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Best practices in design, construction and maintenance of transport infrastructures

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Revision History

Date	Version	Author/Contributor[1]	Revision By[2]	Comments
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06.05.2016	V1	DRAGADOS, M. Segarra, P. Delgado / REFINET Partners/ ENCORD members / ECTP members / NTPs members		Final version of the document. Submitted deliverable.
03.07.2017	V2	DRAGADOS	Miguel SEGARRA	Final version submited to EC/INEA with changes linked to publication on CORDIS (EU emblem, disclaimer).

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ABBREVIATIONS

Acronym	Full name
ACARE	Advisory Council for Aviation Research
ALICE	Alliance for logistics Innovation through collaboration in Europe
CSA	Coordination and Support Action
ECTP	European Construction Technology Platform
ENCORD	European Construction Tecnology Network
ERRAC	European Rail Research Advisory Council
ERTRAC	European Road Transport Research Advisory Council
MEAT	Most Economically Advantageous Tender
SIP	Strategic Implementation Plan

DEFINITIONS

Term	Full name
Taxonomy	Taxonomy is the science or the technique used to make a classification. It is also used to refer to a classification and especially a classification in a hierarchical system.

EXECUTIVE SUMMARY

The objective of this deliverable is twofold:

- On the one hand to provide a framework that allows to define a taxonomy of best practices in design, construction and maintenance of transport infrastructures that have already been applied in practice.
- On the other hand, to select and compile a collection of best practices to learn from these experiences.

It must be understood that the compilation of best practices included in this deliverable cannot be comprehensive given the wide scope of transport infrastructure systems that exist in the real world. Instead, a framework for the taxonomy of best practices in transport infrastructure and relevant numerous examples of the different areas covered by the best practices classification is provided. This deliverable is the commencement of a task of best practice compilation and is to be continued by the Infrastructure and Mobility Committee of ECTP and the ENCORD Working Group on Infrastructure in the next years. The taxonomy scheme is needed as it is the intention of the Infrastructure and Mobility Committee of ECTP and of the Working Group in Infrastructure of ENCORD to continue after REFINET the work started in this deliverable and thus the taxonomy provides a future means for best practice classification. Notice also that the taxonomic scheme defined in this deliverable D3.2 is also used in D3.3 Catalogue of technologies for multi-modal transport infrastructure. The main difference between the content of both deliverables is that D3.2 applies to best practices which are, mostly, widely used today whereas D3.3 reviews practices which are available but not widely used yet bear a potential to increase performance and sustainability.

These relevant examples have been compiled from different sources; by the REFINET partners themselves, by members of the different networks of organizations represented by the partners and by other organizations external to the project partners or their networks. In practice, the source organizations for the best practices introduced in this deliverable cover several of the most important infrastructure designers, constructors and operators in the World as well as renowned academia and research centers in the field of expertise.

1 INTRODUCTION

This document provides a non-exhaustive compilation of best practices in design, construction and maintenance of transport infrastructures. The document is necessarily non-exhaustive given the ample field of expertise and technology that is intended to be covered. However, the distiguishing characteristic of these practices is that they have been widely used in practical experience in most cases. This means the practices provide a bottom line for the preparation of roadmapping activities as they faithfully represent a set of techniques used by the industry in today's infrastructure. At the same time, the practices provide a baseline for improvement of the techniques, as the constraints for their application are also reacorded in this document. In addition, the document provides a practical taxonomy for the classification of the best practices. The taxonomy reflects real-world objects and processes and can therefore be easily applied and extended to the collection of additional practices. The contents of the different sections of this deliverables are the following:

- *Chapter 1: Introduction.* This chapter.
- *Chapter 2: How the practices have been compiled* explains the process followed for producing the set of best practices included in this document. It also sets the Geographical scope sets the scope of the different organisations contributing to the collection of best practices as well as that of the direct contributors.
- *Chapter 3: Taxonomy* defines the classification system defined in this document for the collection of best practices.
- *Chapter 4: Summary of best practices* introduces the list of best practices provided by the different contributors as well as some statistics in relation to their spread across the lifecycle stages and spread across the different types of infrastructure. The details of the individual practices are presented in the next chapters.
- *Chapter 5: Best practices for design* brings together and in detail the forms of practices related to design of infrastructure systems, components or elements.
- *Chapter 6: Best practices for construction* brings together and in detail the forms of practices related to design of infrastructure systems, components or elements.
- *Chapter 7: Best practices for maintenance* brings together and in detail the forms of practices related to design of infrastructure systems, components or elements.
- *Chapter 8: Next steps* provides help and tips on how to use the information of this document for the following roadmapping steps of the REFINET CSA.
- *Chapter 9: Conclusions* summarizes the main findings of this task.

