Horizon 2020
European Union Funding
for Research & Innovation

FR8RAIL

Deliverable D 1.4
Key Performance Indicators for Rail Freight

Project acronym:	FR8RAIL
Starting date:	01/09/2016
Duration (in months):	24
Call (part) identifier:	S2R-CFM-IP5-01-2015
Grant agreement no:	H2020 - 730617
Due date of deliverable:	Month 24
Actual submission date:	30-04-2019
Responsible/Author:	Dr. Roland Bänsch (CON)
Dissemination level:	PU
Status:	Final

Reviewed: (yes)

Document history		
Revision	*Date*	*Description*
0.1	31.12.2018	Draft Structure, Concept of KPI hierarchy
0.2	29.03.2019	Definition of complete set of KPIs for rail freight
0.3	30.04.2019	Text adaptations, graphics adaptations and document revisions
0.4	09.03.2020	Update reflecting comments from PO review report RP3

Report contributors		
Name	Beneficiary Short Name	Details of contribution
Dr. Roland Bänsch	CON	Author
Maxim Weidner	CON	Author

Table of Contents

List of Figures

List of Tables

1. Abbreviations and acronyms

Abbreviation / Acronyms	Description
CMW	Core Market Wagon
CTL	Closed Train Loop
EC	European Commission
EMW	Extended Market Wagon
EU	European Union
FR8RAIL	Project of the IP5 in Shift2Rail
IM	Infrastructure Manager
IP	Innovation Programme (of Shift2Rail)
OTL	Open Train Loop
P2P	Point-to-Point
RU	Railway Undertaking
SMART-RAIL	Lighthouse project
SWL	Single Wagon Load

2. Introduction

The huge potential offered by digitalization enabling automation will boost rail freight productivity and punctuality, creating competitive cost structures and stimulating growth in Europe by providing more efficient, reliable and high-quality rail freight services. WP1 of FR8RAIL addresses the market segments and top-level requirements for greater market uptake.

The segmentation of markets (D1.1 Market Segments) and the development of relevant Key Performance Indicators (KPIs) for the rail freight market will be a starting point for the framework and input to the migration plan (WP1 FR8HUB). But also the top-level requirements for wagon applications and propulsion are valuable inputs for developing KPIs for rail freight business.

Building on survey/estimation of characteristics to the freight rails systems in terms of costs and performance, on existing data on the average performance (mileage) of operations and freight wagons, and on technical specifications, the estimated benefits of the novel technologies addressed in the TDs 5.1 to 5.6 shall be quantified in the form of key performance indicators as required in the S2R Master plan. From the CCA in S2R the superior KPI´s for the rail sector will be broken down and further developed for the freight rail business. The following indicators provide an indication on the KPI´s for the freight sector. They shall be contrasted for model calculations:

- Deadweight per metre/payload to deadweight ratio
- Maximum train capacity and train length
- Energy consumption per payload tonne
- Wagon performance (typical scenarios): payload per year/kilometres per year
- specific cost of transport per unit
- lead-time for total transport operation (depending on the transport type)
- Total life cycle costs.
- Reduction for noise emissions of wagons and locomotives

This final set of key performance indicators for IP 5shall enable shippers and railway companies but also the members of the S2R JU to calculate the expected benefits of using/purchasing the novel IP5 technologies.

The KPIs defined in the following will also enable comparison possibilities for the subject areas listed below. That means quantification of the estimated benefits of the new technology on component and subsystem level in the form of KPIs:
D1.4.1 Novel wagon versus typical UIC standard wagons
D1.4.2 Running gear and automatic coupler
D1.4.3 Locomotive
D1.4.4 Propulsion

As this pre-selection from the project proposal focuses on technical improvements of productions means of the current system which supports but does not provide the full picture of

the market offering of rail freight to the transport market, a more top down approach coming from the customers view has been identified as being more appropriate to serve the objective of this task. At the same time, the KPI descriptions in chapter 5 clearly state the influencing assets of the rail transport system. Therefore, the influence of a technical improvement or new solution becomes directly linked to the competitiveness of the sector. And it becomes measurable. Thus, the direct relationship between (technical) innovations and the competitiveness of the sector, which is the final objective of all Shift^{2}Rail activities, becomes more obvious.

3. Investigation Approach

The FR8RAIL project will develop KPIs to measure progress and assess the Shift2Rail objectives for freight transport. To this end, they will be included in the further investigations and simulations of the Cross-Cutting Activities projects.

The FR8RAIL project therefore, follows a combination of a top-down and a bottom-up approach. The top-down approach is based on the analysis of existing information relating to rail freight services and of course the vision of Shift2Rail with its goals in terms of cutting the life-cycle costs, doubling capacity and increasing reliability and punctuality, whereas the bottom-up approach represents the general information, information coming from the first projects within IP5 and furthermore of the prior investigations performed in the SMART-RAIL project. Two type of KPIs outcomes are therefore presented:

- General KPIs from literature review,
- Investigations of FR8RAIL projects,
- SMART-RAIL specific KPIs.

