Requirements for
Telematics and Sensor Technology

compiled by the
Technical Innovation Circle for Rail Freight Transport (TIS)

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Status 6 May 2014

Revision (German text): 3.9   Updated: 6 May 2014

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1. Summary

The “Innovative Rail Freight Wagon 2030” described in the TIS White Paper calls for a basic package of telematics and sensor technology. This “intelligence” will make the freight car far more productive and substantially boost the growth that rail needs in order to compete with other modes of transport.

By monitoring and tracking routes and mileage, telematic applications make the scheduling of rail freight wagons far more effective, thereby scoring efficiency gains for fleet management.

Cargo can be monitored much more accurately by sensors. This applies both to physical properties such as pressure and temperature and to whether impacts incurred during shunting operations have affected the condition of goods. Sensors to monitor cargo doors or valves reduce the risk of loss. Load status (in digital terms: load / empty) and overloading can also be detected.

Sensor technology helps to enhance operating workflows by identifying wagon sequence and train integrity, simplifying the brake test and signalling derailment at an early stage.

Sensor technology provides major assistance in maintenance processes. By monitoring components and their wear margins, it reduces unscheduled downtime and makes it easier to plan visits to the workshop. This improves logistical scheduling, workshop capacity planning and spare part inventory management.

Telematics and sensor technology also facilitate integration into logistical and transportation chains by making loading and unloading easier to manage. Administrative processes, such as billing for wagon rents, can also be simplified.

Investment in the latest electronic equipment ranges – depending on the features selected – from three- to lower four-digit figures. These applications provide value for money due to greater availability and the productivity gains derived from smarter fleet management.

Moreover, the image of rail freight transport will be boosted by the inclusion of state-of-the art technologies that can be integrated into the logistic chain.

It makes sense to include telematics and sensor equipment when building new rail cars. In these situations, wagon keepers should make a commitment to incorporate a basic package in the standard option. Retrofitting is usually feasible too, and in many cases it makes commercial sense and is thus an essential step to take.

The protection against explosion required for certain applications is a highly complex issue that makes exacting demands of telematics and sensor technology for freight wagons.

Until a trainline is installed, power requirements have to be met by batteries. Energy harvesting technologies (e.g. axle generator) can improve availability and considerably prolong the intervals between battery exchange. In the long term, however, power will have to be available in the car (from centre buffer couplers or an independent power supply). Limited battery capacity is taken into account in the choice of sensors and external communication.

It is particularly important to have a communication interface with the outside world that is universal and able to cater for future needs in response to advances in IT systems. Moreover, solutions should not be implemented on a one-off or stand-alone basis, as it is important that the sector as a whole can derive the benefits.

2. Introduction

Telematic and sensor applications have been developing extremely fast in recent years. Processes are economically more viable and simpler as a result. There is also broad potential in the field of passenger rail traffic.

In the rail freight sector, however, and especially in freight wagons, their introduction has only been pursued on an isolated basis.

The Technical Innovation Circle for Rail Freight Transport (TIS) has set itself the task of tackling this backlog and modernising rail freight wagons through concerted action between all the parties involved in the rail freight sector:

- wagon keepers
- the wagon manufacturing industry
- railway operators
- forwarding agents
- shippers and
- researchers.

The efficient deployment of freight cars is key to improving the competitiveness of rail freight, as wagon costs account for 15 % to 25 % of the total costs of rail freight transportation.

3. Our approach

The remit for the Telematics and Sensor Technology Task Force set up by the Technical Innovation Circle for Rail Freight Transport is to consider applications for telematics and sensor technology in rail freight wagons, to review the options for technical solutions and to evaluate these with the aid of a morphological box.

The Task Force also assesses applications in terms of their suitability for newbuild or retrofitting. Questions such as who derives the benefit, how does the technical feasibility shape up, what one-off and recurrent costs are incurred, and what return on investment can be expected are all key factors in this work.

The best solutions are then fed into an overall assessment, and this has been issued as a recommendation to the sector for a basic package of telematics and sensor technology plus optional add-ons, which can be incorporated during conversions and, in particular, when constructing new freight wagons.

4. Technical and operational requirements

4.1 General objectives for the use of telematics and sensor technology

The use of telematics and sensor technology in rail freight wagons serves the following objectives:

- enhancing productivity
- reducing costs
- providing additional services
- making business models more flexible

4.2 User clusters

The use of telematics and sensor technology in rail freight wagons potentially benefits the following user groups:

- customers / shippers
- transport operators
- wagon keepers
- railway undertakings
- maintenance providers / workshops
- infrastructure managers
- the wagon manufacturing industry

4.3 Applications

By combining the use of sensors in freight wagons and by continuously transmitting and processing the captured data, additional insights can be generated around five process clusters, and positive effects can be achieved by applying follow-up processes. Combining these different applications offers the potential to boost the positive impact.

A Fleet management

The freight wagon is a pivotal means of production in the rail freight transport sector and must be perceived as an integral part of the transport chain. Given the need for further productivity gains in the transport process, stringent monitoring and management of rolling stock stands to generate added value for customers, shippers, keepers and railway undertakings alike.

Basic **tracking and tracing** functionality permits the position of wagons to be identified and charted. Building on this (real time) data on the wagon's geoposition, any deviations in the productive workflow can be communicated and suitable counter-measures can then be adopted. This brings advantages in schedule management for individual consignments, and it also gives customers the chance to adjust their own logistics if deviations occur.

Extended **fleet scheduling** functionality enables the status and position of wagons to be captured. That lays the foundations for pro-active wagon management which is both rules-based and event-driven. Any deviations in wagon circulation can be countered at an early stage (if Wagon A sends the message: “I have been standing unloaded in X for five days”, it will be dispatched to Y), thereby optimising the wagon deployment schedule.

The **mileage tracking** function permits an accurate record to be kept of the distances travelled by each wagon without the need to draw on train management systems. This is reflected in additional potential for dedicated maintenance management.

B Load data

Apart from monitoring the wagon itself, monitoring load status generates further added value and can even be marketed. Sector-specific capture of individual freight parameters (temperature, pressure, door opening, etc.) as part of continuous **load monitoring** enables sensitive goods to be kept under thorough surveillance. This means that security requirements defined by customers can be observed and downstream production processes can also be ensured. In addition to this, **load measurement** establishes whether the wagons are under load (wagon status: load/empty), thereby optimising wagon deployment. Monitoring limit values serves to detect **overloading** (wagon status: overload), and any subsequent need for maintenance can then be attributed to its causes; specialised applications allow precise **weight measurement** of cargo independently of stationary weighing facilities (wagon X is carrying Y kilograms). This can be supplemented by accurate logging of **shipment punctuality**, optimising the precise coordination of transport chain logistics.

C Transport process (train operation)

Safe train operation is a field for additional technical features to replace traditional manual processes. Monitoring **train integrity**, for example, permits the use of ETCS Level 3, dispensing with the need for sporadic manual consistency checks during both dispatching procedures and journeys. **Automatic capture of train formation** furthermore reduces the manual effort required to check the order of wagons when preparing the train. It replaces the protracted procedure for manual verification and/or correction of train data in production management systems, which is required, among other things, for calculating the braking percentage. By monitoring for excessive acceleration, the system can detect **derailments** and identify the causes more efficiently. Monitoring horizontal acceleration falso permits the detection of **shunting shocks**, helps to establish responsibility and flags up possible training needs. Technical options for **automated brake testing** can, moreover, replace manual brake testing procedures during train preparation.

D Support process: Maintenance

Apart from these operational applications, equipping freight wagons with features enabling technical measurement presents an opportunity to optimise support processes for maintenance. **Monitoring wear margin** for specific modules enables the components concerned to be replaced as their condition demands, preventing both wasteful exploitation of wear margins and component downtime. Continuous **monitoring of the technical condition** of structural components can flag up an undesirable status (e.g. part failure). This reduces the risk of spontaneous failure, injecting plannability into in-service maintenance and operations. Moreover, continuous **component identification** can make it easier to track parts in multi-stage maintenance loops, enabling different maintenance cycles to be disaggregated and granting additional insights that will promote the systematic revision of maintenance rules.

E Support process: Other

The additional technical options also play a role in the automation of further support processes. Improving the traceability of rolling stock and of wagon condition opens the door to **automated billing** and innovative settlement models. Additional interfaces permit the **automation of loading and unloading** processes, thereby enhancing integration into customer logistics and promoting the overall networking of transportation processes.

No.	Application	Logging interval	Transmission interval	Geo-localisation	Motion capture	Acceleration capture	Derailment capture	Mileage capture	Weight capture
									digital (load/ empty)
1.	**Fleet management**								
1.1.	Tracking & tracing	60 min	event-driven	yes	yes				
1.2.	Scheduling wagon -> fleet	event-driven		yes	yes				yes
1.3.	Mileage tracking	analysis-driven	daily	yes				yes	
2.	**Load data**								
2.1.	Load condition	permanent							
2.2.	Load status	permanent							yes
2.3.	Overloading	event-driven			yes				yes
2.4.	Weighing	event-driven			yes				yes
2.5.	Shipment punctuality								
3.	**Transport process (train operation)**								
3.1.	Train integrity	permanent			yes				
3.2.	Train formation	event-driven			yes				
3.3.	Derailment	permanent		yes	yes	yes	yes		
3.4.	Shunting shocks	event-driven		yes	yes	yes			
3.5.	Automated brake test	event-driven							

4.	**Support process: Maintenance**								
4.1.	Component monitoring (wear margin)								
4.2.	Component monitoring (condition)								
4.3.	Tracking critical components								
5.	**Support process (Other)**								
5.1.	Automated billing	event-driven		yes	yes				
5.2.	Data transition from carrier to customer	event-driven		yes					yes
5.3.	Automated loading/unloading	event-driven		yes					yes

Table 1: Applications evaluated in the light of various criteria (basic applications are marked)

4.4 Criteria for assessing feasibility of applications

The definition of relevant applications is followed by the definition of various assessment criteria. The Task Force discussed each application and how well or how simply each criterion can be met.