It must be noticed that some practices apply to several lifecycle stages. The practices are only presented once in this document in the lifecycle chapter where they appear first. For completeness, a reference to the first appearance of the practice is provided when a best practice belongs to more than one lifecyle stages.

2 HOW THE PRACTICES HAVE BEEN COMPILED

There have been three main sources of information for the best practices of this document: ENCORD, ECTP, and the network of NTPs. For all them, the main criterium has been that the practice has to be of actual use in the development of transport infrastructure. Therefore, techniques under research or those that do not have wide acceptance in the industry are not considered in this document.
The main sources of information for the collection of this document are presented in the following sections.

2.1 ENCORD

ENCORD is the European Network of Construction Companies for Research and Development. Founded in 1989. In 2014, ENCORD celebrated the 25th anniversary. It was founded by a small group of construction companies and today there are twenty two leading global European contractors and suppliers of the construction industry. Just as a remark, ENCORD was the *seed* of ECTP when the ETPs were launched.

ENCORD members operate worldwide. The member companies are found regularly in the Top 50 European and Global Contractor lists and all together employ over 1.15 Million people and have combined annual revenue of over 205 Billion Euro. Because of the relevance to this document of the participation of the construction industry in the collection of best practices, a few introductory lines of the members of ENCORD is presented in the next table (in alphabetical order, source: ENCORD).

ENCORD Member	Description
acciona	**ACCIONA Infraestructuras, S.A.** is the leading company of the Infrastructure Division of ACCIONA. The strong growth of its parent companies has made ACCIONA Infraestructuras into one of the leaders in the Spanish construction sector, with noteworthy international operations that currently involve over thirty countries.
AUTODESK	**Autodesk, Inc.**, is a leader in 3D design, engineering and entertainment software. Since its introduction of AutoCAD software in 1982, Autodesk continues to develop the broadest portfolio of 3D software for global construction markets.
Balfour Beatty	**Balfour Beatty** is a world-class infrastructure services business operating across the infrastructure lifecycle, with leading positions in major markets. In over 80 countries, in diverse markets and economies, providing the assets societies need to function, develop and thrive.
bam	The **Royal BAM Group** is a 125 year old group of companies, active in design, engineering and construction. Activities range from housing, and general contracting to specialised work such as marine construction, and large infrastructural works.
	Bouygues BOUYGUES TRAVAUX PUBLICS, is a world specialist for large civil works project like Tunnels, Bridges, Highways, Harbour, Power Plant, Water and Sewage Treatment plant, etc. The Group demonstrates their capacity to manage large projects during all phases in France and International.
CCC	**Consolidated Contractors Company (CCC)** is a multinational construction company operating in the Middle East, Africa, Europe, the Carribean, Central America, C.I.S and South East Asia, with its main office in Athens, Greece. In more than five decades of operation, CCC has grown to become one of the leading contractors in the international construction field, with over 70,000 employees composed of more than 60 nationalities. CCC provides Engineering, Project Management, Procurement and Construction services for Buildings, Civil and Municipal Works, Pipelines (Oil, Gas and Water), Petrochemical Plants and Refineries, Industrial Plants, Marine Works
doka	**Doka** is a world leader in developing, manufacturing and distributing formwork technology for use in all fields of the construction sector. With more than 160 sales and logistics facilities in over 70 countries, the Doka Group has a highly efficient distribution network which ensures that equipment and technical support are provided swiftly and professionally. An enterprise forming part of the Umdasch Group, the Doka Group employs a worldwide workforce of more than 6000.
DRAGADOS	**DRAGADOS** is a general and specialized contractor with global activities in civil works structures, tunnels, engineering, hydraulics, transport infrastructure, building construction, restoration, real estate activities, off-shore, energy, water cycling, community services, environmental control, integral maintenance, social equipment and services (integral services).
FCC CONSTRUCCION	**FCC – Fomento de Construcciones y Contratas, S.A.** – is the controlling company of the leading Spanish construction firm. It works as general contractor in the whole range of construction works and services, such as