The focus for the KPI selection was streamlined to the three objectives of Shift2Rail, i.e.:

- Cutting the life-cycle cost of railway transports by as much as 50%,
- Doubling railway capacity,
- Increasing reliability and punctuality by as much as 50%.

This document is preceded by general research and research based on SMART-RAIL's findings. The investigations of this lighthouse project have mainly focused on the perspective of shippers and logisticians. Accordingly, the performance of the rail system was considered in the development of the KPIs there. Nevertheless, the list also includes KPIs that draw on the performance of certain technologies or assets.

The FR8RAIL approach will ultimately also contribute to the evaluation of the economic efficiency and competitiveness of the rail freight transport system. However, this study will focus less on operational processes but more on the influence of technologies and technical solutions. The following figure illustrates the different research approaches graphically:

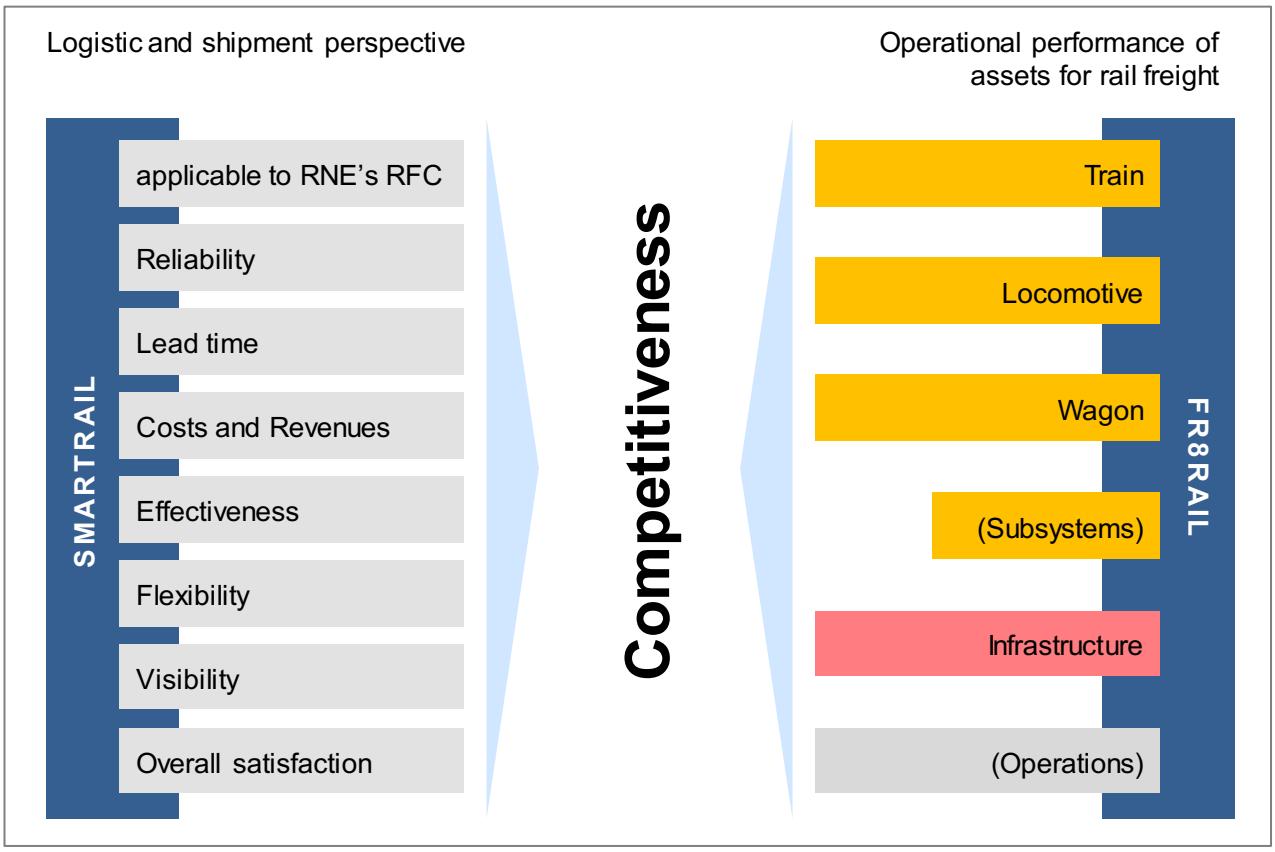


Figure 1: Comparison of different approaches of SMARTRAIL and FR8RAIL

What unites both approaches is the desire for greater competitiveness. As mentioned at the beginning, SMART-RAIL focuses on the perspective of shippers and logistics providers, for whom a reliable transport system and a closed information chain are at the centre of the drive for more competitiveness.

SMART-RAIL has identified essential reasons that inhibit the current system:

- **Mind-set of the rail sector:** Focus on timetable and train operations instead of supply chain orientation.
- **Transparency:** No digital workflow from end-to-end. Shippers and Forwarders and their customer do not get the right status of the transport in time.
- **Efficiency:** direct rail transport costs only +/- 50% of total rail related Supply Chain Costs (Shunting, Transfer to marshalling yards, train set-up, complexity costs, waiting time)
- **Innovation:** Rail sector is captured in mutual dependencies between the various involved companies and stakeholders. The status quo is very hardly to change.
- **Flexibility:** The adaptability of the production system to incidents in operation is not part of its design.