The assessment criteria defined are:

1. Benefit to customers
2. Technical feasibility
3. Migratability (& time frame)
4. One-off costs (using White Paper system)
5. Recurrent costs (using White Paper system)
6. Business case in terms of cost / benefit ratio (using White Paper system)
7. Priority (to strengthen competitiveness)
8. Potential for rapid implementation in the demonstrator

Table 2 below summarises these assessments of telematics and sensor technology applications based on the above systematic approach.

No.	Application	Who benefits?	Technical feasibility	Migratability (& time frame	One-off costs (using White Paper system)	Recurrent costs (using White Paper system)	Business case in terms of cost/ benefit ratio (using White Paper system)	Priority (to strengthen competitive-ness)	Rapid implementation in the demonstrator
1.	***Fleet management***								
1.1.	Tracking & tracing	customer/shipper ++	++	++	++	+	**+**	++	++
1.2.	Fleet scheduling	user/keeper ++	o	+	o	o	**++**	++	+
1.3.	Mileage tracking	RU/keeper/ECM ++	++	++	++	+	**+**	+	++
2.	***Load data***								
2.1.	Load status (load > 20 % net load)	customer/shipper ++	++	++ (retrofit +)	++ (retrofit +)	++	**++**	++	++
2.2.	Overloading (limit value exceeded)	ECM/shipper ++	+	-	+ (retrofit o)	++	**+**	+	+
2.3.	Weighing (precise measurement)	customer + / infrastructure ++	o	--	o (retrofit -)	--	**--**	o	--
3.	***Transport process (train operation)***								
3.1.	Train integrity	infrastructure/RU ++	o	--	?	++	**?**	++ (especially fully automatic)	o
3.2.	Train formation	RU ++	o	-	?	++	**?**		+
3.3.	Brake test (supportive/fully automatic)	RU ++	+ (fully automatic -)	o	+ (fully automatic -)	++	**++**		++ (supportive)
3.4.	Derailment	keeper / RU / infrastructure ++	+ (slab track ++)	+	+	++	**+**	o	++

3.5.	*Shunting shocks*	*customer / shipper / RU ++*	++	++	++	++	**+**	+	++
4.	***Support process: Maintenance***								
4.1.	*Monitoring components (wear margin)*	*keeper / ECM ++*	*brake shoes, wheel disc -*	++	+	++	**+**	++	-
4.2.	*Monitoring components (condition)*	*keeper/ECM/RU ++*	*runout --, brake shoes & wheel flats*	+	+	++	**+**	+	+ *(wheel flat)*
4.3.	*Tracking critical components*	*keeper / ECM +*	++	++	++	++	**++**	*o*	++
5.	***Support process (Other)***								
5.1.	*Automated billing*	*keeper +*	+	+	*o*	+	**+**	*o*	--
5.2.	*Automated loading/unloading*	*customer/shipper +*	*interface ++, chem. palettes o*	--	--	++	***o***	*o to ++*	--

Table 2: Assessment of applications based on a range of criteria

4.5 General system requirements

The system requirements are generated from two different sources. First, there are the requirements identified by the Task Force devoted to Telematics and Sensor Technology. In addition to this, the list includes sensor requirements for innovative bogies taken from the TIS Task Force on Innovative Bogies.

4.5.1 Requirements from the TIS Task Force on Telematics and Sensor Technology

Functional requirements from the TIS Task Force on Telematics and Sensor Technology

FR-TE001	The standard telematic solution is linked via GSM/GPRS (2G) or UMTS (3G) by means of a mobile network based on an IP protocol to a back office, i.e. a central server solution. Note 1: Scenarios without a server connection or where a WLAN solution is only available at certain points are excluded below. Note 2: Use may be made in future of LTE (4G) mobile telephony or later generations of mobile telephony data transmission. Note 3: Communication is via a secure connection (VPN).
FR-TE002	The solution tracks and traces a smart freight wagon by means of geolocalisation with data transmission to a back office solution.
FR-TE003	The solution permits management of individual wagons in the fleet by means of geolocalisation, motion detection and digital weight detection (empty/load) with data transmission to a back office solution.
FR-TE004	The solution permits mileage tracking for each wagon, bogie and axle, with data transmission to a back office solution. This also requires geolocalisation with data transmission to a back office solution.
FR-TE005	The solution permits sensor-based detection of the load status (digital = empty/load) of a freight wagon with data transmission to a back office solution.
FR-TE006	The solution permits sensor-based detection of overloading in a freight wagon with data transmission to a back office solution.
FR-TE007	The solution permits accurate sensor-based weighing of a freight wagon with data transmission to a back office solution.
FR-TE008	The solution permits detection of shipment punctuality by means of geolocalisation with data transmission to a back office solution.
FR-TE009	The solution permits sensor-based detection of train integrity, geolocalisation and data transmission to the locomotive and to a back office solution.

FR-TE010	The solution permits sensor-based detection of train formation, geolocalisation and data transmission to the locomotive and to a back office solution.
FR-TE011	The solution permits detection of derailment by means of acceleration sensors with reliable, secure data transmission to the locomotive.
FR-TE012	The solution permits detection of shunting shocks by means of acceleration sensors with data transmission to a back office solution.
FR-TE013	The solution permits performance of an automatic brake test before the journey begins, data transmission to the locomotive and to a back office solution, and transmission of brake system malfunction during a stop or while in motion.
FR-TE014	The solution permits monitoring of component wear margins with data transmission to a back office solution.
FR-TE015	The solution permits monitoring of component condition with data transmission to a back office solution.
FR-TE016	The solution permits tracking of critical components with data transmission to a back office solution.
FR-TE017	The solution permits automated billing.
FR-TE018	The solution detects that information has passed between transporter and customer.
FR-TE019	The solution permits automatic loading/unloading.
FR-TE020	Power supply is provided by a battery that can be replaced independently.
FR-TE021	As an option, power supply can be provided by a power cable through the train.
FR-TE022	As an option, an energy harvesting unit can be operated to feed the battery. 022a: Energy harvesting with waves/radiation 022b: Energy harvesting with vibration 022c: Energy harvesting with thermal 022d: Energy harvesting with solar 022e: Energy harvesting with axle generator

Non-functional requirements from the TIS Task Force on Telematics and Sensor Technology

NFR-TE001	Mobile telephony data transmission to back office server: 001a: Data transmission only occurs at distinct points (start, stop, intermediate halt, …). 001b: Data transmission occurs during stop and go. 001c: Data transmission occurs several times a day (every x hours). 001d: Data transmission occurs every morning at empty freight car distribution. 001e: Data transmission occurs hourly. 001f: Data transmission occurs several times an hour (every y minutes). 001g: Data transmission occurs at intervals of 5 minutes. 001h: Data transmission occurs at specific events. 001i: Data transmission occurs when energy supply is sufficient.
NFR-TE002	Geolocalisation – periods/intervals: 002a: Position is only logged at distinct points (start, stop, intermediate halt, …). 002b: Position is logged during stop and go. 002c: Position is logged several times a day (every x hours). 002d: Position is logged every morning at empty freight car distribution. 002e: Position is logged hourly. 002f: Position is logged several times an hour (every y minutes). 002g: Position is logged at intervals of 5 minutes. 002h: Position is logged as a function of distance travelled.
NFR-TE003	Geolocalisation – definition of position: 003a: Position is defined by RFID tags on both sides of the wagon with trackside RFID readers. 003b: Position is defined by GSM cell location. 003c: Position is defined by GSM tower triangulation. 003d: Position is defined by GPS/Galileo signal. 003e: Position is defined by GSM cell location (when in motion) and GPS when stationary. 003f: Position is defined by GSM cell location and back-office network layer allocation (when in motion) and GPS when stationary.
NFR-TE004	Motion detection: 002a: Motion is detected by an acceleration sensor. 002b: Motion is detected by a rotation sensor on the wheelset.

	002c: Motion is detected through permanent GPS capture.
NFR-TE005	Digital weight detection (empty/load): 003a: Weight is digitally detected by an acceleration sensor (in motion). 003b: Weight is digitally detected by a “spatial” sensor (e.g. light beam). 003c: Weight is digitally detected by a weighing valve sensor. 003d: Weight is digitally detected by a path sensor – suspension travel. 003e: Weight is digitally detected by a path sensor – distance to top of rail. 003f: Weight is digitally detected by a force sensor with vibrating wire. 003g: Weight is digitally detected by a force sensor with strain gauge.
NFR-TE006	Logging period for load status, overload and weighing: 006a: Logging is manually initiated upon loading/unloading. 006b: After loading/unloading capture is automatic. 006c: Regular capture is automatic during operation.
NFR-TE007	Data transmission for load status, overload and weighing: 007a: Data transmission is manually initiated upon loading/unloading. 007b: Data transmission is initiated automatically after loading/unloading. 007c: Data transmission is regularly initiated automatically during operation.
NFR-TE008	Derailment – capture period 008a: Detection is only performed while in motion. 008b: Detection is always performed (24/7).
NFR-TE009	Derailment – data transmission 009a: Detection is only reported while in motion. 009b: Detection is always reported (24/7).
NFR-TE010	Shunting shocks – capture period 010a: Detection is performed automatically when loading/unloading. 010b: Detection is performed automatically when loading/unloading and during reformation at nodes. 010c: Detection is always performed (24/7).
NFR-TE011	Shunting shocks – data transmission 010a: Detection is reported automatically when loading/unloading. 010b: Detection is reported automatically when loading/unloading and during reformation at nodes. 010c: Detection is always reported (24/7).

