Prototype of a Smart Load-Sensor

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Involved partners / Version control

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3D	Three-dimensional
Abb.	Description of Abbreviation
°c	Celsius
CATIA	Computer Aided Three-Dimensional Interactive Application
CREAM	Customer-driven Rail-freight services on a European mega-corridor based on Advanced business and operating Models (FP 6 project)
CSD	Circuit Switched Data
DB	Deutsche Bahn
EGNOS	European Geostationary Navigation Overlay Service
EMC	Electromagnetic compatibility
FDMA	Frequency Division Multiple Access
Hz	Hertz
IABG	Industrieanlagen-Betriebsgesellschaft
g	Gravitional force
GLONASS	Globalnaya navigatsionnaya sputnikovaya sistema
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
kbps	Kilobit per second
kg	Kilogramme
km	Kilometre
LED	Light-emitting diode
m	Metre
M2M	Machine-to-Machine
m/s	Metre per second
Mhz	Megahertz

MSAS	Multi-functional Satellite Augmentation System
PCB	Printed Circuit Board (electronic board)
SBAS	Satellite-based augmentation system
SMS	Short Message Service
TCCU	Telematics Communication Control Unit
tkm	tonne-kilometre
UIC	International Union of Railways
v	Velocity
W	Watt
WAAS	Wide Area Augmentation System
WPAN	Wireless Personal Area Network

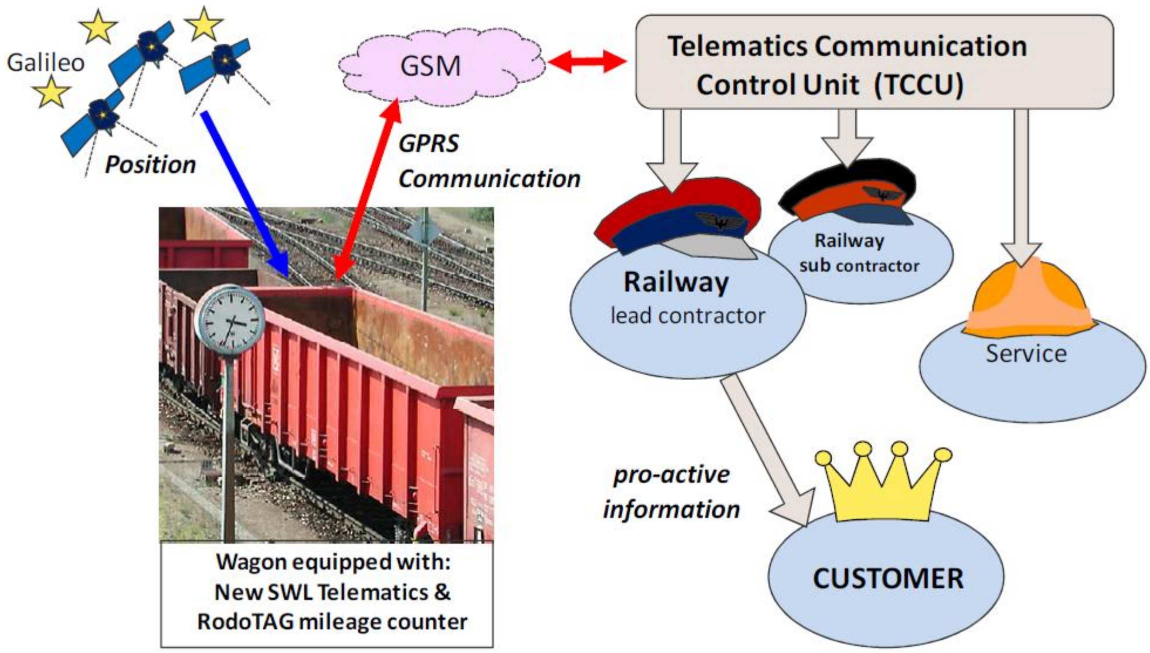
1 Background and objectives

1.1 Telematics information needs in rail freight transport

Unlike road transport, load tracking and tracing is still not widely used in single wagonload traffic. ViWaS seeks to accelerate the introduction of communication technology in rail freight. With on-board communication technology freight operators improve the dispatching of wagons and the rescheduling processes in case of disturbances. Based on reliable and "on-line" telematics data, the dispatchers will be able to inform their customers about changes in the transport schedule earlier than today. This pro-active customer information will increase the reliability and thus satisfy the stakeholders.