On this basis, KPIs were developed that address the weaknesses of the overall system (see Figure 1, and in detail chapter 4). This shows that many KPIs initially focus on processes and the availability of information for the large number of stakeholders, while others are of course also

related to individual technologies and assets. Suggestions for key performance indicators have been developed for this as well.

Since S2R is primarily concerned with technology development, KPIs have been developed for the present document within the framework of FR8RAIL, on which the assets of the overall system have a significant influence, that is: train, locomotive, wagon and the infrastructure. The improvements that can be achieved as a result of new and innovative technologies should be measurable with the proposed key performance indicators.

Through the KPI hierarchy developed and presented in Chapter 5.2, its influence on the overall competitiveness of rail freight transport can thus be made visible.

4. SMART-RAIL KPIs

The following tables show SMARTRAIL's KPIs for the various categories:

Table 1: KPIs to measure reliability

KPI Title	KPI Description	Stakeholder
Punctuality	% of trains departing/arriving on time or within defined tolerance	- IM - RU
	% of cancelled services – due to reasons on whatever side (IM, RU, terminal)	
	Average delay time (hours)	
Reliability of the train paths	Downtime on railway infrastructure	- IM - RU
	No. of disrupting events and their impact (as delay)	
	Train path availability (% of successful satisfaction vs. rejections)	
	Time deviation of the demanded train path (demanded vs. assigned)	
Delays	Average and maximum delay of a train	- IM - Terminal - Port - Logistic operator
	Average and maximum delay of the loading/unloading process in terminal	
	Delay in various services, as transloading from/to a ship	
	Reasons for delay: Classification (e.g. caused by customer, by the infrastructure manager, by the operator)	
Overall reliability	% of the transports meeting the scheduled and promised time	- RU - Logistic operator

Table 2: KPIs to measure lead time

KPI Title	KPI Description	Stakeholder
Time to load/unload	Average and maximum time necessary to load/unload a wagon or a train in a terminal or in an end point	- RU - Terminal
Time to assemble train	Average and maximum time necessary to get wagons coupled to form a train	- RU - Terminal
Idle times	Average and maximum idle time (or exceeded idle time): - waiting in terminal - waiting for departure - waiting for handling in the port - waiting for the equipment (engine) - etc.	- IM - RU - Terminal - Port

Waiting for equipment	General availability of the equipment	- RU - Terminal
	Time to wait for assigning equipment or resources (engine, driver)	
	Time to wait with an assembled train for physical equipment	
	Waiting for another train to assume the wagons/cargo	
Operations in transit	Handover time between the partners	- RU - Terminal
	Various other services (technical inspections, customs, commercial inspections etc.)	
Total delivery time	Total transit time between terminals	- RU - Logistic operator
	Total transit time door-to-door	
	Average transit speed	

Table 3: KPIs to measure costs and revenues

KPI Title	KPI Description	Stakeholder
Cargo composition	Type of commodities on a train	- RU
	No. of different commodities on a train	
	No. of different customers on a train	
	Specific cargo transport (dangerous goods, oversize cargo etc.)	
Railway access fees	Fees for accessing the railway infrastructure - for different train services - for different daytime and weekdays - for different routes	- IM - RU
	Unit fee for 1 tonne, for 1 wagon	
Shipment costs	Costs of the railway leg, road leg, shortsea leg	- RU - Logistic operator
	Mileage costs of each leg	
	Total transit costs (terminal-terminal, or door-to door), mileage costs	

Table 4: KPIs to measure effectiveness

KPI Title	KPI Description	Stakeholder
Train capacity	Average and maximum train capacity in the service, the really utilized capacity	- RU - Logistic operator
	No. of wagons/containers/transport units on a train	
	Tonnage and % of the maximum allowed tonnage of the trains	

	Length and % of the maximum allowed length of the trains	
Efficiency of resources	Utilisation of the train capacity	- RU - Terminal
	Utilisation of the engine power (of the maximum tonnage)	
	% of empty runs of wagons	
	Average movements of empty wagons or containers	
Cancellations	No. of cancellations of a train service	- RU - Logistic operator
	No show % on a train	
Directional Balance	Utilisation of train capacity by direction	- RU - Logistic operator
	Planned loading rate percentage of the trip (one direction)	
	Payload tonnes per train/gross tonnes per train	
	Actual loading rate percentage of the trip	
Marshalling	Planned utilisation rate % of the marshalling yard	- RU - Logistic operator
	Actual utilisation rate % of the marshalling yard	
Terminals	Time used for loading at terminals	- RU - Logistic operator
	Time used for discharging at terminals	
Energy Consumption	Energy consumption; kWh/year or kWh/train	- RU
Management and utilisation of rolling stock	Locomotive availability, Blockades of locomotives for maintenance	- RU
	Locomotive productivity; tonnekm per locomotive per unit time	
	Empty engine runs. Distance per week, month or year	

