Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing

Report on User Requirements (WP-1)

Deliverables 1.1 and 1.2

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1 Description of WP-1 according to Grant Application

Work package number	**1**	**Start date or starting event:**			1		
Work package title	**Users Requirements**						
Activity Type[1]	RTD						
Participant number	1	2	3	4	5	6	7
Participant short name	TERN	ED	DPC	EMPA	LCPC	ULUND	TEL AVIV
Person-months per participant:	2	1	5	4	1	3	3
Participant number	8	9					
Participant short name	TDE	NEO					
Person-months per participant:	1	1					

Objectives

- To define use-cases and scenarios
- To describe the existing processes and technologies
- To identify organization and technological constraints

Description of work

The aim of WP is the definition of the users requirements of the monitoring system based on the electromagnetic sensing techniques. In particular, the WP activities aim to describing the application context and the user and system interactions. The achievement of the objectives of WP requires strict interaction between domain experts and ICT experts.

The output of the WP1 will provide all the information required for the proper design of the system.

Task 1.1 Expert group setup

This task is the first step of the WP and concerns the definition of the expert group devoted to the user requirement definition. Domain experts and ICT experts will participate to the group.

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[1] Please indicate one activity per work package:
RTD = Research and technological development; DEM = Demonstration; MGT = Management of the consortium; OTH = Other (This type of activity applies only to Capability projects submitted in the Security Theme. STREPs in the ICT Theme do not include a cost category "Other").

Task 1.2 Application domain user requirements

This task aims to defining the users requirements according to application domain concepts. The attention is focused on factors such as the constructive typology of the infrastructures, the physical/mechanical parameters to be monitored, the spatial scale of investigation (large and small), the necessity of a real time or not and of surface or/and subsurface monitoring. The attention is focused on factors such as:

- Kind of infrastructures to be monitored;
- Parameters of interest to be extracted (strain, temperature, pressure, mechanical parameters, detection and characterization of embedded defects..);
- Spatial scale of the investigation;
- Depth of investigation, required spatial resolution in the reconstruction;
- Necessity or not of a real time diagnostics.

Task 1.3 Use cases definition

The objective of this task is to identify a set of well-defined use-cases describing the possible interactions between users (humans or machines) and the system. The case studies must be considers as guidelines for the description of other useful scenarios. This task can be viewed both as a refinement of the results of task 1.2, and a first step in the translation of application domain requirements in corresponding processing and communication system requirements.

Task 1.4 Existing analysis

This task aims to provide a description of existing solutions in terms of technologies and processes for the considered application domain. This analysis is useful to define possible technological and organization constraints that could affect functional and non-functional requirements.

Deliverables

D1.1 month 6 “Users-cases description”, Report

D1.2 month 9 “Overall description of used methodologies and end-user experience”, Report

2 Further Definition of tasks

2.1 Task 1.1 Expert group setup

It was suggested and decided during the ISTIMES kick-off meeting in Rome in June 2009 to form a core group with one member from each organization participating in the project. The members of the core group would then contact further experts on different levels as described below. A request was sent to all project members in August 2009 to name their core group member. The core group was complete on September 29, 2009. Please refer to the appendix for a list of core group members.

2.2 Task 1.2 Application domain user requirements

This task aimed to answer the following guiding questions:

- Which organizations are responsible for structures relevant for the project?
- What types of structures?
- Number of structures and overall value?
- Current monitoring and inspection processes?
- Desired monitoring processes?
- Limitations?

It was decided to create a questionnaire (see appendix) covering all relevant issues. It was planned that each core group member should contact two organizations personally to discuss the relevant issues and fill out the questionnaire. The creation of the questionnaire was based on internal discussion at Empa, feedback by the core group members and relevant literature [Cox and Cox, 2008, Post 2008].

First the guiding questions (see above) were defined. Then, the guiding questions were operationalized into a limited and observable set of questions with a similar level of specificity. After those questions were grouped and put into a first draft, this draft was discussed internally at Empa and updated. The process of discussion and update was repeated several times. Then, the updated draft was sent to core group members for their item of written comment. This lead to another minor update and to the final questionnaire. Before the final version was sent to core group members, some instructions were added (see appendix) to ensure a common understanding of the questionnaire details. In addition, a short description of the ISTIMES project (see appendix) was created to support the core group members when contacting their interview partners.

2.3 Task 1.3 Use cases definition

It was decided to clarify the cases concerning future implementation of the monitoring system in two steps. First, the basic issues were evaluated with the help of the questionnaire (see appendix). The second step was carried out during meetings with the Swiss Federal Roads Authority and Swiss Federal Railways. Possible implementations of the system, limitations and the desired output was discussed and described.

2.4 Task 1.4 Existing analysis

The analysis of existing solutions was carried out in two steps. First, the questionnaire (see appendix) covered existing monitoring and inspection systems. As an additional step, the literature on Structural Health Monitoring (SHM) was reviewed and documented in this report. The focus of this documentation is on advanced systems relevant for this project.

3 Potential end users

Potential end users were defined by the core group members for their countries.

3.1 List of possible end users of ISTIMES in Norway

The following is a list of possible Norwegian end users of the ISTIMES system: Included are also survey and research institutes that typically will be consulted with regards to geohazards.

Organisation	English	Field of work	Relevance, ISTIMES end user
Statens vegvesen	Norwegian Public Roads Administration.	Owns/manages roads, bridges, tunnels	Many roads that are exposed to geohazards
Jernbaneverket	The Norwegian National Rail Administration	Own/manages railway infrastructure, tracks, bridges etc	Installations exposed to geohazards
Direktoratet for samfunnssikkerhet og beredskap	The Directorate for Civil Protection and Emergency Planning	Avoid accidents, manage crisis situations	Coordinator on the national level, assists local authorities
Norges geoglogiske undersøkelser	Norwegian geological surveys	Geological surveys	TBD
Norges geotekniske institutt	Norwegian Geotechnical Institute	Research and consulting within geohazards and geophysics	TBD
International Centre for Geohazards	-	Research etc. on geohazards	TBD

Statens vegvesen

Web: www.vegvesen.no

The Norwegian Public Roads Administration.

Statens vegvesen is responsible for planning, construction and maintenance of road infrastructure including bridges and tunnels. Many roads in Norway are exposed to geohazards like avalanches, landslides, rock-slides, quick clay etc. Some bridges are also exposed to extreme weather conditions.

Jernbaneverket

Web: http://www.jernbaneverket.no/

From their web-site:

Jernbaneverket (the Norwegian National Rail Administration) is the national railway authority. Jernbaneverket is responsible for the management of the national railway network, on behalf of the Ministry of Transport and Communication.

Through public funding and with a socio-economic perspective, our objective is to operate, maintain and develop the national railway network.

The Norwegian Parliament determines the annual funding through the national budget. Long-term planning is dealt with through Norsk Transportplan (the Norwegian Transport Plan), in which the Parliament draws up the economic framework for the four year period.

Jernbaneverket is responsible for:

- Developing and operating a rail network that meets the requirements of society and the market
- Railway stations and terminals
- Timetabling
- Traffic management
- Regulation of the public rail network
- Studies and planning in the rail sector

Direktoratet for samfunnssikkerhet og beredskap (DSB)

www.dsb.no

The Directorate for Civil Protection and Emergency Planning.

On their web-site they state:

“The Directorate for Civil Protection and Emergency Planning (DSB) shall maintain a full overview of risk and vulnerability in society in general. We promote measures, which prevent accidents, crises and other undesirable incidents. We shall ensure sufficient emergency planning and efficient management of accidents and crises. “

DSB is under the responsibility of the Ministry of Justice and the Police.

Norges geoglogiske undersøkelser (NGU)

Web: www.ngu.no

Norwegian geological surveys, member of EuroGeoSurways.

Performs geological surveys including indications of geohazards.

Norges geotekniske institutt (NGI)

Web: www.ngi.no

Norwegian Geotechnical Institute (private foundation)

Geohazards are one of the main topics NGI focuses on. NGI has had national responsibilities for avalanche research in Norway, but has competence on geohazards in general. NGI is doing research and consulting.

International Centre for Geohazards (ICG)

(hosted by NGI)
Web: http://www.geohazards.no/

From their web site:

NGI is the host of the INTERNATIONAL CENTRE for GEOHAZARDS, one of Norway's first Centres of Excellence (CoE). NGI's partners are NORSAR, the Geological Survey of Norway (NGU), the University of Oslo (UiO) and the Norwegian University of Science and Technology (NTNU).

The International Centre for Geohazards (ICG) carries out research on the assessment, prevention and mitigation of geohazards, including risk of landslide in soil and rock due to rainfall, flooding, earthquakes and human intervention, and the geological risks in deep waters, especially underwater slides. The Centre also contributes to the education of researchers and specialists in these fields.

The Centres of Excellence are an initiative to provide funding for internationally leading research groups in Norway. The Research Council of Norway announced on 12th June 2002 that NGI's application to establish the International Centre for Geohazards was one of the 13 winners.

3.2 List of possible end users of ISTIMES in Switzerland

Organisation	**English**	**Field of work**	**Relevance, ISTIMES end user**
ASTRA, Bundesamt für Strassen	FEDRO, Federal Roads office	Owns/operates Swiss motorways	Owns/operates numerous structures (bridges, tunnels)
SBB, Schweizerische Bundesbahnen	Swiss Federal Railways	Owns/operates most of Swiss railway system	Owns/operates numerous structures (bridges, tunnels)
BLS, Lötschbergbahn	BLS	Owns/operates parts of Swiss railway system	Owns/operates numerous structures (bridges, tunnels)
Rhätische Bahn, RHB	RHB	Owns/operates parts of Swiss railway system	Owns/operates numerous structures (bridges, tunnels)
ALPIQ	ALPIQ	Energy and Energy services	Owns/operates several dams
Le Officine Idroelettriche di Blenio SA		Energy	Owns/operates Blenio dam
Verzasca SA officina Idroelettrica		Energy	Owns/operates Blenio dam
Electricité d'Emosson SA		Energy	Owns/operates Emosson dam
Forces Motrices de Mauvoisin SA		Energy	Owns/operates Mauvoisin dam
Kantone	Cantons	Public bodies, Traffic	Own/operate cantonal roads network

ASTRA, Bundesamt für Strassen

Swiss Federal Roads Office

http://www.astra.admin.ch/

Swiss Federal Roads Office is responsible for planning, construction and maintenance of the Swiss motorways including a large number of bridges and tunnels. The motorway network has length of 1763,6 kilometers. Many roads in Switzerland are exposed to geohazards like avalanches, landslides, rockslides etc.

SBB, Schweizerische Bundesbahnen

Swiss Federal Railways

http://www.sbb.ch/

Swiss Federal railways (SBB) is responsible for planning, construction and maintenance of the most of Switzerland’s railway network including a large number of bridges and tunnels. The network has a length of 3011 kilometers and transports 322 millionen passengers and about 54 million tons of goods per year. Many railway lines in Switzerland are exposed to geohazards like avalanches, landslides, rockslides etc. From 2016, Swiss Federal Railways will operate the 57km long Gotthard Base Tunnel, the longest tunnel in the world.

BLS, Lötschbergbahn

BLS

The second largest railway company in Switzerland operating (amongst others) the 35km long Lötschberg Tunnel.

Rhätische Bahn, RHB

RHB

http://www.rhb.ch

RHB is responsible for planning, construction and maintenance of the railway network in the mountainous Canton Grisons (Graubünden). Several famous railway sections are part of the RHB network such as the Glacier Express or the Unesco World Heritage Albula-Bernina.

ALPIQ

ALPIQ

http://www.alpiq.ch

Alpiq, a group of companies is one of Europe's largest energy companies operating in Switzerland and all over Europe. Alpiq owns several energy companies.

Le Officine Idroelettriche di Blenio SA

Verzasca SA officina Idroelettrica

Electricité d'Emosson SA

Forces Motrices de Mauvoisin SA

These companies are owning and operating the largest dams in Switzerland.

Kantone

Cantons

There are 26 cantons in Switzerland constituting the Swiss Confederation. The cantons operate a large road network the so-called “cantonal roads” which includes almost everything except motorways and in-town streets. Many roads in Switzerland are exposed to geohazards like avalanches, landslides, rockslides etc., particularly in mountainous cantons such as Grisons (Graubünden), Berne, Uri, Glarus or Schwyz.

3.3 List of possible end users of ISTIMES in Israel

Organisation	Field of work	Relevance to ISTIMES
Israel Railway	Managing roads, bridges, tunnels	Many roads that are exposed to geohazards
Ministry of Transport and Road Safety of Israel	Managing railway infrastructure, tracks, bridges, etc.	Installations exposed to geohazards
Geological Survey of Israel	Geological surveys	Experts-geologists participating in the mapping of areas adjacent to railways
Geophysical Institute of Israel	Research and consulting within geohazards and geophysics	Expert-geophysicists estimate the earthquake probability and their degree in the areas of railway infrastructure development.
Ministry of Ecology of Israel	Investigation and monitoring of some environmental phenomena	Railway infrastructure is sensitive to environmental phenomena

Israel Railway

http://www.rail.co.il/EN/Pages/HomePage.aspx

From their web-site:

Israel Railway is the national railway authority which responsible for the management of the national railway network, on behalf of the Ministry of Energy and Infrastructure and the Ministry of Transport and Communication. Established – 2003 (prior to that the company operated as a unit in the Ports and Railways Authority). Area of activities – carriage and passenger transport. Development, management, maintenance and operation of the railway infrastructure in Israel.

In recent years Israel Railways corporation ltd. has been spearheading a revolution in the transportation system in Israel. After its establishment as an independent government-owned corporation in 2003, Israel Railways has started to implement a comprehensive development plan, which has turned it into the most rapidly growing transportation company in Israel, and the largest transportation infrastructure company in Israel. The corporation has 1,900 employees; its annual turnover is about 1 billion NIS (≅ 267 mln $) in routine operations and over 2 billions NIS in development activities. It is planned to construct about new 400 km^2 of railways during the 2011-2016 years.

Ministry of Transport and Road Safety of Israel

http://info.mot.gov.il/EN/

The Ministry's main objectives are: to plan and develop the transport network with emphasis on increased safety, security and efficiency; to provide integrated transport solutions; to ensure a more environmentally sustainable transport system, and to utilize advanced technologies in the operation of transport facilities. The Ministry of Transport and Road Safety is connected to *various corporations* operating in the transport sector, including Israel Railway.

Geological Survey of Israel (GSI)

Web: http://www.gsi.gov.il/eng/

The Geological Survey of Israel (GSI), founded in 1949, is a government institute operating under the Earth Science Research Administration within the Ministry of National Infrastructures, and is involved in earth science research and development in the broadest senses, adapting itself to the changing needs of a small and dynamic country. The objectives of the GSI are: to document, study and conduct research in all aspects of the country's geology, to act as an advisory body to all government branches and major public and private enterprises, to maintain a national and regional earth sciences data base, and to maintain an analytical infrastructure. Stability of the infrastructure and earthquake damage is one of the main application problems of the GSI.

Geophysical Institute of Israel (GII)

Web: http://geo.gii.co.il/

A sign of our times is an acute demand for infrastructure development, environmental protection and planning of new building sites and installations. Hazard-assessment surveys have become a must and GII has the seismological expertise to carry them out. The GII Sismology Division offers services for measuring and estimating site amplification for critical sites. Local geological site conditions play an important role in the determination of the site-specific seismic hazard. The phenomenon of seismic wave amplification in sedimentary deposits and topographical conditions is a major factor affecting overall damage and loss during strong earthquakes. GII Seismologists are engaged in various projects for estimating site amplifications at critical locations both in Israel and overseas.

Ministry of Environment of Israel

Web: http://www.sviva.gov.il

The Ministry of Environment of Israel (MEI) has been participating in monitoring of dangerous geodynamic events at a depth (earthquakes) and some subsurface geological phenomena (e.g., karst and rockslide). MEI experts investigate also such natural events as floods. Unfortunately, financial support of the MEI yields to budget of other ministries.

3.4 List of possible end users of ISTIMES in Italy

Organization	**Field of work**	**Relevance for ISTIMES project**		**Website**
Rete Ferroviaria Italiana (RFI)	The Italian National Rail Administration	Own/manages railway infrastructure, tracks, bridges etc	Installations exposed to geohazards	http://www.rfi.it/
Rete Ferroviaria Italiana (RFI) – Alta Velocità	The Italian National High-Velocity Rail Administration	Own/manages railway infrastructure, tracks, bridges etc	Installations exposed to geohazards	http://www.rfi.it/cms/v/index.jsp?vgnextoid=e4ae8c3e13e0a110VgnVCM10000080a3e90aRCRD
Autostrade per l'Italia SpA	An Italian National Motorway Administration	Owns/manages Motorway, bridges, tunnels	Many roads that are exposed to geohazards	http://www.autostrade.it/
ANAS, società che gestisce la rete stradale italiana	An Italian National Roads and Highways Administration	Owns/manages Roads, Highways, bridges, tunnels	Many roads that are exposed to geohazards	http://www.stradeanas.it/
Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italian Volcanology and Geophisics Institute	Research and consulting within geohazards and geophysics	TBD	http://portale.ingv.it/
Dipartimento di Protezione Civile	The Italian Directorate for Civil Protection and Emergency Planning	Avoid accidents, manage crisis situations	Coordinator on the national level, assists local authorities	http://www.protezionecivile.it/

Stato Maggiore della Difesa	The Italian Defence	Manage crisis situations, foreign missions, peace keeping	TBD	http://www.difesa.it/SMD/
ENI	Italian oil and gas Company	Energy and Energy services	TBD	http://www.eni.com/it_IT/home.html
ENEL	Italian oil and gas Company	Energy and Energy services	TBD	http://www.enel.it/it-IT/

4 Completed questionnaires

4.1 Switzerland

4.1.1 Swiss Federal railways (SBB)

The questionnaire was filled in on December 10, 2009 in the presence of Johannes Hugenschmidt from Empa and Helmut Heimann and Senta Haldimann both from SBB. In addition several e-mails were exchanged to clarify certain issues and topics discussed during several phone conversations.

The organization

SBB is responsible for most of Switzerland’s railway infrastructure and for most of the railway transport. In addition, there are several smaller railway companies in Switzerland. SBB is a joint-stock company owned 100% by the Swiss confederation. It has about 28000 employees and a turnaround of CHF 8.0 billion. SBB owns the railway infrastructure and the rolling stock. SBB is active mainly in the transport business but also produces electricity for its own use and for sale.

Objects

The SBB railway network has a length of more than 3000km (Figure 4-4). There are 6027 bridges, 305 tunnels and 757 stations on the network (2008 figures). In addition, SBB owns 5 power plants and about 170km of sound insulating walls

Example 1 – Simplon tunnel

Simplon tunnel, connecting Brig (Switzerland) and Domodossola (Italy) forms part of transalpine route Basel – Lötschberg – Brig – Milano. There are two parallel single track tunnels with two cross-overs in the middle of the tunnel (Figure 4-1) and cross-passages every approx. 500 m. The first tunnel was opened in 1906, the second in 1921. The length is 19.7km. The Height of north portal at Brig is at 685.80 m above sea level, the crest at 704.98 m and the south portal at Iselle at 633.48 m (Figure 4-2). There is up to 2’300 m overburden over the tunnel (Figure 4-3).

It was the longest railway tunnel in the world until the opening of the Seikan Tunnel (Japan) in 1988. It was electrificated from 1906 on.

Construction:

Tunnel I: (1906): Masonry lining with natural stones
Tunnel II: (1921) Masonry lining with bricks.

Rehabilitation:

1991 – 2002: lowering bas, larger profiles for Huckepack (Piggy-back) trains.
2012 -14: Installation of a TSI-conform self-rescue illumination + marking entries cross-passages +1 new doors cross-passages. New electrical high tension cables.