NFR-TE012	Key battery data (service life, rating, …) must be derived from telematic energy requirement and external specification of independent service life (energy balance).
NFR-TE013	Key data for the energy harvesting system (rating, …) must be derived from telematic energy requirement and external specification of independent service life (energy balance).
NFR-TE014	Electromagnetic compatibility (EMC) requirements must be met.
NFR-TE015	For application scenarios where explosion risk is a factor, explosion protection requirements must be met.
NFR-TE016	Software maintenance 016a: Software can only be maintained when stationary. 016b: Software can be maintained when in motion. 016c: Software can only be maintained manually. 016d: Software can be maintained remotely.

4.5.2 Requirements from the TIS Task Force on Innovative Bogies

Functional requirements from the TIS Task Force on Innovative Bogies

FR-DG001	The telematic solution must perform a fully automatic brake test.
FR-DG002	The telematic solution must track mileage.
FR-DG003	The telematic solution must detect hot boxes.
FR-DG004	The telematic solution must recognise axle load.
FR-DG005	The telematic solution must detect acceleration along three axes by means of an acceleration sensor.
FR-DG006	The power supply is provided by a power cable in the centre buffer coupler.
FR-DG007	There is also an independent, battery-based power supply.
FR-DG008	Where appropriate, telematics must comply with the requirements of explosion protection.
FR-DG009	Apart from a cable-free interface between components in the bogie and car body, provision must be made for a cabled interface.

Non-functional requirements from the TIS Task Force on Innovative Bogies

NFR-DG001	Standard interfaces are to be used for telematics wherever available.
NFR-DG002	Open interfaces are to be used where available.

4.6 Functional systems architecture

A functional systems architecture was defined by building on these fields of application and the associated requirements. Its purpose is to fulfil the requirements and to serve as a basic architecture for the applications that will be implemented.

Of course, each application scenario will require the implementation or adaptation of a sensor technology, data capture, data pre-processing, data storage and data transmission. However, this will all be done over the existing systems architecture without the need to install or implement a completely new system for each new application. It should be noted that the systems architecture can be implemented in many different ways. There will, at the very least, be a low-cost version capable of meeting a minimum set of requirements, and a more expensive full-scale solution that fulfils all the requirements described. It should also be noted that some parts of the architecture are essential, while others are available as optional extras.

By the same token, the compulsory elements in the systems architecture will not suffice to tackle every application scenario. For this reason, there are optional elements which complement the architecture and permit additional applications.

The functional systems architecture that has been defined is visualised below.

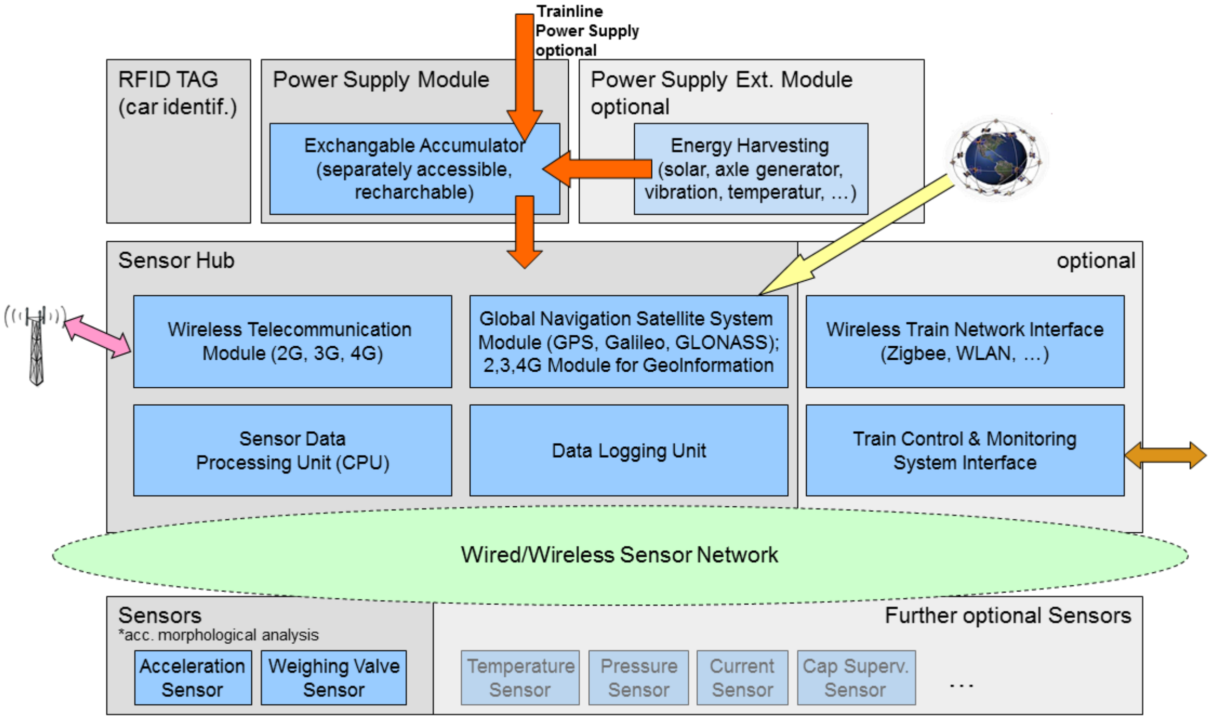

Figure 1: Functional systems architecture for telematics and sensors in a smart freight car

The functional systems architecture contains the following components:

1. **Sensor hub:** A central component in the freight car, responsible for (pre-) processing sensor and telematic data, for logging data, for determining position, and for wireless data transmission. The sub-components are:
    a. sensor data processing unit
    b. data logging unit
    c. wireless module for remote data transmission over a mobile network (2G = GPRS,
    3G = UMTS, 4G = LTE)
    d. global navigation system via satellite (GPS, Galileo, GLONASS) or mobile network cell

    Optional components are:

    e. wireless train network interface
    f. train control & monitoring system interface
2. **Sensors** (linked to the sensor hub via radio or cable)
    a. acceleration sensor

    Other optional sensors:

    b. weighing valve sensor
    c. temperature sensor
    d. pressure sensor
    e. voltage/current sensors …
    f. cap supervision sensor
    g. additional sensors
3. **Power supply**
    a. replaceable battery (in its own box)

    Energy harvesting technologies are an additional option:

    b. energy harvesting module for recharging the battery, with the following technologies
        i. solar
        ii. vibration
        iii. temperature
        iv. axle generator

    Optionally, a power cable can be run the full length of the freight train, and when the freight car is part of the formation the battery can be recharged using this trainline supply.

    c. power trainline.

4.7 Commercial requirements

OR-001	The investment costs for a low-cost solution should be well below 500 euros (status 2014).
OR-002	The investment costs for a full-scale solution should be in the range of several thousand euros (status 2014).
OR-003	The recurrent operating costs per month for a low-cost solution (mobile communication, battery exchange) should be in the range of a few euros (status 2014).
OR-004	The recurrent operating costs per month for a full-scale solution (mobile communication, battery exchange) should be well below 50 euros (status 2014).
OR-005	The annual maintenance and service costs for a low-cost solution should be less than 100 euros.
OR-005	The annual maintenance and service costs for a full-scale solution should be less than 200 euros.

4.8 Morphological analysis

A morphological box derived from the system layout outlined above serves to demarcate the scope for technological implementation. It yields an initial estimate of what is technically feasible and what costs might result. This evaluation matrix is founded on the basic module described, and for the time being it leaves aside any particular sector-specific scenarios.

In a target version of this system, the **power supply** will be permanently available on-board. During the transition stage, the system will draw on stored power, with the option to recharge this unit by means of energy harvesting.

Data transmission is via a mobile network interface, and the choice of mobile standard will depend on power consumption and data volume requirements.

During the initial period, **geolocation** will adopt a dual approach in order to optimise energy consumption. When the wagon is stationary, GPS will be used: although it consumes a lot of energy, it provides relatively accurate location data. When the wagon is moving, its location will be identified via the transmission areas (cells) in mobile telephony networks, which can then be matched against a pre-stored profile of the rail network. This calls for much less energy, but the location data is less precise than with GPS.

Both motion and acceleration can be captured by means of a 3D acceleration sensor. The components cost very little but are sufficiently accurate.

The chosen solution will track mileage in the same manner as described above, applying a dual approach to geolocation, which can then be layered over the potential routes mapped in a rail network.

While the wagon is moving, acceleration sensors can also be used to establish whether or not it is loaded, but when the wagon is stationary this task will be performed by an alternative technology, using the weighing valves that feature in a self-adjusting load-proportional braking system.

Table 20 below provides a decision matrix for potential technological solutions.