Table 5: KPIs to measure flexibility

KPI Title	KPI Description	Stakeholder
Service frequency or quality	No. of departures per day, per week	- RU - Logistic operator
	No. of destinations served by the terminal or by the whole network	
Service parameters	Additional capacity available on the existing train services	- RU
	Availability of an additional services in case of special needs (e.g. additional train load)	
Last-minute booking	The shortest time necessary to book a slot on a train	- Terminal

	Cut-off time – when the transport unit needs to come to the terminal	- Logistic operator
Rebooking and changing the transport	Ability to rebook or change transport (its destination or parameters)	- RU
	The shortest time necessary to rebook or change	
Rail services altered	Number of times the actual plan of the rail service is altered prior to departure and why?	- RU

Table 6: KPIs to measure visibility

KPI Title	KPI Description	Stakeholder
Infrastructure visibility	Scope of information on infrastructure provided	- IM
Visibility of service	% of cargo for which the information in transit are available	- RU - Logistic operator
	% of mileage on which the information in transit are available	
	No or % of partners who provide data	
Tracking and tracing	Availability of the precise tracking	- RU
	Availability of the tracing	
Disruption visibility	Availability of information in case of disruptions	- IM
	Idle time between arising an event and getting informed	
	Visibility of the alternate or diverted route	
Data exchange	No. of different messages, processes, and communication dialogues covered by the data exchange	- IM - RU
	Alternatively, number of correct messages (or ratio correct/corrupt messages)	
	Data exchange standards supported by the ICT systems	
Data traffic	No. of messages exchanged	- RU - Logistic operator
	Network throughput used	
	Overall system load	

Table 7: KPIs to measure overall satisfaction

KPI Title	KPI Description	Stakeholder
Perceived availability of service	How much the customers perceive the service as "available", i.e. to what extent are their requirements met and not rejected or postponed	- Customers
Perceived reliability of service	How much the customers perceive the service as "reliable", i.e. to what extent they feel their transit requirements to be fulfilled with the specified time and quality	- Customers
Perceived visibility of service	How much the customers perceive the service as "available", i.e. to what extent they feel that they have enough information on position and status	- Customers
Overall satisfaction from the service	How the customers feel the service as satisfying their requirements and needs	- Customers
Claims	Percentage of shipments with claims	- Customers
Inclination to using the rail	How the customers trust the transport services which include railway leg	- Customers

5. FR8RAIL KPIs for Rail Freight Assets and Components

5.1. Guiding Principles

As mentioned in the introduction, the following studies are based on the objectives of S2R. These are:

- Cutting the life-cycle cost of railway transports by as much as 50%,
- Doubling railway capacity,
- Increasing reliability and punctuality by as much as 50%.

The increase in capacity is primarily related to the fact that the EU Commission wants to shift more traffic to the more environmentally friendly and energy-efficient railways - 30% of road traffic longer than 300 km is to be shifted to rail by 2030, and 50% of road freight traffic longer than 300 km by 2050.

But if one considers the development of the main performance indicators – the transport performance in tonne-km and transport volume in tonnes – of the freight sector in the last decade, one cannot not see any significant increases of the rail freight business.

As the Smart-Rail project has examined in their living labs, there is a remarkable lack of belief and trust that the freight rail sector will change and adapt to the needs of modern logistics. The main driver to regain trust is predictability of the rail transport service. It is the essential basis to

create new and reliable business. In case of deviations the shippers expect immediate and transparent information, so that they can inform their customers and, if necessary, to take appropriate measures.

So, one could conclude from this that it is not only a capacity issue. And as it is more unlikely, that new investments in rail infrastructure will happen to raise capacity physically, the industry should think of alternatives. Operational and logistical concepts must be adapted. New concepts must be developed to meet the customers' needs. The increase of average train length is one measure to increase transport capacity up to the maximum given by track length and signal distance. Trains that can run at higher speed and with better longitudinal dynamics allow more train runs during daytime, when the networks are usually packed with faster passenger trains. Finally, block train operations on a timetable basis can attract more transport orders on specific relations especially for the extended market. However, this also requires appropriate hubs in order to make rail freight traffic accessible for these transports that are today handled by road.

Finally, it seems that rail freight transport, due to its rigid processes and partly very outdated assets – infrastructure and rolling stock –, can no longer cope with the developments (mainly on road) and today's requirements of modern logistics. The core issue is therefore the competitiveness of the railways – essentially in comparison to road freight transport.

The task now is to identify suitable parameters that contribute to the overall objective competitiveness. Three things play a central role in competitiveness. These are, of course, costs for the customer, but also transport time and predictability.