Current monitoring: Full inspection every 6 years. In pressure zone every year.

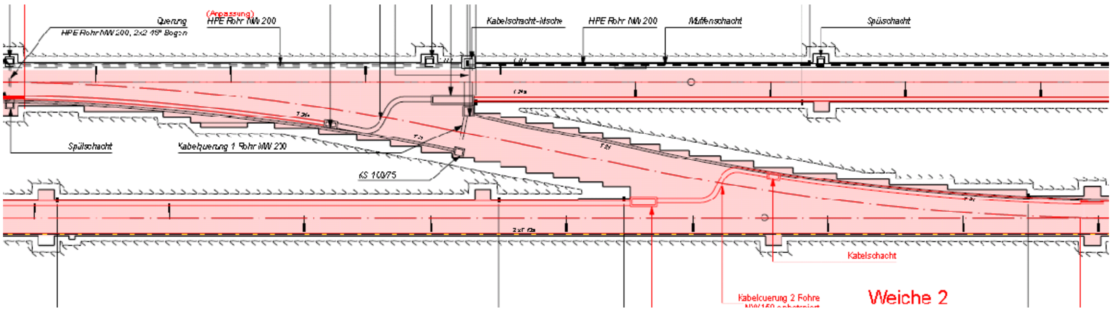

Figure 4-1: One of two cross-overs in the middle of the tunnel

Figure 4-2: South portal at Iselle

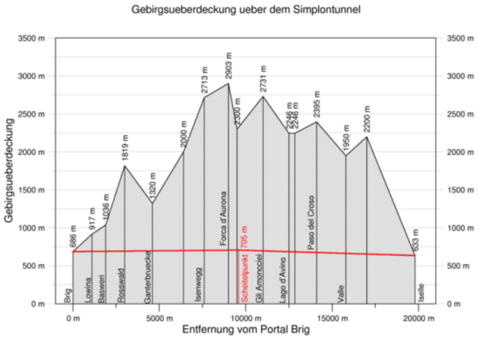

Figure 4-3: Overburden

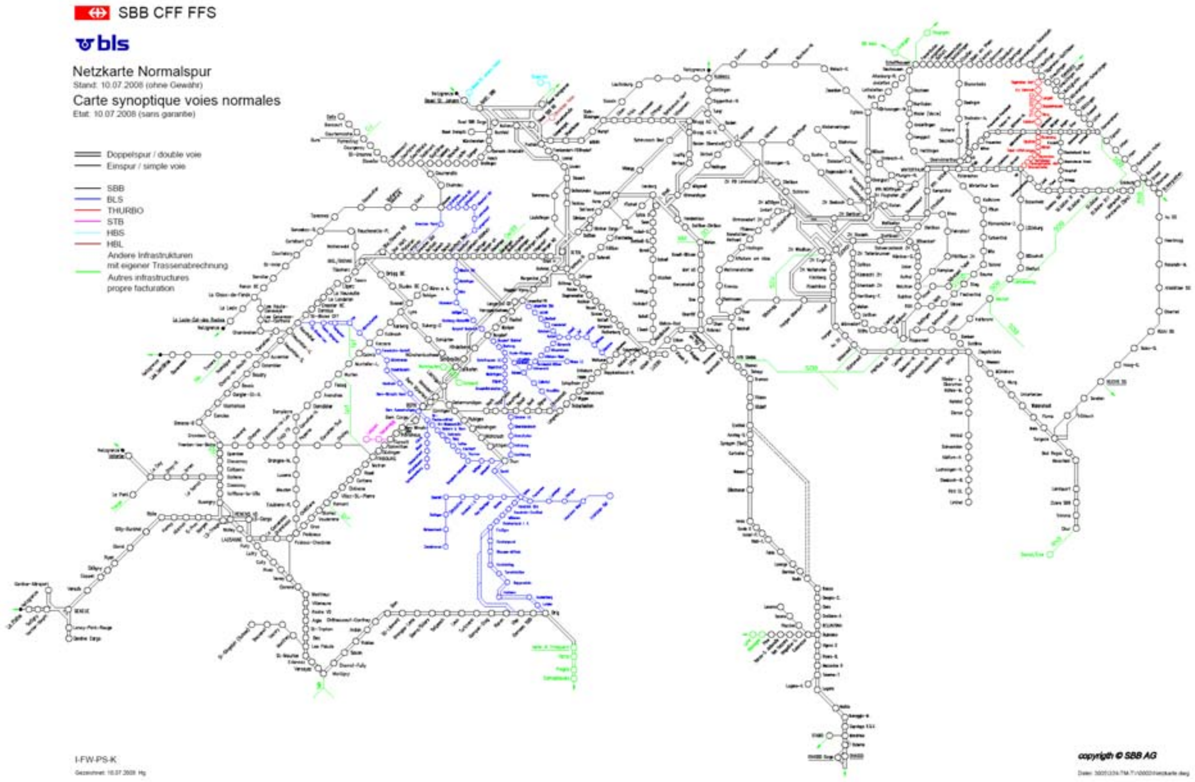

Figure 4-4: SBB network (black), from [4]

Current practice for inspection and monitoring

Level 0:

Reporting by engine drivers

Level 1:

Weekly inspections by foot

Level 2:

Most common level, the whole railway network including bridges and tunnels is inspected every 6 years. This includes visual inspection and inspection with the help of vehicles for the scanning of tunnel walls or the assessment of track geometry. If required, for example after special events such as floods or in places with known problems such as deformation zones in tunnels, additional inspections are carried out. Non-destructive is used for testing anchored and pre-stressed structures according to guidelines of the Swiss Federal Roads Authority. Destructive testing is carried out only if required and is focused on masonry structures and retaining walls. Visual inspection for corrosion is carried out on steel structures during main inspections with immediate repair.

During the 6 years inspection the following parameters concerning the condition of structures are assessed:

Damage detection and localization, corrosion of steel elements, sealing integrity, crack detection and monitoring with plaster markers, delamination, ageing of materials, joint movements.

If required, the following parameters concerning the condition of structures are assessed in addition to the ones listed above: Depth of carbonatization, chloride penetration, humidity in concrete, compressive strength of concrete, permeability of concrete, depth of rebar. Natural frequencies, tendons positions and depth of rebar is controlled only for quality control after construction work.

Meteorological data are not recorded but external data are used if required. Traffic data (weight, number of vehicles and traction current) is recorded at specific sites because of the free access to network by other companies.

Related to safety, excessive movements, settlements, changes of geometry and tilt are assessed.

Main motivations for inspections are safety, an assessment of the condition of structures, the optimization of maintenance and rehabilitation and disaster warning as whole sections of the network at risk of natural hazards. There has been an increase of traffic of 40% since 1995. The inspection/monitoring process is audited by the Swiss Federal Office of Transport.

It is a grown approach that is optimized constantly based on cost-benefit analysis and by benchmarking with other railway companies. SBB is obliged by law to inspect and maintain its network. There are no known shortcomings as this approach is permanently evaluated and optimized.

Advanced practice for inspection and monitoring – Example Rheinbrücke Eglisau

Rheinbrücke Eglisau (Figure 4-5) will be monitored during one year continuously with data transfer in real time with about 100 wired strain sensors. The aim of the monitoring is the optimization of traffic load assumptions and an optimization of the examination of old steel bridges. This is expected to lead to an optimized rehabilitation. Computations suggested an insufficient structural safety in some places. In addition, the test of the monitoring system as such is a secondary aim.

The approach was chosen because strain gauges are an established method giving local information. The system will monitor the bowing under traffic loads. Additional load tests will be carried out. The air temperature will be recorded and traffic data are available from existing stations. There is also a safety aspect of the monitoring as abnormal behaviour of the structure will be detected.

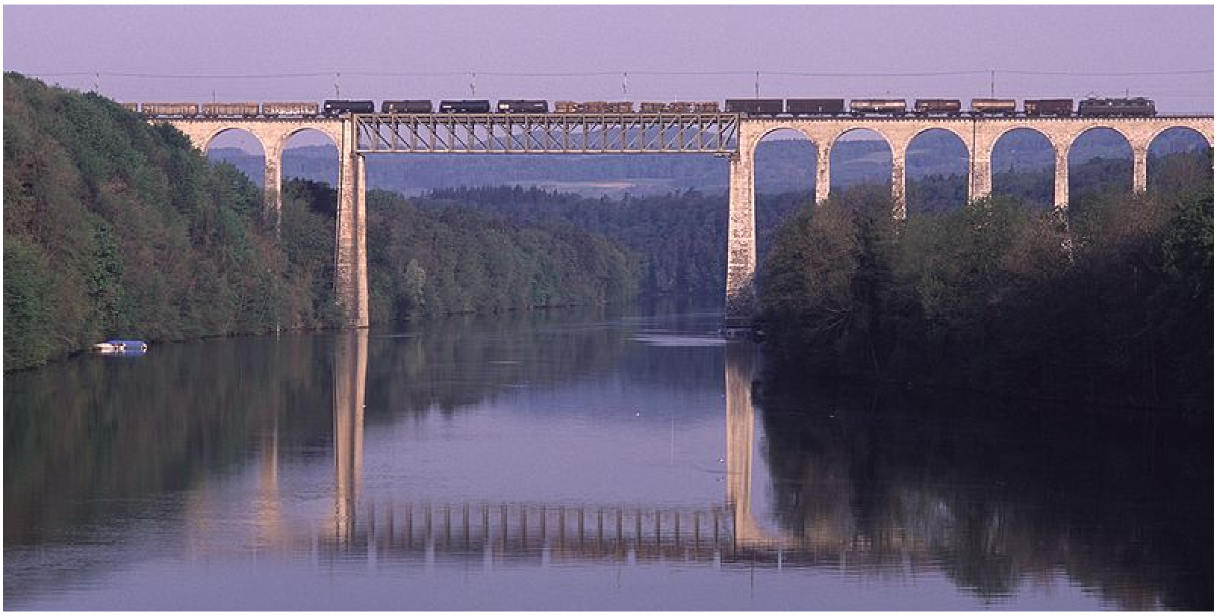

Figure 4-5: Rheinbrücke Eglisau, from [5]

Desired processes

The definition of desired processes was based on an extension of the Rheinbrücke Eglisau project. Areas of interest are safety, the assessment of the condition of structures, the optimization of maintenance and rehabilitation, the optimization of future structures and processes and the investigation of the problem of high loads as a starting point for damages. A wireless sensor network recording natural frequencies and strain with data transfer in real time is desirable. Forces caused by vibration and dynamic coefficients should be monitored on a small number of objects.

Heavy showers are of interest, but other meteorological data can be obtained from external sources. As far as safety is concerned, excessive movements, settlements and abnormal behaviour should be monitored via strain gauges.

The relevance of various factors is presented in Figure 4-6.

Relevance of various factors	On a scale from 1 (irrelevant) to 10 (very important), how would you rate the relevance of the following factors?									
Cost	**1**									**X** **10**
Reliability	**1**									**X** **10**
Easy to handle	**1**							**X**		**10**
No obstruction to use of structure (e.g. traffic)	**1**									**X** **10**
Automated system	**1**									**X** **10**

Figure 4-6: Relevance of various factors related to desired processes

4.1.2 Swiss Federal Roads Authority (FEDRO)

The questionnaire was filled in on December 22, 2009 in the presence of Johannes Hugenschmidt from Empa and Lukas Geel and Frank Bosch both from FEDRO. I another meeting held on November 20 at FEDRO (participants: Francesco Soldovieri – IREA, Romeo Bernini – IREA, Jürg Röthlisberger – FEDRO Vice-president, Lukas Geel – Fedro and Johannes Hugenschmidt – Empa) the implementation of the ISTIMES system and the expectations from FEDRO were discussed.

The organization

FEDRO is responsible for Switzerland’s national roads including the complete motorway network with a length of 1763,6 kilometres. FEDRO is a public body with a budget of CHF 1.2 billion and about 550 employees. It owns the network and is responsible for it by law.

Objects

FEDRO owns about 1100 bridges with a total estimated value of CHF 16 billions, 224 tunnels with a tube length of 213km and an estimated value of CHF 24 billions and 1764km of roads with an estimated value of CHF 40 billions.

Example 1 - Sihlhochstrasse

Sihlhochstrasse is a bridge with a length of about 1.5km (without ramps) situated near Zurich on the motorway A3. Sihlhochstrasse was completed in 1973 and major rehabilitation was carried out in the years 2000-

2001. An overview is presented in Figure 4-8, the main cross section is presented in Figure 4-9. Two views are shown in Figure 4-10 and Figure 4-11.

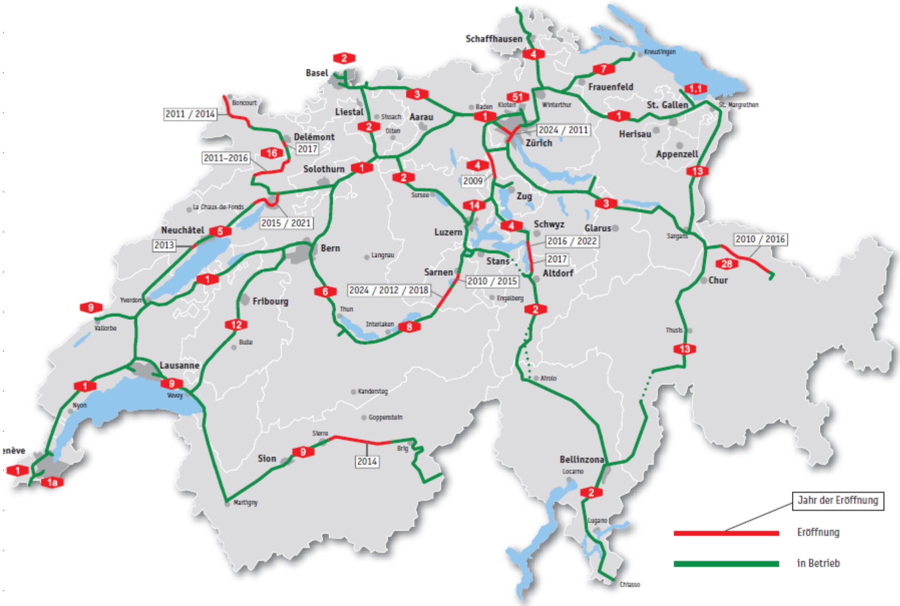

Figure 4-7: Swiss national roads, from [3]

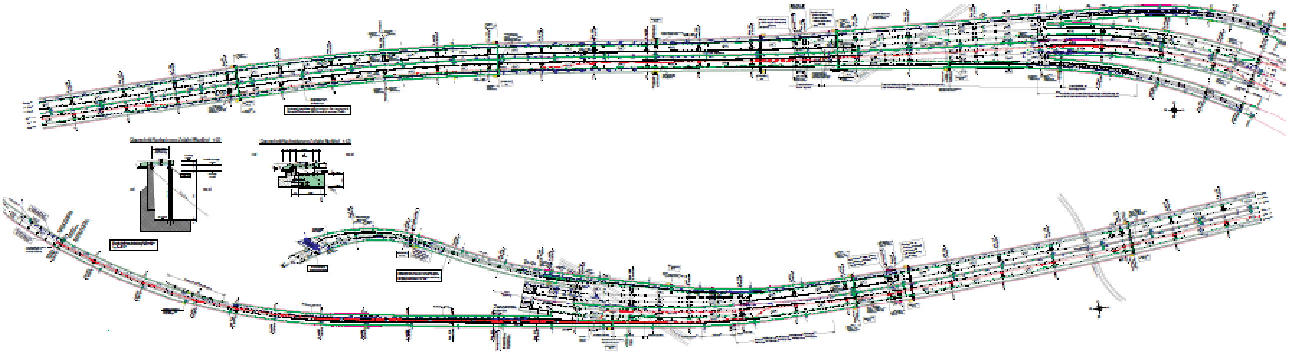

Figure 4-8: Sihlhochstrasse, overview

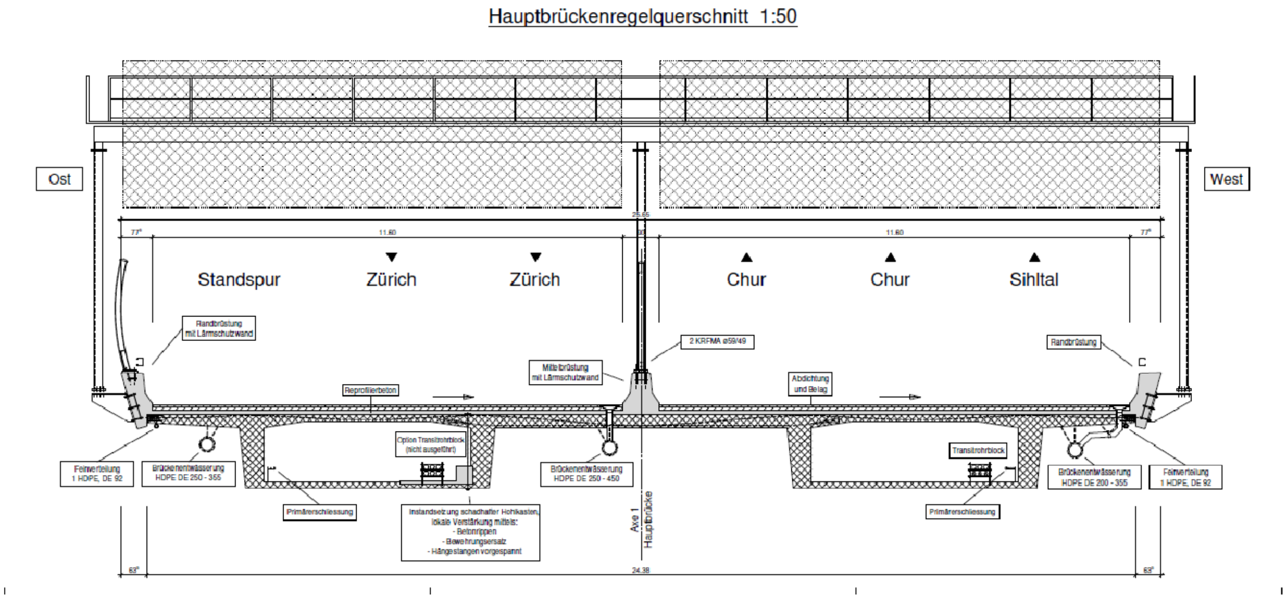

Figure 4-9: Sihlhochstrasse, main cross section

Figure 4-10: Sihlhochstrasse

Figure 4-11: Sihlhochstrasse

Example 2 – Rosenbergtunnel

Rosenbergtunnel is a 1.4km long tunnel with 2 tubes on the motorway A1 near St. Gallen (Figure 4-12). It was completed in 1987, it's height above sea level is 648m-653m. In 2008, 73300 vehicles used the tunnel per day. Most of the tunnel was built with a tunnel boring machine but one section was constructed by open cast mining. Two cross sections (tunnel boring machine, open cast mining) are presented in Figure 4-13 and Figure 4-14. The east tympanum of the tunnel is shown in Figure 4-15, the situation beneath the deck slab is presented in Figure 4-16.

