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Deliverable D4.2

Evaluation Framework

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Consortium - List of partners

Partner No	Short name	Name	Country
1	UIC	International Union of Railways	France
2	VTT	VTT Technical Research Centre of Finland Ltd	Finland
3	NTNU	Norwegian University of Science and Technology	Norway
4	IFSTTAR	French institute of science and technology for transport, development and networks	France
5	FFE	Fundación Ferrocarriles Españoles	Spain
6	CERTH-HIT	Centre for Research and Technology Hellas - Hellenic Institute of Transport	Greece
7	TRAINOSE	Trainose Transport – Passenger and Freight Transportation Services SA	Greece
8	INTADER	Intermodal Transportation and Logistics Research Association	Turkey
9	CEREMA	Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning	France
10	GLS	Geoloc Systems	France
11	RWTH	Rheinisch-Westfaelische Technische Hochschule Aachen University	Germany
12	UNIROMA3	University of Roma Tre	Italy
13	COMM	Commsignia Ltd	Hungary
14	IRU	International Road Transport Union - Projects ASBL	Belgium
15	SNCF	SNCF	France
16	DLR	German Aerospace Center	Germany
17	UTBM	University of Technology of Belfort-Montbéliard	France

Executive summary

The aim of the SAFER-LC project is to develop cost-efficient measures for increasing the safety at level crossings. The project will develop such measures for different types of level crossings and different kinds of road users. The measures developed by the project will be installed and tested in simulators and pilot sites in order to evaluate their effects and to demonstrate the improvement of safety.

As a basis for the evaluation, this document describes the Evaluation Framework in order to show which parameters should be measured, how this is possible and which pilot or simulator is able to provide these data. The Key Performance Indicators to be evaluated are clustered into the five categories “Safety”, “Traffic”, “Human behaviour”, “Technical” and “Business”. For each category, a set of potentially relevant parameters has been identified. These parameters which are of interest in principle have been contrasted to the capabilities of the simulators and pilot sites in order to determine where the different parameters can be measured.

It is likely that during the tests not the full set of all parameters will be measurable. The Evaluation Framework should serve as a guideline to be considered for setting up the tests in order to consider all relevant aspects of a certain measure. The question of which parameters need to be gathered, strongly depends on the specific design and intended effect of each measure. As the measures are yet to be developed and the test sites are still to be planned and equipped, the measurability of the KPI cannot yet be determined. The currently selected KPIs can also be changed considering the test sites conditions and collected data from the test sites.

Table of content

1. INTRODUCTION

SAFER-LC aims to improve safety and minimise the risk of level crossing (LC) accidents by developing innovative and user-centred measures and tools to enhance safety. A toolbox that contains smart technological as well as non-technological measures will be a key result of the project. The overall project results aim to help both rail and road managers to improve safety at level crossings.

While the work packages (WP) 2 and 3 are designed to understand the human factor at level crossings and to design countermeasures, the central task of WP4 is to test and evaluate the proposed measures. As the first step towards the evaluation, Task 4.1 (T4.1) will define the "Testing Framework" that will be followed in the SAFER-LC project for the monitoring and evaluation of the safety measures developed and piloted within the project. The "Testing Framework" consists of two parts: the D4.1Iimplementation Guidelines" and the D4.2 Evaluation Framework".

In this document – "D4.2 Evaluation Framework" - a set of key performance indicators (KPIs) will be established in order to measure the achievement of the piloted measures in terms of their impact on safety, road and rail traffic and human behaviour, together with their technical performance and business costs. The data to be collected for the measurement or estimation of these indicators is also defined in detail together with a separate section on the "contextual factors" influencing the performance of the measures.

The purpose of this document is to serve as a collection of relevant KPIs for the evaluation of safety measures which will be piloted in the SAFER-LC project. This document, together with the Deliverable Report D4.1 "Implementation Guidelines", enables pilot test leaders carrying out the evaluation to choose test sites and to design experiments that allow testing as well as analysis of measures according to relevant KPI. It will describe in detail:

- Methodology employed to create "D4.2 Evaluation Framework",
- Description of KPIs from a generic perspective,
- Description of data needed to evaluate measures according to the KPIs,
- Determining how KPIs are measurable with data from actual available simulators and field tests.

2. METHODOLOGY

The methodology used to develop this Evaluation Framework contains three steps. The first is the generic identification of KPIs for the evaluation of developed and tested safety measures. The second step is the identification of data which will be used to measure the previously identified KPI. This step is essential since in test sites data is usually collected instead of direct results for the KPI. This data needs to be analysed and possibly combined with other data sets to get results for KPI. The third step is the matching of KPIs with the test sites available in this project. Therefore, it will be investigated if the test sites can provide necessary data to evaluate the selected KPIs for each test sites. In summary, KPI for the evaluation are identified and it is investigated with which available test sites the different KPI can be evaluated (see Figure 1).

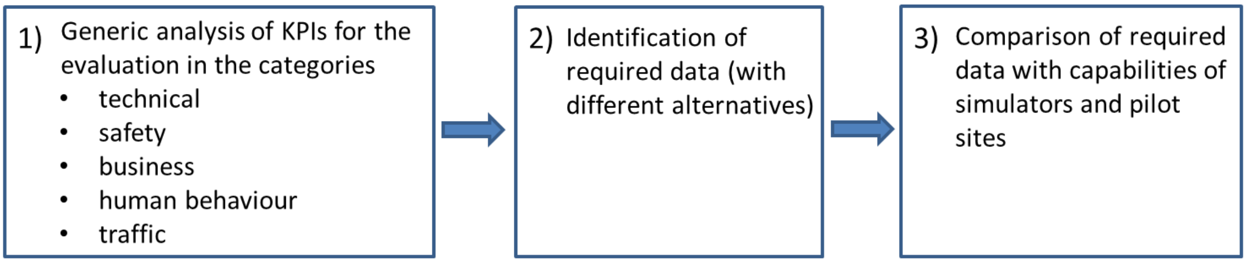

Figure 1: Approach for evaluation framework

3. KPI AND THEIR DATA BASIS FROM A GENERIC PERSPECTIVE

The KPIs are divided into five generic categories. Given that the focus of the SAFER-LC project is to increase safety around LC the first of these KPI categories is “Safety”. At the same time LCs are a part of transportation systems. A core task of transportation systems is to provide mobility through traffic. Therefore “Traffic” is another category to be evaluated. The before mentioned categories are influenced by human behaviour and technical frame conditions. That leads to the categories “Human behaviour” and “Technical”. Finally, measures can only be realised if they can be financed. Therefore “Business” is another category to be evaluated.

The measures to be developed will influence parameters and KPIs from each of the categories which interact with each other. One example for possible interaction is shown in Figure 2. A measure could e.g. influence the waiting time for the road users, which is a traffic-related parameter. On the one hand, this can have an influence on the behaviour of the traffic participants (a human behaviour parameter) which can influence safety parameters. On the other hand, the waiting time can influence other traffic-related parameters like the road capacity and therefore the overall capacity of the LC. At the same time, the LC measure can directly influence the human behaviour. Furthermore, it will have technical parameters like Reliability, Availability and Safety (RAM). They can influence the safety, but will also have effects on the costs of the LC. As the measure also causes procurement and operation costs, it will affect the operational and capital expenditures, which are business-related KPI. Business-related KPI are linked with traffic-related KPI like the capacity of the transportation system.

This generic example is neither complete nor can all interdependencies be sketched unambiguously, but is shall illustrate the interdependencies that the various parameters can have. These interdependencies will strongly depend on the specific measures to be developed.