Application/Sensor technology	Power supply	Telematics	Geo-localisation	Motion capture	Acceleration capture	Mileage capture	Weight capture
Minimum version (--)	Accumulator (rating status as per 2015)	Manual reading by handheld device	Wagons are RFID-tagged on both sides with trackside readers across Europe	Acceleration sensor	Acceleration sensor	Rotation counter on wheelset axle	Acceleration sensor (when in motion)
Solution-based version	Energy harvesting "Waves/ Radiation"	"WLAN" => Infrastructure hotspot at major nodes/ stations	Position roughly captured through GSM cell	Rotation sensor on the wheelset		Mechanical counter in axle box	Spatial sensor: e.g. light beam
	Energy harvesting "Vibration"	"WLAN" => loco as hotspot	Captured through GSM tower triangulation	"Permanent" GPS		Induction counter in axle box	Sensor: Weighing valve
	Energy harvesting "Thermal"	Mobile telephony (GSM, UMTS, LTE)	Galileo (2030)-/ GPS localisation			Geolocalisation + layer algorithm	Path sensor: Suspension travel
	Energy harvesting "Solar"		Combination of GPS/GSM localisation				Path sensor: Distance to top of rail
	Wheelset generator		Combination of GSM and network layer while in motion + GPS when out of service				Force sensor: Vibrating wire

	Power supplied by air turbine via trainline	Satellite	DGPS		Force sensor: Strain gauge
Maximum version (++)	Continuous trainline (2030)				

Table 3: Decision matrix for potential technological solutions

5. Data ownership: implications for use

5.1 Do data protection laws apply?

Questions are bound to arise about the legal framework for collecting and transmitting data about freight wagons. The legal advice below, drawn from the German-language link displayed here, sums up the law as it currently applies to "cloud-based" services. In the cases compared here, the data being used is available on or transmitted via public networks:

http://www.e-recht24.de/artikel/blog-foren-web20/7115-rechtssicher-in-der-cloud-ihre-daten-bei-dropbox-icloud-google-drivea-co.html

> *"German data protection law applies to 'cloud-based' services if the data stored in the cloud is 'personal data' in the meaning of § 3 no. 1 of the German Data Protection Act, i.e. 'details of personal or factual circumstances that concern an identified or identifiable natural person' – in other words, data about an individual.*
>
> *What German data protection law does not cover, then, is data about legal entities (e.g. limited or joint stock companies, etc.) and anonymous data. It is a different matter if the data has been pseudonymised in the meaning of § 3 no. 6a of the German Data Protection Act; in this case, no direct reference is made to an individual, but the personal reference can be traced back (e.g. if someone has a number and can be identified by means of that number). Whether or not the data sets in the cloud contain a personal reference therefore determines whether or not they are protected under the Act.*
>
> *To ascertain which data protection law is applicable, we need to take a closer look at the provider and user of the cloud-based service. If the cloud service provider is based in the EU and the cloud customer is domiciled in Germany, we can usually assume that German data protection law will apply.*
>
> *According to the European Personal Data Directive (Directive 95/46/EC), cross-border data transmission within the EU explicitly no longer poses a legal barrier (cf. Art. 1 (2)), and so Germany's data protection law will always apply if personal data relating to an individual living in Germany is processed by a cloud service provider based in the EU."*[1]

It follows from this that data recorded on a smart freight car is not subject to German data protection law because no personal data has been captured.

We can conclude that the parties who participate in a telematic solution are themselves responsible for designing ways to protect the data from theft, deletion, distortion and publication. In other words, the participants must make solutions available to the parties concerned to ensure an appropriate level of data security and confidentiality.

[1] The German source text was downloaded on 25 April 2014 from http://www.e-recht24.de/artikel/blog-foren-web20/7115-rechtssicher-in-der-cloud-ihre-daten-bei-dropbox-icloud-google-drivea-co.html.

5.2 Who owns the data?

The basic principle is this: data belongs to whoever collects it and hence to the owner of the telematic solution (on-board communication unit plus sensor system). That might be the owner of the wagon, or it might be someone contracted by the wagon owner.

The following distinctions are made when recording data:

- Data is recorded about the load. The carrier is responsible for the load. However, the service provider, shipper and customer might also be involved.
- Data is recorded about the condition of the wagon. The wagon owner is responsible here. But this data may also be of relevance to the carrier, the railway undertaking (RU), the infrastructure manager and maintenance units.
- Data is recorded about location. This data may be relevant to everyone.

One thing is clear: everyone involved must understand what data is being recorded and how, and who has access by what means to that data. This access needs to be clarified, as do the right to use and exploit the data under the private law governing contractual agreements between the parties (wagon owner, wagon user, shipper, owner of the sensor technology and telematic units).

5.3 Data interface

5.3.1 Data interface and data requirements

Functional data interface and data requirements

FR-DA001	Every telematic unit with a data interface must be distinctly identifiable.
FR-DA002	Every telematic unit with a data interface must be clearly attributed to a specific smart freight wagon.
FR-DA003	Upgrades of operating system, firmware, application software and configuration parameters can be performed from the command and control package.
FR-DA004	The administrator can access the telematic unit from the control centre.
FR-DA005	Two-way communication must be ensured between the telematic unit and the command and control package.
FR-DA006	Data communication is based on IP protocol at network layer 3 in the ISO-OSI reference model.
FR-DA007	Communication is always initiated by the telematic solution, which sets up a communication pathway to the command and control package. (This dispenses with the need for fixed IP addresses.)
FR-DA008	Both communication partners have appropriate authentication solutions.
FR-DA009	Data transmission is encrypted. The encryption solution must be sufficiently powerful.

Non-functional data interface and data requirements

NFR-DA001	Open standards are to be used as far as possible to format data for transmission.
NFR-DA002	Transmission frequency can be adjusted from “once, event-triggered” to “periodically recurring” (see NFR-TE001)
NFR-DA003	The communication paradigm is “push notifications=data”. As soon as transmittable data is generated, an attempt is made to push it to a control centre or to a telematic unit. If the data cannot be transmitted, attempts to transmit are made at periodic intervals until successful transmission is reported. However, the application must be designed to include a fall-back solution if a message cannot be transmitted.
NFR-DA003	Loose-linked systems are to be used for data communication (message format is transmitted with confirmation of successful transmission in the protocol; not a subroutine system, e.g. explicit Remote Procedure Calls to retrieve data).

5.3.2 Ideas for implementing the data interface

It makes sense to use an XML-based data format. XML has proven itself to be a practicable solution in many industrial applications in recent years, allowing data to be read by people but at the same time permitting automated XML processing (generate, read, modify) with the aid of standard software tools. XML has the advantage that value ranges can be coded as well as names and descriptors. Many processing features from other fields (HR-XML, MathML, GML, AIXM) can be adapted for rail use, which reduces development time, cuts costs and minimises potential error thanks to standardisation.

Initial research suggests there are two activities in the rail sector that build on XML and are of relevance to TIS objectives:

- UIC Leaflet 559 “Specification Diagnostic Data Transmission from railway vehicles”, which sets out specifications for data in XML,[2]
- railML® (Railway Markup Language), an initiative to standardise railway data exchange.[3]

Work is currently proceeding apace under the railML.org initiative, which has brought rail operators, railway undertakings, software developers, consultancies, universities and research institutes together around the table to produce a standard interface for the rail sector, with the aim of keeping the number of interfaces between applications to a minimum. Since 2012, the international railway association UIC has been coordinating the project and providing an all-encompassing platform for the work focused around railML.org. Together with railML.org, it has published the UIC RailTopoModel, which will be available and in some cases compulsory from 2015 as an international railway standard for UIC members and the rail industry.

RailML uses so-called XML subschemata to define how data can be structured and exchanged. The following three schemata are already available:

- infrastructure,
- rolling stock and
- timetable.

The railML schemata for stations and interlocking are currently under development. railML is subject to a specially adapted CreativeCommons licence, and so it can be used free of charge following registration. Users can add some of their own extensions where appropriate, but commercial applications must be certified.

railML.org has been at work since 2002. The railML 2 schemata have been used in the productive environment since 2009, and further development towards a railML Release 3 is to begin from 2015 in collaboration with the UIC.[4]

[2] See http://uic.org/etf/codex/codex-detail.php?langue_fiche=E&codeFiche=559
[3] See http://www.railml.org/
[4] For further details see http://www.railml.org

6. The security, reliability, availability, safety and time-critical use of data in a telematic and sensor system

Essentially all sensor and telematic applications in a smart rail freight car will have to meet functional demands and at the same time incorporate non-functional features. The requirements will have to be aligned to the chosen field of application and use profile.

The specific requirements defined for the application will determine how much cost and effort are needed in order to meet them, so to make migration feasible it might have to be broken down into development stages (cf. Chapter 8).

For the functional systems architecture, three different communication channels have been defined for data transmission (cf. Chapter 4.6):

1. wireless data transmission to a control centre via a mobile network (2G, 3G, 4G)
2. wireless data transmission via a local area network (Zigbee, …) within a networked train formation
    a. with a master node in the locomotive
    b. with a sensor hub as the local master node in each smart freight car
3. cable or wireless communication with a Train Control and Monitoring System (TCMS)

The requirements with regard to data capture, data transmission and data evaluation can be broken down according to the following criteria:

- security
- reliability
- availability
- safety
- time-critical use (real time capability)

6.1 Security

Security is about protecting technical information processing and it is a functional feature of the system. It is designed to prevent unauthorised data manipulation and disclosure (source: German Wikipedia).

IT security serves the following defined protective functions:

- Confidentiality: data may only be used or modified by authorised users, both when accessing saved data and when transmitting data.
- Integrity: alterations to data must not pass unnoticed; any changes must be traceable.
- Availability: system outages must be prevented; access to data must be ensured within an agreed time frame (cf. also Chapter 0).
- Authenticity embraces a number of features: the object must be genuine, verifiable and reliable.
- Non-repudiation: this is about assuring that a party cannot illegitimately deny an action after performing it. It is important, for example, when contracts are concluded electronically, and one way to achieve it is the digital signature.

- Accountability: An action can be clearly attributed to a communication partner.
- Anonymity (anonymity has little significance in the application scenarios described here).

There are a number of threat scenarios that jeopardise security. These threat scenarios must be countered by appropriate IT measures, which are influenced by how important it is to protect particular objectives.