	highways, hydraulic and marine works, air and rail transport, housing, non-residential building, refurbishment and maintenance, concessions, infrastructure maintenance, oil and gas pipelines, etc., either in Spain or abroad.
ferrovial agroman	**Ferrovial Agromán** is, with more than 80 years of experience, one of the world's leading construction companies with international presence in more than 50 countries and projects on five continents. Apart from its expansion and consolidation in other European and Latin American countries, Ferrovial Agromán has focussed part of its future growth in the United Kingdom, Poland, Eastern European countries and United States through its subsidiaries.
HILTI	With some 22,000 employees, in more than 120 countries around the world, **HILTI** provides leading-edge technology to the global construction industry. Hilti products, systems and services offer the construction professional innovative solutions with outstanding added value. Hilti excels through outstanding innovation, top quality, direct customer relations and effective marketing. The company upholds a clear value orientation. Integrating the interests of all the company's partners – customers, suppliers and employees – into its strategy and actively honoring its social and ecological responsibility creates the foundation of trust that makes possible the long-term success of the company.
HOCHTIEF	**HOCHTIEF** is one of Europe's leading players in the construction industry. As one of Europe's leading civil engineering companies, HOCHTIEF is expanding continuously into the broader fields of construction related services. The related range of services comprises design, finance, build and operate for every type of project. As a result, HOCHTIEF is taking its own unique stand as system leader for complex construction-related projects on a national and international scale.
Implenia	**Implenia**, Switzerland's leading construction and construction services company, also has a strong position in the German, Austrian and Scandinavian infrastructure markets. Established in 2006, Implenia can look back on around 150 years of construction tradition. It brings the expertise of its highly skilled sectorial and regional units together under the roof of a company active throughout Europe. With its integrated business model and specialists operating in all areas of construction, the Group can manage a building project through its entire lifecycle and deliver work that is economical, integrated and customer-centric. The focus is on striking a sustainable balance between financial success and social and environmental responsibility. Implenia has its headquarters in Dietlikon near Zurich and employs approximately 8100 people around Europe. The company is listed on the SIX Swiss Exchange (IMPN, CH0023868554).
NCC	**NCC** is one of the leading construction and property-developing companies in the Nordic region. NCC develops residential and commercial property projects and builds offices, industrial facilities, housing, roads, civil engineering structures and telecommunications infrastructure.
OHL	The **OHL Group** is one of the biggest construction, concessions and services groups in Spain with a track record of over 95 years and a noteworthy presence in 21 countries on four different continents. Main business lines are construction (domestic, abroad, industrial), infrastructure concessions, environmental services, urban and infrastructure services and developments. Associated activities are engineering and design, maintenance and operation.
SKANSKA	**Skanska** is a leading international project development and construction company, developing offices, homes and infrastructure projects, such as schools and roads. It creates sustainable solutions and aim to be a leader in quality, green construction, work safety and business ethics. Skanska is employing 53,000 employees in selected home markets in Europe (Sweden, Norway, Finland, Poland, Czech Republic, Slovakia, Hungary, UK), the US and Latin America.
TEIXEIRA DUARTE	Having started its activity in 1921, **Teixeira Duarte** is now leading one of the largest Portuguese Economic Groups. Based on its structuring values: Ability, Efficiency, Pledge, Truth, Commitment, Reliability and Respect, Teixeira Duarte continue performing its mission: Execute, contributing towards the construction of a better world.
uponor	**Uponor** is a leading international supplier of plumbing and heating systems for the residential and commercial

	building markets. In Europe, Uponor is also a prominent regional supplier of municipal infrastructure pipe systems. The Group's key applications are sold in over one hundred countries.
	Veidekke is the largest Norwegian construction company and the fourth largest in Scandinavia. Veidekke's business involves a network of Scandinavian construction operations, rehabilitation work, major heavy construction contracts and development of dwellings for the company's own account as well as buildings for public use. Other business segments are asphalt operations, production of crushed stone and gravel (aggregates) and maintenance of public roads.
	VINCI is the world's leading company for concessions, construction and related services. VINCI designs, finances, builds and manages infrastructures and facilities for public sector and private organisations. The group has a presence in over 100 countries, through 3000 companies. It operates in four different lines of business: Concessions, Energy and Information, Roads and Construction. In each one it holds a leading position in Europe and around the world. VINCI Construction UK is an international developer with three inter-related businesses in Housing, Property and Construction. Its principal areas of activity are in the UK, USA, Canada, Spain, and Africa.
	YIT Corporation was founded 1912 and is at the moment the largest construction and mechanical contracting company in Finland. YIT`s services cover building construction, civil engineering, mechanical contracting, industrial piping, water and environmental services and maintenance services for industry, properties and infrastructure. YIT has operated internationally since 1956 in over 60 countries.
	Ed. Züblin AG ranks amongst the top German construction companies. Founded in 1898 and based in Stuttgart, Züblin operates worldwide with more than 70 branch offices and subsidiaries. Züblin covers all fields of construction services with particular expertise in tunnel design and construction, ground engineering and demanding turnkey projects.