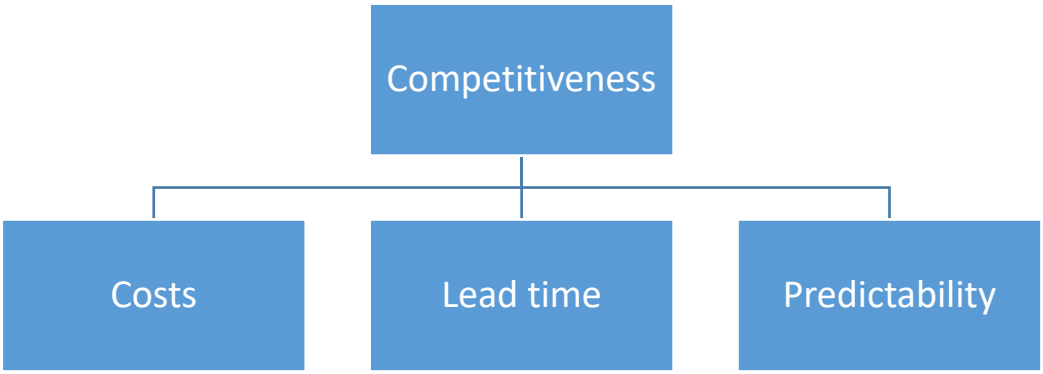


Figure 2: KPI hierarchy approach

5.2. FR8RAIL KPI hierarchy

The three main parameters of cost, lead time and predictability were further broken down as the work progressed. This also includes the fact that cause-effect relationships were recorded and assigned accordingly.

In the following chapters, the statements of the individual key performance indicators and measures are defined. In addition, the influencing factors such as infrastructure, terminal, marshalling yard and, in the case of rolling stock, locomotives and wagons are assigned to the various KPIs. This is intended to point out which asset or its technological improvement has a direct or indirect influence on which control variable (costs, lead time, reliability).