The threat scenarios are:

- data interception
- insertion, deletion or alteration of data
- time lag or replay
- masquerade (false identity)
- breach of authorisation
- repudiation
- sabotage

6.2 Reliability

"The reliability of a technical product or system is a feature (property) that describes how reliably a product or system fulfils the allocated function within a specific time interval. It is subject to a stochastic process and can be described in qualitative but also quantitative (probability of survival) terms; it cannot be measured directly." (German Wikipedia)[5]

If reliability is poor, there is a greater likelihood that a function will not be met. This has to be taken into account in the application. If a function, a product or a system needs to offer good reliability, the functional and non-functional requirements of the features and properties of a telematic and sensor system will increase accordingly.

[5] German source: http://de.wikipedia.org/wiki/Zuverlaessigkeit

6.3 Availability

"The availability of a technical system is the probability or measure of the system's ability to meet specific requirements at a specific point in time or within an agreed period." (German Wikipedia)[6]

More stringent demands are reflected in correspondingly higher functional and non-functional requirements of the features and properties of a telematic and sensor system.

6.4 Functional safety

"Functional safety denotes the safety features of a system that rely on the proper functioning of safety-rated (sub-)systems and external risk mitigation. It does not include factors such as electrical safety or protection from fire and radiation. As safety can also be achieved, if necessary, by terminating the intended function and entering safe mode, another term often applied to systems is 'safety integrity'.

As electronic – especially programmable – systems become more and more complex, the potential sources of error have also multiplied. The standards published in series as IEC 61508 'Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems' therefore call for a variety of methods to be implemented in order to manage errors:

- avoid systematic errors during development, e.g. specification and implementation errors
- monitor operations to detect incidental errors
- manage recognised errors safely and transition to a state previously defined as safe." (German Wikipedia)[7]

The quintessence here is:

- Safety means excluding unacceptable risks.
- Risk means a combination of the likelihood that damage will occur and the extent of that damage.
- Damage means human injury or death or a disastrous environmental impact.

The purpose of safety management is to reduce risk to a reasonable level.

Here again, more stringent demands on the safety of a function, a product or a system will be reflected in correspondingly greater functional and non-functional requirements placed on the features and properties of a telematic and sensor system.

[6] German source: http://de.wikipedia.org/wiki/Verfuegbarkeit

[7] German source: http://de.wikipedia.org/wiki/Funktionale_Sicherheit

6.5 Quality of Service (QoS)

Telematic systems for monitoring rail freight cars enable conclusions to be drawn from measurable parameters about the state of the freight car. The data is made available to downstream systems or services, and as a direct consequence of this the quality of communications within the telematic system chain must also meet certain requirements. This is known as Quality of Service (QoS).[8] QoS refers to the measurable quality of data transmission to ensure a particular service. From a technical perspective, it will be determined not only by the type of transmission procedure applied but above all by the structure and parameters of the transmission behaviour inscribed in the protocol. To meet the (real time) demands of transmitting time-critical data, limits must be defined for all the factors and parameters that influence transmission, such as

- the delay in data transmission from source to destination (latency)
- the mean variation in this delay (jitter)
- bit/symbol error rate during transmission (physical layer)
- the percentage of dropped packets (data transmission by packet)
- required bandwidth (bandwidth provisioning and data prioritisation).

Currently, however, the implementation and practicalities of QoS are dominated by proprietary solutions, which means that there is no standard or common industry practice. Some initial, isolated efforts in this direction – all of them application-oriented – have been undertaken by the International Telecommunication Union (ITU), the Internet Engineering Task Force (IETF), the ATM Forum and Open Systems Interconnection (OSI).[9]

If the service or (real time) application provided by a telematic solution sets, for example, a maximum latency for data packet receipt or guarantees a low dropped packet rate in order to ensure transmission quality, then these QoS parameters will impose higher demands on the hardware and software right across the telematic chain. The greater or more stringent the QoS requirements, the more complex and costly the system solution.

6.6 Data transmission options

The requirements must be analysed in the context of the chosen communication pathway.

6.6.1 Wireless data transmission to a control centre via mobile network (2G, 3G, 4G)

Wireless data transmission to a control centre via a mobile network (2G, 3G, 4G) is a standard interface in the functional systems architecture (see Chapter 4.6).

The first step is to consider merely those applications that are not safety-relevant, do not make major demands of reliability and availability, and impose only moderate requirements on security (e.g. encrypted data transmission, authentication, …). If the application is not available, or does not deliver reliable data, there is a fall-back level, either IT-based or workflow-based, to ensure the system can continue to function.

[8] German Wikipedia: http://de.wikipedia.org/wiki/Quality_of_service; For English Wikipedia see: https://en.wikipedia.org/wiki/Quality_of_service
[9] http://www.itwissen.info [German IT lexicon]

The next step is to address the more stringent requirements in terms of reliability, availability, security and functional safety.

6.6.2 Wireless data transmission via local area network (Zigbee, …) within a networked train formation with a master node in the locomotive

Wireless data transmission via a local area network (Zigbee,…) within a networked train formation with a master node in the locomotive is an optional component in the functional systems architecture (see Chapter 4.6).

More stringent requirements in terms of reliability, availability, security and functional safety are therefore addressed as a following step.

6.6.3 Wireless data transmission via local area network (Zigbee, …) within a networked train formation with the sensor hub as local master node in each car

Wireless data transmission via a local area network (Zigbee, …) within a networked train formation with the sensor hub in each smart freight car functioning as a local master node is an optional component in the functional systems architecture (see Chapter 4.6).

More stringent requirements in terms of reliability, availability, security and functional safety are therefore addressed as a following step.

6.6.4 Cable or wireless communication with a Train Control and Monitoring System (TCMS)

Cable or wireless communication with a Train Control and Monitoring System (TCMS) is an optional component in the functional systems architecture (see Chapter 4.6).

More stringent requirements in terms of reliability, availability, security and functional safety are therefore addressed as a following step.

7. Explosion control

Explosion control is a very complex issue and each case needs to be considered in the light of local conditions, so the following sections are confined to core aspects.

7.1 Essentials

Inflammable substances in the form of gas, vapour, mist and dust are handled in many economic and industrial sectors. Key sectors in this regard are chemicals, petrochemicals, oil and gas production, mining, food processing, milling and wastewater. When combined with oxygen, these inflammable substances can form an explosive atmosphere. If ignited, the explosions can cause serious human injury and material damage.

Three things are needed for an explosion to happen: an inflammable gas or dust, oxygen and an ignition source. A primary protection measure could be, for example, to render the gas atmosphere inert, i.e. to force ambient oxygen out with an inert gas such as argon, nitrogen or carbon dioxide. Secondary protection, by contrast, seeks to prevent sources of ignition from arising. For the manufacturers of equipment and protective systems, this means developing and designing their products in such way that no sources of ignition can form in the event of a failure. Tertiary (design-based) protection adopts a technical approach to limiting the impact of explosion.

Most industrialised countries have statutory regulations for explosion control in order to prevent explosive hazards. In the European Union, protection has been standardised by means of the ATEX Directives 94/9/EC (ATEX 95) and 1999/92/EC (ATEX 137).

Following the implementation of ATEX Directive 94/9/EC, a manufacturer must issue a declaration of compliance for each product, covering all relevant provisions governing the construction and operation of protected equipment and protective systems. The scope of this Directive includes mines and surface installations endangered by firedamp and/or combustible dust. It is also the first legal instrument to address non-electrical explosion control. Minimum rules for industrial safety in endangered sectors are set out in the second ATEX Directive 1999/92/EC.

7.2 Rail transport

When inflammable substances are transported by rail, this means that hazard assessment must be carried out not only for tank cars, but also, for example, for container wagons and bulk cargo carriers.

A separate hazard assessment must be performed for every substance transported, so that the right choice can be made about the category of devices for telematic and sensor installations on rail cars. Detailed consideration should be given, in particular, to loading and unloading procedures.

At BASF SE in Ludwigshafen, for example, rail cars that will in future be equipped with telematics are, on safety grounds, always fitted with devices authorised under ATEX Zone 1 – 2G (temperature class T4 / surface temperature < 135 °C) for areas subject to gas explosions and Zone 21 – 2 D (maximum surface temperature 125 °C) for areas subject to dust explosions. They are assembled as far away as possible from loading and unloading installations. They can therefore be used for almost all transportable substances.

8. A staged approach to implementing the telematic solution

The previous chapters defined various requirements to be met by the telematic unit.

There are two dimensions to these requirements:

A number of requirements concern the hardware and software for the telematic unit. There There is a basic sensor hub package (see Chapter 4.6, Figure 1: Functional systems architecture for telematics and sensors in a smart freight car

-) and there are optional components providing additional functionality. Other requirements relate to explosion control and must be considered in a specific light.
- Various requirements derive from the telematic application to be served. The simplest version imposes no particular requirements on the security, availability, reliability, real time capability and safety of the application. The requirements increase as we progress through the next stages.

	Basic sensor hub package	plus optional components (WiFi, sensors,…)	Telematics for explosion control applications
Basic applications (plot, pre-process, transpose)	A	B	D
Applications with more stringent requirements (reliability, availability, real time capability)	B	B	D
Applications which also feature security requirements	C	C	D

Figure 2: Staged approach to implementation

The applications are addressed and implemented in sequence in the following four stages.

- **Stage A**: Applications that can be implemented with the basic sensor hub package
- **Stage B:** Applications based on additional sensor technology and thus able to meet greater demands of reliability, availability and real-time capability
- **Stage C**: Applications with security-relevant requirements
- **Stage D**: Applications for explosive environments

9. Implementing the findings

9.1 Migration strategy

9.1.1 Critical mass

It is a characteristic of several innovative technical solutions in rail freight, especially in freight car technology, that the costs and benefits are not incurred simultaneously. Often the cost ramp-up is linear, as every unit purchased is reflected in investment or cost. However, the positive operational, and hence commercial, benefits cannot be generated until a certain number of units have been implemented. Classical examples of this are the introduction of automatic central buffer coupling and, indeed, telematics for freight cars. The benefits kick in once the fleet has achieved a critical mass, whereas the costs increase in a steady line as more units are implemented.