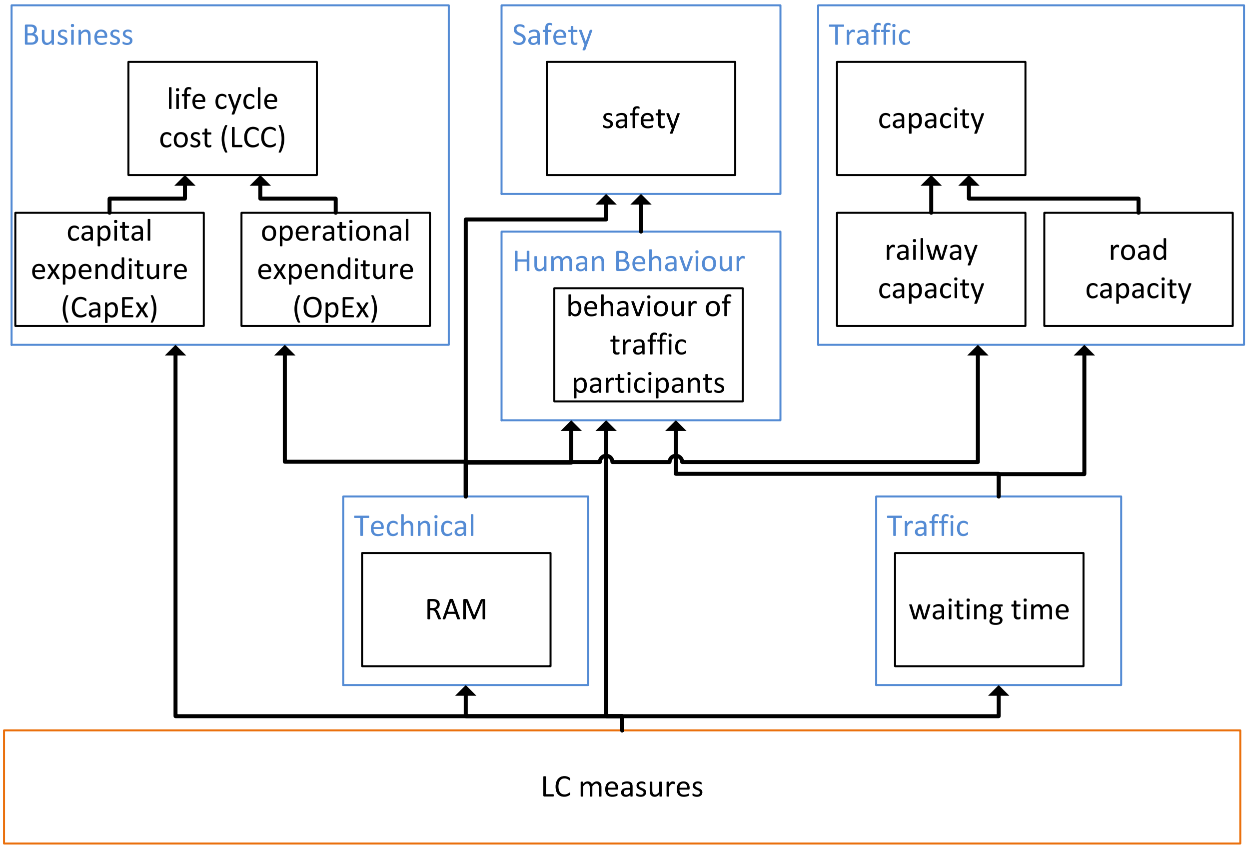

Figure 2: Categorisation and possible interdependencies of KPI

Each of the following sections of this deliverable focusses on one of the KPI categories. In each section the associated KPI are described. The majority of the KPI is of quantitative nature. The description of the KPI includes the indicator

- ID,
- name,
- unit,
- verbal description,
- literature references in which the importance of the KPI is discussed,
- data needed to measure the KPI.

For some KPIs, different types of data can be used to determine the KPI independently of each other. This approach has two advantages: On the one hand triangulation of the data used to evaluate the KPI increases the quality of the evaluation. On the other hand, offering alternative data sources can increase the possibility to evaluate the measure in the event that the collection of one set of data is not realisable at available test sites.

The sources where the different parameters were derived from are indicated in the following tables as footnote. Where no sources are given, the indicators are based on the judgement of experts from SAFER-LC participating organisations, relying on experience from previous relevant projects in the traffic safety domain.

3.1. Safety-related parameters

The KPI category "Safety" focusses on indicators which describe the amount of actual accidents (i.e. collisions) around a level crossing (KPIs grouped under 'Collisions') as well as indicators which reflect the accident risk at a level crossing (KPIs grouped under 'Surrogate safety measures' and 'Kinematic indicators'). Indicators which reflect the accident risk contain aspects regarding movement of traffic participants as well as reliability of a safety measure (see Table 1).

The probability of measuring actual accidents while testing a certain measure depends on the duration of the testing period. The concrete test design is not set up yet. However it seems relatively unlikely to observe this kind of incidents in reality. However, these generic KPIs should not be excluded a priori.

Table 1: Safety KPI and their data basis

ID	Name	Unit	Description	Required data
Collisions				
S.C1	Number of collisions	1 / a	Number of collisions between different traffic participants or traffic participants and infrastructure at the LC	• Visual records of the LC, • Accident reports
S.C1 a	Number of near misses	1 / a	Number of near misses (i.e. critical situations that almost lead to a collision) that could be detected by short TTC or PET (the threshold value needs to be defined).	• TTC • PET • Video surveillance
S.C2	Traffic injuries / per time unit	1 / a	Number of injured persons due to collisions	• Accident reports
S.C3	Traffic death / per time unit	1 / a	Number of deaths due to collisions	• Accident reports
S.C4	Material damage	EUR / a	Material damage in Euro due to collisions	• Accident follow-up reports on financial impacts of material damage
Surrogate safety measures				
S.S1	TTC between approaching road traffic participants	s	=Time to collision TTC1=assuming prevailing velocities and distance TTC2=assuming prevailing velocities, accelerations and distance [1, 2, 3]	• Velocity and acceleration of different vehicles of road traffic participants, • Positions and heading of different vehicles of road traffic participants
S.S2	PET on the LC between last passing road traffic	s	=Post-Encroachment Time =Time between departure of the encroaching road traffic participant from the conflict point and arrival of the train at the conflict point [2]	• LC leaving time of road traffic participants' vehicles, • LC arrival time of trains

[1] Astarita, V., et al. (2012)

[2] U.S. Department of Transportation, (2003)

[3] Zhang, Y., Antonsson, E. K., & Grote, K. (2006)

ID	Name	Unit	Description	Required data
	participant and train			
S.S3	PET on the LC between last passing road traffic participant and closing gates	s	=Post-Encroachment Time =Time between departure of the encroaching road traffic participant from the conflict point and arrival of the gate at the conflict point [2]	• LC leaving time of road traffic participants' vehicles, • Visual recording or control of technical processes at LC
S.S4	THW between approaching road traffic participants	s	=Time headway =Time the following driver has to react in case the lead vehicle suddenly brakes at maximum deceleration [3]	• Distance between different approaching vehicles of road traffic participants, • Velocity of different vehicles of road traffic participants
S.S5	ET of road traffic participants on the LC	s	=Encroachment time =Time duration during which the encroaching road traffic participant infringes upon the LC [2]	• Positions of train and road traffic participant's vehicle, • Data about a barrier in terms of road traffic participants' vehicle on track at LC
S.S6	DR of road traffic participants in conflict with gates or train	m / s²	=Deceleration rate =Rate at which the crossing vehicle must decelerate to avoid collision [1], [2]	• Velocity of approaching road traffic participants' vehicle, • Distance between road traffic participants' vehicle and LC, • Appearance of gates or trains, when road traffic participants' vehicle reaches LC
S.S7	DRAC	m / s²	=Deceleration Rate to avoid crash =Rate at which a vehicle must decelerate to avoid a collision with an ahead moving vehicle [1]	• Distance between different approaching vehicles of road traffic participants, • Velocity of different vehicles of road traffic participants
			Kinematic indicators	
S.K1	Velocity over time around LC	m / s	Function of velocity over braking distance around the LC showing the velocity of road traffic participants and its changes while the participants are approaching and leaving LC (reaction + orientation + braking distance)	• Velocity of road traffic participants' vehicle within the considered range
S.K2	Acceleration and deceleration over time around LC	m / s²	Function of acceleration and deceleration over braking distance around the LC showing the acceleration and deceleration of road traffic participants and its changes while the participants are approaching and leaving LC (reaction + orientation + braking distance)	• Velocity change of road traffic participants' vehicle within the considered range, • Derivation of the function of velocity over time
S.K3	Velocity maximum around LC when LC is closed	m / s	Maximum velocity of approaching road traffic participant within the stopping distance around the LC in the time frame of + /- 30 s of the closed LC (reaction + orientation + braking distance)	• Velocity of road traffic participants' vehicle within the considered range
S.K4	Velocity maximum around LC when LC is open	m / s	Maximum velocity of approaching road traffic participant within the stopping distance around the LC when LC is open , i.e. not within +/- 30 s of the closed LC (reaction + orientation + braking distance)	• Velocity of road traffic participants' vehicle within the considered range
S.K5	Acceleration maximum around LC when LC is closed	m / s²	Maximum acceleration of approaching road traffic participant within the stopping distance around the LC in the time frame of + /- 30 s of the closed LC (reaction + orientation + braking distance)	• Velocity change of road traffic participants' vehicle within the considered range, • Derivation of the function of velocity over time

ID	Name	Unit	Description	Required data
S.K6	Acceleration maximum around LC when LC is open	m / s²	Maximum acceleration of approaching road traffic participant within the stopping distance around the LC when LC is open, i.e. not within +/- 30 s of the closed LC (reaction + orientation + braking distance)	• Velocity change of road traffic participants' vehicle within the considered range, • Derivation of the function of velocity over time
S.K7	Deceleration maximum around LC when LC is closed	m / s²	Maximum deceleration of approaching road traffic participant within the stopping distance around the LC in the time frame of + /- 30 s of the closed LC (reaction + orientation + braking distance)	• Velocity change of road traffic participants' vehicle within the considered range, • Derivation of the function of velocity over time
S.K8	Deceleration maximum around LC when LC is open	m / s²	Maximum deceleration of approaching road traffic participant within the stopping distance around the LC when LC is open, i.e. not within +/- 30 s of the closed LC (reaction + orientation + braking distance)	• Velocity change of road traffic participants' vehicle within the considered range, • Derivation of the function of velocity over time
S.K9	Time to LC at which velocity is safe	s	Statistically descriptively edited time at which velocity = safe velocity Time = Time needed to reach the LC keeping current velocity Safe velocity = Velocity at which maximum deceleration leads to stopping 0.2*(reaction + orientation + braking distance) in front of LC	• Velocity of road traffic participants' vehicle within the considered range, • Distance between road traffic participants' vehicle and LC
S.K10	Distance to LC at which velocity is safe	m	Statistically descriptively edited time at which velocity = safe velocity Distance = Distance between road traffic participant and LC Safe velocity = Velocity at which maximum deceleration leads to stopping 0.2*(reaction + orientation + braking distance) in front of LC	• Velocity of road traffic participants' vehicle within the considered range, • Distance between road traffic participants' vehicle and LC
Functional safety				
S.F1	Functional safety of the technical processes	Rating 0 (none) to 2 (com-pletely)	Ranges from back-up system for no technical device to back-up systems for some devices to back-up systems for any devices	• Details out technical plans and descriptions, • Subjective ratings done by technical developer or maintenance personnel
S.F2	Functional safety of the operational processes	Rating 0 (none) to 2 (com-pletely)	Ranges from back-up process for no operational process to back-up process for some processes to back-up process for any process	• Details out of process plans and descriptions, • Subjective ratings done by process planner or manager

3.2. Traffic-related parameters

The KPI category "Traffic" focusses on indicators regarding the influence of a safety measure on road and railway traffic. Thereby effects on movement of individuals as well as groups of vehicles (cars and trains) are considered (see Table 2 and Table 3).