The members of ENCORD have their main headquarters in the countries filled in light blue colour in the map below (Figure 1) and offices worldwide (Portugal, Spain, France, United Kingdom, The Netherlands, Switzerland, Liechtenstein, Germany, Austria, Greece, Finland, Norway, Sweden):

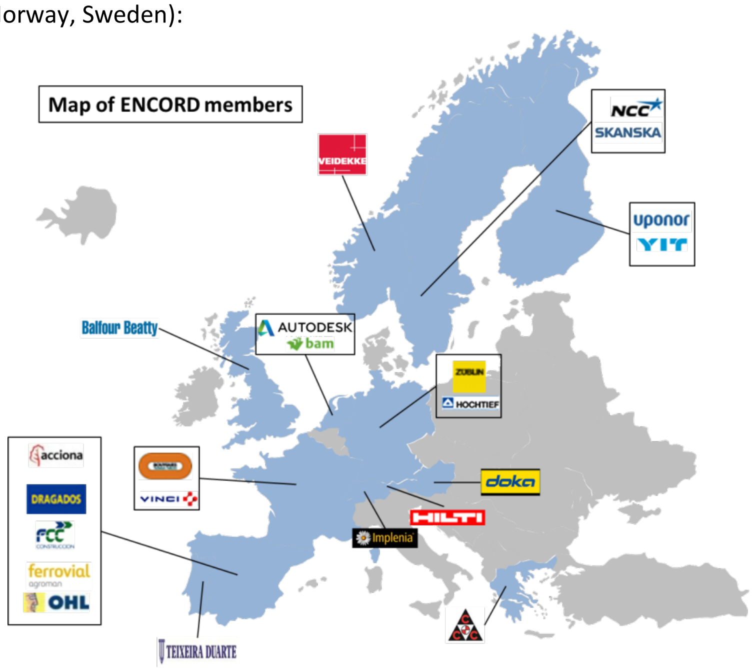
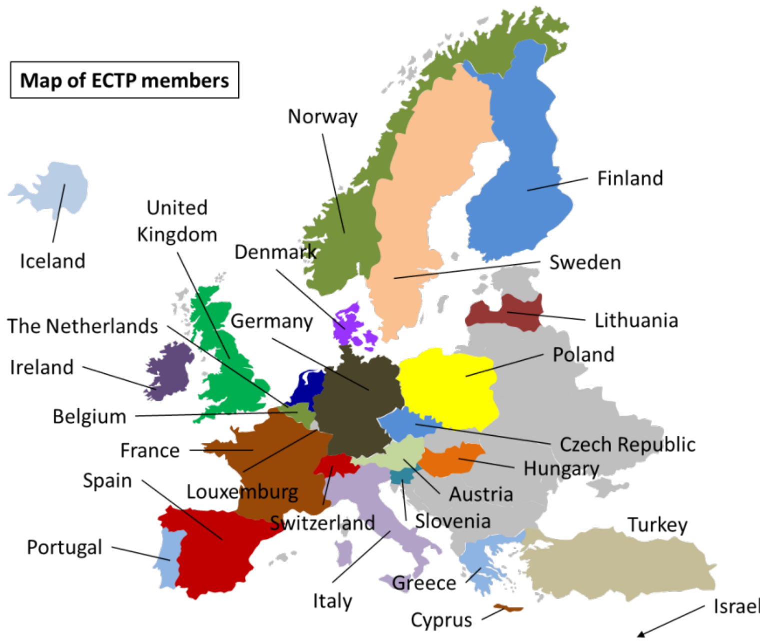


Figure 1: Map of ENCORD members headquarters

2.2 ECTP

The European Construction Technology Platform by means of its infrastructure and mobility committee has been another one of the main contributors to the collection of best practices.



2.3 Network of NTPs

Under the coordination of the Spanish Construction Technology Platform (PTEC) a network of construction NTPs is linked to the activities of the ECTP. This network of NTPs has also been addressed to provide input for best practices. The map below shows the countries participating in the network.

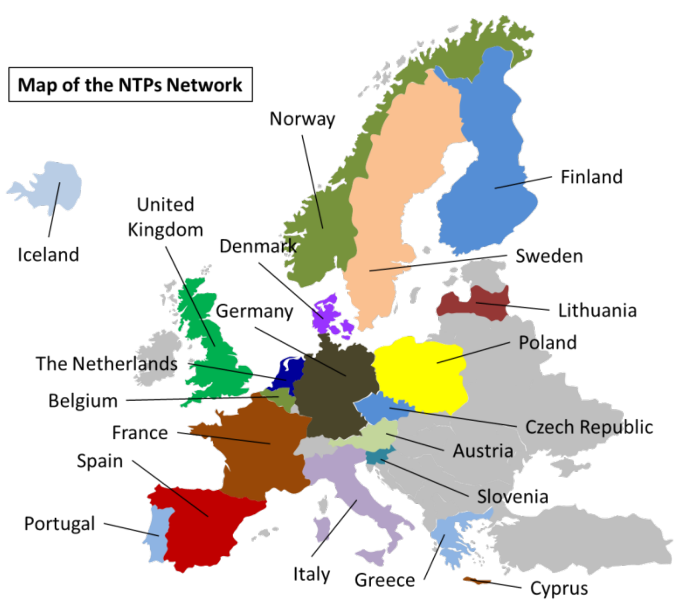


Figure 2: Map of the NTPs network

2.4 Direct Origin of the Contributions

The following map (Figure 3) shows the country where the member from anyone of the previous organizations sent the best practice form.