The aim must be either to identify a series of “island clusters” or “specialty freight services” that can generate commercial gains on a small scale, or else to select applications which ramp up the benefit in a similarly linear fashion. Depending on the technology, it might be necessary in some cases to equip a given number of wagons with a system (e.g. radio-based communication) before the overall strategy can be implemented.

9.1.2 The importance of a coordinated sector

The above examples of innovation in freight car technology serve equally well to illustrate another feature of the rail freight environment – the interplay between different market players. A key distinction is made in the rail freight sector between infrastructure managers, carriers, rolling stock keepers and customers. The carriers, as railway undertakings, are responsible for the operational aspects of transporting goods in the form of shunting services and the running of trains. To do this, they deploy not only their own freight wagons, but also those belonging to other keepers and other transport operators. The railway undertaking DB Schenker Rail, for example, only performs a little more than half its traffic volume with its own freight wagons. So to achieve the critical mass mentioned above, it is not enough for one company to take action. It calls for the concerted efforts of an entire sector, but given the very different conditions and commercial interests under which the players operate, that is very difficult to achieve.

The situation is exacerbated by the fact that the costs and benefits are not only not simultaneous, as mentioned above, but are distributed across highly dissimilar players. A graphic example is the innovative running gear for freight cars with radially adjustable wheelsets. The wagon keepers have to invest in the technology, but the benefits fall fundamentally into two categories:

- the railway undertaking saves energy due to reduced rolling friction,
- the infrastructure manager is the first to benefit from the reduced wear resulting from smaller lateral forces in curves.

This means that either a transfer mechanism has to be applied between the players, or else the innovations will not happen because the original investor does not have enough of a commercial incentive. One possible basis for transfer are the bilateral settlement arrangements between players. For infrastructure managers and railway operators, that is the track fee, and between the railway operator and the wagon keeper it is wagon rent. In this context, care must also be taken to ensure that the costs and benefits relating to sensor technology and telematics are attributed fairly to each player and that any imbalances are offset.

9.1.3 Compatibility is key to the distributed track/vehicle system

The migration across Europe of the train control system ETCS illustrates a process whereby legacy national systems – both track- and vehicle-based – are gradually being replaced by the new European system. At every point in this process lasting several decades, it has to be ensured that the track and the rolling stock remain operationally compatible. Given that ETCS is not usually founded on the same technologies as the old national systems, this migration has become a complex procedure, with several track and vehicle systems running in parallel for a certain period. When it comes to freight car telematics, attention must likewise be given to EMC and potential interaction between the wagon sensors and the trackside technology, and these issues must be factored into migration plans.

9.1.4 Cost-benefit distribution during migration

The relationship between the investment ramp-up and the payback in terms of benefits often means that, although implementing an innovation is ultimately intended to achieve a commercially attractive state of affairs, the positive commercial effects are not felt along the route. Given that a business case has to be constructed in advance, this means that the innovation may never be pursued at all. By making intelligent choices about how quickly to ramp up, about the right application and the right wagons, and about a concerted effort in the rail freight sector, a positive cost-benefit ratio must also be obtained for sensor technology in freight cars. From a maintenance perspective, for example, the correct choice of wagons may be decisive. Condition-based maintenance for selected major components should first be applied to wagons whose last general overhaul lies furthest in the past, where the likelihood of faults is greater. Alongside this, priorities can be set for other applications.

9.1.5 Push-principle innovation

Since the rail reform in 1994, if not before, the rail freight sector has been engaged in focussing on core value creation. Developing the track and rolling stock technology has been left to the suppliers, with the operators at most retaining a crucial degree of competence as the party placing the orders. In the innovation process, this division of labour results in research and development being primarily concentrated in the industry and usually having to be pushed onto the market. To drive the innovation capacity of the sector forward, that process needs to be reversed.

9.2 Applications in the basic unit

In line with the functional description (cf. Chapter 4.6), the basic module consists of the following components:

- power supply
- energy management
- data transmission module
- data processing module
- data storage module
- localisation module
- motion / acceleration capture

These module components have the potential to cover a wide variety of application scenarios in the field of tracking & tracing, fleet scheduling, mileage logging and wagon condition.

The next chapters contain specimen calculations for these various application scenarios. We explicitly point out that these calculations are founded on assumptions agreed by the TIS Task Force on Telematics and Sensor Technology. Under the concrete circumstances of a specific user, the calculation might result in quite different quantitative benefits, depending on the application scenario, fleet size and other criteria. The illustrations below are intended to offer guidance for users to perform their own individual calculations.

9.2.1 Tracking & tracing

Information about the wagon's position makes it possible to respond quickly to any delays, thereby averting claims for compensation from customers. Based on the conservative assumption that the customer would only claim the costs of capital arising from a delay in delivery, the example shows that, if the freight is worth 120,000 EUR and the return on capital employed is 10%, damages of 32 EUR per event would be incurred if the resulting delay was one day. If the measure prevents one event per wagon per year, the monthly benefit is 2.7 EUR per wagon:

Fleet size	100 wagons		
Delay	1 day		
Freight value	120,000 EUR	**Return**	10%
Savings potential per event	32 EUR	**Frequency**	1 event per wagon & year
Savings potential fleet	270 EUR per month		
Savings potential per wagon	2.7 EUR/month		

Table 4: Sample calculation of benefit: Tracking & tracing for freight worth 12,000 EUR

If the value of the freight is only 20,000 EUR, but all other parameters remain the same, the monthly benefit in this situation falls to just 0.45 EUR per wagon:

Fleet size	100 wagons		
Delay	1 day		
Freight value	20,000 EUR	**Return**	10%
Savings potential per event	5.33 EUR	**Frequency**	1 event per wagon & year
Savings potential fleet	45 EUR per month		
Savings potential per wagon	0.45 EUR/month		

Table 5: Sample calculation of benefit: Tracking & tracing for freight worth 20,000 EUR

9.2.2 Fleet scheduling – faster turnaround

If reliable location data is available about wagons that remain idle for long periods, much can be done to influence and speed up the turnaround times for freight cars (loaded trip to the customer and empty return). In the example, the turnaround for a fleet of 100 wagons is reduced from 30 to 28 days (i.e. shortened by 2 days), which means that the fleet can provide the same service with 7 fewer cars. Assuming a rental fee of 25 EUR per month, this results in a monthly benefit of 7,350 EUR for the total fleet of 100 wagons or 10.5 EUR per month per sensor-based telematic device:

Fleet size	100 wagons	**Turnaround**	30 days
Turnaround reduced by	2 days		
Fleet size	93 wagons	**Turnaround**	28 days
Hire cost per car	35 EUR/day		
Savings potential/ fleet	7,350 EUR /month		
Savings potential/ wgn	10.5 EUR/month		

Table 6: Sample calculation of benefit: Fleet scheduling – faster turnaround

9.2.3 Fleet scheduling – enable reload

Given the aim of rigorously tracking individual wagons outside the operator’s own production network, additional benefits can be generated by further optimising the deployment of rolling stock. Assuming that freight transport planning is generally based on end-to-end turnaround, the distance wagons must be dispatched to collect each load can be reduced by efficiently linking several jobs. This cuts the cost of transporting empty wagons to the shipper. In the example, reducing the dispatch distance by 400 km could save 16,000 EUR per wagon per month (assuming one case per month).

Fleet size	100 wagons		
Dispatch reduced by	400 km	**Transport costs**	0.01 EUR per tkm
Reduced costs per wagon (40t payload)	160 EUR		
No. wagons/month	10		
Savings potential/wgn	16 EUR		

Table 7: Sample calculation of benefit: Fleet scheduling – enable reload

9.2.4 Capture freight wagon mileage independently

Given how difficult it is today to access mileage data about freight wagons outside the operator's own sphere of control, capturing this information can generate benefits. Assuming a charge of 25 EUR per enquiry every time mileage data is transmitted, and assuming that a fleet of wagons is operated by three service providers, no longer having to pay this charge generates a benefit of approx. 0.1 EUR per wagon per month.

Fleet size	100 wagons		
Costs per enquiry	50 EUR	**No. enquiries**	3
Total costs p.a.	150 EUR		
Annual savings potential per wagon	1.5 EUR		
Monthly savings potential per wagon	0.1 EUR		

Table 8: Sample calculation of benefit: Capturing mileage independently

9.2.5 More accurate capture of freight car mileage

More accurate capture of individual wagon mileage makes it easier to estimate maintenance requirements and thus to reduce the safety mark-ups inherent in present-day calculations that result in wagons being dispatched for maintenance too early (before reaching their mileage limits). Consequently, wear margins can be better exploited and resources will be invested more efficiently.

Assuming a fleet size of 100 wagons with an average of 3.7 wheelsets, the wheelset pool will amount to 370. If we assume that only 10% of the wheelsets have to be exchanged because they have reached their mileage limit, our figures will be based on 37 wheelsets. The other wheelsets are refurbished prematurely on other grounds.

Assuming that wheelset mileage is currently overestimated by 10%, improved mileage tracking generates a change in the requirement for wheelsets. In this instance, it means that only 2.8 wheelsets a year have to be refurbished instead of 3.1. An average reduction of 0.3 wheelsets per year at a refurbishment cost per wheelset of 2,000 EUR yields a monthly savings potential of 0.5 EUR per wagon.

