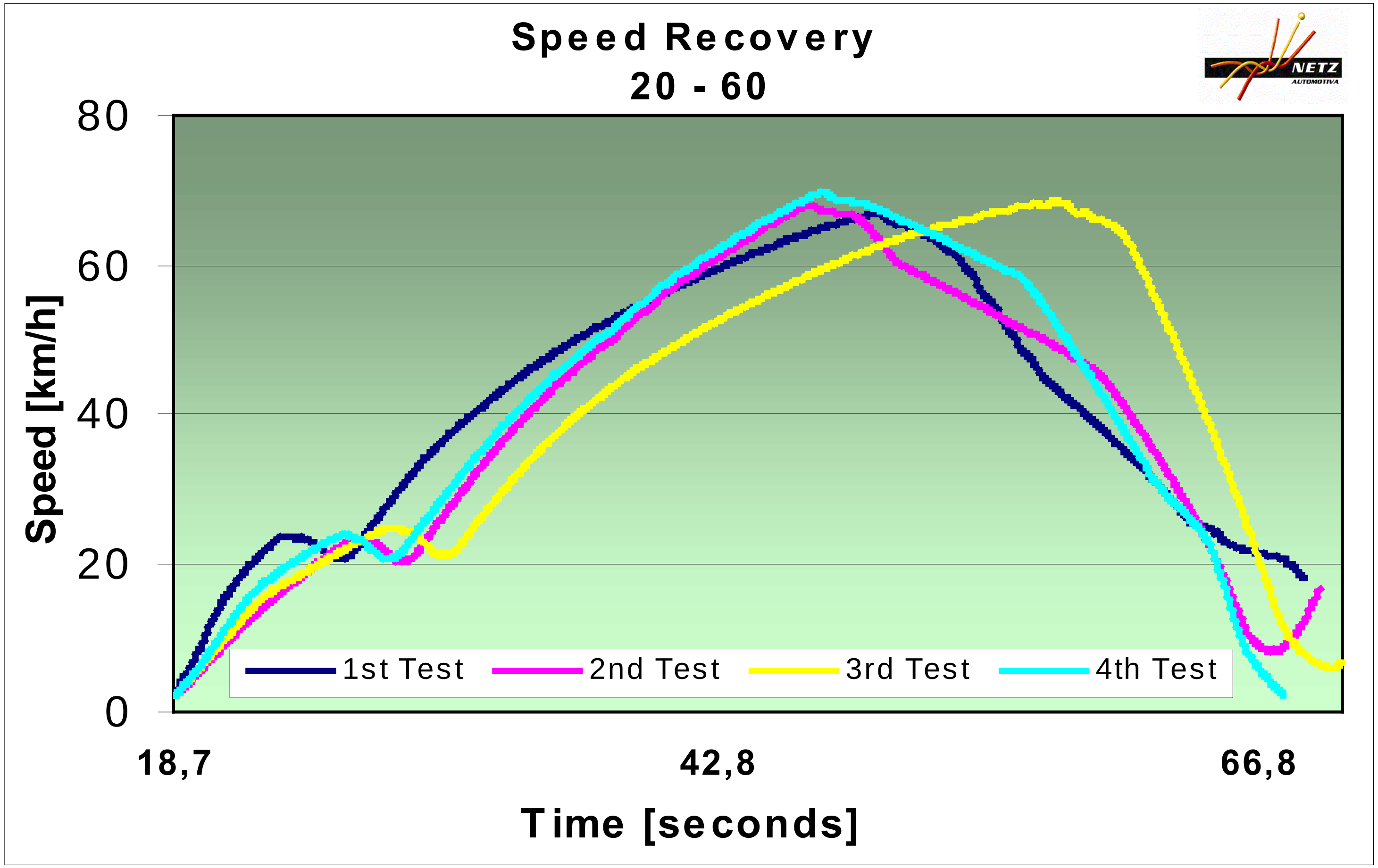
- **Instrumentation**



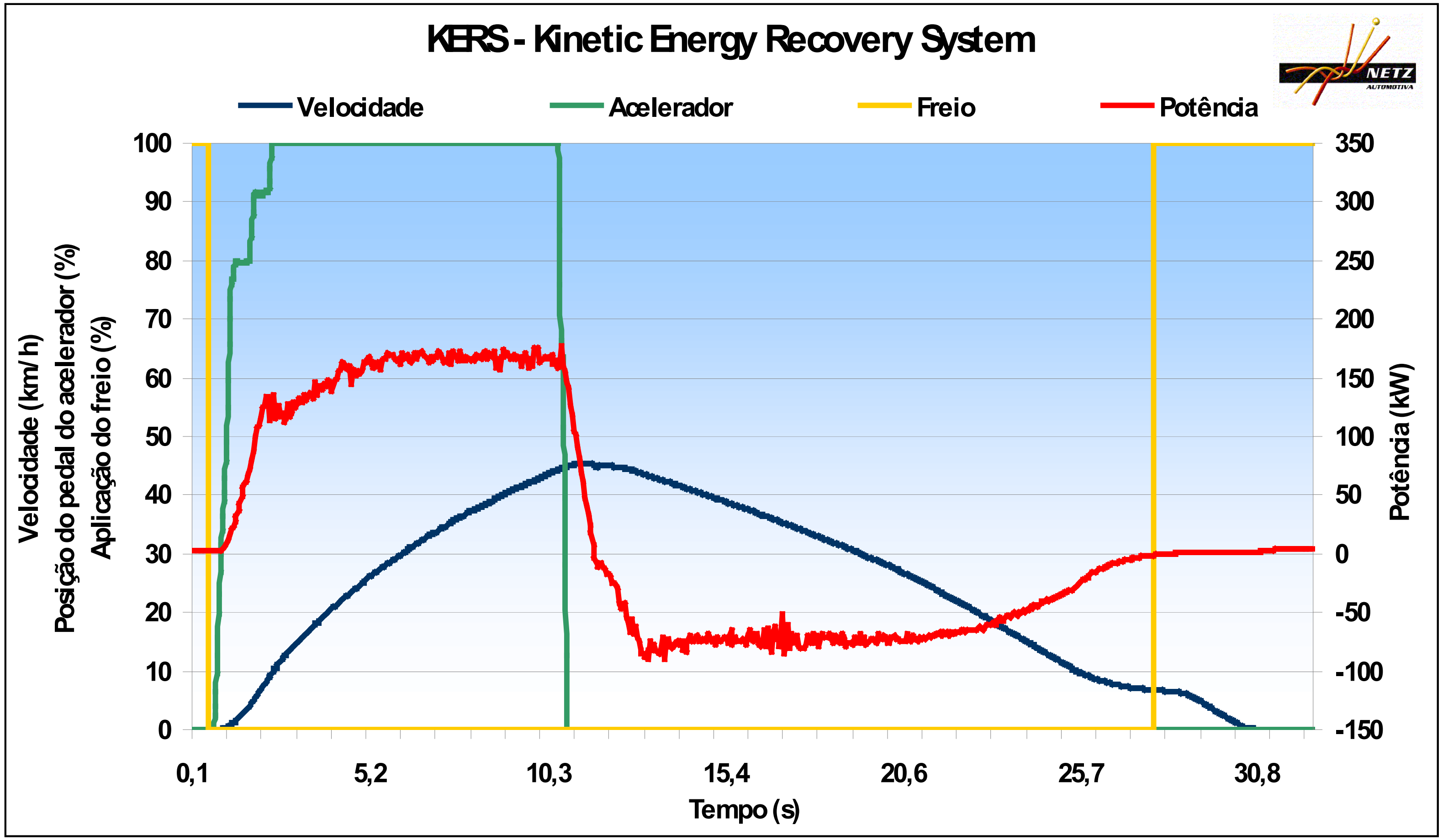
RESULTS


Service Brake - 60 km/h
Test III
Speed [km/h]
Pedal force [kgf]
Pressure of brake system [barx0,1]
Time (s)
0,13228
0,19046
0,23337
0,29049
0,33223
0,39056
0,43395
0,4905
0,53233
0,59052
0,63352
0,69054
0,73227
0,79056
Speed
Pressure Front Axle
Pedal Force
Pressure Rear Axle

RESULTS


Speed Recovery
20 - 60
80
60
40
20
0
Speed [km/h]
1st Test
2nd Test
3rd Test
4th Test
18,7
42,8
66,8
Time [seconds]

RESULTS


KERS - Kinetic Energy Recovery System
Velocidade
Acelerador
Freio
Potência
100
90
80
70
60
50
40
30
20
10
0
350
300
250
200
150
100
50
0
-50
-100
-150
0,1
5,2
10,3
15,4
20,6
25,7
30,8
Tempo (s)
Velocidade (km/h)
Posição do pedal do acelerador (%)
Aplicação do freio (%)
Potência (kW)