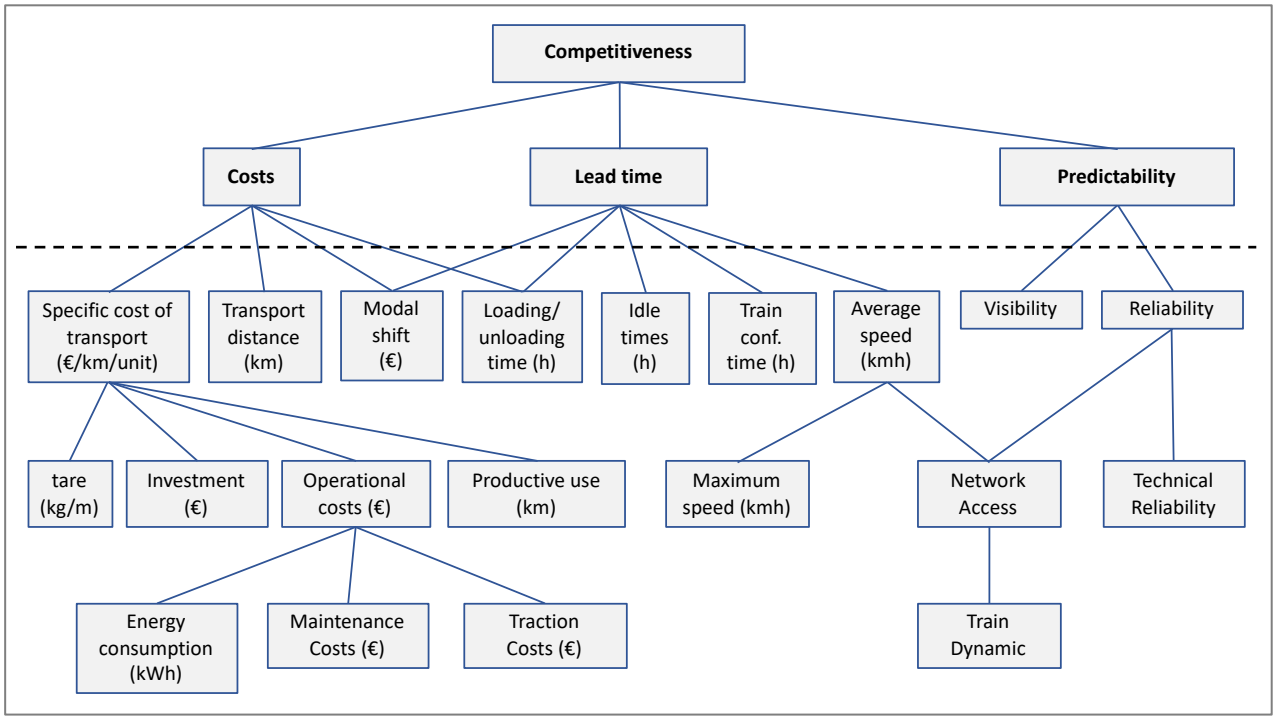


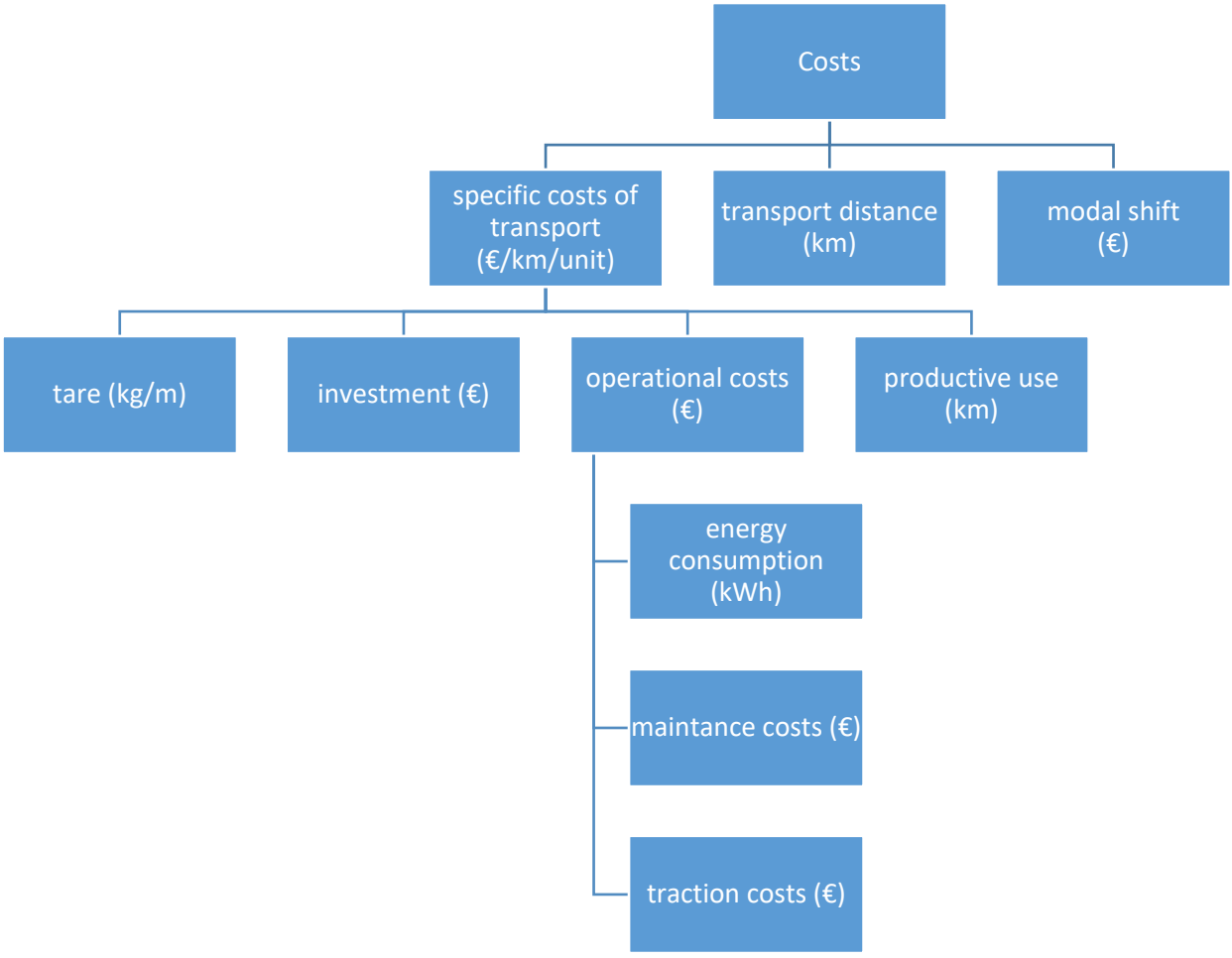
Figure 3: Full hierarchy of FR8RAIL KPIs

With this selection of KPIs, the Cross-Cutting Activities projects are to be supported in requesting suitable parameters from the stakeholders regarding their actual state for the various applications in rail freight transport.

The supplementary assessment by the (technical) experts of the extent to which the solutions and new technologies developed in IP5 contribute to the improvement (target state) of individual assets will make a significant contribution to whether and to what extent the goals of S2R can be achieved.

5.3. Costs

The costs break down as follows:



5.3.1. Specific Costs of Transport

Description	Cost of transport for the customer in euro per transport kilometre and unit
Measuring Unit	€/km/unit
Affected by	Network, terminal, marshalling yard, locomotive, wagon

5.3.1.1. Tare

Description	The tare weight is the difference between the gross or total weight and the net weight of the transported goods. The smaller the tare weight, the greater the payload and thus the greater the transport capacity of a train.
Measuring Unit	kg/m
Affected by	Wagon

5.3.1.2. Investment

Description	Includes acquisition costs and incidental investment costs, such as debt service.
Measuring Unit	€
Affected by	Locomotive, wagon

5.3.1.3. Operational Costs

Description	Operating costs include the cost of energy consumption, traction costs, maintenance and repair.
Measuring Unit	€
Affected by	Locomotive, wagon

5.3.1.3.1. Energy consumption

Description	Total energy consumed for the transport task
Measuring Unit	kWh
Affected by	Locomotive, wagon