Fleet size	100 wagons	**Average no. wheelsets per wagon**	3.7 WS
No. wheelsets	370 wheelsets	**Mileage limit for refurbishment**	660,000 km
Percentage of wheelsets reaching mileage limit	10%	**No. wheelsets reaching mileage limit**	37 wheelsets
Assumed annual mileage	50,000 km	**Wheelsets p.a.**	2.8 wheelsets
Increase in mileage	10%		
Feasible annual mileage	55,000 km	**Wheelsets p.a.**	3.1 wheelsets
Cost of wheelset refurbishment	2,000 EUR	**Prematurely refurbished wheelsets**	0.3
Annual savings potential fleet	600 EUR		
Monthly savings potential per wagon	0.5 EUR		

Table 9: Sample calculation of benefit: More accurate capture of freight car mileage, 10% wheelsets affected, 10% deviation from current mileage estimate

If we assume that 40% of wheelsets have to be refurbished due to a mileage limit and that the mileage calculation only deviates by 2%, the annual number of wheelsets falls from 11.1 to 9.7. This average reduction of 1.4 wheelsets per year will result, at a refurbishment price of 2,000 EUR per wheelset, in a monthly savings potential per wagon of 2.3 EUR.

Fleet size	100 wagons	**Average no. of wheelsets per wagon**	3.7 WS
No. wheelsets	370 wheelsets	**Mileage limit for refurbishment**	660,000 km
Percentage of wheelsets reaching mileage limit	40%	**No. wheelsets reaching mileage limit**	128 wheelsets
Assumed annual mileage	50,000 km	**Wheelsets p.a.**	9.7 wheelsets
Increase in mileage	2%		
Feasible annual mileage	52,000 km	**Wheelsets p.a.**	11.1 wheelsets
Cost of wheelset refurbishment	2,000 EUR	**Prematurely refurbished wheelsets**	1.4
Annual savings potential fleet	2,800 EUR		
Monthly savings potential per wagon	2.3 EUR		

Table 10: Sample calculation of benefit: More accurate capture of freight car mileage, 40% wheelsets affected, 2% deviation from current mileage estimate

9.2.6 Detection of dynamic overload

By monitoring wagons to detect acceleration in excess of admissible limits, we can identify and document dynamic overload (e.g. as a result of excessive payload). Continuous logging of this data serves, especially in risk sectors (e.g. scrap or timber transportation), to allocate the costs of repairing damage in accordance with the cause of the problem. For a fleet of 100 wagons of which 5% p.a. are damaged by dynamic overload of this kind, assuming average maintenance costs of 5,000 EUR (sum of dispatch to workshop, downtime, material costs and labour costs for maintenance), the potential benefit amounts to 20 EUR per wagon and per month.

Fleet size	100 wagons		
Damage rate	5%	**No. damaged wagons**	5
Cost per damage event	5,000 EUR	**Compensation rate**	100%
Annual savings potential fleet	25,000 EUR		
Monthly savings potential per wagon	20 EUR		

Table 11: Sample calculation of benefit: Detection of dynamic overload

9.2.7 Detection of shunting shocks with allocation of costs to cause

By monitoring wagons to detect acceleration rates in excess of the permitted maximum value, and documenting any resulting damage, we can reduce compensation claims, risk of freight loss and repeat freight costs. Assuming a 10% loss in value following a shunting shock, the absolute loss that risks being incurred on freight worth 120,000 EUR is 12,000 EUR, a sum that will not have to be paid out if the handling is appropriate. Assuming an annual event of one per wagon, the monthly savings potential is 12 EUR:

Fleet size	100 wagons		
Freight value	120,000 EUR		
Loss in value	10%	**Absolute loss**	12,000 EUR
Frequency per wagon	1 event p.a.		
Annual savings potential per wagon	12 EUR	**Annual savings potential for the fleet**	12,000 EUR
Monthly savings potential per wagon	1 EUR		

Table 12: Sample calculation of benefit: Detection of shunting shocks at a freight value of 120,000 EUR

If our assumption is that a shunting shock causes a 10% loss in freight value, the absolute risk incurred for a freight value of 20,000 EUR is 2,000 EUR, a sum that will not have to be paid if the handling is appropriate. Given one event per wagon per year, the monthly savings potential is only 0.17 EUR.

Fleet size	100 wagons		
Freight value	20,000 EUR		
Loss in value	10%	**Absolute loss**	2,000 EUR
Frequency per wagon	1 event p.a.		
Annual savings potential per wagon	2 EUR	**Annual savings potential for the fleet**	2,000 EUR
Monthly savings potential per wagon	0.17 EUR		

Table 13: Sample calculation of benefit: Detection of shunting shocks at a freight value of 20,000 EUR

9.3 Selecting additional applications for extended sensor technology

By incorporating additional sensor technology, further benefits can be generated in terms of both extra value for customers and more efficient maintenance. Working towards the objective of predictive, condition-based maintenance, there will be a need for additional data about the condition of wagon components and any advancing changes in this condition. This additional data can be used to enhance maintenance strategies by adopting a preventive approach that reduces downtime. Rather than being performed at regular intervals defined by time or mileage, maintenance will respond to changes in condition or to a failure to observe a defined limit.

9.3.1 Monitoring the axle box

Based on the assumption that all major axle box failures in freight cars develop over a lengthy period and can furthermore be detected early by means of axle bearing temperatures, monitoring these temperatures presents an opportunity to reduce regular manual supervision. A rise in axle bearing temperatures can flag up a defect in advance and indicate that it may result in the near future in a specific failure. Appropriate threshold values can trigger an appropriate response to prevent a threatened operational outage and initiate follow-up processes (maintenance and customer information). While this application clearly stands to generate added value, it is not easy to formulate the assumptions that enable us to express a commercial benefit.

9.3.2 Monitoring the brake valve

Based on the assumption that a faulty brake valve can be detected from changing pressure curves, monitoring those parameters offers an opportunity to modify the maintenance regime for the brake valve component. This could be shifted from a time-triggered regular inspection interval of 12 years to a condition-based maintenance procedure. This application likewise has the potential to offer added value that cannot yet be accurately quantified.

9.3.3 Avoiding wheel flats

Based on the assumption that the majority of significant wheel flats (larger than 6cm) resulting in wheelset replacement arise either because of sticky hand brakes (75%) or because of damaged brake valves (20%), monitoring both these components would prevent those outages.

Whichever the cause, if we assume one day of delay or wagon downtime, the cost of processing the wheelset and the cost of dispatching the wagon to a workshop, avoiding all this outlay would result in a total benefit of 2,567 EUR per event.

Fleet size	100 wagons		
Freight value	120,000 EUR		
Annual frequency per wagon	0.2		
Delay due to exchange of brake pad	1 day	**Customer claim due to delay**	32 EUR

Lost wagon time	1 day	**Cost of lost wagon time**	35 EUR
		Cost of wheelset (exchange)	2,000 EUR
		Wagon dispatch costs	500 EUR
		Savings potential per event	2,567 EUR
Annual savings potential per wagon	513.4 EUR	**Annual savings potential for the fleet**	51,340 EUR
Monthly savings potential per wagon	42.78 EUR		

Table 14: Sample calculation of benefit: Avoiding wheel flats

9.3.4 Scheduled brake pad replacement

If the residual wear margin of the brake pad component can be detected, monitoring this will permit an optimal shift from reactive maintenance to scheduled brake pad replacement. Early planning of pad replacement requirements helps to reduce wagon downtime. Assuming a fleet size of 100 wagons and a freight value of 120,000 EUR, combined with a resulting delay of one day and an annual event probability of 2.5 (occurrence: 0.2), the savings potential per event is approx. 317 EUR. This is essentially due to not having to settle claims from customers following the delay, lower shunting costs and the prevention of downtime costs for the freight car.

Fleet size	100 wagons		
Freight value	120,000 EUR		
Annual frequency per wagon	0.2		
Delay due to exchange of brake pad	1 day	**Customer claim due to delay**	32 EUR
		Cost of additional shunting	250 EUR
Lost wagon time	1 day	**Cost of lost wagon time**	35 EUR
		Savings potential per event	317 EUR
Annual savings potential per wagon	63.4 EUR	**Annual savings potential for the fleet**	6,340 EUR
Monthly savings potential per wagon	5.28 EUR		

Table 15: Sample calculation of benefit: Scheduled brake pad replacement

9.4 Total benefit from telematics: a visualisation

Drawing on the calculations of benefit for the various telematic application scenarios set out in the chapters before this chapter estimates the total benefits accruing from a specimen low-cost telematic solution and a specimen full-scale telematic solution. The resulting benefits are compared with the commercial requirements (target costs) listed in Chapter 4.7 for the purchase and ongoing maintenance of telematic systems. We can then determine whether, on balance, the use of telematic systems generates an overall positive benefit.

It should be noted that the calculations of benefit in Chapters 0 and 9.3 are founded on a number of assumptions, and that circumstances may well be different in the actual scenarios in which different users operate. For that reason, operators should perform their own user- and fleet-specific calculations in each case.

In the overwhelming majority of calculations performed here, it was assumed that a fleet of 100 wagons was to be equipped with telematics and sensor technology and that the average freight value per wagon was € 120,000.

As telematic systems with all the functionalities described in this status report are not yet available in the market, there is still no empirical evidence of procurement costs, recurrent operating costs or annual maintenance and service costs. Chapter 4.7 therefore sets out commercial requirements for two options: a “low-cost” and a “full-scale” telematic system (see Table 16):

Table 16: Target costs for low-cost and full-scale telematic solutions

Target costs	Low-cost solution	Full-scale solution
Procurement costs (hardware per wagon)	500,00 €	4.000,00 €
Recurrent operating costs (per month, e.g. for data transmission)	10,00 €	30,00 €
Cost of maintenance and service (per year, hardware per wagon)	100,00 €	200,00 €
Service life of the telematic system (in years)	10	10

A low-cost solution means a telematic system that serves the basic functions defined in Chapter 4.3. These include:

- tracking & tracing
- wagon / fleet scheduling
- mileage tracking
- monitoring of load status
- monitoring of load
- derailment detection
- shunting shock detection.