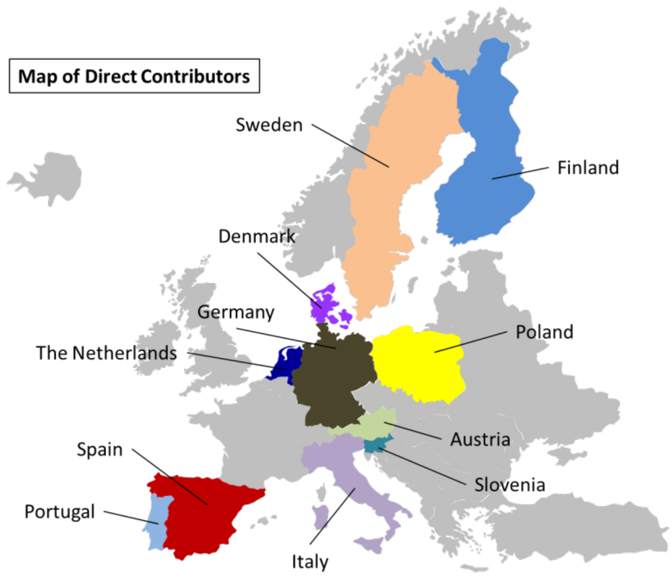


Figure 3: Map of countries of origin of contributions

2.5 Way of Work and Workshops

For the collection of the best practices, a template was prepared containing the fields needed as input to record each best practice. The template is shown in Chaper 3 Taxonomy (Classification) of Best Practices.

The members of the different organisations, ENCORD, ECTP and the network of ECTPs were addressed by means of an email providing instructions to complete the template and explaining the type of data that was required as input.

In addition, the following workshops have been held in relation to the work ongoing in Work Package 3:

- **1st REFINET Workshop - Technological demands of transport infrastructures**. Instituto Eduardo Torroja, Madrid, Spain, 2nd December 2015.
- **2nd REFINET Workshop - Strategic Implementation Plan (Technological demands of transport infrastructures)**, ARUP Offices, London, United Kingdom, 16th March 2016.
- **ENCORD WG on Infrastructure Meeting – REFINET Workshop**, AICCOPN (Associação dos Industriais da Construção Civil e Obras Públicas),Porto, Portugal, 29th February 2016.

For the first two workshops several experts from the REFINET network of experts were invited to the meetings. In the case of the third REFINET workshop, the meeting was kept private to the ENCORD Working Group on Infrastructure members. As it has already been explained, whereas the other organizations memberships include a variety of actors from the industry, research centers, academia, universities, etc., ENCORD is just the industry and its input is considered to be valuable as it represents current practice in transport infrastructure.

Figure 4 below shows a picture of the ENCORD WG on Infrastructure held in Porto (Portugal) on the 29th of February.

Figure 4: ENCORD WG on Infrastructure meeting. Topic: REFINET Workshop

3 TAXONOMY (CLASSIFICATION) OF BEST PRACTICES

The REFINET taxonomy for the collection of best practices (D3.2) and for the catalogue of technologies for multi-modal transport infrastructure (D3.3) is defined in this section. The taxonomy follows mainly a hierarchical taxonomic scheme as it has been found out that the hierarchical approach provides a good decomposition of how transport infrastructure systems are organised (see Figure 5). Neverhetless, other forms of relationship are not precluded by the taxonomic scheme.