5.3.1.3.2. Maintenance Costs

Description	The maintenance costs are all costs incurred in the course of scheduled overhauls and unscheduled repairs.
Measuring Unit	€
Affected by	Locomotive, wagon

5.3.1.3.3. Traction Costs

Description	Costs for the locomotive and the operating personnel
Measuring Unit	€
Affected by	Locomotive, wagon

5.3.1.4. Productive Use

Description	Describes the mileage per year of a wagon or locomotive. The higher the effective mileage, the lower the impact of investments costs.
Measuring Unit	km
Affected by	Locomotive, wagon

5.3.2. Transport Distance

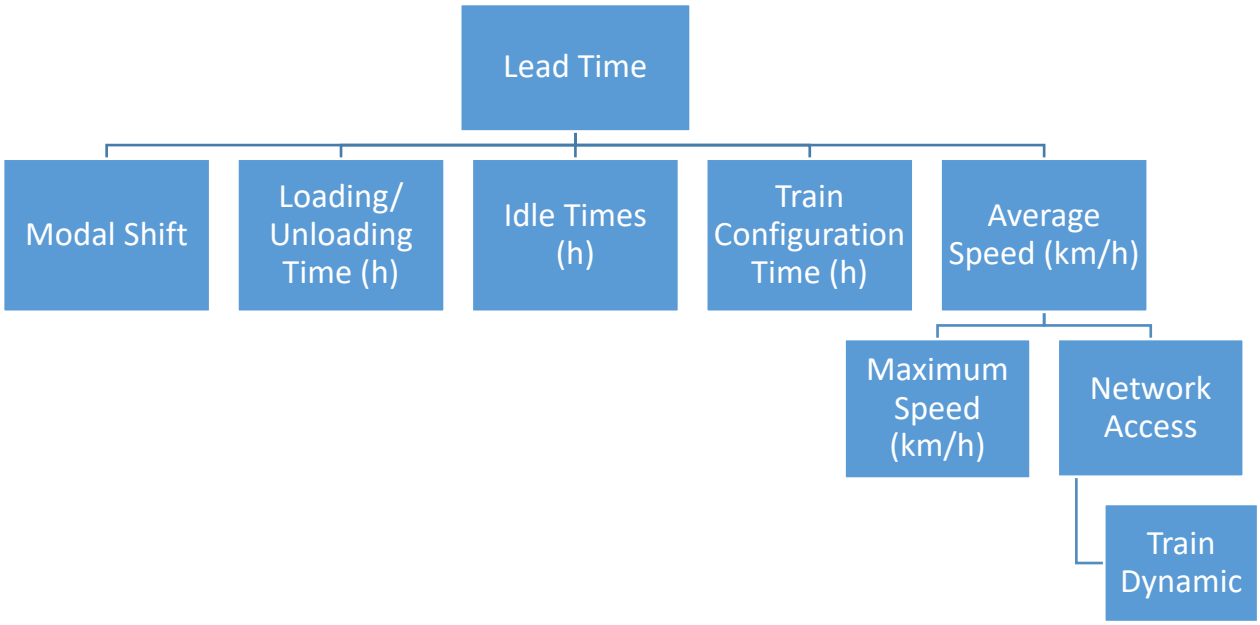
Description	Distance covered for transport.
Measuring Unit	km
Affected by	Network route, type of network

5.3.3. Modal Shift

Description	Change of loading from or to the railway system
Measuring Unit	€
Affected by	Terminal design, logistics concept, use of containers

5.4. Lead Time

The lead time breaks down as follows:



5.4.1. Modal Shift

Description	Change of loading from or to the railway system
Measuring Unit	hours
Affected by	Terminal design, logistics concept, use of containers

5.4.2. Loading/Unloading Time

Description	Average and maximum time necessary to load/unload a wagon or a train in a terminal or in an end point
Measuring Unit	h
Affected by	Wagon, terminal

5.4.3. Idle Times

Description	Average and maximum idle time (or exceeded idle time): - waiting in terminal - waiting for departure - waiting for handling in the port - waiting for the equipment (engine) etc.
Measuring Unit	h
Affected by	Network (schedule, signal distance, track layout), locomotive + wagon (availability, train dynamics), terminal, marshalling yard

5.4.4. Train Configuration Time

Description	Average and maximum time necessary to get wagons coupled to form a train
Measuring Unit	h
Affected by	Logistics concept (operational mode block train vs SWL: coupling, train integrity concept)

5.4.5. Average Speed

Description	Average train speed is an overall measure of physical railway performance (both train and infrastructure). The average speed is partly determined by train operator factors such as locomotive power and whether the operator picks up and drops off freight in route. Prevailing speeds reflect a range of infrastructure-based factors, including the number of stops (especially when there are intermediate cities to traverse), track alignment and condition.
Measuring Unit	km/h
Affected by	Network, train (loco, wagon)

5.4.5.1. Maximum Speed

Description	Maximum permitted track speed, maximum speed of Loco and Wagon
Measuring Unit	km/h
Affected by	Train (loco, wagon)