Table 2: Road Traffic KPI and their data basis (in particular car, bike, pedestrians)

ID	Name	Unit	Description	Required data
TR.O1	Traffic volume	Vehicles / d	Statistically descriptively edited daily traffic in terms of vehicles which have crossed LC in one day	• Continuous measure of the different LC passing road traffic participants' vehicles

ID	Name	Unit	Description	Required data
TR.O2	Traffic density	Vehicles / m	Statistically descriptively edited number of vehicles per length of the roadway in stopping distance in front of LC and on LC (stopping distance = reaction + orientation + braking distance) during, after but close to and further after the LC is closed	• Distribution of the different road traffic participants' vehicles around the LC
TR.O3	Number of waiting participants	[-]	Statistically descriptively edited number of vehicles waiting in front of LC after the LC was closed	• Distribution of the different road traffic participants' vehicles around the LC, • Visual recording or control of technical processes while LC is closed
TR.O3 p	Number of waiting pedestrians	[-]	Statistically descriptively edited number of pedestrians waiting in front of LC after the LC was closed	• Distribution of pedestrians around the LC, • Visual recording or control of technical processes while LC is closed
TR.O4	Length of vehicle queue at LC	m	Statistically descriptively edited length of the queue of vehicles in front of LC while the LC is closed	• Distance between the LC and the end of the rear part of the last waiting vehicle, • Visual recording or control of technical processes while LC is closed
TR.O5	Waiting time of vehicles (per participant and in total)	s	Statistically descriptively edited waiting time for vehicles in front of LC when LC is closed, (differentiated for individual vehicles and in sum of all vehicles)	• Movement of the different road traffic participants' vehicles in front of the LC, • Visual recording or control of technical processes while LC is closed
TR.O5 p	Waiting time of pedestrians (per participant and in total)	s	Statistically descriptively edited waiting time for pedestrians in front of LC when LC is closed, (differentiated for individual vehicles and in sum of all pedestrians)	• Movement of pedestrians in front of the LC, • Visual recording or control of technical processes while LC is closed
TR.O6	Headway (road traffic participants)	s	Statistically descriptively edited time that elapses between one vehicle and the next vehicle at stopping distance in front of LC and on LC (stopping distance = reaction + orientation + braking distance) during, directly after and later after LC was closed (inverse of flow)	• Measure of different passing road traffic participants' vehicles and time between passes at the measuring points
TR.O7	Velocity (road traffic participant)	m / s	Statistically descriptively edited space mean velocity (average over all vehicle on a road way segment) within stopping distance around LC and on LC (stopping distance = reaction + orientation + braking distance) directly after and later after LC was closed	• Continuous measure of the velocity of different road traffic participants' vehicles within the considered range
TR.O8	Acceleration and deceleration	m / s^2	Statistically descriptively edited space mean acceleration and deceleration (average over all vehicle on a road way segment) within stopping distance around LC and on LC (stopping distance = reaction + orientation + braking distance) directly after and later after LC was closed	• Continuous measure of the velocity change of different road traffic participants' vehicles within the considered range
TR.O9	Standing vehicles on LC danger zone	Vehicles / d	Statistically descriptively edited number of vehicles standing on and around LC within a range in which a risk exists, that an accident occurs, if a train is passing	• Continuous recording of data about barriers in terms of road traffic participants’ vehicle on the track at the LC
TR.O9 p	Standing pedestrians on LC danger zone		Statistically descriptively edited number of pedestrians standing on and around LC within a range in which a risk exists, that an accident occurs, if a train is passing	• Continuous recording of data about barriers in terms of pedestrians on the track at the LC

Table 3: Rail Traffic KPI and their data basis

ID	Name	Unit	Description	Required data
TR.A1	Traffic delay	s	Difference of actual train delay at stopping distance before the LC in compare to actual train delay at stopping distance behind the LC (stopping distance = reaction + orientation + braking distance)	• Train delay before the LC, • Train delay behind the LC
TR.A2	Headway	s	Statistically descriptively edited minimum time that must elapse between one train and the next train passing LC at stopping distance in front of LC	• Measure of different passing trains and minimum time between passes at the LC, • Regulations for the LC
TR.A3	Line velocity (train)	m / s	Statistically descriptively edited space mean velocity of LC (average over track way segment) within stopping distance around LC and on LC (stopping distance = reaction + orientation + braking distance)	• Continuous measure of the velocity of the train within the considered range

3.3. Indicators related to human behaviour

The KPI category "Human behaviour" focusses on behaviour of traffic participants. The category contains indicators regarding the effect of safety measures on the visual and auditive perception of relevant information and indicators regarding the effects of a safety measure on road users' observable behaviour (see Table 4 and Table 5 for users on the road and pedestrians, respectively).

This list of performance indicators related to human behaviour is a general introduction to useful measures of the appropriateness of traffic participants' information processing and behaviour. Since maladaptive behaviour of road traffic participants is the central reason for accidents at level crossings, the topic of assessing human behaviour in the context of level crossings will be broadened in a detailed methodological framework. This assessment tool will be the subject of the SAFER-LC Deliverable *D2.2: Test version of the "Human factor" methodological framework and application guide for testing*.

Table 4: Human behaviour KPI and their data basis for on-road users

ID	Name	Unit	Description	• Required data
Perception				
H.P1	Visual checking for trains or measures	Rating 0 (no) to 1 (yes)	Describes, if on-road traffic participants check at all for trains or status of technical protection at the LC [4], [5]	• Eye tracking data, • Subjective answers from on-road traffic participants
H.P1.1	Distance to LC at first check for trains or measures	M	Distance to the LC at which on-road traffic participant visually checks for trains or measures at the LC for the first time [4]	• Eye tracking data, • Distance of the on-road traffic participant from the LC
H.P2	Line of sight	S	Moment that road traffic participants first perceive safety measures and relevant traffic objects	• Eye tracking data

[4] Grippenkoven, J., & Dietsch, S. (2015)

[5] Liu, J., et al. (2016)

ID	Name	Unit	Description	• Required data
H.P3	Distance to LC at first perception of the measure	M	Distance to the LC at which on-road traffic participant perceives a LC measure for the first time	• Verbal expression of the on-road traffic participant regarding the perception, • Distance of the on-road traffic participant towards the LC
H.D1	Velocity choice	m / s	On-road traffic participants' choice of velocity before stopping distance, at stopping distance and at half stopping distance from the LC as well as on the LC (stopping distance = reaction + orientation + braking distance) [4, 5, 6]	• Speed data in relation to position from simulators or GPS-data, • Speed data from trajectories, • Subjective answers from on-road traffic participants, • Measurement of on-road traffic participant speed during LC approach.
H.D3	Trajectories	M	Approaching on-road traffic participants' distance to the middle of the own lane in range of stopping distance before and braking distance behind LC (stopping distance = reaction + orientation + braking distance) [7]	• Trajectories of vehicles of on-road traffic participants, • Trajectory along the middle of the lanes around the LC
Queuing behaviour				
H.Q1	Stopping distance	m	= reaction + orientation + braking distance, based on the speed limit around the LC, without consideration of speed limits dictated particularly due to the LC	• Speed limit around the LC
H.Q2	Distance between traffic participants and LC while LC is closed	m	Distance from the LC at which the first on-road traffic participant stops while LC is closed [7]	• Distance of the on-road traffic participant from the LC, • Distance to LC at the moment when the on-road traffic participant visually fixates on a piece of technical level crossing equipment for the first time.
Traffic violations				
H.T1	LC connected traffic violation against safety measures when LC is closed	1 / a	E.g. crossing LC, half-barrier passing, overtaking close to LC, turning on LC, standing on LC, entering LC without being able to clear LC fast [7, 8]	• Continuously measured trajectories of vehicles of on-road traffic participants, • Continuous visual recording or control of technical processes while LC is closed, • Continuous visual recording of the LC and LC surrounding area, • Subjective answers from on-road traffic participants about their driving behaviour

[6] Shinar, D., & Raz, S. (2007)

[7] Grippenkoven, Gimm, Stamer, Naumann & Schnieder, 2015

[8] Mulvihill, C. M., et al. (2016)

ID	Name	Unit	Description	• Required data
H.T2	LC connected traffic violation against safety measures when LC is open	1 / a	E.g. overtaking close to LC, turning on LC, standing on LC, entering LC without being able to clear LC fast [7, 8]	• Continuously measured trajectories of vehicles of on-road traffic participants • Continuous visual recording or control of technical processes while LC is open • Continuous visual recording of the LC and LC surrounding area • Subjective answers from on-road traffic participants about their driving behaviour
H.T3	Other traffic violations	1 / a	e.g. U-turning, … [8]	• Continuously measured trajectories of vehicles of on-road traffic participants, • Continuous visual recording of the LC and LC surrounding area, • Subjective answers from on-road traffic participants about their driving behaviour
Other				
H1	Subjectively recognised perceptibility and effect of measures on road traffic participants	Rating 0 (none) to 5 (very strong)	On-road traffic participants' subjective judgement about the perceptibility and effect of measures a) for themselves and b) on other road traffic participants [8]	• Subjective answers from on-road traffic participants