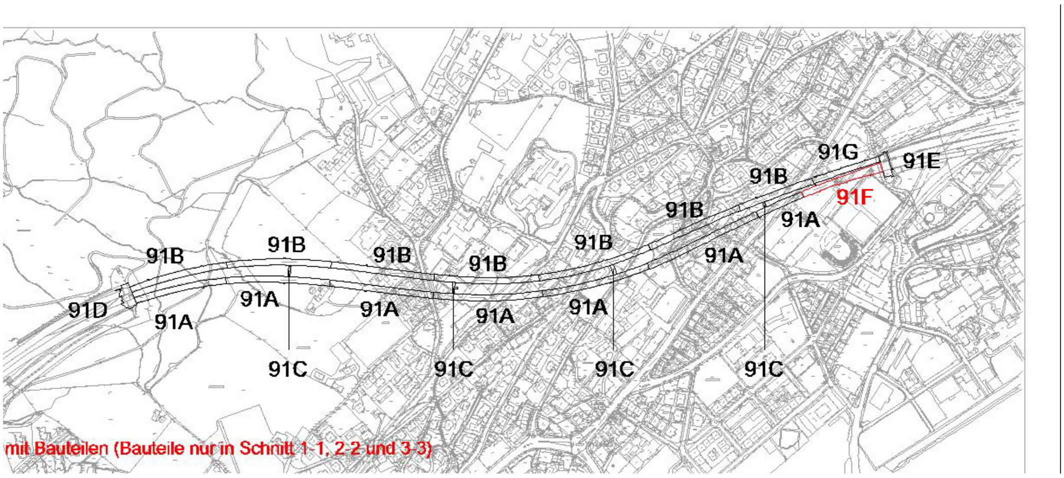

Figure 4-12: Rosenbergtunnel, overview

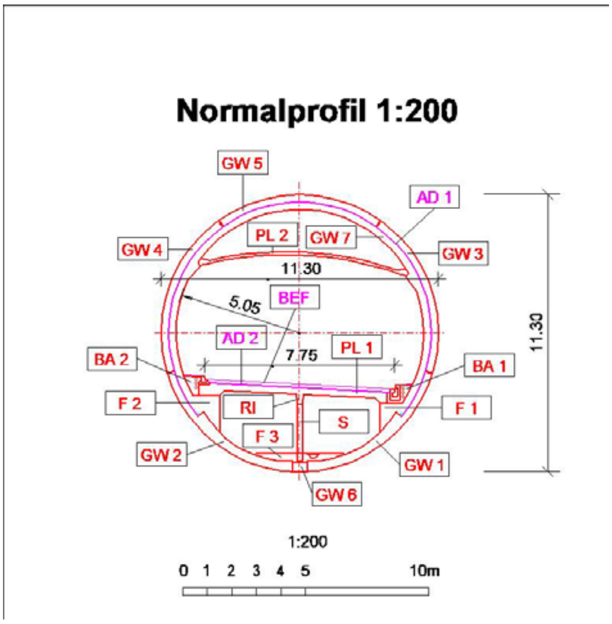

Figure 4-13: Rosenbergtunnel, cross section built with tunnel boring machine

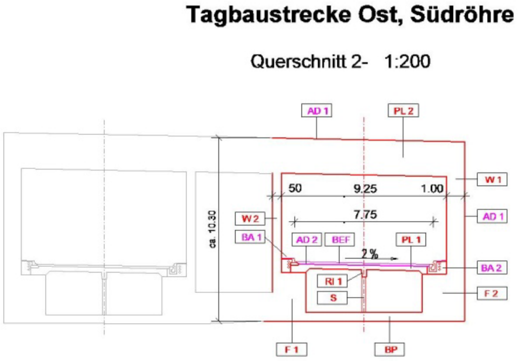

Figure 4-14: Rosenbergtunnel, cross section built by open cast mining

Figure 4-15: Rosenbergtunnel, portal east

Figure 4-16: Rosenbergtunnel, beneath deck slab

Example 3 – Schoren retaining wall (Stützwand Schoren)

Schoren retaining wall was built in1987 on motorway A1 and has a length of about 0.2km. In 2009, major rehabilitation work was carried out (replacement of anchors).

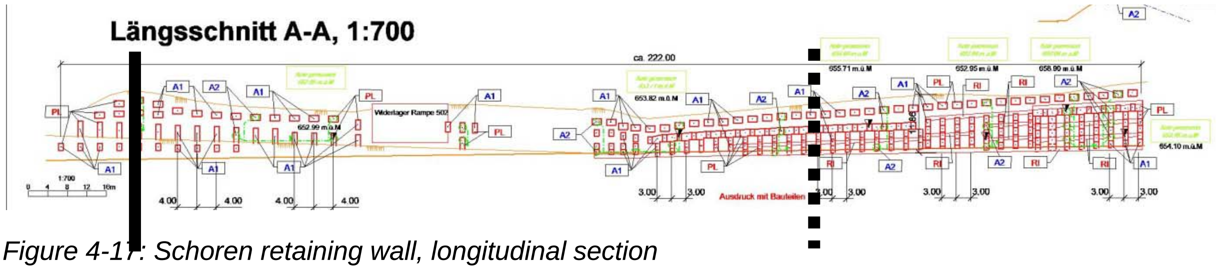

Figure 4-17: Schoren retaining wall, longitudinal section

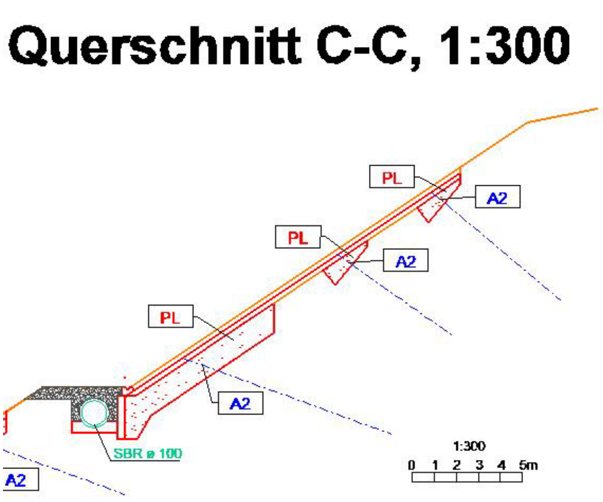

Figure 4-18: Schoren retaining wall, cross section from solid vertical line in Figure 4-17

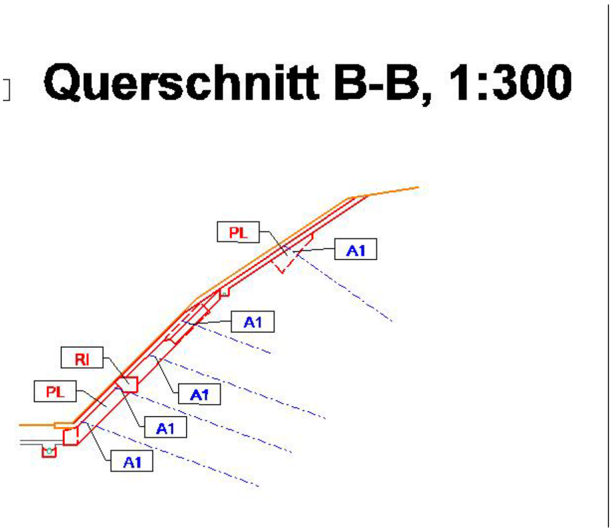

Figure 4-19: Schoren retaining wall, cross section from dashed vertical line in Figure 4-17

Figure 4-20: Schoren retaining wall

Current practice for inspection and monitoring

Level 0:

Input of road users via FEDRO website

Level 1:

Yearly report by maintenance/cleaning staff, daily inspection by driving across.

Level 2:

Most common level, every object (roads, tunnels, bridges and safety equipment) is inspected every 5 years (some objects every 2 years) by private companies. The main motivations are safety, the evaluation of the condition of structures, the optimization of maintenance and the evaluation and elimination of natural hazards. In addition, FEDRO is obliged by law to ensure the safety of national roads but details can be defined by itself.

During the 5 years inspection the following parameters concerning the condition of structures are assessed:

Damage detection and localization, corrosion of steel elements, broken wires (every 10 years), sealing integrity, crack detection, delamination, ageing of materials, joint movements.

If required, the following parameters concerning the condition of structures are assessed in addition to the ones listed above: Depth of carbonatization, chloride penetration, humidity in concrete, compressive strength of concrete, permeability of concrete, depth of rebar and natural frequencies.

As far as meteorological data are concerned, air temperature and the temperature of the inspected object are recorded. Sunshine and precipitation are recorded if required. Traffic data (weigh in motion, number of vehicles and vehicle speed) are recorded in separate stations not directly linked to the inspected objects.

Related to safety, excessive movements, settlements, changes of geometry and tilt are assessed. If required, particularly after events, abnormal behaviour of structures, man made impact (accidents, plane crash, collision of ships with piles), fire or accidents are also evaluated.

Human bias is considered the main shortcoming of the present approach. FEDRO rates its current approach with 8 a on a scale of 1-10 with 1 being useless and 10 being a perfect solution.

Rating of Type-1									
1							X		10

Figure 4-21: Rating of current practice

Advanced practice for inspection and monitoring – Example Rosenbergtunnel

Several objects are under advanced monitoring or inspection. Rosenberg tunnel is inspected with a vehicle for data acquisition equipped with cameras for automated crack detection every 2 years. This is an experimental approach. The main reasons for doing this is the assessment of the condition of the object and of possible changes, ideally information on the reason for the cracks, scientific research and an optimization of future rehabilitation. FEDRO considers this approach as to expensive with suboptimal value for money. The rating of this approach is 7 a on a scale of 1-10 with 1 being useless and 10 being a perfect solution.

Rating of Type-1									
1						X			10

Figure 4-22: Rating of crack monitoring for Rosenberg tunnel

Desired processes

There is a wide range of desired processes for a wide range of existing problems. The following approach refers to the example of Stadtergasse bridge. There, it has to be decided whether this bridge can be strengthened or has to be replaced. It would be desirable to have a monitoring system supporting this decision and delivering more information concerning the overall safety of the structure. Continous monitoring with data transfer in real time and an automated alarm system are considered appropriate. Wired or wireless sensors should monitor the position of the under-side of the bridge deck with additional sensors on the abutments of the object for monitoring their positions. Excessive movements, tilt, geometry changes, settlements and abnormal behaviour have to be monitored and detected. Damage should be detected and ideally localized. In particular, broken wires and cracks are of interest. Natural frequencies and joint movements are considered relevant.

Air temperature snow/ice loads and the water level beneath the bridge should be monitored whereas traffic data can be recorded in separate station (as today).

No obstruction to traffic is the most relevant factor for the desired system (Figure 4-23).

Relevance of various factors	On a scale from 1 (irrelevant) to 10 (very important), how would you rate the relevance of the following factors?									
Cost	**1**						**X**		**10**
Reliability	**1**									**X**
Easy to handle	**1**						**X**		**10**
No obstruction to use of structure (e.g. traffic)	**1**							**X**	**10**
Automated system	**1**					**X**			**10**

Figure 4-23: Relevance of several factors

An important subject of interest for FEDRO is the monitoring of natural hazards and related issues such as retaining walls. When agreeing on Sihlhochstrasse on November 20, 2009, as a test bed for WP-5, FEDRO stated that there are many locations, particularly in the Alps, where advanced monitoring would be desirable. An example is given in Figure 4-24. In 2006 a rockfall killed two persons on motorway A3 and the motorway had to be closed for several weeks.

Figure 4-24: Rockfall on Gotthard motorway (A2), 2006

4.2 Italy

4.2.1 Italian Civil Protection Department (Dipartimento di Protezione Civile, DPC)

The questionnaire was filled out by Claudio Moroni on February 18, 2010.

The organization

The Italian Civil Protection Department (DPC) is a public organisation with about 450 employees working in the field of civil protection.

Objects

DPC is interested in about 100 bridges with an estimated value of about 250 Million Euros, about 1000 kilometers of roads, 10 dams and 50000 buildings with the emphasis on public safety.

Examples

This section is not applicable to DPC because they are interested in a simple monitoring system than can be used on any type of structure.

Current practice for inspection and monitoring

DPC is currently inspecting 20 bridges and 2 dams by visual inspection. This is done whenever there has been a strong earthquake. The main motivation for this approach is the assessment of possible damages and to ensure public safety. Main points of interest are the detection and the localization of damages in particular cracks, changes of geometry, tilt and abnormal behaviour of structures. This approach is considered to expensive, not state-of-the-art and the intervals between inspections are considered to long.

DPC rates its current approach with 4 a on a scale of 1-10 with 1 being useless and 10 being a perfect solution.

Rating of Type-1									
1			X						10

Figure 4-25: Rating of common current practice

Advanced practice

In about 50 building wired sensor networks using accelerometers are installed. The main motivations for this approach are safety, disaster warning, an estimation of the damage scenario and scientific research (building behaviour). The parameters of interest are damage detection and localization in particular cracks, natural frequencies, abnormal behaviour and accelerations due to earthquakes.

This approach was chosen based on cost-benefit analysis. Main shortcomings are that it is to expensive and that lead time for disaster warning is too short. DPC rates this advanced current approach with 5.5 a on a scale of 1-10 with 1 being useless and 10 being a perfect solution.

Rating of Type-1									
1				X	X				10

Figure 4-26: Rating of advanced current practice

Desired processes

The desired process records accelerations and displacements with real-time data transfer. Main motivations are safety, monitoring the condition of structures, disaster warning, scientific research, an optimization of operation (e.g. traffic flow) and emergency management. Relevant parameters concerning the condition of structures are damage detection and localization, in particular cracks, joint movements and natural frequencies. Relevant safety parameters are excessive movements, geometry changes, tilt, abnormal behaviour and acceleration due to earthquakes. The relevance of various factors concerning the desired process is shown in Figure 4-27.

Relevance of various factors	On a scale from 1 (irrelevant) to 10 (very important), how would you rate the relevance of the following factors?									
Cost	**1**									**x**
Reliability	**1**								x	**10**
Easy to handle	**1**						x			**10**
No obstruction to use of structure (e.g. traffic)	**1**									**x**
Automated system	**1**								x	**10**

Figure 4-27: Relevance of various factors related to desired process

5 Application domain user requirements

Kinds of infrastructures to be monitored

According to the present (29. 01. 2010) results, there is a wide range of infrastructures that would benefit from monitoring. Whole road or rail networks seem to be of minor interest but parts thereof have to be considered relevant. Natural hazards and related infrastructure such as retaining walls or avalanche galleries are a main focus in the Swiss Alps. Bridges and tunnels are of interest whenever there are problems such as uncertainty concerning the structural safety or if processes have started that will lead to future rehabilitation. Such processes include for example the occurrence of cracks in tunnel walls or corrosion of steel bridges.

Parameters of interest

The parameters of interest are by nature closely related to the problems justifying advanced monitoring. In some cases, such as Rheinbrücke Eglisau, a very limited set of parameters such as strain and possibly parameters defining the geometrical shape of the structure are sufficient. Parameters that have been named as relevant are:

Cracks and their development in time

Strain

Corrosion

Delamination

Joint movements

Ageing of materials

Sealing integrity

Broken wires

Parameters relevant for safety such as accelerations, abnormal behavior, settlements, tilt, excessive movements or tilt

Detection of damage in a general sense

Parameters that are of interest mainly for quality control of new structures or after rehabilitation:

Depth of rebar

Position of tendons

Natural frequencies

Asphalt thickness

Parameters that are of interest if there are known problems, often related to the planning of rehabilitation:

Depth of carbonatization

Chloride penetration

Humidity in concrete

Compressive strength of concrete

Permeability of concrete

Natural frequencies

Meteorological and traffic parameters are relevant but are recorded in separate and independent stations.

Spatial scale of investigation

The approach by the organizations interviewed is clearly object based. This means that a future monitoring system should cover single but complete objects such as a single bridge or a single tunnel.

Necessity of real time diagnostics

Real time diagnostics is required for safety related monitoring. For other cases it is in many cases desirable.

6 Use cases definition

Case -1

A wireless strain sensor network for the monitoring of steel bridges with data transfer in real time. Real time diagnostics with automated alarms is desirable for natural frequencies and the geometry of the structure.

Case – 2

A wired or wireless sensor network for concrete bridges including abutments with automated alarms for safety relevant parameters such as abnormal behavior, settlements, tilt, excessive movement and geometry changes. The main purpose of the monitoring system is to support the decision on whether to replace or rehabilitate the structure. Relevant parameters are existence and location of damage in a general sense, cracks, broken wires, joint movements and natural frequencies. In this case, meteorological data are relevant, in particular snow loads, the water level beneath the bridge and air temperature.

Case – 3

A simple system that can be installed everywhere and on every type of building for monitoring and surveillance with the emphasis on safety parameters. Data transfer should be in real time and accelerations and displacements due to earthquakes would be the most important parameters.

Case – 4

Systems for the monitoring of natural hazards such as rockfalls or landslides. Such a system needs an automatic warning and possibly automated consequences such as switching traffic lights.

7 Analysis of existing solutions

7.1 Introduction

Structural health monitoring (SHM) has been defined as the acquisition, validation, and analysis of technical data to facilitate life-cycle management decisions (Cawley and Adams 1987). SHM is a system that has the ability to detect and interpret changes in the structure. The first challenge of an SHM design is to determine what is being monitored in the system, such as strain, displacement, natural frequencies, mode shape, modal strain energy, etc. The damage behavior in structures can be predicted by monitoring changes in its natural frequencies (Adams et. al. 1978, Chen et al. 1995, Kessler et. al. 2002, Lee and Shin 2002), modal properties (Yuen 1985, Liu 1995, Abdelgham et. al. 1999, Sampaio et. al. 1999, Bedewi et. al. 1997, Park and Reich 1999, Narayana et. al. 1999, Kawiecki 2001), and strain energy (Otieno et al. 2000, and Shi et. al. 2002). Once the dynamic responses of infrastructures are selected to be monitored, it is equally critical to determine the measurement method, which will distinguish the changes in the natural frequencies, mode shapes, or strain energies. There have been many examples in the development of structural health monitoring technology for surveillance, evaluation and assessment of existing or newly built civil infrastructures. Some long-term monitoring systems have been implemented on bridges in Europe (Andersen and Pedersen 1994, Myrvoll et al. 2000, Brownjohn 2003, Casciati 2003), the United States (Pines and Aktan 2002), Canada (Cheung and Naumoski 2002, Mufti 2002), and Asian countries (Fujino and Abe 2004, Koh et al. 2003, Xiang 2000). Structural health monitoring systems are generally envisaged to: (i) validate design assumptions; (ii) detect anomalies in loading and response, and possible damage to ensure structural and operational safety; (iii) provide real-time information for safety assessment; (iv) provide evidence and instruction for planning and prioritizing infrastructure inspection, rehabilitation, maintenance and repair; (v) monitor repairs and reconstruction with the view of evaluating the effectiveness of maintenance and repairing works; and (vi) obtain massive amounts of in-situ data. The development and implementation of a structural health monitoring system capable of fully achieving the above objectives and benefits is still a challenge at present, and needs well coordinated interdisciplinary research for adaptation of innovative technologies in civil infrastructures. Actually, structural health monitoring has been a subject of major international research on various civil infrastructures such as roads (NCHRP-632 2009) and railways (Barke and Chiu 2005) in recent years.

This report aims to provide overviews of existing integrated health monitoring systems (IHMS) as guidelines of possible useful scenarios for ISTIMES project. The contents will cover several aspects, which are general strategies of SHM, designing and implementation procedures of IHMS, examples of existing IHMS, and benefits and challenges in integrated health monitoring systems.

7.2 Integrated Structural Health Monitoring Systems

It is fundamentally important that a monitoring system is designed as an integrated system, with all data flowing to a single database and presented through a single user interface. The integration between different sensing technologies that can be simultaneously installed on the structure, e.g., electromagnetic sensors

(Fornaro et al. 2003), fibre optic sensors (Kersey 1997 and Glisic and Inaudi 2007), hyperspectral spectroscopy (Gomez 2002), electrical resistivity tomography (Colella et al. 2004), ground penetrating radar (Hugenschmidt and Mastrangelo 2006), can be achieved at several levels. Different sensors can be connected to a single data management system, which can be installed either on site or at a remote location. The data management system should interface to all types of data-loggers and translate the incoming data into a single format that is forwarded to the database system as shown in Figure 7-1. Since a monitoring project often requires the integration of several technologies, it is important to provide the end-users with a single integrated interface that does not require them to learn and interact with several different user interfaces.