TESTS RESULTS SUMARY				
CONTENT	**TEST**	**SPECIFICATIONS**	**RESULT**	**VALIDATION**
1	Validation of overall capability to operate on the EMTU track		Approved	The vehicle has full capability to operate on the EMTU track as regards tested and analyzed items.
2	Fuel Consumption	TOR: minimum 300km autonomy; 15kg H^2 / 100km.	Approved	15,72kg H^2 / 100km average consumption on EMTU track.
3	Noise	CONAMA 272/2000	Approved	The vehicle meets the CONTRAN resolutions concerning to interior and pass-by-noise.
4	Acceleration	The vehicle shall be able to reach the following accelerations on slopes: 1,10 m/s² @ 0%; 1,00 m/s² @ 5%; 0,5 m/s² @ 10%; 0,1 m/s² @ 15%.	Approved	The final acceleration results meet the basic technical specification to a 0%, 5% and 10% slope. Due to route availability the test wasn’t done on a 15% slope.
5	Speed Recovery	Time required for recovery: from 20 to 60km/h; from 40 to 60km/h.	Approved	The final acceleration results, numbers and driver feeling, are similar to a Diesel powered vehicle.
6	Maximum Speed	When the vehicle exceeds 55 km/h, a sound signal shall be activated.	Conditional approval	Vehicle doesn’t have a 55km/h excess sound alert signal. This item can be easily solved by either using the vehicle software or a GPS navigation system available on the market.

TESTS RESULTS SUMARY				
CONTENT	**TEST**	**SPECIFICATIONS**	**RESULT**	**VALIDATION**
7	Startability	The vehicle, at 18,5t total gross weight condition, shall reach 50km/h at most in 15 seconds.	Approved	The final acceleration results meet the basic technical specification to a 0% slope, even with 20% overload
8	Gradeability	The vehicle must be able to go down a slope minimum speeds, from the rest position, on a straight line: 60 km/h @ 0%; 40 km/h @ 5%; 30 km/h @ 10%; 20 km/h @ 15%.	Approved	The vehicle reached a higher speed than the specified to a 0%, 5% and 10% slope. Due to route availability the test wasn't done on a 15% slope.
9	Backward Movement	The vehicle shall be started with an automatically controlled acceleration, regardless of its load and the slope, preventing the backward movement of the vehicle, allowing the motor to be exerted in the limit conditions, without detrimental surges.	Approved	Approved. In both conditions, upward and downward.
10	Service Brake	Test according to CONTRAN 777/93 rules, applied to "Standard Bus", M3 category (vehicle over 8 passengers plus driver with gross total weight over 5t).	Approved	Deceleration and response time better than the specified.

TESTS RESULTS SUMARY				
CONTENT	**TEST**	**SPECIFICATIONS**	**RESULT**	**VALIDATION**
11	Emergency Brake	The vehicle must be braked from 60 to 0 km/h using only the parking brake, instead of the service brake. A 2,5m/s² average deceleration must be obtained / reached.	Approved	Due to safety reasons in the road test the vehicle as not pushed to the braking limit, however the deceleration value (2,42m/s²) was very close to the specification
12	Parking Brake	The vehicle shall remain stationary on a 20% slope at total gross weight condition.	Approved	The parking brake was able to keep the vehicle stopped without using the service brake.
13	Brake Fading	Test according to ABNT NBR 10967 (Based on ECE 13). The vehicle shall be subjected to a 20 times braking cycle from 60km/h to 30km/h. The minimum time between each braking (including speed increasing at full power) is 60 (-0 +10) seconds.	Approved	No efficiency loss was observed on the braking cycle. Average deceleration, in Caxias test, greater than the specified. The test was repeated in SP with positive results.
14	Regenerative Brake	The control equipment shall promote a maximum deceleration between 1,0m/s² and 1,3m/s².	Approved	The system was suitable for use and had a much better performance than a conventional engine brake from a Diesel Powered vehicle in this category.
15	Steering Force	The tangential effort applied by the driver, in case of a total loss of hydraulic assistance in any maneuver, shall not be higher than 500N.	Approved	The average tangential effort applied by the driver, without hydraulic assistance, was 371,6N. The maximum value was 374,1N.

Results and Findings

⇨ The results of the tests carried out shows the high level of maturity of the Hydrogen Brazilian Bus project on the tested topics.

⇨ The vehicle responded positively to all trials carried out, generally reacting far beyond the limits established by both norms and the contract.

⇨ During the tests, the Netz technicians and drivers always weaved positive comparative impressions on the H2 Bus’s reactions, especially regarding safety in the operation and general performance.

⇨ It was positively evaluated in the EMTU corridor as its general performance, with a better performance than the conventional diesel powered vehicle fleet.

⇨ The vehicle has full capability to operate on the EMTU track as regards tested and analyzed items.

Thank you!