Table 5: Human behaviour KPI and their data basis for pedestrians

ID	Name	Unit	Description	• Required data
Perception				
H.P1p	Visual checking for trains or measures	Rating 0 (no) to 1 (yes)	Describes, if pedestrians check at all for trains or status of technical protection at the LC [8]	• Subjective answers from pedestrians
H.P3p	Distance to LC at first perception of the measure	m	Distance to the LC at which pedestrians perceives a LC measure for the first time [9]	• Verbal expression of pedestrians regarding the perception
H.D3p	Trajectories of pedestrians	m	Trajectories chosen by pedestrians when crossing the LC [9]	• Trajectories of pedestrians
Traffic violations				
H.T1p	LC connected traffic violation against safety measures when LC is closed	1 / a	E.g. crossing LC, half-barrier passing, standing on LC, entering LC without being able to clear LC fast [8]	• Continuously measured trajectories of pedestrians, • Continuous visual recording or control of technical processes while LC is closed, • Continuous visual recording of the LC and LC surrounding area, • Subjective answers from pedestrians about their behaviour
H.T3p	Other traffic violations	1 / a	Any other traffic violation by pedestrians [9]	• Video surveillance • Questionnaires
Other				
H1p	Subjectively recognised perceptibility and effect of measures on pedestrians	Rating 0 (none) to 5 (very strong)	Pedestrians´ subjective judgement about the perceptibility and effect of measures a) for themselves and b) on other road traffic participants[10]	• Subjective answers from pedestrians

3.4. Technical parameters

The "Technical" KPI category focuses on indicators regarding operational processes and the maintainability of the LC and the safety measure. Operational process related KPI focus on technical behaviour of the LC and the safety measure. KPI related to maintainability focus on the frequency of failure and time needed to repair the identified failure in the LC and / or in the implemented safety measure (see Table 6).

Table 6: Technical KPI and their data basis

ID	Name	Unit	Description	Required data
TE1	LC closure time	s	Time between gate starts closing and finishes opening	• Visual recording or control of technical processes at LC,

[9] Read, G. J., et al. (2016)

[10] Ellinghaus, D., & Steinbrecher, J. (2006)

ID	Name	Unit	Description	Required data
				• Subjective answers from road traffic participants
TE2	LC warning time (red light, sound, flashing etc.)	s	Time between traffic control light turns on and turns off	• Visual recording or control of technical processes at LC,
TE3	Train approach warning time	s	Pre warning time (red light, sound, flashing) + gate closing time + remaining time before train crossing	• Visual recording or control of technical processes at LC, • Subjective answers from road traffic participants
TE4	After train crossing time	s	Remaining time after train crossing + gate opening time + post warning (red light, sound, flashing) time	• Visual recording or control of technical processes at LC, • Subjective answers from road traffic participants
TE5	Queue clearance time	s	Statistically descriptively edited time between beginning of clearance phase a vehicle that is queued across the LC completely clears the LC [11]	• Visual recording of the conflict point or vehicles' size and trajectory data, • Visual recording or control of technical processes of signals indicating train approach
TE6	MTTF – MeanTime-ToFailure	h	Statistically descriptively edited time between first start of system operation and first failure [12]	• (Automatically) minuted failures, • Minimal expected life cycle length for newly installed components of the measure
TE7	MTBF – MeanTime-BetweenFailure	h	Statistically descriptively edited time between failures during system operation [12]	• (Automatically) minuted failures, • Gantt chart for expected life cycle length of different components of the measure
TE8	MTTR – MeantTime-To Repair	h	Statistically descriptively edited time it takes to repair a failed installed system [12]	• (Automatically) minuted failures, • Minuted time needed to repair

Table 7 contains indicators related to the performance of the video-based smart detection system. These KPIs are used to analyse the impact of a system for instance on safety, traffic, etc. The smart detection system is a technical device that is able to detect potentially dangerous situations around LC and this will contribute to the safety, performance, etc., if this system is used in the daily management loop of the level crossing.

The smart system will be evaluated on very different datasets coming from real-world situations.

Table 7: KPI for sensors and detection algorithms

ID	Name	Unit	Description	Required data
SE1	Detection accuracy	%	Measurement of the recall and precision indicators calculated from false positive and false negative detections. From recall and	• Ground truth video data, video, detection result, recall, precision

[11] Roads and Traffic Authority (2008)

[12] CENELEC EN 50126 (1999)

ID	Name	Unit	Description	Required data
			precision F_measure is derived, which represent the quality of detection [13]	
SE2	Detection rate	%	Consideration of an entire event (car stopped for instance), zigzagging, queuing, etc. [14]	• Ground truth data, result of detection (yes or no)
SE3	Processing time	Frames/second	Evaluate if the system is able to monitor the situation in real time. Here real-time means, the possibility to recognise any event occurring at the level crossing (that could be 10f/s, 20f/s, etc.) [15]	• Video data, processing algorithm in which a clock to estimate the processing time is included
SE4	Sample size	Absolute number	Definition of the number of repetitions of the same use case (car stopped for instance) in order to demonstrate that the use case is automatically detected [16]	• Ground truth, detection results and comparison between the two.
SE5	Usability	Time of installing the system on site	Estimation of the usability of the system by a non-specialist: installation, running, fixing parameters, etc. [17]	• Global system including the hardware and the architecture of the software
SE6	Stability	Number of hours	Measuring of the stability (hardware + software) of the processing system. Duration of the system going to work without any problem [18]	• Global system (Hardware + Software)
SE7	Environment conditions for processing	Qualitative description (sun, snow, rain, low illumination, storm, …)	Ability of the software to detect and recognise use cases whatever the environment conditions	• Global system and test under different environmental conditions
SE8	Ability to work in hard conditions	Degrees	Measurement of the ability of the global system to work with very high temperature	• Global system, extreme condition
SE9	Ability to transmitted the information	Binary: reception/or not	Measurement of the ability of communication system to transmitted the information concerning state of LC in terms of response time, range	• Global system and test under different environmental conditions

3.5. Business-related parameters

The KPI category "Business" focusses on indicators concerning financial effort required to realise, maintain, enhance and recycle a safety measure. The category contains capital as well as operational expenditure (including maintenance) (see Table 8).

These costs could vary depending on the number of sites considered. As a consequence, different volumes shall be considered to determine these various costs.

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[13] Powers, D. M. (2011)

[14] Sokolova; M., & Lapalme, G. (2009)

[15] Wikipedia contributors. (2018)

[16] Beleites, C. et al. (2013)

[17] Mifsud, J. (2015)

[18] Alenezi, M (2016)

Table 8: Business KPI and their data basis

ID	Name	Unit	Description	Required data
Capital Expenditure (CapEx)				
B.C1	Planning and procurement costs	€	Project planning, purchasing (of device and estate), development and production costs [19]	• Costs for needed personnel, • Purchasing costs for services, • Operating costs for development and production of components, • Purchasing costs for components, • Rent for estates for the measure,
B.C2	Implementation costs	€	Installation, initiation and specific technical approval costs [19]	• Costs for needed personnel, • Purchasing costs for services
B.C3	Depreciation costs	€ / a	Imputed cost for value reduction of (parts of) the measures [19]	• Most reasonable depreciation processes, • Value (development) of the measure
Operational Expenditure (OpEx)				
B.O1	Operational costs	€ / a	Costs arising from regular operation of the measure in terms of costs for resources need to operate the measure, like energy and personnel costs [19]	• Costs for needed personnel, • Purchasing costs for services, • Purchasing costs for resources (like energy)
B.O2	Maintenance costs	€ / a	Costs due to resources needed to keep the measure running or repair it meaning costs for preventive, predictive as well as corrective (repairing) maintenance and in this sense costs for e.g. spare parts and personnel [20], [21]	• Costs for needed personnel, • Purchasing costs for services, • Operating costs for development and production of components, • Purchasing costs for components
B.O3	Follow-up costs in case of unavailability	€ / a	Costs arising from consequences of non-functioning of the measure [19]	• Costs due to accidents, • Costs in terms of loss due to traffic delays and cancelations
Other				
B1	Life cycle length or life span	d	Time between installation and deconstruction of a measure	• Life cycle length expectations for component of the measure, • Time span expectation for which it makes sense to repair and modernise the measure
B2	Disposal costs	€	Costs arising from the disposal and / or re-use of the measure and its' components [19]	• Hourly rates of personnel needed, • Purchasing costs for services
B3	installation time	h	Time for installing the measure at the test site	• Time records

3.6. Contextual factors

Additional data will be collected in order to better understand possible variations of the KPI within the day or between different days. This data will be composed of external factors related to contextual conditions which are not related to the tested safety measures as such but may have a significant

[19] IEC 60300-3-3:2004 (2004)

[20] Garcia, Sanz-Bobi, & Del Pico (2006)

[21] National Standards Authority of Ireland (2001)

impact on their performance. The factors will differ among pilot sites due to the different conditions under which the measures will be tested, but also due to the important differences between the measures. For example, a measure making use of image recognition may be affected by light, while measures based on the location of the vehicles will not be affected by light conditions. These factors will be related to the technical performance of the measures such as the impact of light to the image recognition component but also to the users' reaction to the alerts, which may differ depending on the time of the day or on the weather conditions (e.g. rain).

These factors will be collected when possible and used during the analyses of Task 4.3, analysing their co-variance with the KPI and therefore providing insights on the variability of the measures. This better understanding of the performance of the measures is important when promoting them to road and rail operators.

A selection of the most important contextual factors to be considered here is listed in Table 9. The list is not complete as it needs to be adapted to the specific measures and test sites.