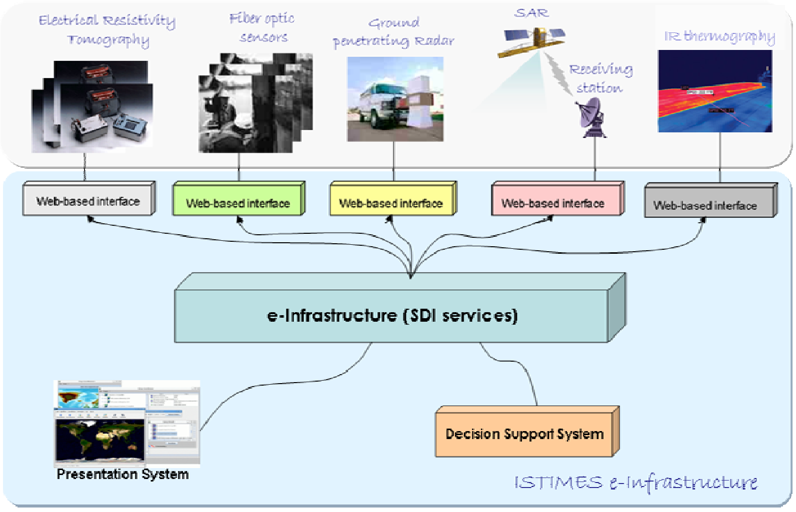

Figure 7-1: Schematic of single data management system for different measurement technologies

7.2.1 Monitoring strategies

Each health monitoring system presents its own characteristics and strategies although it is possible to standardize most elements of a monitoring system. It is also possible to classify the monitoring components according to following several categories (Glisic and Inaudi 2003, Glisic et al. 2002, Measures 2001).

Scale

- **Local scale**: the performance is analyzed by considering local properties of construction materials. Local strain distributions or chemical penetration in concrete are examples of measurements at this scale.
- **Global scale**: structures are observed from the point of view of overall performance and responses, e.g., structural deformations observed.
- **Network scale**: the monitoring of several structures belonging to an infrastructure system allows the owner to make decisions at the system level, e.g. allocating budget and planning repairs on several structures in the same highway.

Parameter

- **Mechanical**: force, strain, displacement, curvature, rotations, etc
- **Physical**: material temperature, water saturation, etc
- **Chemical**: pH, chlorine, sulfates, etc
- **Environmental**: temperature, humidity, solar irradiation, wind, etc

Periodicity

- **Periodic**: manual measurements at pre-defined intervals
- **Semi-continuous**: automatic measurements over pre-defined time periods
- **Continuous**: permanent automatic measurements

Response

- **Static**: measurement of slowly varying parameters
- **Dynamic**: measurement of vibrations and other dynamic responses

Data collection

- **None**: sensors are installed but not measured.
- **Manual**: measurements are performed by an operator on site.
- **Off-line**: data is collected automatically by the system and downloaded periodically through a data line or manually.
- **On-line**: all data is permanently available online.
- **Real-time**: data is collected on-line and analyzed immediately to allow immediate feed-back to the owner and users.

All these types of monitoring can be mixed and combined according to the specific need of infrastructure. These various monitoring components require a rigorous design approach to select the appropriate health monitoring system.

7.2.2 Designing and implementing structural health monitoring systems

Designing and implementing an effective structural health monitoring system is a process that should be carried out following a logical sequence of analysis steps and decisions. SHM systems have been installed often without any realistic consideration of owner needs only based on the desire to implement a new technology. These monitoring systems often provide data that is difficult to analyze or which cannot be used by the owner to support management decisions. Following procedures can cover enough the needs of all parties involved in design, construction, and operation of structures (Inaudi et al. 2009).

Step 1: Identify structures needing monitoring

Before considering a structural health monitoring system, it is important to consider if a specific structure will really have benefits from it. The following list includes some of the situations that SHM system is believed to be beneficial:

- New structures including innovative aspects in the design, construction procedure, or materials used.
- New structures with unusual associated risks or uncertainties, including geological conditions, seismic risk, meteorological risk, aggressive environment, vulnerability during construction, quality of materials and workmanship.
- Structures that are critical at a network level, since their failure or deficiency would have a serious impact on the rest of the network and the users.
- New or existing structure which is representative of a larger population of identical or very similar structures. In this case, most information obtained from a subset of structures can be extrapolated to the whole population.
- Existing structures with known deficiencies or very low rating results from visual inspections.
- Candidates for replacement or major refurbishment works. In this case, SHM is used to assess the real need for such action and to better design and execute the repair.

Step 2: Risk analysis

The SHM system design engineers, the engineers in charge of the structural assessment, and the owner should jointly identify the risks associated with the specific structure and their probability. The risk analysis will lead to a list of possible events and degradations that can possibly affect the structure. The severity and probability of each risk will be classified using analysis procedures to produce a ranking of risks.

Step 3: Responses to degradations

For each of the retained risks, we now need to associate one or several responses that can be observed directly or indirectly. For example corrosion will produce a chemical change, but also a section loss. Subsidence will produce a settlement or a change of pore pressure. At this stage, it is useful to roughly quantify expected responses. It is also possible to determine which responses are easily and efficiently observed by a periodic visual inspection and which others require instrumentation. The physical locations where these responses are expected or will appear at their maximum extend also need to be established. The output of this step is a list of responses that need to be detected and measured, their estimated amplitudes and their location.

Step 4: Design SHM system and select appropriate sensors

This is typically the first step that is approached by inexperienced SHM system proponents or by those offering a specific sensing technology. The goal is now to select the sensors that have the appropriate specifications to sense the expected responses and are appropriate for installation in the specific environmental conditions and under the technical constraints found in the structure. At this stage one should also consider the required lifetime of the SHM system and the available budget. Too many data acquisition systems will increase the system cost and complexity, so a good balance on the variety and necessity is required. The system design also needs to take into account the constraints associated with its installation and the construction schedule in the case of a new structure.

Step 5: Installation and Calibration

Installation of all systems must adhere to the supplier's specifications. The system calibration and testing must be carried out by the SHM contractor and can sometimes be divided in different phases if the sensors are not all installed at the same time. The result of this step is an as-built plan of the SHM system, a system manual and a calibration report.

Step 6: Data Acquisition and Management

This is the operational part of process. The data is acquired and stored in a database with appropriate back-up and access authorizations. Documentation of all interventions on the structure and on the system is also important in this phase.

Step 7: Data Assessment

This is often the most difficult step but the engineer will be able to identify by analyzing the responses of the structure if any of the foreseen risks and degradations have materialized. At this step the owner will also establish procedures to respond to the detection of any degradation. The output of this step is a series of alerts, warnings and periodic reports.

Summary

Designing and implementing a structural health monitoring system for civil infrastructure requires experienced professionals and a combination of multidisciplinary skills. Unfortunately, this process is difficult to be formalized in the same way. Recommendations and drafts codes for the implementation of SHM system are certainly important steps towards the matured level of SHM.

7.3 Examples of existing integrated health monitoring systems

Successful implementation and operation of long-term structural health monitoring systems on bridges have been widely reported. So far about 40 long-span bridges (with spans of 100m or longer) worldwide have been instrumented with structural health monitoring systems (Ni and Hua 2004). Typical examples are the Great Belt Bridge in Demark (Andersen and Pedersen 1994), the Confederation Bridge in Canada (Cheung et al. 1997), the Tsing Ma Bridge in Hong Kong (Lau et al. 1999), and the Commodore Barry Bridge in the United States (Barrish et al. 2000), the Akashi Kaikyo Bridge in Japan (Sumitro et al. 2001), and the Seohae

Bridge in Korea (Kim et al. 2002). Several recent trends in structural health monitoring practice for large-scale bridges are worth mentioning. (i) The design of a monitoring system is required in the tender as part of the infrastructure design. Integration of infrastructure design and monitoring system design ensures that design engineers' important concerns are reflected in the monitoring system while civil provisions for implementing a monitoring system are considered in the infrastructure design. (ii) The implementation of long-term monitoring systems on new bridges is accomplished in synchronism with the infrastructure construction progress. In this way some specific types of sensors, e.g., corrosion sensors, strain gauges and fiber optic sensors can be embedded into the structure during certain bridge erection stages. (iii) The recently devised long-term health monitoring systems emphasize multi-purpose monitoring of the infrastructure integrity, durability and reliability.

In the past decade, significant progress has been made in sensing technology and kinds of innovative sensing systems such as fiber optic sensors and wireless sensors are now becoming commercially available. A sensing system is essential to realizing structural health monitoring of bridges. The envisioned future for structural health monitoring uses an array of inexpensive, spatially distributed, wirelessly powered, wirelessly networked, embedded sensing devices supporting frequent and on demand acquisition of real-time information about the loading and environmental effects, structural characteristics and responses. Fiber optic sensors have successfully been applied for long-term structural health monitoring of bridges (Mufti et al. 1997, Chan et al. 2004). Figure 7-2 illustrates such an application where fiber optic sensors are deployed along the deck length of the suspension Jiangyin bridge in China for both strain and temperature measurement. The most attractive feature of fiber optic sensors is their capability of distributed sensing and measurement which will result in elaborate condition monitoring for large-scale bridges. The existent main obstacle to wide acceptance of fiber optic sensors for bridge monitoring application is the lack of engineering demonstration of the durability of the sensors in a harsh environment and long-term performance of their attachment to construction materials. Another promising application of fiber optic sensors for cable-supported bridges is the embedment of sensors inside the bridge cables for both temperature and strain measurement. A research team in Hong Kong has devised such a fiber optic sensing system for the cable-stayed Sutong bridge in China. In this design shown in Figure 7-3, seven out of the wires composing the cable cross-section have been replaced by stainless steel tubes for the deployment of fiber optic sensors. Optic fibers in terms of the Brillouin scattering sensors are laid 'strain-free' inside each steel tube for distributed temperature measurement along the cable length (Ni et al. 2004).

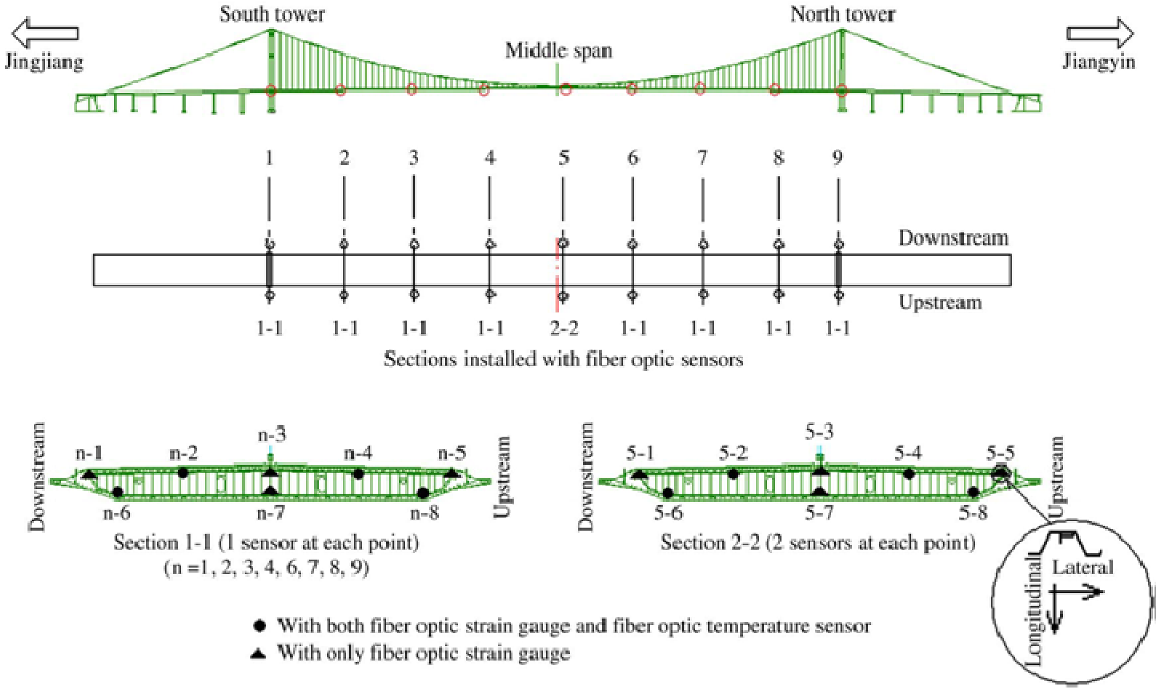

Figure 7-2: Layout of fiber optic sensors on the Jiangyin bridge

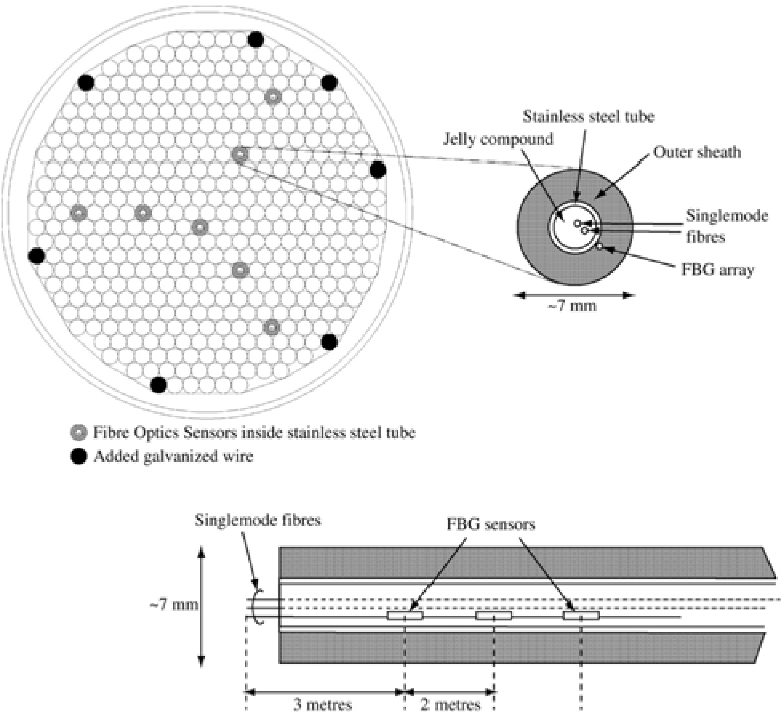

Figure 7-3: Fiber optic sensors embedded inside a bridge cable cross-section.

Railways using wayside detection equipment can achieve significant savings by preventing derailments and also by detecting conditions which would lead to rapid vehicle or track deterioration (Steets and Tse 1998).

Under these circumstances, savings can be made through reduced wear on vehicles and track, and through programmed maintenance. Many wayside detection systems can be connected to a railway's computer network to provide extensive information about vehicle performance. Vehicles tagged with automatic equipment identification (AEI), can be monitored and data can be processed and analyzed to determine the condition of the vehicle. Vehicle condition is then reported through one of the many communication means available. Mechanical detection of sliding wheels can be achieved with the use of a roller, pressed in contact with the flange of each passing wheel, as shown in Figure 7-4 (Barke and Chiu 2005). The information generated by wayside detection systems is often recorded in an extensive database, providing information on the vehicle condition and performance over an extended period of time. This database can be interrogated to provide information on maintenance strategies or the relative properties of different components.

Strain in the rail foot or web may be used as a direct measure of the load at the rail head, which bends the rail. The advantage of this system is that the relationship between the applied load and the sensor output can be calibrated by mechanical means. Therefore, an exact measure of the load (dynamic or static) applied to the rail and the strain-based systems have won favor in some circles, since there is a conceptual link between large applied loads and damage. (Stone et al. 1992, Johansson and Nielsen 2001, Kalay et al. 1992, Partington 1993)

Figure 7-4: A mechanical sliding wheel detector

7.4 Benefits and challenges of health monitoring systems

7.4.1 4.1 Benefits of HMS

The benefits of having a structural health monitoring system installed on civil infrastructures are many and depend on the specific application. The detail benefits are explained as following.

Reducing uncertainty

The infrastructure owners are facing a lot of uncertainties such as the real state of the materials, the real loads acting on the structure, and aging. When making any decision on infrastructure, they have to take these unknowns into account and keep the structure on the safe side by assuming the worst case scenario for all uncertainties. Monitoring helps reducing uncertainty and therefore allows the owner to take informed decisions supported by factual data. Monitoring can also reduce insurance costs by reducing the uncertainty associated with the insured risk.

Discovering deficiencies in time and increasing safety

A few structures might present deficiencies which cannot be identified by visual inspection or modeling. In these cases, it is crucial to undertake appropriate remedial or preventive actions before it is too late. Repairing works will be cheaper and will cause less disruption to the use of the structure if it is done at the right time. Having permanent and reliable monitoring data from a structure can guarantee the safety of the structure and its users.

Insuring long-term quality

Each quality control policy requires measurements and feed-back to insure that the objectives are attained and that corrective actions can be taken in case of deviations. By providing continuous and quantitative data, a monitoring system helps in assessing the quality of the structure during construction, operation, maintenance and repair. Most defects and damages in a structure are built-in during the construction process. However, many of them will produce visible results when the repairing cost becomes much more expensive and no longer covered by the contractor’s warranty.

Optimizing structural management

Monitoring data can be used to perform “maintenance on demand” to optimize the operation. Maintenance and repairing of structures should be based on reliable and objective monitoring data. Qualitative decisions in integrated structural management systems can be conducted by providing reliable and unbiased information.

Increasing knowledge

Learning how a structure performs in real conditions will help to design better structures for the future. Increased knowledge will lead to cheaper, safer and more durable structures with higher reliability and better performance.

7.5 Challenges of HMS

In civil infrastructures, continuous monitoring requires the use of robust sensors that can withstand the damaging effects of the environment and the alkali or salt that are often associated with infrastructures, since these sensors are expected to operate for the life of the infrastructure that may be as long as 50 or 100 years. Robust sensors are expected to perform reliably for the life of the structure. Non-destructive evaluation techniques remain as one of the important part of health monitoring of civil infrastructure. Their ability to specifically identify one type of damage may be viewed as a useful part of damage detection, as global methods often do not give enough information to determine the exact mode of failure.

A main distinction of structural health monitoring systems from conventional measurement systems is that the former incorporates damage diagnostic and prognostic algorithms. Extensive research on structural damage identification algorithms has been conducted in the past decades (Doebling et al. 1998, Sohn et al. 2004). Most widely studied are vibration-based damage detection methods. The vibration-based damage detection methods use measured changes in dynamic features (mainly modal parameters) to evaluate changes in physical properties that may indicate structural damage or degradation. In reality, however, a civil structure is subjected to varying environmental and operational conditions such as traffic, humidity, wind, solar-radiation and, most important, temperature. These environmental effects also cause changes in modal parameters which may mask the changes caused by structural damage. The evaluation results on the effectiveness of a variety of vibration-based damage detection methods applied to the I-40 Bridge built in Oklahoma of the United States indicated that the environmental effects were one of the main pitfalls limiting the practical applicability of modal-based methods (Pines and Aktan 2002, Farrar and Jauregui 1998). For reliability performance of damage detection algorithms, it is of paramount importance to discriminate abnormal changes in dynamic features caused by structural damage from normal changes due to environmental and operational fluctuations, so that neither will the normal changes raise a false-positive alarm nor will the abnormal changes raise a false-negative alarm in damage detection. With a thorough understanding of the effect of environmental variability on modal properties, it is possible to detect subtle structural damage by incorporating a well defined environmental effect model into appropriate damage detection algorithms (Alampalli 1999, Worden et al. 2002, Lloyd et al. 2003).