A full-scale solution means a telematic system incorporating all the applications outlined in this report (see Chapter 4.3).

Drawing on the target costs listed in Table 16 for procurement, recurrent monthly operating costs and annual maintenance and service costs, the following annual costs arise over a service life of 10 years (see Table 17).[10]

[10] The procurement costs do not include depreciation and interest; the purchase costs have simply been distributed over a service life of 10 years.

Table 17: Assumed annual costs of telematic applications (target costs)

	Low-cost solution		Full-scale solution	
	per month	per year	per month	per year
Procurement costs (hardware per wagon)	4,17 €	50,00 €	33,33 €	400,00 €
Recurrent operating costs (per month, e.g. for data transmission)	10,00 €	120,00 €	30,00 €	360,00 €
Cost of maintenance and service (per year, hardware per wagon)	8,33 €	100,00 €	16,67 €	200,00 €
Total	22,50 €	270,00 €	80,00 €	960,00 €

Table 18 below summarises the savings potential from the calculations of benefit in Chapters 0 and 9.3 for the low-cost version of a telematic system.

Once again, the authors explicitly point out that the assumptions on which calculations of benefit have been made may vary between users and between fleets.

Table 18 shows the annual savings potential from the applications indicated in a low-cost telematic solution. The annual savings potential estimated here amounts to € 608. This compares with annual costs for procurement, operation and maintenance & service of € 270 (see Table 17). On balance this scenario demonstrates a positive benefit derived from these telematic applications of € 338 per annum for each wagon equipped.

Table 18: Potential savings from a telematic system: low-cost version

	Savings potential	
	per month	per year
Fleet management		
Tracking & tracing	2,70 €	32,40 €
Fleet scheduling wagon -> fleet (faster turnaround)	16,00 €	192,00 €
Fleet scheduling wagon -> fleet (enable reload)	10,50 €	126,00 €
Mileage capture 10% wheelsets affected, 10% deviation from current mileage estimate	0,50 €	6,00 €
Load data		
Load condition		
Load status		- €
Overloading	20,00 €	240,00 €
Weighing		
Shipment punctuality		
Transport process (train operation)		
Train integrity		
Train formation		
Derailment		- €
Shunting shocks	1,00 €	12,00 €
Autom. brake test		
Support process (maintenance)		
Monitoring components (axle box)		
Monitoring components (brake valve)		
Monitoring components (wheel flats)		
Monitoring components (exchange brake shoe)		
Monitoring components (condition)		
Tracking critical components		
Support process (other)		
Automated billing		
Data transition from carrier to customer		
Autom. loading/unloading		
	50,70 €	608,40 €

Table 19 shows, this time for the full-scale version, the annual saving that can potentially be generated from the various telematic applications. In this scenario the estimated annual savings potential totals € 1,185. After offsetting the annual costs of procurement, operation and maintenance & service, which amount to € 960 (see Table 17), the telematic applications again generate a positive benefit, in this case € 225 per annum per wagon equipped.

Table 19: Potential savings from a telematic system: full-scale version

	Savings potential per month	per year
Fleet management		
Tracking & tracing	2,70 €	32,40 €
Fleet scheduling wagon -> fleet (faster turnaround)	16,00 €	192,00 €
Fleet scheduling wagon -> fleet (enable reload)	10,50 €	126,00 €
Mileage capture 10% wheelsets affected, 10% deviation from current mileage estimate	0,50 €	6,00 €
Load data		
Load condition		- €
Load status		- €
Overloading	20,00 €	240,00 €
Weighing		- €
Shipment punctuality		- €
Transport process (train operation)		
Train integrity		- €
Train formation		- €
Derailment		- €
Shunting shocks	1,00 €	12,00 €
Autom. brake test		- €
Support process (maintenance)		
Monitoring components (axle box)		- €
Monitoring components (brake valve)		- €
Monitoring components (wheel flats)	42,78 €	513,36 €
Monitoring components (exchange brake shoe)	5,28 €	63,36 €
Monitoring components (condition)		- €
Tracking critical components		- €
Support process (other)		
Automated billing		- €
Data transition from carrier to customer		- €
Autom. loading/unloading		- €
	98,76 €	1.185,12 €

The overall picture is that, based on the assumptions made and the target costs for telematic applications in both the “low-cost” and “full-scale” versions, the impact of the benefits is positive.

It should be borne in mind at this point, however, that – depending on the telematic application in question – this benefit accrues to different stakeholders in the rail freight business, be they wagon keepers, railway undertakings, rail infrastructure managers or end users. The ramifications of this were outlined above in Chapter 4.4 and summarised in Table 2.

Depending on the user-specific selection of telematic applications, it is therefore always important to consider how much benefit will fall to each of the stakeholders. As the additional costs of procuring telematic systems will be assumed by wagon keepers, transfer models (e.g. pricing models) will have to be designed so that wagon keepers reap at least some of the advantages gained from these telematic applications.

10. Impact on the Innovative Rail Freight Wagon 2030

The use of telematic and sensor systems in freight cars offers the opportunity to implement innovations at several stages in the logistic chain, and with that to leverage this pivotal production tool to enhance the competitiveness of the system as a whole.

We see below how each functional element in the system enhances the various aspects of the Innovative Rail Freight Wagon initiative:

Innovation projects: Basic innovations for rail freight wagons	**Systems + modules** including impact on maintenance (rules & scheduled / unplanned maintenance)	**Objectives of the 5L approach**				
		Light-weight	Low-noise	Long-running	Logistics-enabled	LCC-oriented
2. Future Sensors / Telematics	a) System: Telematics		x	x	x	x
	b) Module: Basic module			x	x	x
	c) Module: Monitoring condition		x	x		x
	d) Module: Maintenance strategy			x		x
	e) *Module: Additional sensors*			x	x	x

Table 20: Impact of telematic/sensor modules on the Innovative Rail Freight Wagon 2030

Annex: Specimen description of a basic telematic and sensor technology unit for rail freight wagons

Technical structure of mobile / basic unit

A basic telematic unit essentially consists of components for:

- **Power supply**

  The power supply should permit a guaranteed minimum service life of 5 years given an average of 3 system messages per day. Currently the only inexpensive way to achieve this is with batteries. The user must be able to replace the battery unassisted when due. It must also be possible to access external power for additional capacity.

- **Sensor data capture**

  The following must be available for connecting the cabled sensor equipment generally available in the market:

  - two analogue inputs (4-20mA)
  - two digital inputs (0/I), floating contacts
  - two inputs for measuring temperature
  - a switchable digital output (relay contact)

  Motion and idle states can be detected by an inbuilt vibration sensor. A 3D acceleration sensor detects whether pre-defined limits have been exceeded, indicating that a wagon is bumping too hard against other wagons. Flats can be detected, although not attributed to a particular axle or wheel, as can derailments. There is so far no empirical data on the last two features.

- **Localisation**

  A sensitive (preferably -140 dBm) multisystem GNSS receiver (parallel operation with GPS, GLONASS, Galileo and possibly BeiDou) with a sufficient number of channels (at least 50) is required for rapid, robust tracking. To ensure speed and sensitivity, the receiver should also offer assisted GNSS functionality (currently A-GPS, from 2014 also A-Galileo) and SBAS (in particular EGNOS). Additionally important is an aerial that is suitable for placement on the housing or any box-based positioning, as installation in the rail car and its environment usually only allow limited reception.

- **Communications**

  It should be possible to use the four globally available GSM frequencies to transmit messages / data to the communication server. This requires a quad band GSM modem. Transmission should normally be via GPRS. As GPRS is not available everywhere in all countries, SMS should be enabled as a fall-back, e.g. for alarm messages.

- **Housing and equipment features**

  The housing must at least comply with an IP67 rating (dustproof and protected against temporary immersion) and be sufficiently resilient to chemical influences. All components must at least permit operating temperatures between -25°C and +75°C.

Mobile unit functionality

Messages via the mobile unit should be time-triggered (set time or cyclical) or event-triggered. Events might be sensor messages relating to motion, idle state, impact, exceeded limit, geofence, or a combination of events. All functions must be configurable by radio.

Essentially the functions can also deliver data on wagon mileage. Tests of this kind are currently being carried out at BASF SE Ludwigshafen, but as yet there are no definite results.

Portal functionality

Messages and positions have to be reported via a Web portal:

- multi-client enabled, i.e. for a number of users with different user rights, each with their own device designation
- multi-language visualisation and time data in local time (no conversion)
- total message history with location description for the last 3 months in list format
- data can be exported at any time into Excel lists and/or made available via XML interface for successor systems
- mileage is recorded in a trip meter and entered the next day in a control total
- visualisation of the route
- individual designation of the mobile unit (device paired with wagon)
- allocation of a chosen number of wagons to a controller
- global mapping e.g. Google Maps® with satellite and aerial images
- configuration of the mobile device via the portal
- event messages can if required be sent without delay by e-mail or SMS text to alert pre-defined users.

Further requirements

If a tank car is used, for example, to transport inflammable substances that form gases, vapours or mists that could generate an explosive atmosphere, appropriate protected mobile devices and sensor equipment must be used in accordance with the ATEX Directives.

The mobile unit must permit modular retrofitting – for communication with appropriate radio sensors (Zigbee protocol) – so that further stages of the technology can be implemented in the rail car.