Table 9: Contextual factors (selection)

Factor Name	**Description**
Eye-sight	It is interesting to know whether someone has an impaired eye-sight, since this can impact the results of a simulator study.
Age	Age can have an impact on reaction time in simulator studies.
Driving Experience	Driving experience can have an influence on driving performance.
Fatigue	Fatigue can impair driving performance.
Weather (rain, snow)	It may be interesting to see if the indicators variation can be explained (in part) by weather conditions.
Time of day	It may be relevant to see if the drivers' behaviour changes depending on the time of the day (the most interesting differentiation may be day-night).

4. MEASURABILITY OF SPECIFIC KPI AT PROJECT TEST SITES

4.1. Applicable KPI per test site

With the generic identification of parameters of interest to evaluate the different measures as indicated in Chapter 3, it is possible to contrast them with the capabilities of the simulators and pilot sites in order to determine where data can actually be gathered from. For better readability, the result is listed in the tables of the Annex.

In these tables, the operators of the simulators and pilots have been asked to indicate those parameters which they can measure with “Y” (Yes). If marked with a “N” (No) this means that it is currently not possible to measure the respective data.

As at present it is not clear how the test set-up will be designed and how the pilots will be equipped (e.g. with sensors to be procured during the project), only a few parameters have been indicated as measurable to date. Furthermore, the necessity to measure certain sets of data depends on the aim of the measure to be tested and therefore cannot yet be foreseen.

4.1. Data logger

Once the KPI have been connected with specific test sites it is important to define the way in which these will be obtained from the test sites. During the development and implementation of the safety measures done in WP3, data loggers should be developed for all components and put in place. These data loggers will be responsible for collecting the data in a usable format and in a frequency suitable for the estimation of the KPI that will be done in task 4.3 after the end of the data collection period. It is important to highlight the importance of logging the timestamp (synchronising to a common server at every location) together with each raw data element logged, allowing for relating data sets from various components and replicating the situations of the pilot if needed or calculating the KPI in the same time interval.

4.2. Piloted safety measures

The main objective of WP4 is to assess the effects of lab tests and field implementations executed within the SAFER-LC project. Therefore, the next step is to move the focus from the test sites to specific safety measures, targeted to improve the safety of level crossings, which will be piloted in the selected test sites. These piloted safety measures will be selected based on the results of WP1 and WP2. Specifically, the pilot test leaders are advised to select measures a) which will target the scenarios identified in D1.3 and / or b) which will be identified in WP2 to have low implementation costs and which will support the self-explaining and forgiving nature of the level crossings.

5. EVALUATION OF PILOTED SAFETY MEASURES

5.1. Evaluation principles

The piloting of safety measures should be focussed on gaining information on the effects of the piloted measures on the number of level crossing accidents and / or the effects on the railway system recovery time after level crossing accident has occurred. Therefore, the piloted safety measures should primarily aimS

- to reduce the number of level crossing accidents, and / or
- to reduce the consequences of the collisions by reducing the impact of the collision to the road user or by reducing the shut down time.

In order to define the effectiveness of each piloted safety measure, each pilot test leader is advised to carry out an evaluation based on two main principles: (1) safety measure will be piloted in real experimental context in one of the test sites and (2) a field evaluation will be performed in “before” and “after” conditions. It must be noted that in some cases the safety measures are not suitable for experimental or outcome based evaluation designs. In this case, other approaches can be taken into consideration.

Pilot test leaders are advised to be prepared to collect control data whenever possible, especially, in before-after measurements, thus the effect of the safety measure can be separated from other simultaneously affecting factors.

In addition to the effect of the piloted safety measure, the pilot tests should also provide information on the implementation process, e.g. what kind of problems were met and how they were solved, and give recommendations on issues that should be taken into account when planning, piloting or implementing similar safety measures.

5.2. Quantitative estimate on the reduction of accidents and fatalities, if possible

The assessment results should include quantitative estimates of the effects of safety measures, preferably in terms of, for example, annual reductions in the numbers of level crossing accidents. It is recognised that it is hardly possible to give reliable estimates of avoided accidents in small scale pilot tests. However, it is desirable to try to give some estimates on the effect (on annual numbers of level crossing accidents and related fatalities and injuries) if the measure were to be implemented on a large scale (e.g. covering all potential implementation locations). The quantitative estimates are especially important for the cost-benefit analysis (CBA) which will be conducted in the later stages of the SAFER-LC project (WP5).

The challenge of focussing on yearly number of accidents is that typically several years of study is needed to have a sufficient number of accidents for the analysis. In addition, the identification of differences in accident frequencies between the before and after periods cannot be necessarily associated only to the implemented safety measure, but to other external factors too. Hence, alternative indicators are needed to evaluate the effect of safety measures with the aim of avoiding the influence of unknown variables. In addition, these alternative indicators provide support in reaching the quantitative estimates of effectiveness of the piloted safety measure. Risky behaviours, for example, are easy to identify and are more numerous than accidents, providing more data for evaluating the effectiveness of safety measures.

5.3. Collection of data required for evaluation

The data collection during the piloting of safety measures will be supported by implementation and evaluation plans, including plans for collection of data required for the evaluation. Templates for these plans will be provided by the leader of task 4.3 (VTT) and they will cover the most relevant information for the evaluation of the effects. The plans related to each piloted safety measure will be assessed and commented by the WP4 task leaders whose approval will be required before the safety measure is accepted for piloting.

The progress of pilot tests will be monitored via these implementation and evaluation plans which will be delivered by all pilot test leaders to the responsible partner (VTT) and to the work package leader (CERTH-HIT) at predefined intervals (a week or two before the work package meetings).

6. CONCLUSIONS

The purpose of Deliverable D4.2 is to provide an Evaluation Framework for testing (low-cost) measures for increasing the safety at level crossings at the different simulators and pilot sites available in the project. This document describes which parameters should be measured, how this is possible and which pilot or simulator is able to provide these data.

The Key Performance Indicators to be evaluated are clustered into the five categories “Safety”, “Traffic”, “Human behaviour”, “Technical” and “Business”. For each category, a generic set of relevant parameters has been identified. These parameters have been contrasted to the capabilities of the simulators and pilot sites in order to determine where the different parameters can be measured (see Annex). As it is currently not clear how the test set-ups will be designed and how the pilots will be equipped (e.g. which sensors will be procured during the project), only a few parameters have been indicated as measurable for the moment.

It seems evident that during the tests not all parameters listed will be measurable. The question of which parameters need to be gathered strongly depends on the specific design and intention of each measure. As neither the measures to be tested have been developed yet, nor the test sites themselves planned or equipped, it cannot currently be concluded what the measurability of the KPI will look like when the actual test and evaluation starts. It is therefore obvious that during the course of the project the pilot sites have to be further equipped and adapted according to the specific test set-ups, in order to be able to measure the necessary parameters for the evaluation of the measures.

Further, it is rather challenging to collect information on business-related KPIs in a testing environment since some of the tested safety measures are prototypes and not market-ready systems. Where possible, information on KPIs such as equipment cost or installation time will be gathered. However, it seems unlikely that the pilot sites, where the functioning of the measures will be tested and information on effects of the measures will be collected, will be able to provide the data base for proving their economic efficiency. These data will probably have to be derived from other sources, e.g. manufacturers, operators, etc., depending on the characteristics of the measure during the actual cost-benefit-analysis (WP5).

The Evaluation Framework presented in this deliverable can serve as a guideline to be considered for setting up the tests in order to take all relevant aspects of a certain safety measure into account.

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ANNEX: OVERVIEW OF MEASURABILITY OF KPI AT TEST SITES

- Annex 1: Safety KPI and their data basis
- Annex 2: Traffic KPI and their data basis
- Annex 3a: Human behaviour KPI and their data basis for on-road users
- Annex 3b: Human behaviour KPI and their data basis for pedestrians
- Annex 4: Technical KPI and their data basis incl. KPI for sensors and detection algorithms
- Annex 5: Business KPI and their data basis

Annex 1: Safety KPI and their data basis (1/2)