The project addresses particularly more competitiveness through an efficient organisation of transport processes. Cost-efficient and intelligent telematics based information services enable real-time wagon tracking (better quality) and automatically depicted wagon mileage information (cost reduction). A first step to quality improvement is the implementation of some kind of quality measurement. The telematics data service will automatically generate the information which is necessary for a reliable quality recording.

Figure 1: ViWaS telematics at a glance.



Source: Eureka

The usual economic life cycle of freight wagons still foresees a rigid time schedule of six years, which does not represent the actual wear. The reason for this is the lack of mileage information of wagons. Since the accident of Viareggio, the railway authorities are requesting documentation of wagon mileage. This has to be seen as an additional effort that railway operators have to perform from now on. This applies especially to SWL traffic, because the large number of different RU's involved will cause problems to document all movements. A small electronic mile-counter with a radio link to the telematics device could overtake the RU's responsibility of wheel-set individual mileage counting.

1.2 Development objectives

The benefit of single wagon telematics is in general not questioned by RU's, but many potential users. They fear that the costs of such technology would exceed its benefits. The development within ViWaS will be consequently focused on a significant increase of benefits of the use of telematics and a massive reduction of the cost of ownership for such systems.

Figure 2: Relevant KPIs for WP7.4.

KPI	Definition	Measure (compared to initial situation) Reference: CREAM Telematics	Target
Load Sensor	Quantity of sensors required for: Weighing Loaded/empty detection	Number of Load sensors to be required for an Y25 4 axle wagon.	Weighing: max. 4 sensors Load detection: max. 2 sensors ✓
	Information Quality: measure weight accuracy of the load sensor.	Measure sensor results with different calibration weights. Calculate typical and max. weight deviation of sensor.	Max. +/- 3.5% for wagon overweight detection. Max. +/- 1% for weighing with official verification.

Source: Eureka

The following activities were included:

1. Analysis of legal and user requirements for a weighing sensor system.
2. Evaluation of load sensing measurement principles, installation methods and components.
3. Test measurements at a work shop with a weighing sensor and data acquisition system mounted at several positions on the wagon and simulation of different loads.
4. Definition of a system concept for sensing, data processing, data transmission and visualization for weighing and for empty/loaded sensing.
   a. Development of a prototype Smart Load-Sensor with WPAN communication to the ViWaS wagon telematics system.
5. Extension of the WPAN communication protocol and the communication to the Telematics Communication Control Unit (TCCU).
   a. Specify operational requirements (customer's ramp, loading/unloading process, transport container size: 45', wagon).
6. Implement a simple data visualisation in the TCCU.

2 Development of a Prototype Smart Load-Sensor

The goal of WP7 Task 4 was the development of a small, light-weight and cost-reducing (in hardware and in communication) prototype of a Smart Load-Sensor system on basis of the existing aJour telematics technology.