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9 Appendix

9.1 List of core group members

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9.2 Glossary

CHF	Swiss Francs
DPC	Dipartimento di Protezione Civile (Italian Civil Protection Department)
Empa	Swiss Federal Laboratory for Materials Testing and Research
EUR	Euro
FEDRO	Swiss Federal Roads Office
SBB	Swiss Federal Railways

9.3 Questionnaire

Questionnaire

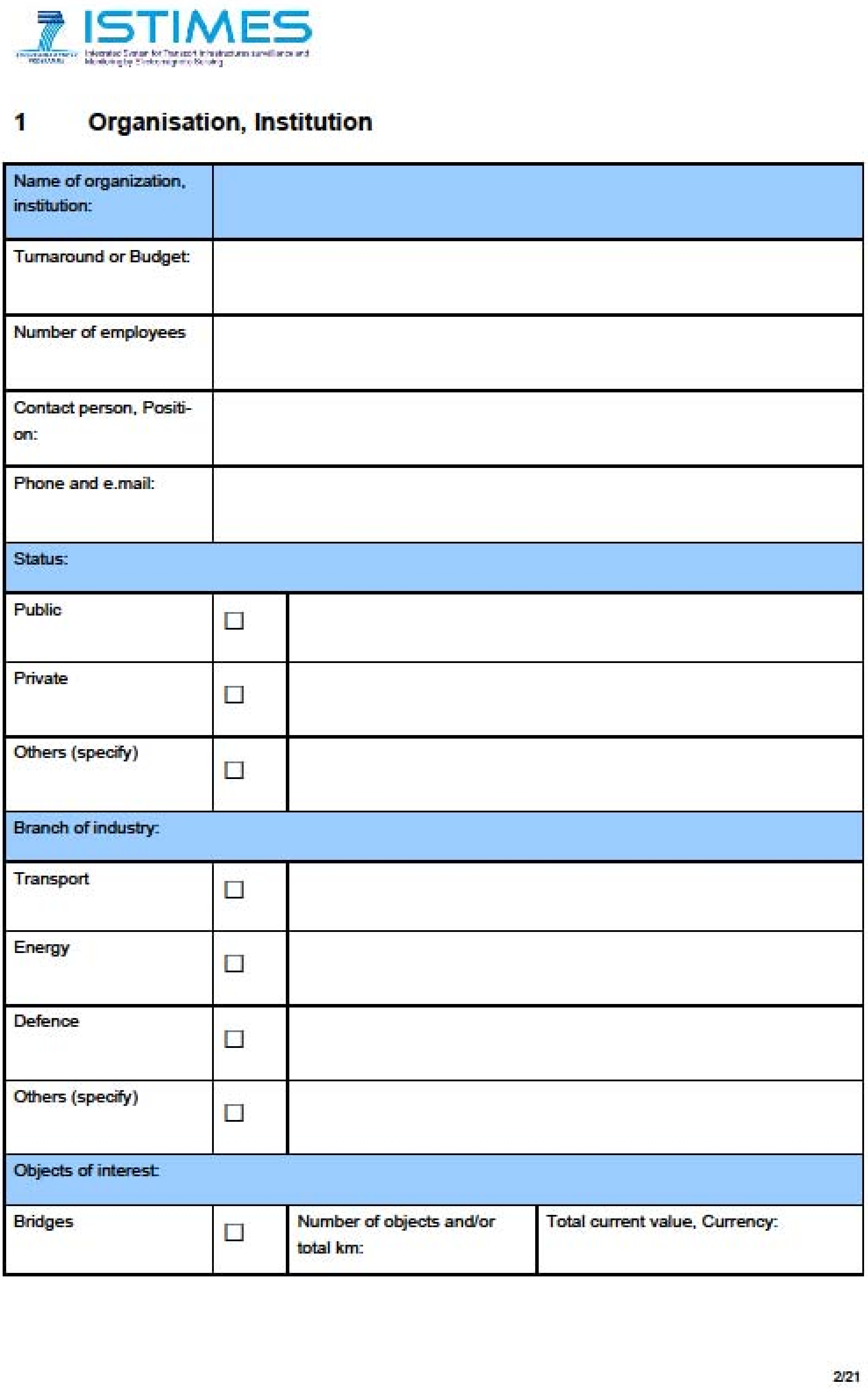
Work Package 1 - User Requirements

Interviewer:	
Interviewers's organization:	
Date:	

Hints:

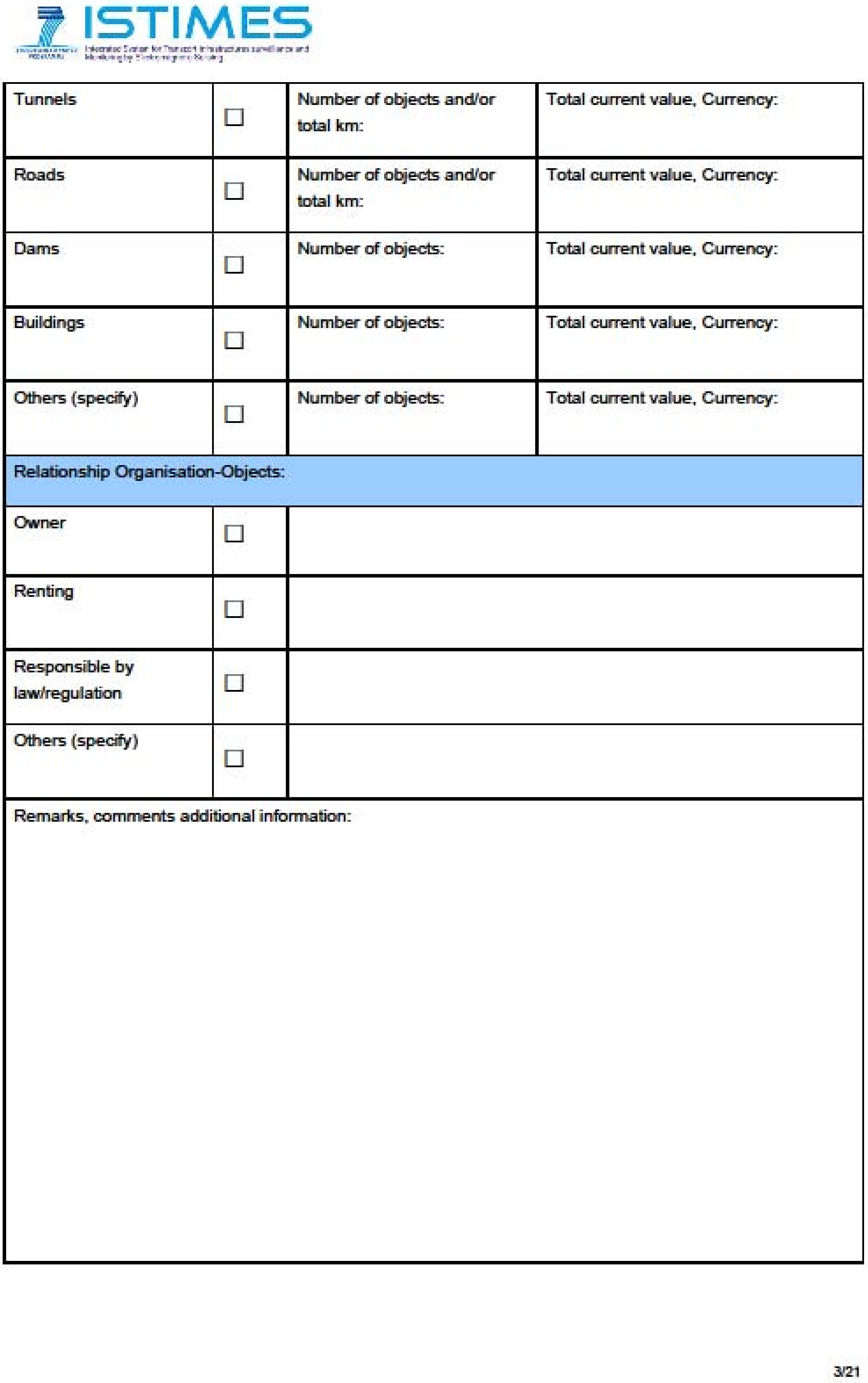
Please tick several boxes where appropriate

ISTIMES
SEVENTH FRAMEWORK PROGRAMME
Integrated System for Transport Infrastructures surveillance and
Monitoring by Electromagnetic Sensing

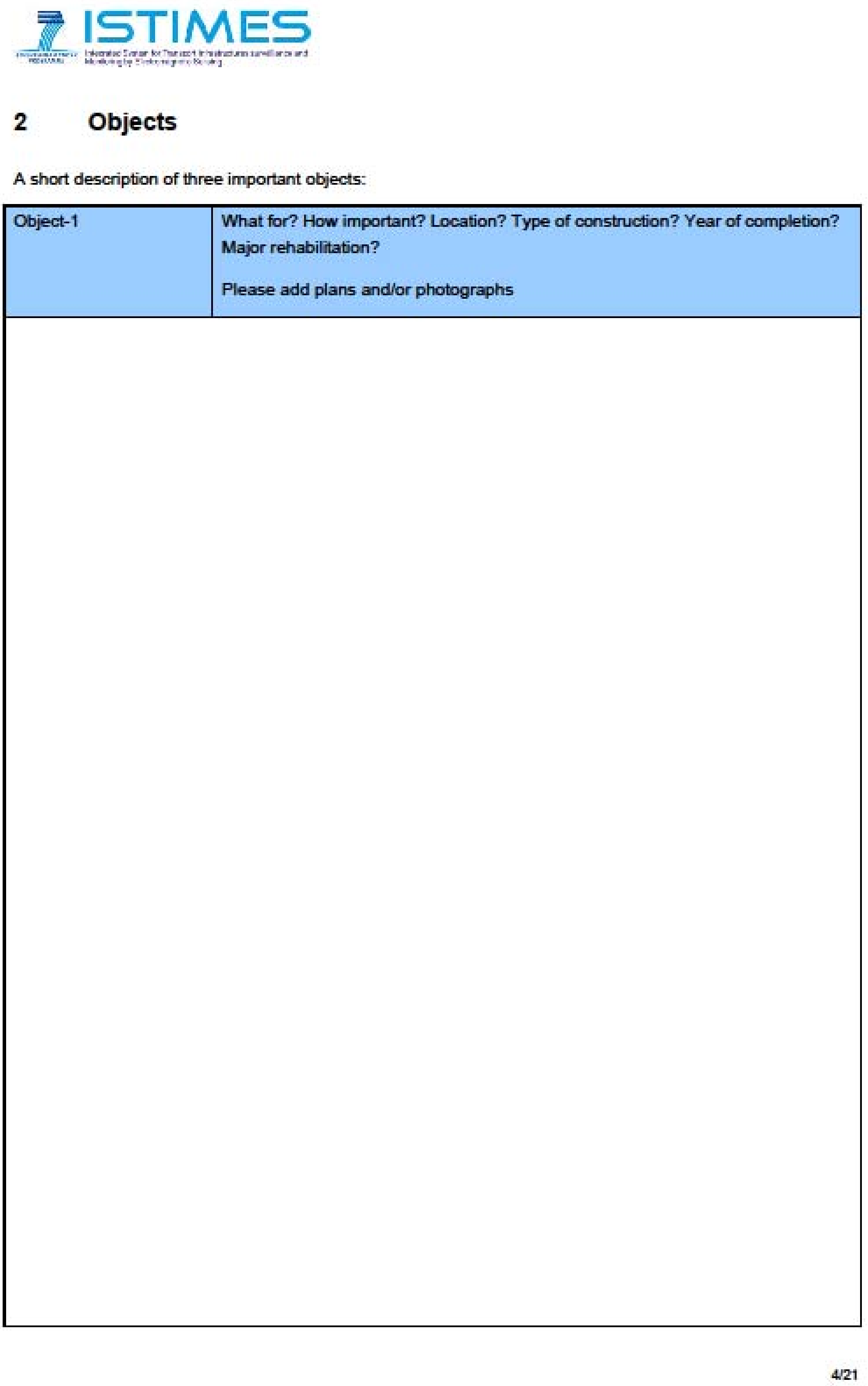


1 Organisation, Institution

Name of organization, institution:			
Turnaround or Budget:			
Number of employees			
Contact person, Position:			
Phone and e.mail:			
Status:			
Public	☐		
Private	☐		
Others (specify)	☐		
Branch of industry:			
Transport	☐		
Energy	☐		
Defence	☐		
Others (specify)	☐		
Objects of interest:			
Bridges	☐	Number of objects and/or total km:	Total current value, Currency:



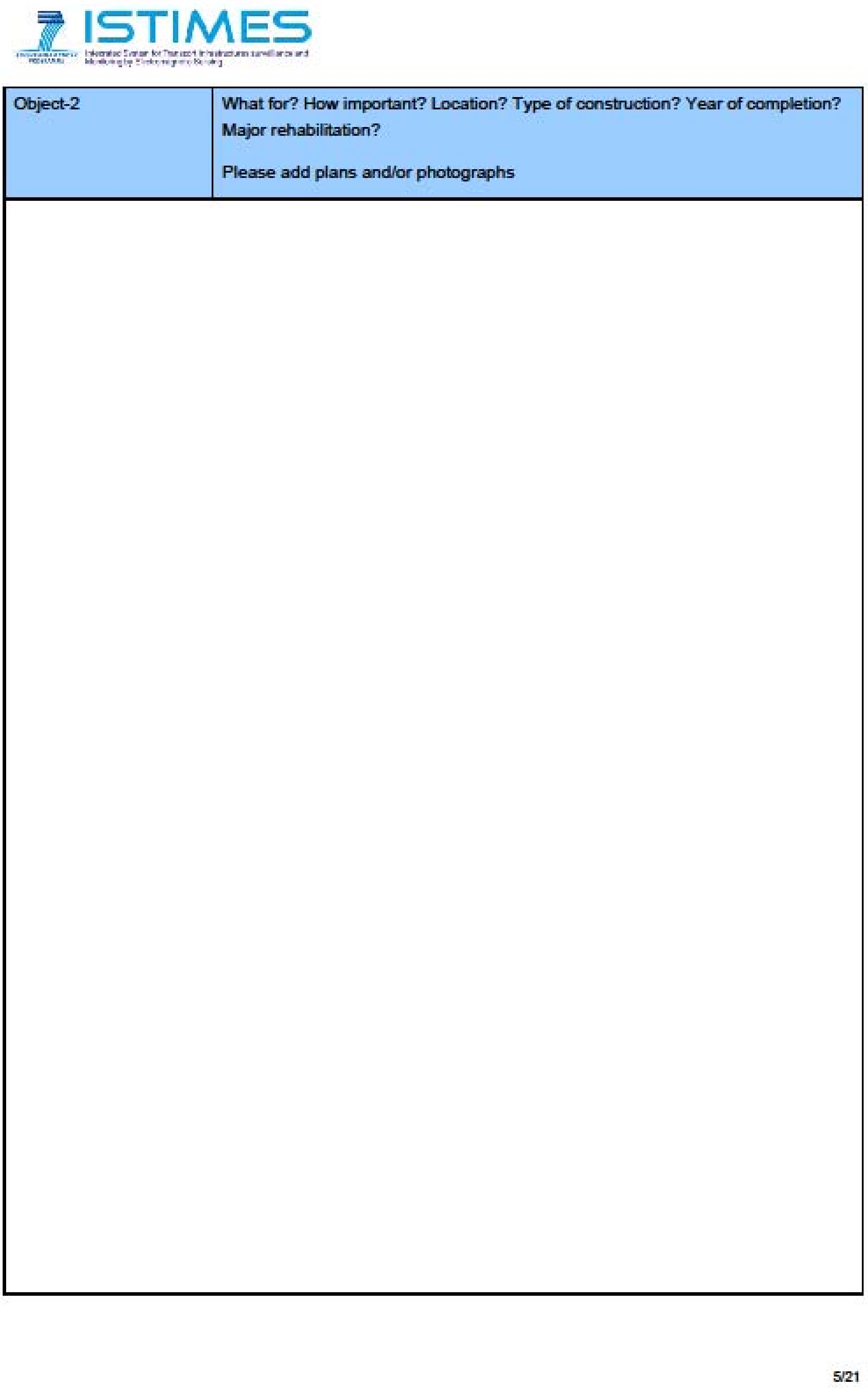
Tunnels	☐	Number of objects and/or total km:	Total current value, Currency:
Roads	☐	Number of objects and/or total km:	Total current value, Currency:
Dams	☐	Number of objects:	Total current value, Currency:
Buildings	☐	Number of objects:	Total current value, Currency:
Others (specify)	☐	Number of objects:	Total current value, Currency:
Relationship Organisation-Objects:			
Owner	☐		
Renting	☐		
Responsible by law/regulation	☐		
Others (specify)	☐		
Remarks, comments additional information:			



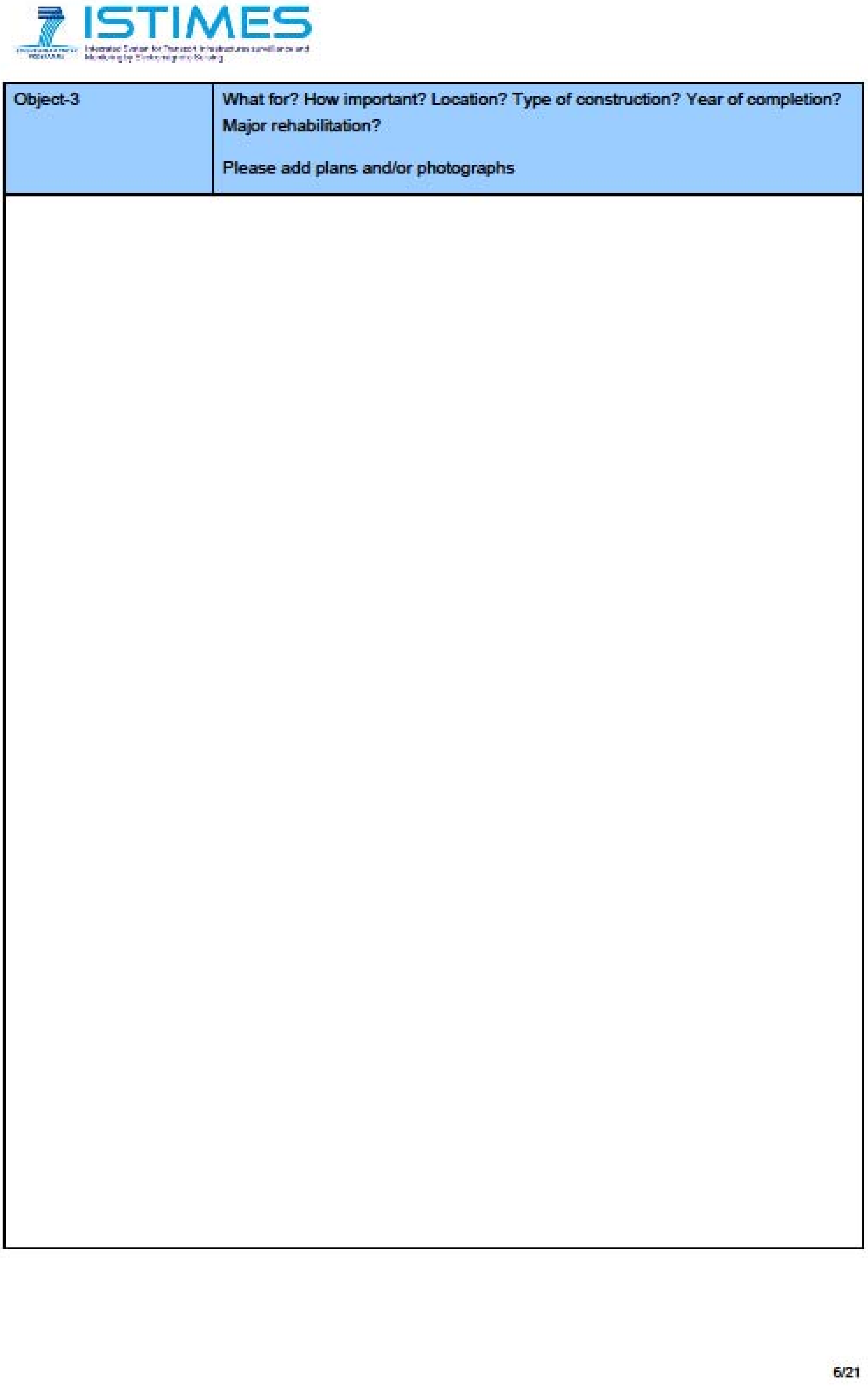
2 Objects

A short description of three important objects:

Object-1	What for? How important? Location? Type of construction? Year of completion? Major rehabilitation? Please add plans and/or photographs



Object-2	What for? How important? Location? Type of construction? Year of completion? Major rehabilitation? Please add plans and/or photographs



Object-3	What for? How important? Location? Type of construction? Year of completion? Major rehabilitation? Please add plans and/or photographs

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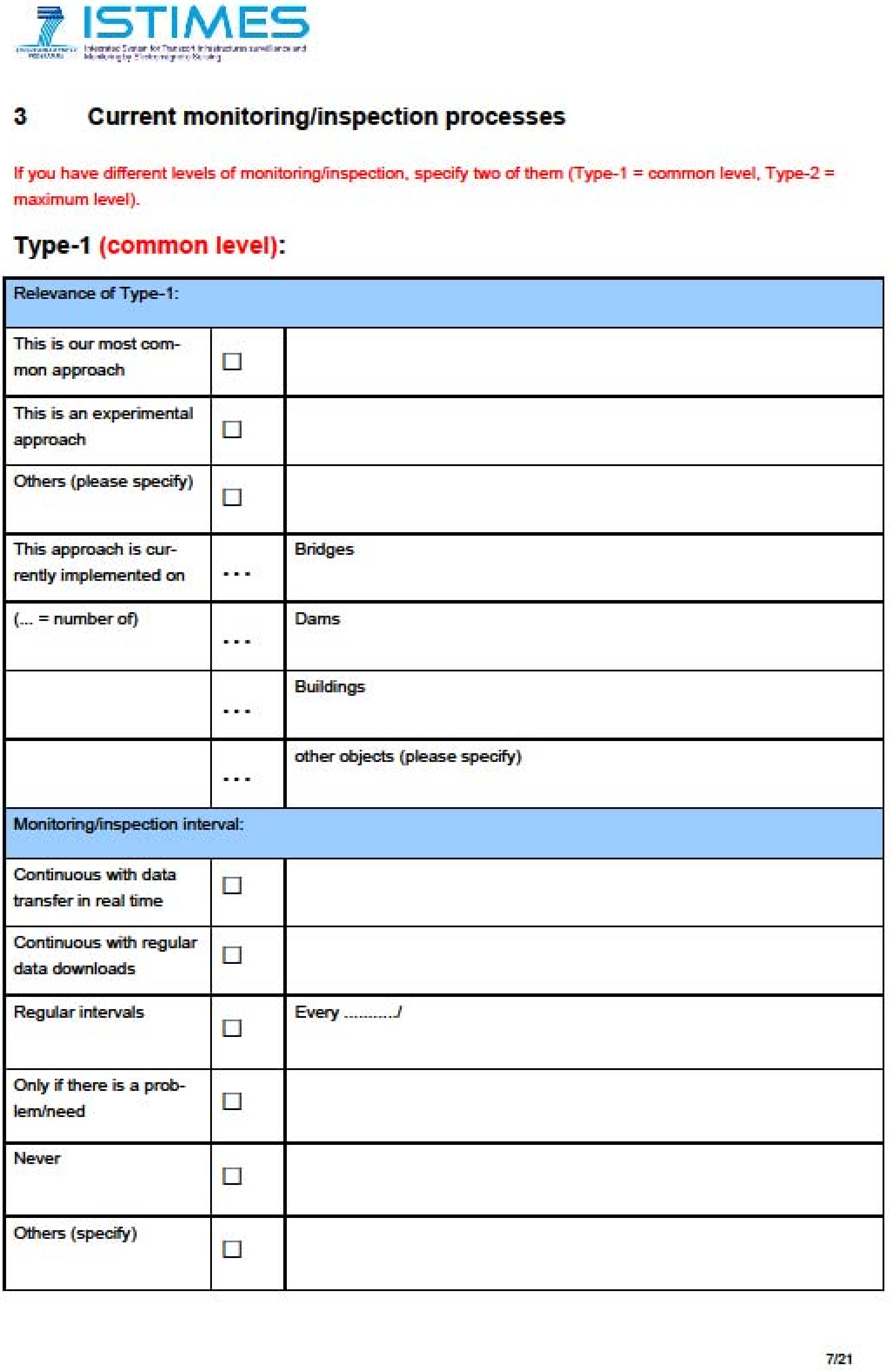

3 Current monitoring/inspection processes

If you have different levels of monitoring/inspection, specify two of them (Type-1 = common level, Type-2 = maximum level).

Type-1 (common level):

Relevance of Type-1:		
This is our most common approach	☐	
This is an experimental approach	☐	
Others (please specify)	☐	
This approach is currently implemented on	...	Bridges
(... = number of)	...	Dams
	...	Buildings
	...	other objects (please specify)
Monitoring/inspection interval:		
Continuous with data transfer in real time	☐	
Continuous with regular data downloads	☐	
Regular intervals	☐	Every ..../
Only if there is a problem/need	☐	
Never	☐	
Others (specify)	☐	

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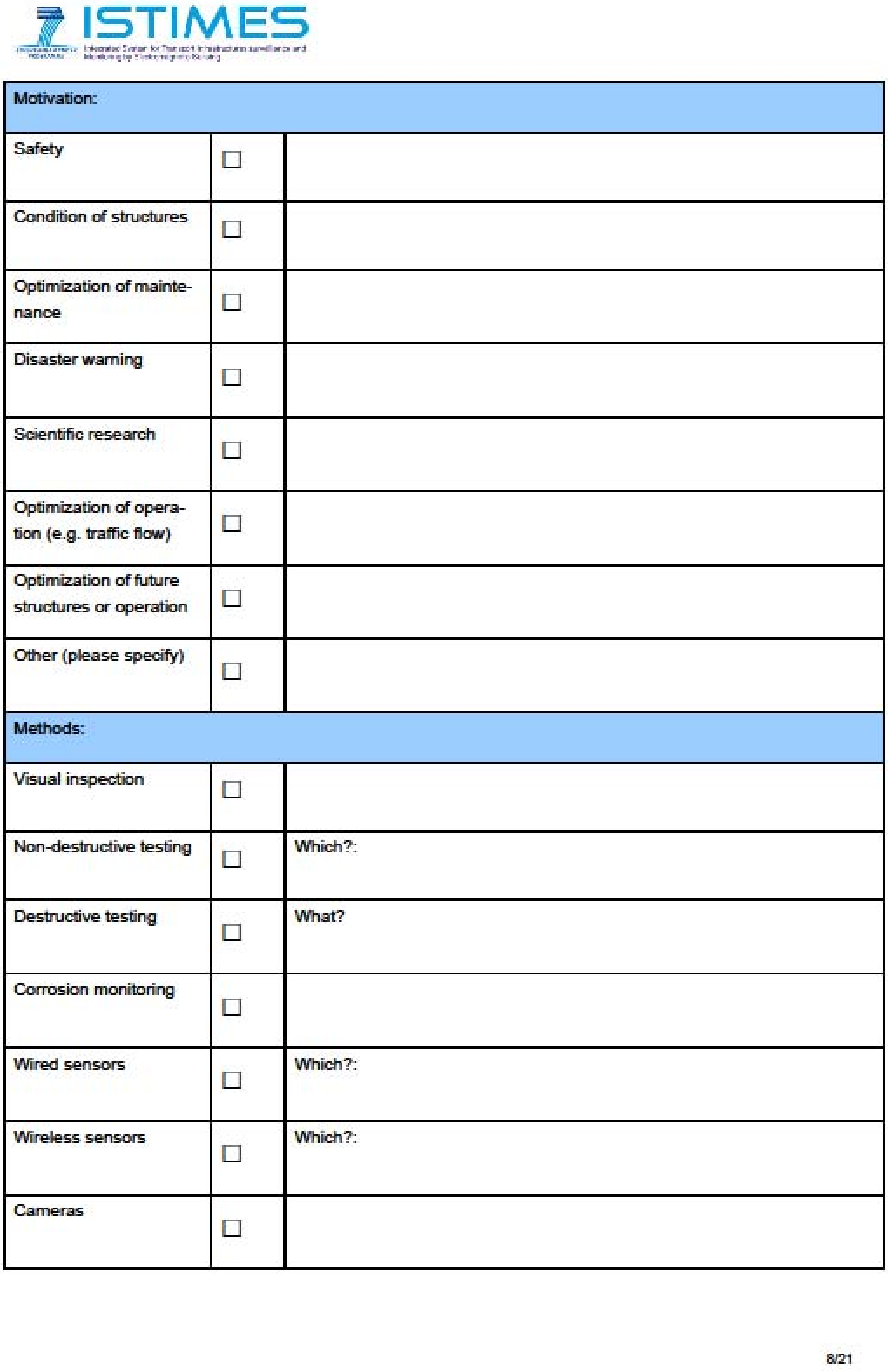
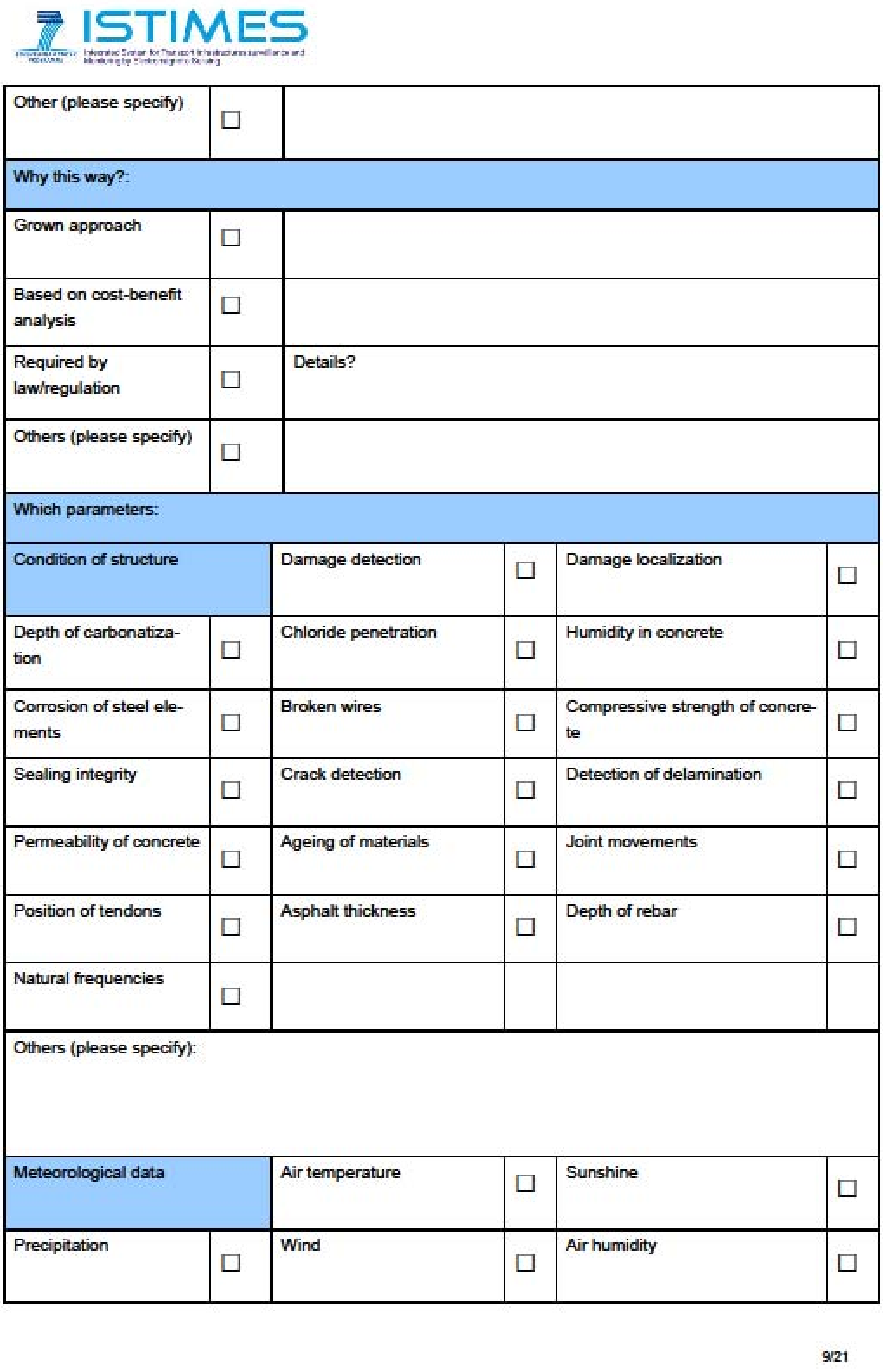


Motivation:		
Safety	☐	
Condition of structures	☐	
Optimization of maintenance	☐	
Disaster warning	☐	
Scientific research	☐	
Optimization of operation (e.g. traffic flow)	☐	
Optimization of future structures or operation	☐	
Other (please specify)	☐	
Methods:		
Visual inspection	☐	
Non-destructive testing	☐	Which?:
Destructive testing	☐	What?
Corrosion monitoring	☐	
Wired sensors	☐	Which?:
Wireless sensors	☐	Which?:
Cameras	☐	



Other (please specify)	☐				
Why this way?:					
Grown approach	☐				
Based on cost-benefit analysis	☐				
Required by law/regulation	☐	Details?			
Others (please specify)	☐				
Which parameters:					
Condition of structure		Damage detection	☐	Damage localization	☐
Depth of carbonatization	☐	Chloride penetration	☐	Humidity in concrete	☐
Corrosion of steel elements	☐	Broken wires	☐	Compressive strength of concrete	☐
Sealing integrity	☐	Crack detection	☐	Detection of delamination	☐
Permeability of concrete	☐	Ageing of materials	☐	Joint movements	☐
Position of tendons	☐	Asphalt thickness	☐	Depth of rebar	☐
Natural frequencies	☐				
Others (please specify):					
Meteorological data		Air temperature	☐	Sunshine	☐
Precipitation	☐	Wind	☐	Air humidity	☐

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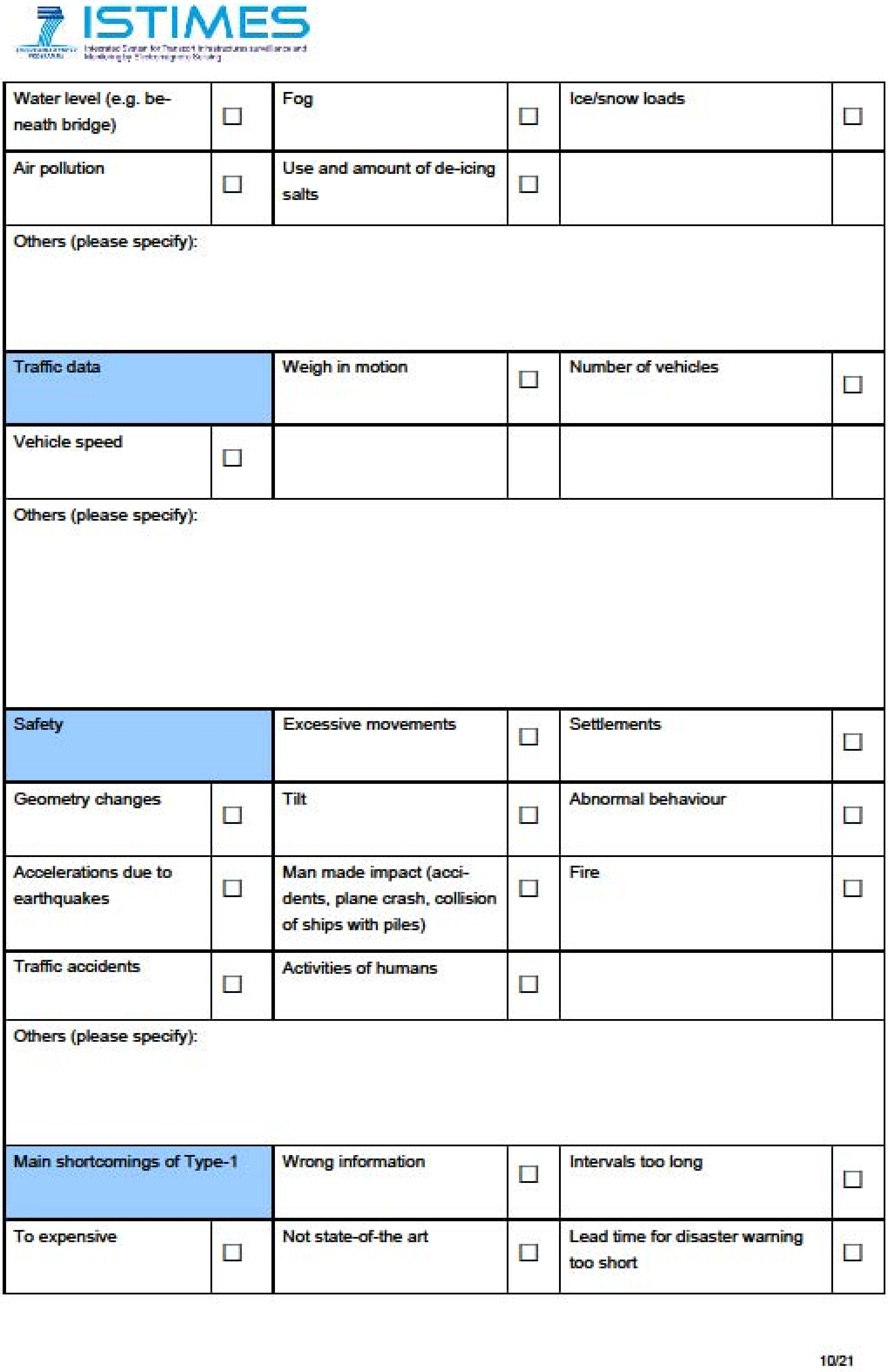

Water level (e.g. beneath bridge)	☐	Fog	☐	Ice/snow loads	☐
Air pollution	☐	Use and amount of de-icing salts	☐		
Others (please specify):					
Traffic data		Weigh in motion	☐	Number of vehicles	☐
Vehicle speed	☐				
Others (please specify):					
Safety		Excessive movements	☐	Settlements	☐
Geometry changes	☐	Tilt	☐	Abnormal behaviour	☐
Accelerations due to earthquakes	☐	Man made impact (accidents, plane crash, collision of ships with piles)	☐	Fire	☐
Traffic accidents	☐	Activities of humans	☐		
Others (please specify):					
Main shortcomings of Type-1		Wrong information	☐	Intervals too long	☐
To expensive	☐	Not state-of-the art	☐	Lead time for disaster warning too short	☐