ID	Name	Unit	Description	References	Required data (Alternatives are different kinds of data, which independently are sufficient to calculate the KPI)	Test sites: DLR Driving Simulators	Test sites: RWTH – mock-up LC field + rail vehicle	Test sites: CEREMA + SNCF Rouen test site	Test sites: DLR mobile traffic surveillance system	Test sites: TRAINOSE + CERTH mobile communications	Test sites: INTADER level crossings
Collisions											
S.C1	Number of collisions	1 / a	Number of collisions between different traffic participants or traffic participants and infrastructure at the LC		Visual records of the LC	N	N	N	Y	N	Y
					Accident reports	N	N	N	N	Y	Y
S.C1a	Number of near misses	1 / a	Number of near misses (i.e. critical situations that almost lead to a collision) that could be detected by short TTC or PET (the threshold value needs to be defined).		TTC	N	Depends on sensors	N	Y	Y	N
					PET	Y	Depends on sensors	N	Y	Y	Y
					Video surveillance	N	N		Y		Y
S.C2	Traffic injuries	1 / a	Number of injured persons due to collisions		Accident reports	N	N	N	N	Y	Y
S.C3	Traffic death	1 / a	Number of deaths due to collisions		Accident reports	N	N	N	N	Y	Y
S.C4	Material damage	EUR / a	Material damage in euro due to collisions		Accident follow-up reports on financial impacts of material damage	N	N	N	N	N	Y
Surrogate safety measures											
S.S1	TTC between approaching road traffic participants	s	=Time to collision TTC1=assuming prevailing velocities and distance TTC2=assuming prevailing velocities, accelerations and distance	(Astarita, Guido, Vitale, & Giofré, 2012; U.S. Department of Transportation, 2003; Zhang, Antonsson, & Grote, 2006)	Velocity and acceleration of different vehicles of road traffic participants	N	Depends on sensors	N	Y	Y	N
					Positions and heading of different vehicles of road traffic participants	N	Depends on sensors	N	Y	Y	N
S.S2	PET on the LC between last passing road traffic participant and train	s	=Post-Encroachment Time =Time between departure of the encroaching road traffic participant form the conflict point and arrival of the train at the conflict point	(U.S. Department of Transportation, 2003)	LC leaving time of road traffic participants' vehicles	Y	Depends on sensors	N	Y	Y	Y
					LC arrival time of trains	Y	Depends on sensors	N	Y	Y	Y
S.S3	PET on the LC between last passing road traffic participant and closing gates	s	=Post-Encroachment Time =Time between departure of the encroaching road traffic participant form the conflict point and arrival of the gate at the conflict point	(U.S. Department of Transportation, 2003)	LC leaving time of road traffic participants' vehicles	Y	Depends on sensors	N	Y	N	N
					Visual recording or control of technical processes at LC	Y	Depends on sensors	N	Y	N	N
S.S4	THW between approaching road traffic participants	s	=Time headway =Time the following driver has to react in case the lead vehicle suddenly brakes at maximum deceleration	(Zhang, Antonsson, & Grote, 2006)	Distance between different approaching vehicles of road traffic participants	N	Depends on sensors	N	Y	Y	N
					Velocity of different vehicles of road traffic participants	N	Depends on sensors	N	Y	Y	N
S.S5	ET of road traffic participants on the LC	s	=Encroachment time =Time duration during which the encroaching road traffic participant infringes upon the LC	(U.S. Department of Transportation, 2003)	Positions of train and road traffic participant's vehicle	Y	Depends on sensors	N	Y	Y	N
					Data about a barrier in terms of road traffic participant's vehicle on track at LC	Y	Depends on sensors	N	N	N	N
S.S6	DR of road traffic participants in conflict with gates or train	m / s²	=Deceleration rate =Rate at which the crossing vehicle must decelerate to avoid collision	(Astarita, Guido, Vitale, & Giofré, 2012; U.S. Department of Transportation, 2003)	Velocity of approaching road traffic participant's vehicle	Y	Depends on sensors	N	Y	Y	N
					Distance between road traffic participant's vehicle and LC	Y	Depends on sensors	N	Y	Y	N
					Appearance of gates or trains, when road traffic participants' vehicle reaches LC	Y	Depends on sensors	N	N	Y	N
S.S7	DRAC	m / s²	=Deceleration Rate to avoid crash =Rate at which a vehicle must decelerate to avoid a collision with an ahead moving vehicle	(Astarita, Guido, Vitale, & Giofré, 2012)	Distance between different approaching vehicles of road traffic participants	N	Depends on sensors	N	Y	N	N
					Velocity of different vehicles of road traffic participants	N	Depends on sensors	N	Y	N	N
Kinematic indicators											
S.K1	Velocity over time around LC	m / s	Function of velocity over braking distance around the LC showing the velocity of road traffic participants and its' changes while the participants are approaching and leaving LC (reaction + orientation + braking distance)		Velocity of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	Y	N
S.K2	Acceleration and deceleration over time around LC	m / s²	Function of acceleration and deceleration over braking distance around the LC showing the acceleration and deceleration of road traffic participants and its' changes while the participants are approaching and leaving LC (reaction + orientation + braking distance)		Velocity change of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	Y	N
					Derivation of the function of velocity over time	Y	Depends on sensors	N	Y	N	N
S.K3	Velocity maximum around LC when LC is closed	m / s	Maximum velocity of approaching road traffic participant within the stopping distance around the LC in the time frame of + /- 30 s of the closed LC (reaction + orientation + braking distance)		Velocity of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	N	N
S.K4	Velocity maximum around LC when LC is open	m / s	Maximum velocity of approaching road traffic participant within the stopping distance around the LC when LC is open , i.e. not within +/- 30 s of the closed LC (reaction + orientation + braking distance)		Velocity of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	N	N

Annex 1: Safety KPI and their data basis (2/2)

S.K5	Acceleration maximum around LC when LC is closed	m / s²	Maximum acceleration of approaching road traffic participant within the stopping distance around the LC in the time frame of + /- 30 s of the closed LC (reaction + orientation + braking distance)		Velocity change of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	N	N
					Derivation of the function of velocity over time	Y	Depends on sensors	N	Y	N	N
S.K6	Acceleration maximum around LC when LC is open	m / s²	Maximum acceleration of approaching road traffic participant within the stopping distance around the LC when LC is open, i.e. not within +/- 30 s of the closed LC (reaction + orientation + braking distance)		Velocity change of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	N	N
					Derivation of the function of velocity over time	Y	Depends on sensors	N	Y	N	N
S.K7	Deceleration maximum around LC when LC is closed	m / s²	Maximum deceleration of approaching road traffic participant within the stopping distance around the LC in the time frame of + /- 30 s of the closed LC (reaction + orientation + braking distance)		Velocity change of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	N	N
					Derivation of the function of velocity over time	Y	Depends on sensors	N	Y	N	N
S.K8	Deceleration maximum around LC when LC is open	m / s²	Maximum deceleration of approaching road traffic participant within the stopping distance around the LC when LC is open, i.e. not within +/- 30 s of the closed LC (reaction + orientation + braking distance)		Velocity change of road traffic participant's vehicle within the considered range	Y	Depends on sensors	N	Y	N	N
					Derivation of the function of velocity over time	Y	Depends on sensors	N	N	N	N
S.K9	Time to LC at which velocity is safe	s	Statistically descriptively edited time at which velocity = safe velocity Time = Time needed to reach the LC keeping current velocity Safe velocity = Velocity at which maximum deceleration leads to stopping 0.2*(reaction + orientation + braking distance) in front of LC		Velocity of road traffic participant's vehicle within the considered range	Y	Y	N	Y	Y	N
					Distance between road traffic participant's vehicle and LC	Y	Y	N	Y	Y	N
S.K10	Distance to LC at which velocity is safe	m	Statistically descriptively edited time at which velocity = safe velocity Distance = Distance between road traffic participant and LC Safe velocity = Velocity at which maximum deceleration leads to stopping 0.2*(reaction + orientation + braking distance) in front of LC		Velocity of road traffic participant's vehicle within the considered range	Y	Y	N	Y	Y	N
					Distance between road traffic participant's vehicle and LC	Y	Y	N	Y	Y	N
Functional safety											
S.F1	Functional safety of the technical processes	Rating 0 (none) to 2 (completely)	Ranges from back-up system for no technical device to back-up systems for some devices to back-up systems for any devices		Details out technical plans and descriptions	N	Y	N	N	N	N
					Subjective ratings done by technical developer or maintenance personnel	N	Y	N	N	N	N
S.F2	Functional safety of the operational processes	Rating 0 (none) to 2 (completely)	Ranges from back-up process for no operational process to back-up process for some processes to back-up process for any process		Details out of process plans and descriptions	N	Y	N	N	N	N
					Subjective ratings done by process planner or manager	N	Y	N	N	N	N

Annex 2: Traffic KPI and their data basis (1/1)