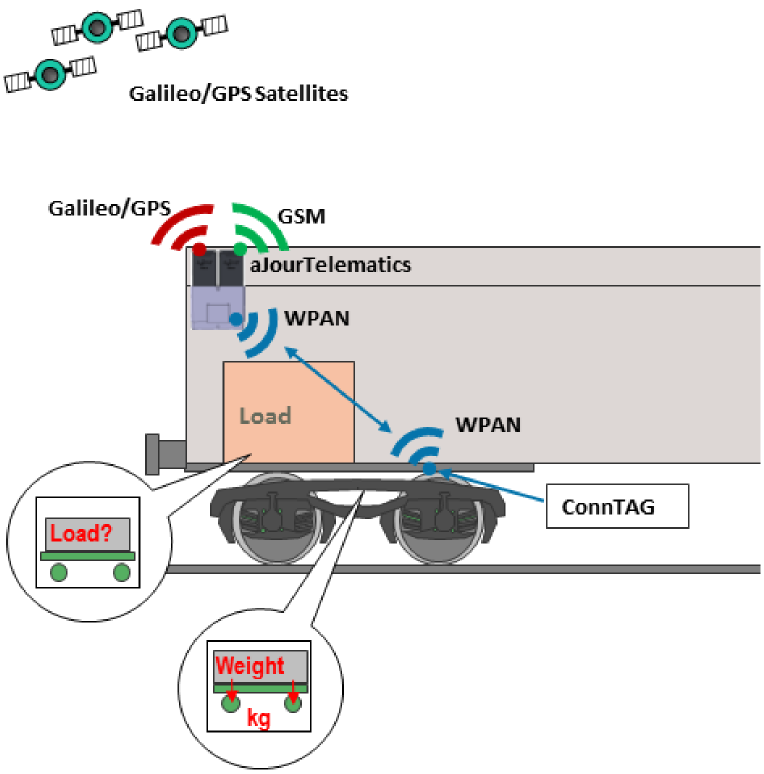
Expected features of the sensor were the following:

- reduction of costs was expected to be higher than 50%
- usage of the Galileo positioning system (as soon as it is in operation)
- installation is expected to be done by a customer or field service (development of a telematics installation and servicing procedure, expensive railway workshop visits should be avoided)
- integration of a radio interface (WPAN) for communication between the components
- evaluation of a simple and low-cost load detection sensor

During the whole development process a frequent communication with the customers technical and project management took place.

The components which are necessary to operate the Smart Load-Sensor, and the ways of communication between the components, can be obtained from Figure 3.

Figure 3: The necessary components and their communication channels.



Source: Eureka

2.1 Smart Load-Sensor Concept

A Smart Load-Sensor is considered to fulfil the following requirements:

- It is expected to be a low power sensor, which means low in current and voltage consumption. Furthermore it should be a signal conditioning device which also is able to perform an analogue digital conversion.
- The data transmission is expected to work wireless and therefore use the worldwide GSM network either 868MHz (distance 50 to 200 meters) or 2.4GHz (distance 10 to 50 meters) and an intelligent protocol (mesh).
- The energy supply is expected to be self-sufficient by using a battery or harvesting it (using solar or motion). Also an energy management is an absolute necessity.
- An intelligent processing is essential as threshold monitoring, intelligent data analysis and compressed storage is required.

2.1.1 Railway Insider Options Regarding a Load-Sensor Technology

Several shippers, railway undertakers, wagon keepers and maintenance service suppliers were asked regarding benefits and consequences if a reliable load sensing technology would be available for freight cars.

The interviewed insiders were highly interest in answering their daily questions:

1. Is the wagon still loaded? Yes/No?

   And as a result: When can a wagon be dispatched for the next transport?

2. What is the weight of the load?
3. How can the shipper’s personnel load wagons up to the maximal allowed wagon capacity? (Use total load capacity of wagons.)
4. Are the maximal axle loads exceeded? (Reduction of maintenance costs.)
5. Is the load on the wagon unequally distributed (center load required according to general loading instructions)?
6. How can tonne-kilometers be calculated?

The evaluation identified two positive business cases from the received answers:

a. Empty/Loaded detection for optimizing the dispatching (mainly railway undertakers).

b. Weight measurement and overload indication (all parties expressed highest interest).