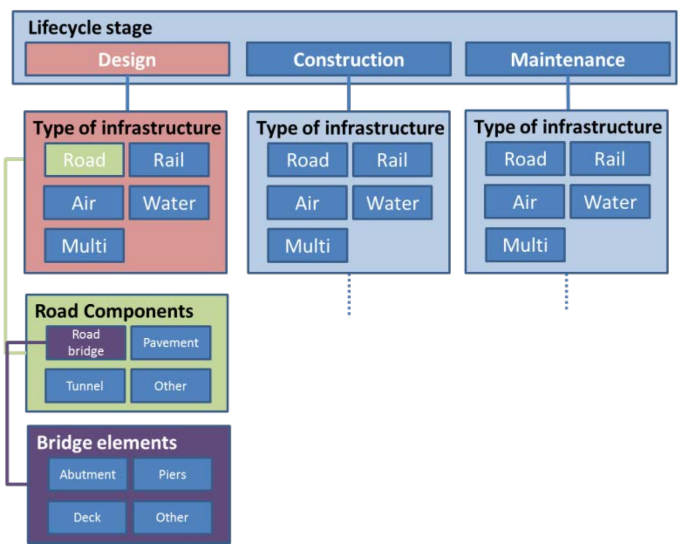


Figure 5: Hierarchical taxonomic scheme for the REFINET taxonomy

This document needs to follow a pragmatic approach, in which practisioners (with a main focus in the industry that designs-builds-maintains the infrastructure) can easily search for information and advice on specific practices. This is the other reason why the classification is organised hierarchically in this way, because industry experts are familiar with the proposed structure.

Other forms of classification of the transport infrastructure are possible and equally valid. For instance, it could have been decided to use a classification based on Processes (design, construction and maintenance processes) and Operations (governance or others). However, the fact that the proposed taxonomy directly links the best practices to the physical tangible assets of the infrastructure gives added value in the view of the authors as it provides a framework that can be easily understood by a majority of readers.

Notice that as explained in the executive summary, the compilation of best practices included in this deliverable cannot be comprehensive given the wide scope of transport infrastructure systems covered in the REFINET project and also because of the hierarchical structure of the taxonomic scheme proposed. However, for the purpose of the future work after REFINET, the template fits the need of the Infrastructure and Mobility Committee of the ECTP and that of the Working Group in Infrastructure of ENCORD. To put an example of how easily the number of best practices can grow in the hierarchical structure above the following numbers are given.

A. Suppose it is decided to record the best practices for the 3 elements of the presented Lifecycle stages (Design, Construction, Maintenance) and not taking De-commissioning into account.
B. Suppose that the best practices for everyone of the 5 types of infrastructure are accounted for (Road, Rail, Water, Air, Multi).
C. Suppose that only 4 components of every type of infrastructure are identified for which best practices are classified and,
D. Suppose that for each one of the components 6 best practices are identified which correspond to elements of every component of the infrastructure.
E. Therefore, the number of best practices identified would be A*B*C*D = 3*5*4*6 = 360 best practices.

Notice that the number above refers to 6 practices identified at level E (the element level) but in our hierarchy there will be also best practices identified at the lifecycle (level A), infrastructure type (level B) and component (level D), meaning that the calculation above is only considering best practices identified at the most refined level of the hierarchy which could not be the case for REFINET.

In relation to the template for the collection of the best practices, there has been a discussion with the other two CSAs running in parallel to REFINET, FOX and USE-IT, on the fields and format of the template for the collection of best practices and catalogue of technologies. The template proposed by REFINET in the paragraphs below has also been discussed at Project Meeting #3 in Madrid on December 3rd 2015 and it was agreed that it will be used for REFINET. It does not however exclude cooperation, collaboration or comparison with the information on best practices generated by the other CSAs as in our view the REFINET template includes the information of the USE-IT and FOX template. The REFINET template contains the following fields of data (see Table 1).

Best Practice / Catalogue of Technologies template	
Field	**Description**
Title and Keywords.	Title of the best practice or technology and main keywords
Source of best practice	Organization providing the best practice or technology or other reference to the source (e.g. conference, etc.).
Lifecycle stage	Design, Construction or Maintenance.

Type of infrastructure	Road, Rail, Air, Water, Multi-modal.
Component of infrastructure	Bridge, tunnel, pavement, etc.
Element of the infrastructure	Specific element belonging to a component. For instance, in a bridge it could be a pier, segment of a deck, abutment, foundation, etc.
Short Description	scenario for application, technology and how is applied, geographical coverage
Success factors	For example, what are the conditions for successful replication.
Constraints	Which are the factors that restrain the application of the best practice (e.g. environmental or weather conditions).
Main impacts	For instance economic or environmental benefits, advantages to users, increased safety, reduction of disturbance, etc.
Maturity and degree of implementation	For example technically feasible, replicable, adaptable.
Key Performance Indicators (optional)	Indicators according to the definition of the RMMTI model that help to assess the efficiency of the described practice.
Further information	Links, references and / or contact details for further information.

Table 1: Template and field description for the REFINET best practices and catalogue and of technologies collection

4 SUMMARY OF BEST PRACTICES

The list of best practives can be seen in Table 2.