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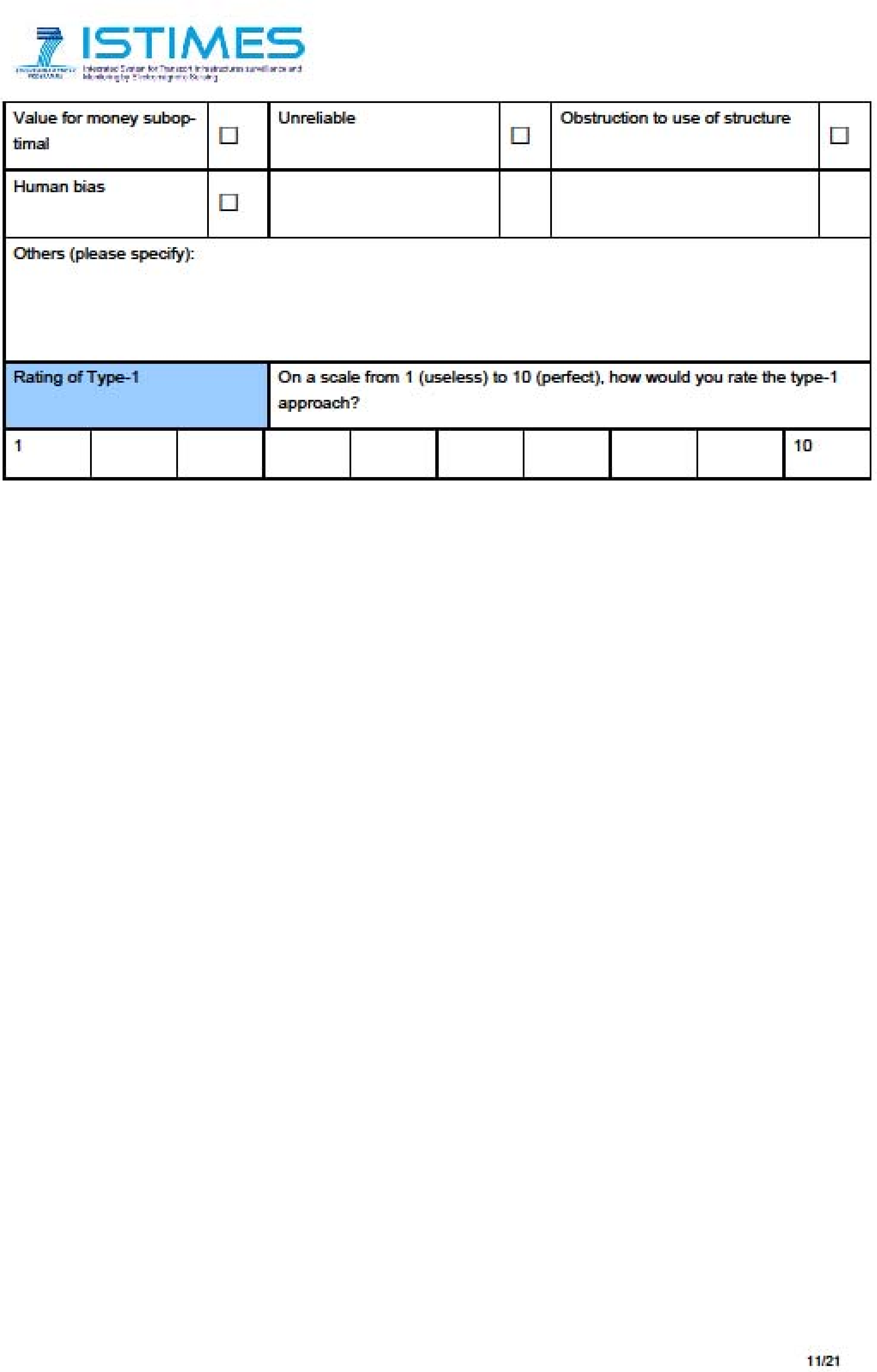

Value for money suboptimal	☐	Unreliable	☐	Obstruction to use of structure	☐
Human bias	☐				

Others (please specify):

Rating of Type-1	On a scale from 1 (useless) to 10 (perfect), how would you rate the type-1 approach?

1									10

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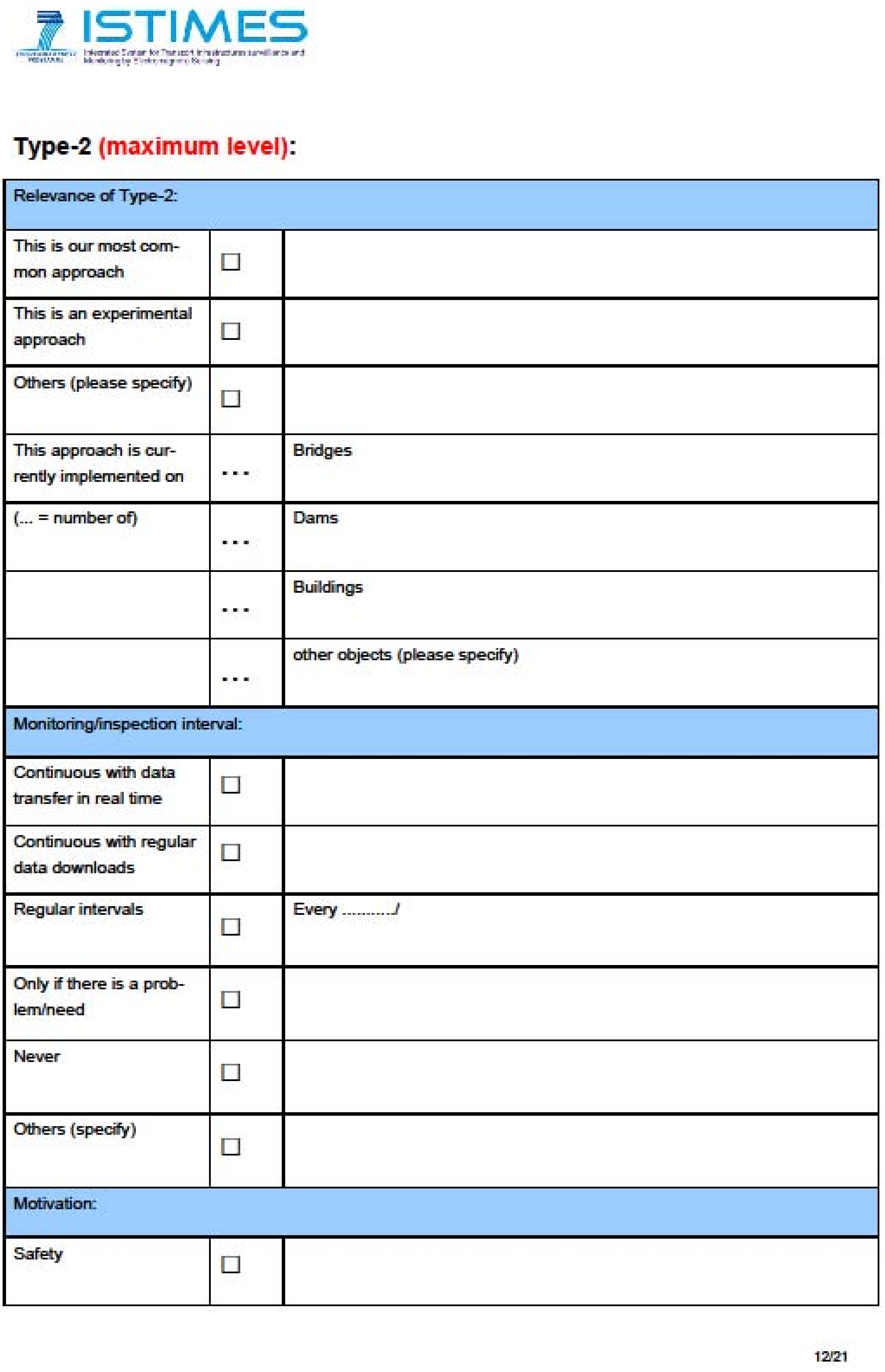
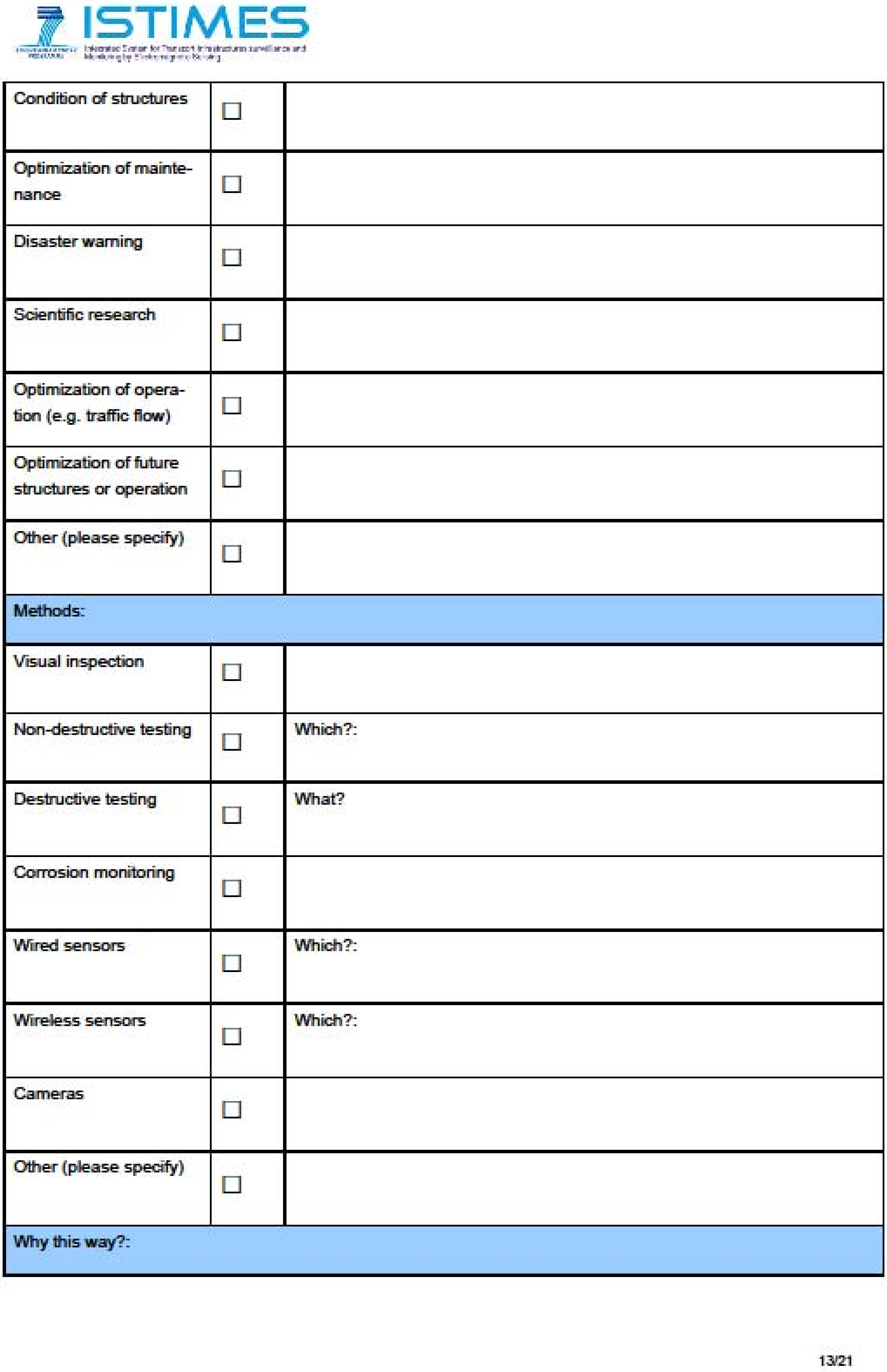


Type-2 (maximum level):

Relevance of Type-2:		
This is our most common approach	☐	
This is an experimental approach	☐	
Others (please specify)	☐	
This approach is currently implemented on	...	Bridges
(... = number of)	...	Dams
	...	Buildings
	...	other objects (please specify)
Monitoring/inspection interval:		
Continuous with data transfer in real time	☐	
Continuous with regular data downloads	☐	
Regular intervals	☐	Every ..../
Only if there is a problem/need	☐	
Never	☐	
Others (specify)	☐	
Motivation:		
Safety	☐	



Condition of structures	☐	
Optimization of maintenance	☐	
Disaster warning	☐	
Scientific research	☐	
Optimization of operation (e.g. traffic flow)	☐	
Optimization of future structures or operation	☐	
Other (please specify)	☐	
Methods:		
Visual inspection	☐	
Non-destructive testing	☐	Which?:
Destructive testing	☐	What?
Corrosion monitoring	☐	
Wired sensors	☐	Which?:
Wireless sensors	☐	Which?:
Cameras	☐	
Other (please specify)	☐	
Why this way?:		

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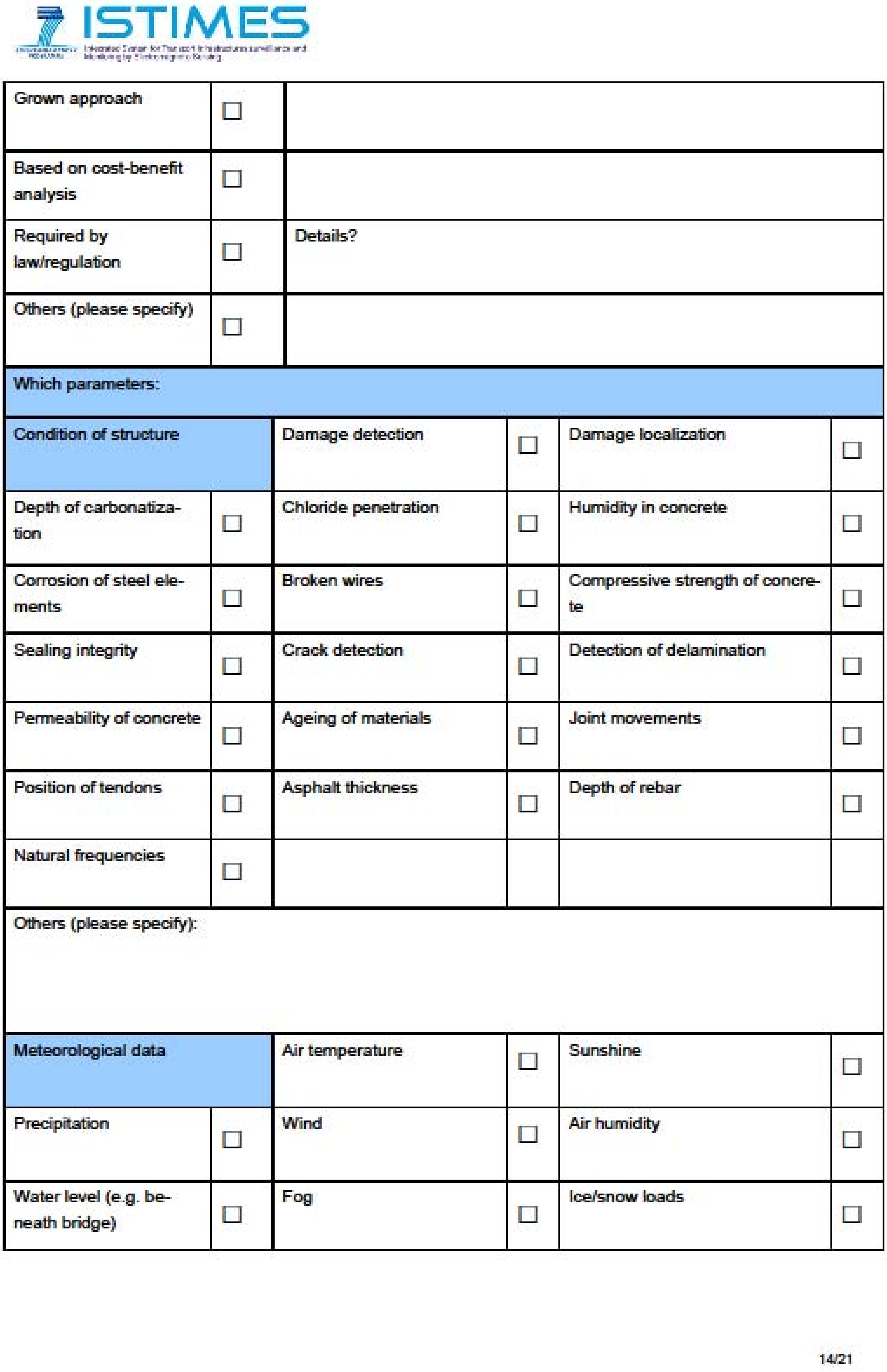

Grown approach	☐	
Based on cost-benefit analysis	☐	
Required by law/regulation	☐	Details?
Others (please specify)	☐	

Which parameters:					
Condition of structure		Damage detection	☐	Damage localization	☐
Depth of carbonatization	☐	Chloride penetration	☐	Humidity in concrete	☐
Corrosion of steel elements	☐	Broken wires	☐	Compressive strength of concrete	☐
Sealing integrity	☐	Crack detection	☐	Detection of delamination	☐
Permeability of concrete	☐	Ageing of materials	☐	Joint movements	☐
Position of tendons	☐	Asphalt thickness	☐	Depth of rebar	☐
Natural frequencies	☐				
Others (please specify):					
Meteorological data		Air temperature	☐	Sunshine	☐
Precipitation	☐	Wind	☐	Air humidity	☐
Water level (e.g. beneath bridge)	☐	Fog	☐	Ice/snow loads	☐

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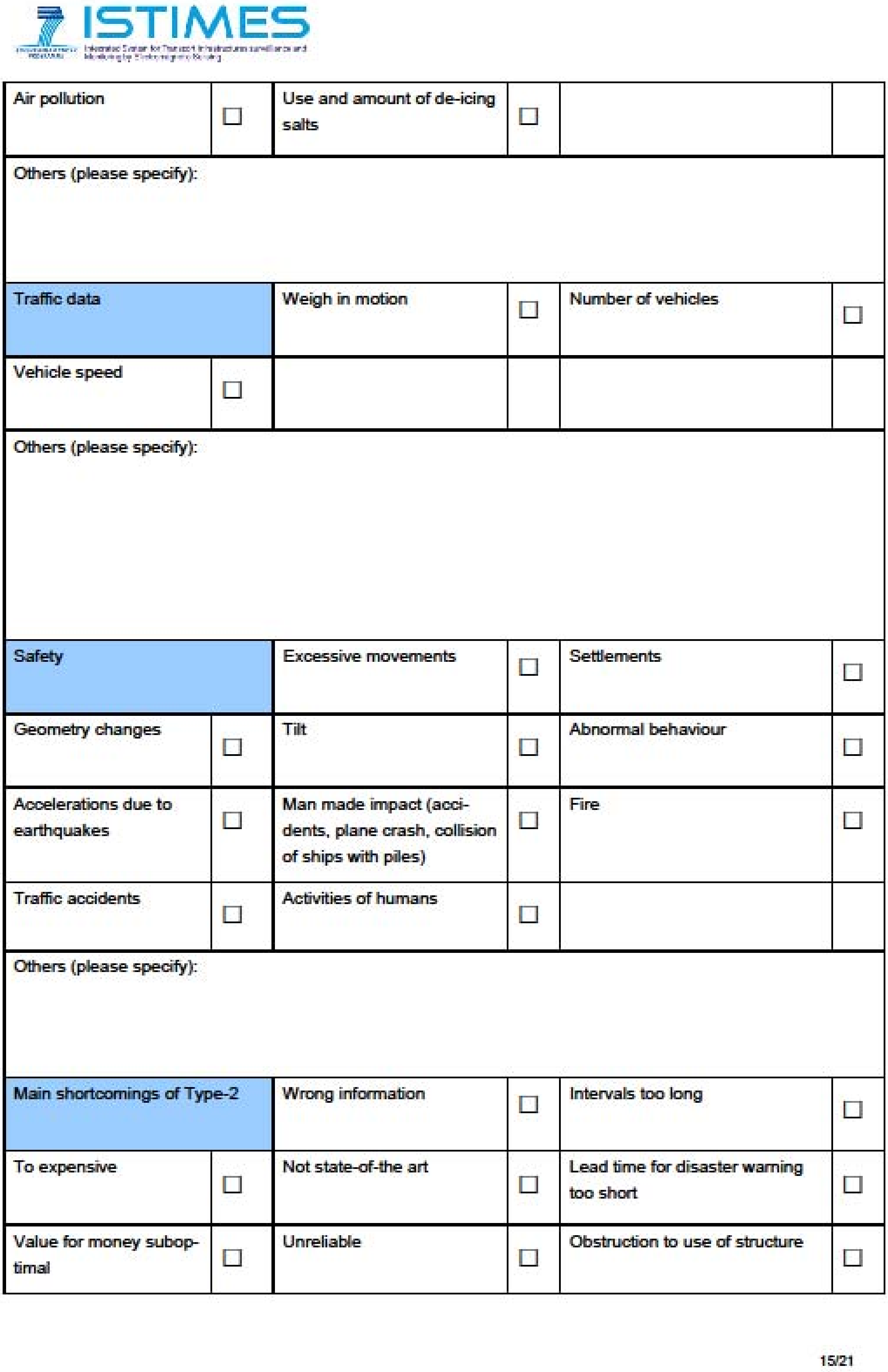