2.1.2 Concept and Market Analysis

During the conception of the Smart Load-Sensor the functionalities, product properties and business cases mentioned above were taken into account. The goal was to develop reasonable variants of the Smart Load-Sensor in addition to energy consumption and supply.

The radio protocol was extended to being able to serve a short time WPAN communication from the Smart Load-Sensor to the telematics unit.

The housing for the Smart Load-Sensor was designed to cover all application cases but being inexpensive anyhow.

A market analysis was done on sensor technologies which are suitable for measuring weight.

According to the requirements the Smart Load-Sensor shows the following main properties:

- 868 MHz WPAN data radio network to aJour Telematics or HotSpot
- unique identification number (RFID)
- internal temperature sensor
- magnetic sensor (reed-contact)
- activation switch on the surface
- two LEDs (green and red) to indicate the status of the sensor
- the device is able to operate using a battery for several years
- size: 75mm x 55mm x 30mm
- the housing is conform to IP69K

2.1.3 Sensor Mounting Concept

The load sensing principles, installation methods and components were evaluated on an Y25 bogie at a workshop, where the test measurements for load detection and weight measurement were done correspondingly, as required.

During the evaluation a competitive and practice-oriented sensor mounting concept was developed, which included a cost-optimized mounting for the sensor and the radio electronics.

Also the tools for the cost-optimized mounting of the Smart Load-Sensors to Y25 bogies were developed.

2.1.4 Mounting Concept - Load Detection

In the case of the loaded/empty detection it was found, that a maximum of two sensors is necessary to perform a loaded/empty detection in an efficient way. Mounting more sensors than these two would just cause redundancy.

As the general loading instructions require a centre loading the best place for mounting the Smart Load-Sensor is also in the centre of the wagon.

A reasonable threshold for considering a wagon loaded or empty was found at 15% of the maximum weight of the wagon.

2.1.5 Mounting Concept - Weight Measurement

As the measurement of weight involves the necessity of being much more precise as in case when just detecting load, it was found that a maximum of four sensors is needed to measure the weight without becoming redundant.

As already mentioned for the load detection, it is required that the general loading instructions are fulfilled, but as the measurement of weight requires a maximum of four Smart Load-Sensors, the ideal mounting positions are on the left and the right side of each, front and backside, bogie.

2.2 Prototype Development

2.2.1 Design and Test of Prototypes

The design of the Smart Load-Sensor prototypes was dealing with the components placement and the PCB routing, according to the specifications from prototype ordering and Holger Leitel (Eureka).

Furthermore functionality tests, to prove current consumption, voltages and in general all hardware, were performed.

Also the calculation of the patch antenna followed the corresponding specification.

During the test phases some issues regarding components placement and PCB routing were found and also some new ideas came up. This was leading to a prototype re-design and the ordering of a new prototype.

As all tests of the Smart Load-Sensor prototypes succeeded, the design of the test place could be started.

2.3 Test Concept

A test concept for an automatic board inspection for the Smart Load-Sensor was developed.

2.3.1 Test place Design

The test place design included the development of a test place concept, the design of a PCB adapter plate and a test process. The related generation of Gerber data was also implemented.

The adapter PCB and adapter plate were mounted during the test place implementation, according to the design.

2.3.2 Prototype Testing

The prototypes were tested on the test place and manufacturing instructions were developed, respectively.

Also the functionality of the radio communication from the Smart Load-Sensor to the aJourTelematics unit using WPAN was validated.

2.4 Test Setup

2.4.1 Laboratory Testing

A test setup was developed to validate the weighing functionality of the system in the laboratory.

Load detection and weight measurement, was tested by simulating the weight by giving pressure onto the Smart Load-Sensors.

2.4.2 Field Testing

The Smart Load-Sensor was also tested on a wagon in the field. Both cases were considered, using a corresponding amount of sensors, as described above. The field test offered the advantage that it was not necessary to simulate the weight, as it was possible to use calibration weights which are gauged to a certain weight, which gave the insurance that the Smart Load-Sensors are working properly.