#	Title	Description	Design	Construction	Maintenance	Type	Road	Rail	Air	Water	Multimodal	Component	Element	High	Medium	Low
1	Foamed Bitumen stabilization	Construction / Maintenance		X	X	Road	X					Pavement	Stabilised layer	X		
2	Improved self-propelled machine for roadway surface constructi	Construction		X		Road	X					Pavement	Road surface	X		
3	Innovative geosynthetics for aspahlt layers reinforcement	Construction and Maintenance		X	X	Road / Airpor	X		X		X	Pavement	Asphalt Layers		X	
4	Nonintrusive monitoring of pavements	Maintenance			X	Road	X					Pavement				X
5	Pavement Management Systems for preventive maintenance	Maintenance			X	Road	X					Pavement	Pavement including sub		X	
6	Recycled asphalt mixtures with high percentage of reclaimed asp	Design	X			Road	X					Pavement	Surface, binder or base laye			X
7	Reducing the noise from roads	Construction		X		Road	X					Pavement	Pavement		X	
8	Road materials made with high RAP (Reclaimed Asphalt Pavemen	Construction and Maintenance		X	X	Road / Airpor	X		X		X	Pavement	Subbase, base and surfa		X	
9	Solar energy harvesting applied to road pavements	Construction / Maintenance		X	X	Road	X					Pavement				X
10	The use of marginal materials (by-products and secondary mater	Construction and Maintenance		X	X	Road / Railwa	X	X	X		X	Pavement	Bound and unbound layers			X
11	The use of Warm Mix Asphalt in flexible pavement for energy savi	Design / Construction / Maintena	X	X	X	Road / Airpor	X		X		X	Pavement	Asphalt Layers		X	
12	Thin polymeric trafficable waterproofing for bridge deck or multi	Construction and Maintenance		X	X	Road	X					Pavement	Surface layers	X		
13	Use of base and sub-base soil-cement solution to low traffic road	Design	X			Road	X					Pavement	Base and sub-base l	X		
14	Use of nanomaterials in the improvement of rheological and mec	Construction and Maintenance		X	X	Road / Airpor	X		X		X	Pavement	Asphalt Layers			X
15	Use of synthetic interlayer reinforcement systems for pavements	Design /Construction / Maintena	X	X	X	Road / Airpor	X		X		X	Pavement	Bituminous interfaces		X	
16	Very thin asphalt overlay	Maintenance (rehabilitation)			X	Road / ports /	X		X	X	X	Pavement	Bituminous mixture	X		
17	: New road pavement materials for hindering the Urban Heat Islar	Construction / Maintenance		X	X	Road	X					Pavement	Bituminous and cement bou			X
18	The use of fibers for the improvement of the resistant of bitumino	Construction		X		Road / railwa	X	X	X	X	X	Pavement / bitumi	Bituminous mixture	X		
19	Foamed asphalt for the production of warm mix asphalt	Construction		X		Road / railwa	X	X	X	X	X	Pavement / bitumi	Bituminous mixture	X		
20	Tire crumb rubber modified asphalt for pavements	Construction		X		Road / Railwa	X	X			X	Pavement / Superi	Bituminous mixture	X		
21	Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)	Construction / Maintenance		X	X	Road / Railwa	X	X			X	Pavement / Superi	Bituminous mixture / Ba		X	
22	Recycled asphalt mixtures with foamed bitumen	Design	X			Road	X					Pavement	Surface, binder or b	X		
23	Asphalt mixtures with foamed bitumen	Design	X			Road	X					Pavement	Surface, binder or b	X		
24	Low reflection structure on the sides of caisson-type quay walls	Construction		X		Port				X		Precast reinforced	caisson shaft	X		
25	Use of concrete floating caissons in gravity quays construction w	Construction		X		Port				X		Quay walls		X		
26	Method for the installation of railway tracks of ballast, without a	Construction		X		Railway		X				Rail	Railway tracks on b	X		
27	Reducing noise from the rail	Maintenance			X	Railway		X				Rail	Rail and Wagons		X	
28	Drainage treatment in outfalls	Design	X			Road	X					Drainage Systems	External ditches, po	X		
29	Reuse of Mining and other Industrial Wastes materials into pave	Design /Construction / Maintena	X	X	X	Road / Railwa	X	X	X		X	Road and Airport I	Bituminous, unbound and h			X
30	Use of Warm Mix and Cold Mix Asphalts for bituminous layers of	Design /Construction / Maintena	X	X	X	Road / Railwa	X	X	X		X	Road and Airport I	Bituminous layers		X	
31	Managed lanes	Operation				Road	X					Road lanes			X	
32	Use of a End-of-Life Tyres (ELT) rubber into asphalt layers of pave	Design / Construction / Maintena	X	X	X	Road / Rail	X	X				Road Pavement / F	Bituminous layers		X	
33	Recycling Construction and Demolition Waste materials into pav	Design /Construction / Maintena	X	X	X	Road / Railwa	X	X	X		X	Road Pavement, Ra	Bituminous, unbour	X		
34	: Intelligent Transport System auditing using road traffic micro-si	Design	X			Road	X					Road Traffic System				X
35	Use of concrete bulky armor units for breakwaters with enhanced	Design / Construction	X	X		Port				X		Rubble mound bre	Armor layers	X		
36	Road safety systems for the protection of motorcyclists	Design /Construction / Maintena	X	X	X	Road	X					Safety Systems	Longitudinal Barriers		X	
37	Elastic elements in railway structures	Construction / Maintenance		X	X	Railway		X				Sleeper / Ballast	Pads / under-ballas	X		
38	Asphalt mixtures for its application in railway tracks	Construction		X		Railway		X				Substructure of th	Ballast, Sub-ballast		X	
39	Stone-blowing process for the maintenance of railway tracks	Maintenance			X	Railway		X				Superstructure of	Ballast			X