ISTIMES
Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing

Air pollution	☐	Use and amount of de-icing salts	☐		
Others (please specify):					
Traffic data		Weigh in motion	☐	Number of vehicles	☐
Vehicle speed	☐				
Others (please specify):					
Safety		Excessive movements	☐	Settlements	☐
Geometry changes	☐	Tilt	☐	Abnormal behaviour	☐
Accelerations due to earthquakes	☐	Man made impact (accidents, plane crash, collision of ships with piles)	☐	Fire	☐
Traffic accidents	☐	Activities of humans	☐		
Others (please specify):					
Main shortcomings of Type-2		Wrong information	☐	Intervals too long	☐
To expensive	☐	Not state-of-the art	☐	Lead time for disaster warning too short	☐
Value for money suboptimal	☐	Unreliable	☐	Obstruction to use of structure	☐

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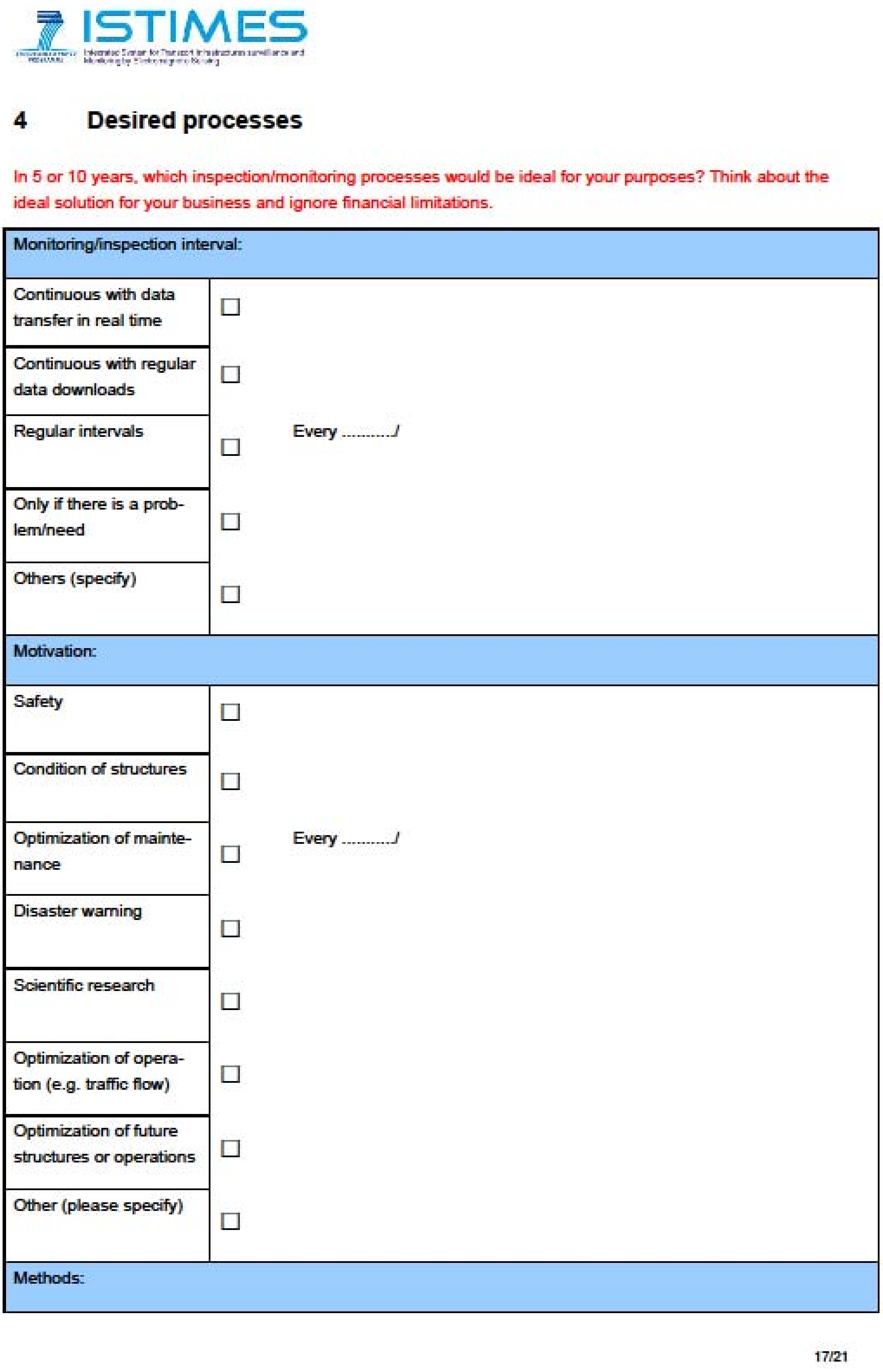
Human bias	☐								
Others (please specify):									
Rating of Type-2			On a scale from 1 (useless) to 10 (perfect), how would you rate the Type-2 approach?						
1									10



4 Desired processes

In 5 or 10 years, which inspection/monitoring processes would be ideal for your purposes? Think about the ideal solution for your business and ignore financial limitations.

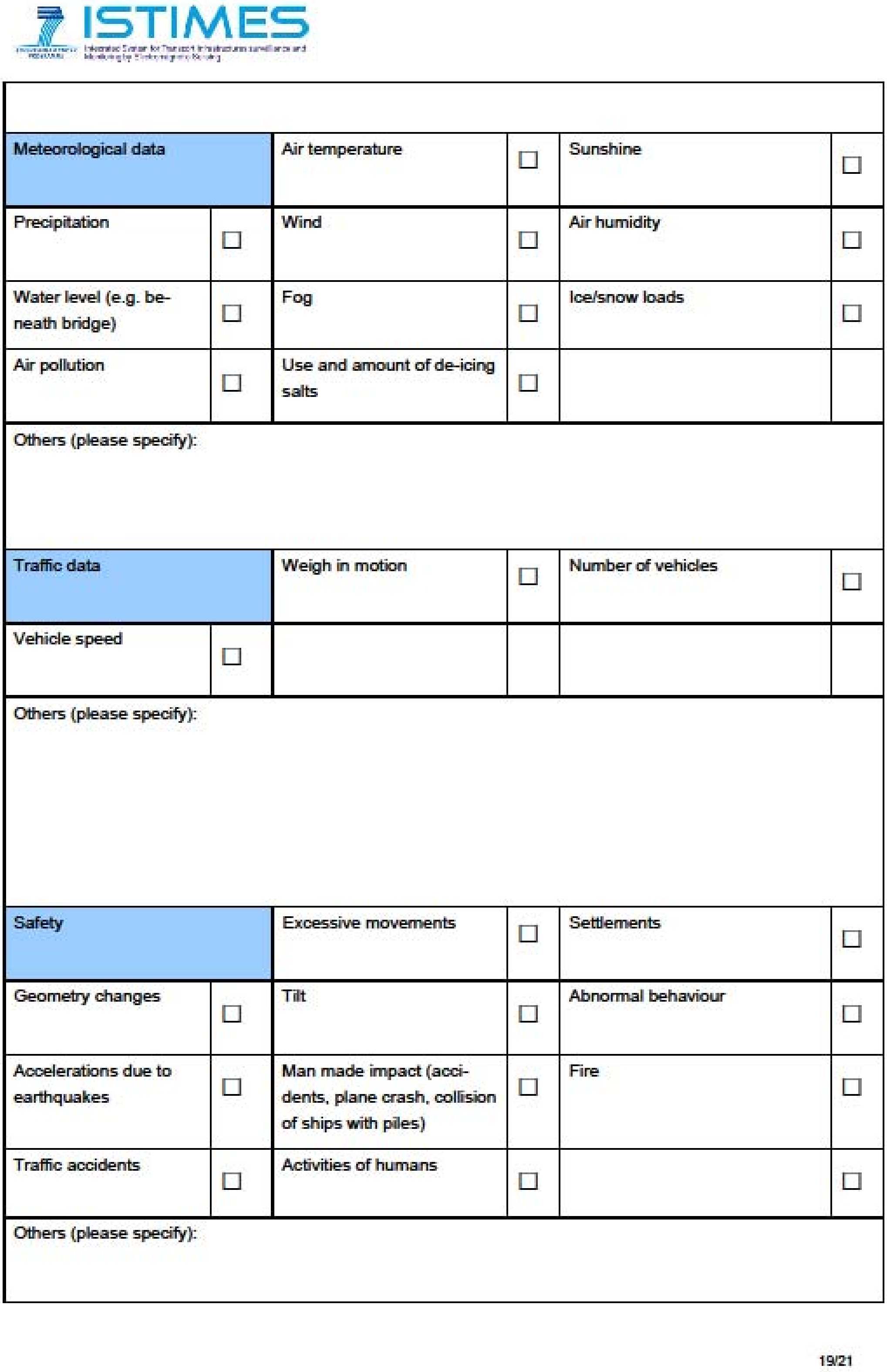
Monitoring/inspection interval:		
Continuous with data transfer in real time	☐	
Continuous with regular data downloads	☐	
Regular intervals	☐	Every ..../
Only if there is a problem/need	☐	
Others (specify)	☐	
Motivation:		
Safety	☐	
Condition of structures	☐	
Optimization of maintenance	☐	Every ..../
Disaster warning	☐	
Scientific research	☐	
Optimization of operation (e.g. traffic flow)	☐	
Optimization of future structures or operations	☐	
Other (please specify)	☐	
Methods:		

Visual inspection	☐	
Non-destructive testing	☐	Which?:
Destructive testing	☐	What?
Corrosion monitoring	☐	
Wired sensors	☐	Which?:
Wireless sensors	☐	Which?:
Cameras	☐	
Other (please specify)	☐	

Which parameters:

Condition of structure		Damage detection	☐	Damage localization	☐
Depth of carbonatization	☐	Chloride penetration	☐	Humidity in concrete	☐
Corrosion of steel elements	☐	Broken wires	☐	Compressive strength of concrete	☐
Sealing integrity	☐	Crack detection	☐	Detection of delamination	☐
Permeability of concrete	☐	Ageing of materials	☐	Joint movements	☐
Position of tendons	☐	Asphalt thickness	☐	Depth of rebar	☐
Natural frequencies	☐				

Others (please specify):



Meteorological data		Air temperature	☐	Sunshine	☐
Precipitation	☐	Wind	☐	Air humidity	☐
Water level (e.g. beneath bridge)	☐	Fog	☐	Ice/snow loads	☐
Air pollution	☐	Use and amount of de-icing salts	☐		
Others (please specify):					
Traffic data		Weigh in motion	☐	Number of vehicles	☐
Vehicle speed	☐				
Others (please specify):					
Safety		Excessive movements	☐	Settlements	☐
Geometry changes	☐	Tilt	☐	Abnormal behaviour	☐
Accelerations due to earthquakes	☐	Man made impact (accidents, plane crash, collision of ships with piles)	☐	Fire	☐
Traffic accidents	☐	Activities of humans	☐		☐
Others (please specify):					

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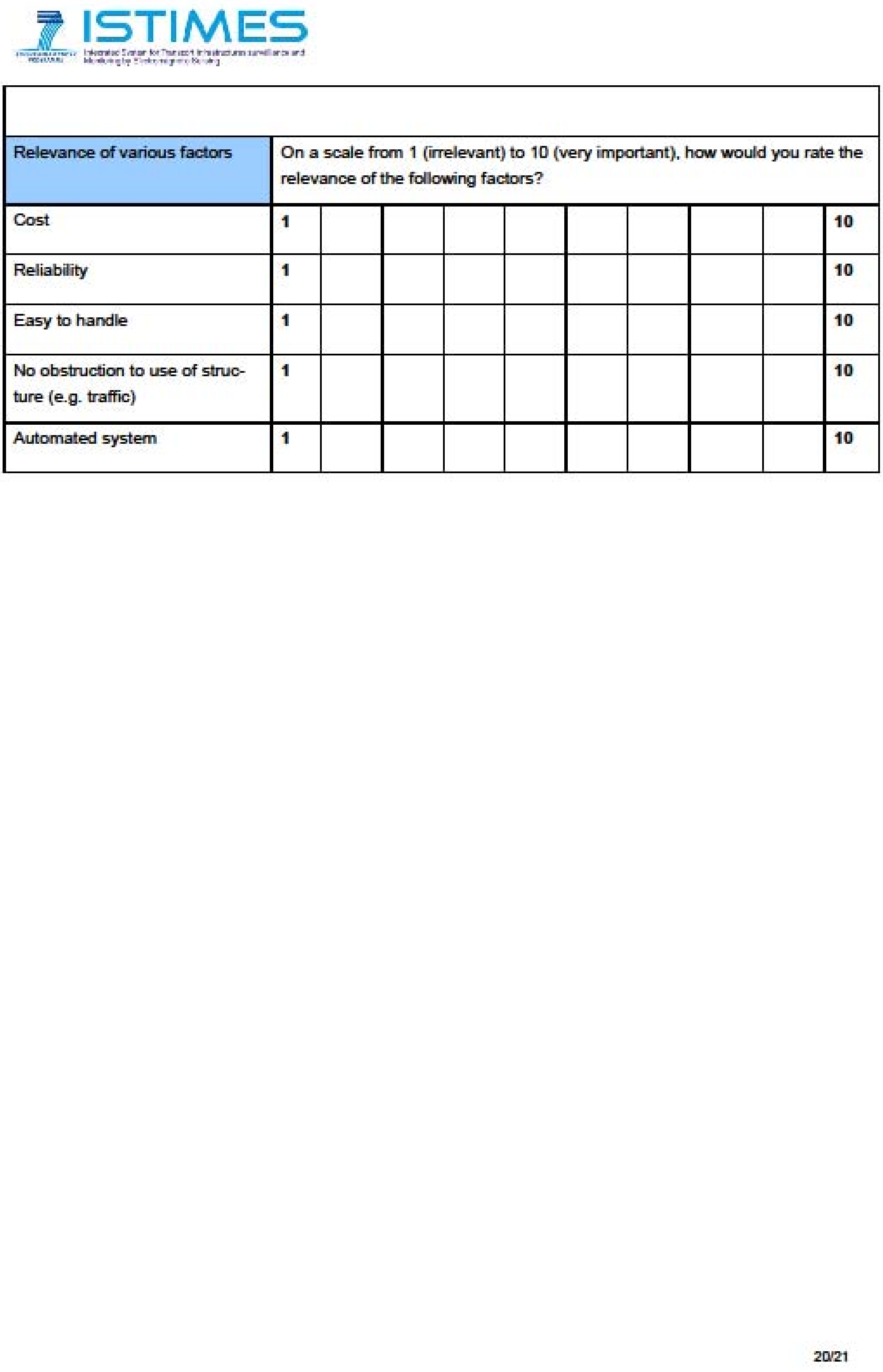

Relevance of various factors	On a scale from 1 (irrelevant) to 10 (very important), how would you rate the relevance of the following factors?									
Cost	**1**									**10**
Reliability	**1**									**10**
Easy to handle	**1**									**10**
No obstruction to use of structure (e.g. traffic)	**1**									**10**
Automated system	**1**									**10**

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5 Additional comments and information

Please add comments or information considered relevant.

9.4 ISTIMES – Short description

ISTIMES
Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing

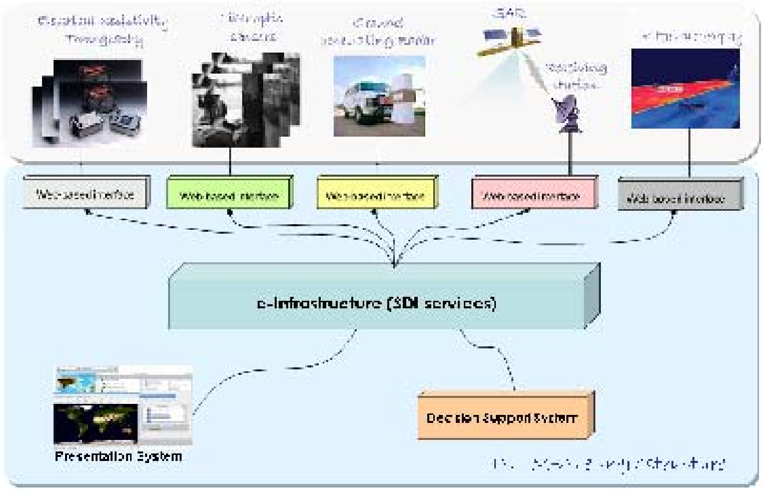
ISTIMES - Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing

Short description

ISTIMES is an international research project within the 7th European Framework Programme. ISTIMES aims at designing and implementing a monitoring and surveillance system for transport infrastructures such as bridges or tunnels. The system will be based on a wide range of mainly electromagnetic methods that will be integrated into an open system architecture to form an autonomous, automated and reliable sensor network. The project starts with an evaluation of end-user requirements, continues with the development and design of the system architecture followed by the improvement and optimization of existing sensor technologies. Finally, the system will be implemented on two existing structures, a motorway bridge and a railway tunnel.

Partners from Industry, research institutes and government bodies are cooperating in the ISTIMES-project:

- Technologies for Earth Observations and Natural Hazards, TERN, Italy
- Elsag Datamat, ED, Italy
- Dipartimento di Protezione Civile, DPC, Italy
- Eidgenoessische Materialpruefungs- und Forschungsanstalt, EMPA, Switzerland
- Laboratoire Central des Ponts et Chaussées, LCPC, France
- Lund University, ULUND, Sweden
- Tel Aviv University, TEL AVIV, Israel
- Territorial Data Elaboration SRL, TDE, Romania
- Norsk Elektro Optikk, NEO, Norway



9.5 Questionnaire – Directions for use

ISTIMES WP-1

Questionnaire – Directions for use

Basics

As decided during the kick-off meeting in Rome on July 14/15, every ISTIMES partner organisation will contact two potential end users in their country and fill out the questionnaire with them.

How to proceed

Contact two relevant organizations in your country.

Do not just send the questionnaire but visit the organization and fill out the questionnaire together with them. If necessary, translate the questions into your language.

Tick several boxes where appropriate.

If your own organization is a potential end user (this may apply for example to Dipartimento di Protezione Civile), then you can fill out one questionnaire yourself.

Add comments generously wherever it makes sense.

The section 3 "Current monitoring/inspection processes aims at the evaluation of current monitoring/inspection processes on two levels (Type-1 and Type-2). Of course this applies only if more than one level exists. Type-1 is the most common monitoring/inspection level that is used for most objects. Type-2 (if existing) is the most advanced approach that may be experimental or used on single objects only, for example for research purposes.

In section 4 "Desired processes" we are aiming at the ideal solution in the future (5-10 years) for the organization being interviewed. Financial limitations should be ignored but the answers should still be realistic. An answer such as "We want to monitor everything with minimum spatial resolution in real time" would not be very useful.

If you have any questions then please do not hesitate to contact me:

Johannes Hugenschmidt, ++41 44 823 43 18, johannes.hugenschmidt@empa.ch

hug113, 19.10.2009
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