2.4.3 Analysing the Results

The results of the weighing functionality tests, in the laboratory and in the field, were analysed and applied to optimize the precision of a weighing.

2.5 TCCU Adaption

The Telematics Communication Control Unit (TCCU) was adapted accordingly, in co-operation with Eurekas software development department. All functionalities that were necessary to perform the weighing process and the load detection were implemented.

As two tasks have to be served, loaded/empty detection and weight measurement, also two corresponding GUIs were implemented. Both GUIs are described in the following.

2.5.1 Loaded/Empty Detection

A wagon is considered to be loaded when the Smart Load-Sensor detects 15% of the maximum wagon weight.

Therefore it is necessary that the GUI for the loaded/empty detection provides an area where the master data (basic claims) of the wagon can be entered, which also shows the weight that equals the 15% threshold.

As the calibration of the Smart Load-Sensor is a necessity, where two values are considered, i.e. the weight of the wagon when it is empty, the so called 'Empty Calibration', and the weight of the wagon when it is loaded with a calibration weight, the so called 'Load Calibration'.

Both calibrations can be performed independently of each other and in arbitrary order. Nevertheless both are absolutely necessary to get reliable results for the load detection.

Only if both calibrations are performed and valid the area to execute a loaded/empty detection is enabled. Otherwise it appears disabled.

In case both calibrations are valid the loaded/empty detection can be started manually by pressing the corresponding button in the GUI. The Smart Load-Sensor is now armed and able to deliver measurement data, loading the wagon can now be started.

In case measurement values below the threshold are delivered the wagon is not considered loaded.

In case measurement values above the threshold are delivered the wagon is considered to be loaded.

What is more, the loaded/empty detection can also be started automatically, which means the Smart Load-Sensor is always in an active mode in the background.

In both cases, manually and automatic measurement, the measurement results are displayed in the GUI.

2.5.2 Measuring Weight

The measurement of the weight of a wagon differs from the loaded/empty detection. Nevertheless also for the weight measurement it is necessary to enter the master data (basic claims) of the wagon, but additionally it is also necessary to specify a warning weight. In case this warning weight is exceeded a corresponding, yellow, traffic light shaped warning semaphore appears. The same in case the maximum weight of the wagon is exceeded, but in this case the semaphore appears in red. In case the detected weight is also below the warning weight, the semaphore appears green.

Only in case both, maximum weight and warning weight, was entered the calibration area will be activated.

Like the calibration for the loaded/empty detection, the calibrations for the weight measurement are both a necessity, but can also be executed independently from each other and in arbitrary order.

In case both calibrations are valid the weight measurement can be started manually, but also the weighing can be executed automatically.

When the weighing of a wagon is done manually it is not possible to cause an overload as it is necessary that the measured weight is confirmed (assumed) by the service personal that is loading the wagon. In opposite is the automatic weighing. As no service personal has to confirm the measured weight there is no control mechanism enabled, which can lead to the situation that the wagon can be overloaded. In case this happens an alert is displayed in the GUI.

2.6 Document Creation

During the development process several documents were created, including the following ones:

- manual for the mounting of the devices
- manual for the mounting of the Smart Load-Sensor
- a maintenance concept

3 Conclusion

The Smart Load-Sensor fulfils both tasks it was developed for:

- Empty/Loaded detection for optimizing the dispatching.
- Weight measurement and overload indication (manually and automatically).

In both cases the optimal functionality of Smart Load-Sensors was evaluated on an Y25 bogie in the field. The optimal functionality for the loaded/empty detection is given when using maximal two Smart Load-Sensors. As the weighing application needs higher precision, the test result lead to the conclusion that the optimal amount of sensors was found when using maximal four Smart Load-Sensors, without getting redundant.

The maximum deviation, as required for the load detection matches a maximum of +/- 3.5%. Also the required +/- 1% accuracy required for the weight measurement was kept.