5.4.5.2. Network Access

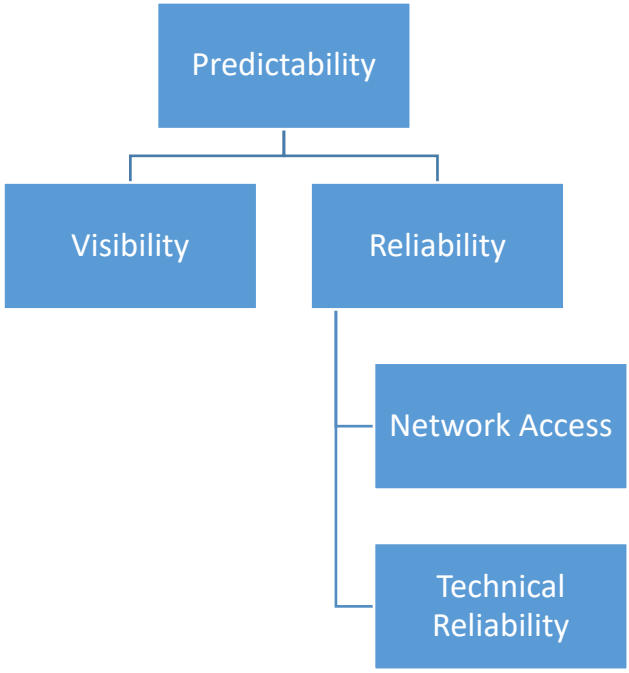
Description	Approved access compared with the number of requests per network are or relation in the network
Measuring Unit	%
Affected by	Train dynamics, train length, network capacity, network design

5.4.5.2.1. Train Dynamics

Description	Braking performance compared with passenger trains
Measuring Unit	% or braking percentage
Affected by	Braking system, brake control, train weight

5.5. Predictability

The predictability breaks down as follows:



5.5.1. Visibility

Description	Infrastructure visibility - Scope of information on infrastructure provided; Visibility of service - % of cargo for which the information in transit are available - % of mileage on which the information in transit are available - No or % of partners who provide data Tracking and tracing - Availability of the precise tracking - Availability of the tracing Disruption visibility - Availability of information in case of disruptions - Idle time between arising an event and getting informed - Visibility of the alternate or diverted route
Measuring Unit	%
Affected by	Data processing, communication, electrification

5.5.2. Reliability

Description	% of the transports meeting the scheduled and promised time
Measuring Unit	%
Affected by	Train (locomotive, wagon), network

5.5.2.1. Network Access

Description	Approved access compared with the number of requests per network or relation in the network
Measuring Unit	%
Affected by	Train dynamics, network capacity, train length, network design

5.5.2.1.1. Train Dynamic

Description	Braking performance relative to passenger train
Measuring Unit	% of brake de-acceleration of passenger train or measuring in braking percentage according UIC
Affected by	Network, train

5.5.2.2. Technical Reliability

Description	- Downtime on railway infrastructure, Locomotive, Wagon - No of disrupting events and their impact (as delay) - Train path availability (% of successful satisfaction vs. rejections) - Time deviation of the demanded train path (demanded vs. assigned)
Measuring Unit	%, h
Affected by	Network, locomotive, wagon

6. Summary and Recommendations

This paper has defined and compiled a number of KPIs. On the basis of these KPIs, improvements in the efficiency of individual technologies can be measured against the status quo but also in the interaction of different solutions.

If the actual values and estimates of the change values are queried accordingly by introducing and penetrating the market with new solutions, these KPIs also allow an assessment of the overall performance development of the rail freight transport system. Such studies are the subject of the Cross Cutting Activities. The present Key Performance Indicators will provide assistance in this respect.

The following figure provides an overview of all KPIs suggested by the FR8RAIL project for rail freight applications and includes reference to the influencing assets.

	Loco	Wagon	Network	Terminal	Marshalling Yard
Costs					
Specific costs of transport	x	x	x	x	x
Tare		x			
Investment	x	x			
Operational costs	x	x			
Energy consumption	x	x			
Maintance costs	x	x			
Traction costs	x	x			
Productive use	x	x			
Transport distance			x		
Modal shift		x		x	
Lead time					
Modal Shift		x		x	
Loading/unloading time		x		x	
Idle times	x	x	x	x	x
Train configuration time	x	x			x
Average Speed	x	x	x		
Maximum speed	x	x	x		
Network access	x	x	x		
Train dynamic	x	x			
Predicability					
Visibility	x	x			
Reliability	x	x	x	x	x
Network access	x	x	x		
Train dynamic	x	x			
Technical reliability	x	x	x	x	x

Figure 4: Overview of KPIs and influencing asset

7. References

FR8RAIL *Deliverable D1.1 - Market Segments*, Report, June 2018

FR8RAIL *Deliverable D1.2 - Top level requirements for Wagon Applications*, Report, October 2018

FR8RAIL *Deliverable D1.3 - Top level requirements Propulsion*, Report, March 2019

SMART-RAIL *Deliverable D2.4 - Guidelines for specification of KPIs,* Report, September 2015