ID	Name	Unit	Description	References	Required data (Alternatives are different kinds of data, which independently are sufficient to calculate the KPI)	Test sites: DLR Driving Simulators	RWTH – mock-up LC field + rail vehicle	CEREMA + SNCF Rouen test site	DLR mobile traffic surveillance system	TRAINOSE + CERTH mobile communications	INTADER level crossings
Road – Traffic participants (in particular car, bike, pedestrian)											
TR.O1	Traffic volume	Vehicles / d	Statistically descriptively edited daily traffic in terms of vehicles which have crossed LC in one day		Continuous measure of the different LC passing road traffic participants' vehicles	N	N	N	Y	N	Y
TR.O2	Traffic density	Vehicles / m	Statistically descriptively edited number of vehicles per length of the roadwa in stopping distance in front of LC and on LC (stopping distance = reaction + orientation + braking distance) during, after but close to and further after the LC is closed		Distribution of the different road traffic participants' vehicles around the LC	N	N	N	Y	N	Y
TR.O3	Number of waiting participants	[-]	Statistically descriptively edited number of vehicles waiting in front of LC after the LC was closed		Distribution of pedestrians around the LC	N	N	N	Y	N	Y
					Visual recording or control of technical processes while LC is closed	N	N	N	Y	N	Y
TR.O3p	Number of waiting pedestrians	[-]	Statistically descriptively edited number of pedestrians waiting in front of LC after the LC was closed		Distribution of pedestrians around the LC	N	N	N	Y	N	Y
					Visual recording or control of technical processes while LC is closed	N	N	N	Y	N	Y
TR.O4	Length of vehicle queue at LC	m	Statistically descriptively edited length of the queue of vehicles in front of LC while the LC is closed		Distance between the LC and the end of the rear part of the last waiting vehicle	N	N	N	Y	N	N
					Visual recording or control of technical processes while LC is closed	N	N	N	Y	N	N
TR.O5	Waiting time of vehicles (per participant and in total)	s	Statistically descriptively edited waiting time for vehicles in front of LC when LC is closed, (differentiated for individual vehicles and in sum of all vehicles)		Movement of the different road traffic participants' vehicles in front of the LC	N	N	N	Y	N	Y
					Visual recording or control of technical processes while LC is closed	N	N	N	Y	N	Y
TR.O5p	Waiting time of pedestrians (per participant and in total)	s	Statistically descriptively edited waiting time for pedestrians in front of LC when LC is closed, (differentiated for individual vehicles and in sum of all pedestrians)		Movement of pedestrians in front of the LC	N	N	N	Y	N	Y
					Visual recording or control of technical processes while LC is closed	N	N	N	Y	N	Y
TR.O6	Headway (road traffic participants)	s	Statistically descriptively edited time that elapses between one vehicle and the next vehicle at stopping distance in front of LC and on LC (stopping distance = reaction + orientation + braking distance) during, directly after and later after LC was closed (inverse of flow)		Measure of different passing road traffic participants' vehicles and time between passes at the measuring points	N	N	N	Y	N	N
TR.O7	Velocity (road traffic participant)	m / s	Statistically descriptively edited space mean velocity (average over all vehicle on a road way segment) within stopping distance around LC and on LC (stopping distance = reaction + orientation + braking distance) directly after and later after LC was closed		Continuous measure of the velocity of different road traffic participants' vehicles within the considered range	N	Y	N	Y	N	N
TR.O8	Acceleration and deceleration	m / s²	Statistically descriptively edited space mean acceleration and deceleration (average over all vehicle on a road way segment) within stopping distance around LC and on LC (stopping distance = reaction + orientation + braking distance) directly after and later after LC was closed		Continuous measure of the velocity change of different road traffic participants' vehicles within the considered range	N	Y	N	Y	N	N
TR.O9	Standing vehicles on LC danger zone	Vehicles / d	Statistically descriptively edited number of vehicles standing on and around LC within a range in which a risk exists, that an accident occurs, if a train is passing		Continuous recording of data about barriers in terms of road traffic participant's vehicle on the track at the LC	N	N	N	Y	N	Y
TR.O9p	Standing pedestrians on LC danger zone		Statistically descriptively edited number of pedestrians standing on and around LC within a range in which a risk exists, that an accident occurs, if a train is passing		Continuous recording of data about barriers in terms of pedestrians on the track at the LC	N	N	N	Y	N	Y
Railway – Trains											
TR.A1	Traffic delay	s	Difference of actual train delay at stopping distance before the LC in compare to actual train delay at stopping distance behind the LC (stopping distance = reaction + orientation + braking distance)		Train delay before the LC	N	N	N	N	Y	N
					Train delay behind the LC	N	N	N	N	Y	N
TR.A2	Headway	s	Statistically descriptively edited minimum time that must elapse between one train and the next train passing LC at stopping distance in front of LC		Measure of different passing trains and minimum time between passes at the LC	N	N	N	Y	Y	N
					Regulations for the LC	N	N	N	N	Y	N
TR.A3	Line velocity (train)	m / s	Statistically descriptively edited space mean velocity of LC (average over track way segment) within stopping distance around LC and on LC (stopping distance = reaction + orientation + braking distance)		Continuous measure of the velocity of the train within the considered range	N	N	N	Y	Y	N

Annex 3a: Human behaviour KPI and their data basis for on-road users (1/1)

ID	Name	Unit	Description	References	Required data (Alternatives are different kinds of data, which independently are sufficient to calculate the KPI)	Test sites: DLR Driving Simulators	Test sites: RWTH – mock-up LC field + rail vehicle	Test sites: CEREMA + SNCF Rouen test site	Test sites: DLR mobile traffic surveillance system	Test sites: TRAINOSE + CERTH mobile communications	Test sites: INTADER level crossings
Perception											
H.P1	Visual checking for trains or measures	Rating 0 (no) to 1 (yes)	Describes, if road traffic participants check at all for trains or status of technical protection at the LC	Grippenkoven & Dietsch, 2015; Liu, Bartnik, Richards & Khattak, 2016	Eye tracking data	Y	N	N	N	?	Y
					Subjective answers from road traffic participants	Y	N	N	Y	?	Y
H.P1.1	Distance to LC at first check for trains or measures	m	Distance to the LC at which road traffic participant visually checks for trains or measures at the LC for the first time	Grippenkoven & Dietsch, 2015	Eye tracking data	Y	N	N	N	?	Y
					Distance of the road traffic participant from the LC	Y	N	N	Y	?	Y
H.P2	Line of sight	s	Moment that road traffic participants first perceive safety measures and relevant traffic relevant objects		Eye tracking data	Y	N	N	N	N	N
H.P3	Distance to LC at first perception of the measure	m	Distance to the LC at which road traffic participant perceives a LC measure for the first time		Verbal expression of the road traffic participant regarding the perception	Y	Y	N	N	?	Y
					Distance of the road traffic participant towards the LC	Y	Y	N	Y	?	Y
Driving parameters											
H.D1	Velocity choice	m / s	road traffic participant's choice of velocity before stopping distance, at stopping distance and at half stopping distance from the LC as well as on the LC (stopping distance = reaction + orientation + braking distance)	Grippenkoven & Dietsch, 2015; Liu, Bartnik, Richards & Khattak, 2016; Shinar & Raz, 2007	Speed data in relation to position from simulators or GPS-data	Y	Y		Y		N
					Speed data from trajectories	Y	Y		Y		N
					Subjective answers from road traffic participants	Y	Y		N		N
					Measurement of road traffic participant speed during LC approach	Y	Y		Y		N
H.D3	Trajectories	m	approaching road traffic participant's distance to the middle of the own lane in range of stopping distance before and braking distance behind LC (stopping distance = reaction + orientation + braking distance)	Grippenkoven, Gimm, Stamer, Naumann & Schnieder, 2015	Trajectories of vehicles of road traffic participants	Y	Y	N	Y	Y	N
					Trajectory along the middle of the lanes around the LC	Y	Y	N	Y	N	N
Queuing behaviour											
H.Q1	Stopping distance	m	= reaction + orientation + braking distance, based on the speed limit around the LC, without consideration of speed limits dictated particularly due to the LC		Speed limit around the LC	Y	Y	N	Y	Y	Y
H.Q2	Distance between traffic participants and LC while LC is closed	m	distance from the LC at which the first road traffic participant stops while LC is closed	Grippenkoven, Gimm, Stamer, Naumann & Schnieder, 2015	Distance of the road traffic participant from the LC	Y	Y	N	Y	N	Y
					• Distance to LC at the moment whenat which the on-road traffic participant visually fixates on a piece of technical level crossing equipment visually for the first time.	Y	Y	N	Y	N	Y
Traffic violations											
H.T1	LC connected traffic violation against safety measures when LC is closed	1 / a	E.g. crossing LC, half-barrier passing, overtaking close to LC, turning on LC, standing on LC, entering LC without being able to clear LC fast	Grippenkoven, Gimm, Stamer, Naumann & Schnieder, 2015; Mulvihill, Salmon, Beanland, Lenné, Read, Walker & Stanton, 2016	Continuously measured trajectories of vehicles of road traffic participants	N	N	N	Y	N	Y
					Continuous visual recording or control of technical processes while LC is closed	N	N	N	Y	N	Y
					Continuous visual recording of the LC and LC surrounding area	N	N	N	Y	N	Y
					Subjective answers from road traffic participants about their driving behaviour	N	N	N	N	N	Y
H.T2	LC connected traffic violation against safety measures when LC is open	1 / a	E.g. overtaking close to LC, turning on LC, standing on LC, entering LC without being able to clear LC fast	Grippenkoven, Gimm, Stamer, Naumann & Schnieder, 2015; Mulvihill, Salmon, Beanland, Lenné; Read, Walker & Stanton, 2016	Continuously measured trajectories of vehicles of road traffic participants	N	N	N	Y	N	Y
					Continuous visual recording or control of technical processes while LC is open	N	N	N	Y	N	Y
					Continuous visual recording of the LC and LC surrounding area	N	N	N	Y	N	Y
					Subjective answers from road traffic participants about their driving behaviour	N	N	N	N	N	Y
H.T3	Other traffic violations	1 / a	e.g. U-turning, …	Mulvihill, Salmon, Beanland, Lenné, Read, Walker & Stanton, 2016	Continuously measured trajectories of vehicles of road traffic participants	N	N	N	Y	N	Y
					Continuous visual recording of the LC and LC surrounding area	N	N	N	Y	N	Y
					Subjective answers from road traffic participants about their driving behaviour	N	N	N	N	N	Y
Other											
H1	Subjectively recognized perceptibility and effect of measures on road traffic participants	Rating 0 (none) to 5 (very strong)	road traffic participants' subjective judgement about the perceptibility and effect of measures a) for themselves and b) on other road traffic participants	Mulvihill, Salmon, Beanland, Lenné, Read, Walker & Stanton, 2016	Subjective answers from road traffic participants	Y	?	N	Y	Y	Y

Annex 3b: Human behaviour KPI and their data basis for pedestrians (1/1)

ID	Name	Unit	Description	References	Required data (Alternatives are different kinds of data, which independently are sufficient to calculate the KPI)	Test sites: DLR Driving Simulators	RWTH – mock-up LC field + rail vehicle	CEREMA + SNCF Rouen test site	DLR mobile traffic surveillance system	TRAINOSE + CERTH mobile communications	INTADER level crossings
Perception											
H.P1p	Visual checking for trains or measures	Rating 0 (no) to 1 (yes)	Describes, if pedestrians check at all for trains or status of technical protection at the LC	Mulvihill, Salmon, Beanland, Lenné, Read, Walker & Stanton, 2016	Subjective answers from pedestrians	N	N		N		Y
H.P3p	Distance to LC at first perception of the measure	m	Distance to the LC at which pedestrians perceives a LC measure for the first time	Read, G. J., Salmon, P. M., Lenné, M. G., & Stanton, N. A. (2016)	Verbal expression of pedestrians regarding the perception	N	Y		N		Y
Driving parameters											
H.D3p	Trajectories of pedestrians	m	Trajectories chosen by pedestrians when crossing the LC	Read, G. J., Salmon, P. M., Lenné, M. G., & Stanton, N. A. (2016)	Trajectories of pedestrians	N	Y		Y		Y
Traffic violations											
H.T1p	LC connected traffic violation against safety measures when LC is closed	1 / a	E.g. crossing LC, half-barrier passing, standing on LC, entering LC without being able to clear LC fast	Mulvihill, Salmon, Beanland, Lenné, Read, Walker & Stanton, 2016	Continuously measured trajectories of pedestrians	N	N		Y		Y
					Continuous visual recording or control of technical processes while LC is closed	N	N		Y		Y
					Continuous visual recording of the LC and LC surrounding area	N	N		Y		Y
					Subjective answers from pedestrians about their behaviour	N	N		N		Y
H.T3p	Other traffic violations	1 / a	any other traffic violation by pedestrians	Read, G. J., Salmon, P. M., Lenné, M. G., & Stanton, N. A. (2016)	video surveillance	N	N		Y		N
					questionnaires	N	N		N		N
Other											
H1p	Subjectively recognized perceptibility and effect of measures on pedestrians	Rating 0 (none) to 5 (very strong)	pedestrians subjective judgement about the perceptibility and effect of measures on judging pedestrians themselves and others	Ellinghaus & Steinbrecher, 2006	Subjective answers from pedestrians	N			N		Y

Annex 4: Technical KPI and their data basis incl. KPI for sensors and detection algorithms (1/1)

ID	Name	Unit	Description	References	Required data (Alternatives are different kinds of data, which independently are sufficient to calculate the KPI)	Test sites: DLR Driving Simulators	RWTH – mock-up LC field + rail vehicle	CEREMA + SNCF Rouen test site	DLR mobile traffic surveillance system	TRAINOSE + CERTH mobile communications	INTADER level crossings
TE1	LC closure time	s	Time between gate starts closing and finishes opening		Visual recording or control of technical processes at LC	Y	Y	N	Y	N	Y
					Subjective answers from road traffic participants	Y	Y	N	N	N	Y
TE2	LC warning time (red light, sound flashing etc.)	s	Time between traffic control light turns on and turns off		Visual recording or control of technical processes at LC	Y	Y	N	Y	N	Y
					Subjective answers from road traffic participants	Y	Y	N	N	N	Y
TE3	Train approach warning time	s	Pre warning time (red light, sound, flashing) + gate closing time + remaining time before train crossing		Visual recording or control of technical processes at LC	Y	Y	N	Y	N	Y
					Subjective answers from road traffic participants	Y	Y	N	N	N	Y
TE4	After train crossing time	s	Remaining time after train crossing + gate opening time + post warning (red light, sound, flashing) time		Visual recording or control of technical processes at LC	Y	Y	N	Y	N	Y
					Subjective answers from road traffic participants	Y	Y	N	N	N	Y
TE5	Queue clearance time	s	Statistically descriptively edited time between beginning of clearance phase a vehicle that is queued across the LC completely clears the LC	(Roads and Traffic Authority, 2008)	Visual recording of the conflict point or vehicle's size and trajectory data	Y	Y	N	Y	N	N
					Visual recording or control of technical processes of signals indicating train approach	Y	Y	N	Y	N	N
TE6	MTTF – MeanTime-ToFailure	h	Statistically descriptively edited time between first start of and first failure during system operation	CENELEC EN 50126 (1999)	(Automatically) minuted failures	N	Y	Y	Y	N	N
					Minimal expected life cycle length for newly installed components of the measure	N	Y	N	N	N	N
TE7	MTBF – MeanTime-BetweenFailure	h	Statistically descriptively edited time between failures during system operation	CENELEC EN 50126 (1999)	(Automatically) minuted failures	N	Y	Y	Y	N	N
					Gantt chart for expected life cycle length of different components of the measure	N	Y	N	N	N	N
TE8	MTTR – MeantTime-To Repair	h	Statistically descriptively edited time it takes to repair a failed installed system	CENELEC EN 50126 (1999)	(Automatically) minuted failures	N	Y	Y	Y	N	N
					Minuted time needed to repair	N	Y	N	N	N	N
SE1	HDetection accuracy	%	Here we measure the recall and precision indicators calculated from false positive and false negative detections. Then from recall and precision we have the F_measure which represent the quality of detection	Powers, D. M. (2011)	Ground truth video data, Vidéo, detection result, recall, precision	N	Y		Y		N
SE2	Detection rate	%	Here an entire event is considered (car stopped for instance), zigzagging, queuing, etc……	Sokolova; M., & Lapalme, G. (2009)	Ground truth data, result of detection (yes or no)	N	Y		Y		N
SE3	Processing time	Frames/second	The idea here is to evaluate if the system is able to monitor the situation in real tin In our case real-time means, the possibility to recognize any event occurring at the level crossing (that could be 10f/s, 20f/s, etc…….)	Wikipedia contributors. (2018)	Video data, processing algorithm in which we include a clock to estimate the processing time	N	Y		Y		N
SE4	Sample size	Absolute number	Here, we have to define the number of repetitions of the same use case (car stopped for instance) in order to demonstrate that the use case is automatically detected.	Beleites, C. et al. (2013)	Ground truth, detection results and comparison between the two.	N	Y		Y		N
SE 5	Usability	Time of installing the system on site	Here we estimate the usability of the system by a non specialist : installation, running, fixing parameters, etc….	Mifsud, J. (2015)	Global system including the hardware and the architecture of the software	N	Y		Y		N
SE6	Stability	Number of hours	Here the idea is to measure the stability (hardware+software) of the processing system. How long is the system going to work without any problem	Alenezi, M (2016)	Global system (Hard + Soft)	N	Y		Y		Y
SE7	Environment conditions for processing	Qualitative description (sun, snow, rain, low illumination, storm, ….	Here we measure the ability of the software to detect and recognize use cases whatever the environment conditions		Global system and test under different environmental conditions	N	Y		Y		N
SE8	Ability to work in hard conditions	degrees	Here we measure the ability of the global system to work with very high temperature		Global system, extreme condition	N	Y		Y		Y
SE9	Ability to transmitted the information	Binary: reception/or not	Here we measure the ability of communication system to transmitted the information concerning state of LC in terms of response time, range		Global system and test under different environmental conditions	N	Y		N		Y

Annex 5: Business KPI and their data basis (1/1)

ID	Name	Unit	Description	References	Required data (Alternatives are different kinds of data, which independently are sufficient to calculate the KPI)	Test sites					
						DLR Driving Simulators	RWTH – mock-up LC field + rail vehicle	CEREMA + SNCF Rouen test site	DLR mobile traffic surveillance system	TRAINOSE + CERTH mobile communications	INTADER level crossings
Capital Expenditure (CapEx)											
B.C1	Planning and procurement costs	€	Project planning, purchasing (of device and estate), development and production costs	IEC 60300-3-3:2004 (2004)	Costs for needed personnel	N	N	N	N	N	N
					Purchasing costs for services	N	N	N	N	N	N
					Operating costs for development and production of components	N	N	N	N	N	N
					Purchasing costs for components	N	N	N	N	N	N
					Rent for estates for the measure	N	N	N	N	N	N
B.C2	Implementation costs	€	Installation, initiation and specific technical approval costs	IEC 60300-3-3:2004 (2004)	Costs for needed personnel	N	N	N	N	N	N
					Purchasing costs for services	N	N	N	N	N	N
B.C3	Depreciation costs	€ / a	Imputed cost for value reduction of (parts of) the measures	IEC 60300-3-3:2004 (2004)	Most reasonable depreciation processes	N	N	N	N	N	N
					Value (development) of the measure	N	N	N	N	N	N
Operational Expenditure (OpEx)											
B.O1	Operational costs	€ / a	Costs arising from regular operation of the measure in terms of costs for resources need to operate the measure, like energy and personnel costs	IEC 60300-3-3:2004 (2004)	Costs for needed personnel	N	N	N	N	N	N
					Purchasing costs for services	N	N	N	N	N	N
					Purchasing costs for resources (like energy)	N	N	N	N	N	N
B.O2	Maintenance costs	€ / a	Costs due to resources needed to keep the measure running or repair it meaning costs for preventive, predictive as well as corrective (repairing) maintenance and in this sense costs for e.g. spare parts and personnel	(Garcia, Sanz-Bobi, & Del Pico, 2006; National Standards Authority of Ireland, 2001)	Costs for needed personnel	N	N	N	N	N	N
					Purchasing costs for services	N	N	N	N	N	N
					Operating costs for development and production of components	N	N	N	N	N	N
					Purchasing costs for components	N	N	N	N	N	N
B.O3	Follow-up costs in case of unavailability	€ / a	Costs arising from consequences of non-functioning of the measure	IEC 60300-3-3:2004 (2004)	Costs due to accidents	N	N	N	N	N	N
					Costs in terms of loss due to traffic delays and cancelations	N	N	N	N	N	N
Other											
B1	Life cycle length or life span	d	Time between installation and deconstruction of a measure		Life cycle length expectations for component of the measure	N	N	N	N	N	N
					Time span expectation for which it makes sense to repair and modernise the measure	N	N	N	N	N	N
B2	Disposal costs	€	Costs arising from the disposal and / or re-use of the measure and its' components	IEC 60300-3-3:2004 (2004)	Hourly rates of personnel needed	N	N	N	N	N	N
					Purchasing costs for services	N	N	N	N	N	N
B3	Installation time	h	Time for installing the measure at the test site		Time records	Y	Y	Y	N	N	Y