40	High output sleepers aligment machine	Construction / Maintenance (renewa	X	X		Rail		X				Track	Sleepers	X		
41	Unloading of Long Welded Rail (LWD) through a provisional Trac	Construction / maintenance (renewa	X	X		Rail		X				Track	Rail	X		
42	Unloading of Long Welded Rail (LWD) with high output gantry	Construction		X		Rail		X				Track	Rail	X		
43	Lattice Girder in tunnels	Construction		X		Road / Rail	X	X			X	Tunnel	Tunnel Support	X		
44	Multilayer susitanable tunnel linings	Design	X	X	X	Road / Railwa	X	X			X	Tunnel	Lining			X
45	Non-steel fibers reinforced concrete segments in tunnels	Design	X			Road / Rail	X	X			X	Tunnel	Segments			X
46	Overburden length	Design / Construction	X	X		Road / Rail	X	X			X	Tunnel	Tunnel alignment		X	
47	Performance-based requirements and recommendations for fire s	Design	X			Road	X					Tunnel	Provision of fire safety		X	
48	Replacement of “elephant foot” into more curved sections	Design	X			Road / Rail	X	X			X	Tunnel	Tunnel Section		X	
49	Shotcrete reinforced by steel and synthetic fibers	Construction		X		Road / Rail	X	X			X	Tunnel	Tunnel Support		X	
50	Tunnel fire safety design – Fire behaviour, sprinkler and ventilati	Design	X			Road / Rail	X	X			X	Tunnel	Requirements and perfo		X	
51	Control of Road Tunnel Ventilation Systems	Design / Maintenance	X		X	Road	X					Tunnel	Ventilation system		X	
52	Distance between twin tunnels	Design / Construction	X	X		Road / Rail	X	X			X	Tunnel	Tunnel alignment		X	
53	Cathodic Protection for Cutter Soil Mix retaining walls	Design / Maintenance	X		X	Road / Rail / \	X	X		X	X	Tunnel and underp	Vertical retaining w	X		
54	Method for the installation of slab tracks in twin tube tunnels	Design / Construction	X	X		Railway		X				Tunnels	Track on a slab of c	X		
55	Tunneling by means of hydroshields or mixshields	Construction		X		Road / Rail	X	X			X	Tunnels with reinf	Excavation and linir	X		
56	Dimensioning of the typical cross section with an horizon year of	Planning / Design	X			Road	X					Typical cross sect	Elements in a typica	X		
57	Standardization of viaducts for infrastructure crossings	Design / Constructyion	X	X		Road / Rail / \	X	X		X		Viaducts	Deckstructures of viaducts a			X
58	Maintenance of transport infrastructures using predictive techni	Maintenance			X	Road / Airpor	X	X	X	X	X					
59	Multimodal Hub Platform Design (GDANSK)	Design	X			Road / Rail	X	X			X	Multimodal hub platform		X		
60	Good coordination between vertical and horizontal alignment	Design	X			Road	X					Alignment and typ	Typical cross sectio	X		
61	Infrastructure Lifecycle Management	Design / Construction / Maintena	X	X	X	Road / Railwa	X	X	X	X	X	All			X	
62	MEAT (most economically attractive tender) stategy in Tenders	Design	X			Road / Rail / /	X	X	X	X	X	All		X		
63	Performance Based Design	Design / Construction / Maintena	X	X	X	Road / Rail / /	X	X	X	X	X	All			X	
64	Use of 4D techniques for Planning the Virtual Construction of all	Design / Construction / Maintena	X	X	X	Road / Railwa	X	X	X	X	X	All		X		
65	Use of techniques of Work Study in Construction activities	Construction		X		Road / Railwa	X	X	X	X	X	All		X		
66	Use of Time Location Management for Planning the construction c	Construction		X		Road / Railwa	X	X	X	X	X	All		X		
67	Wearables	Construction	X			Road / Railwa	X	X	X	X	X	All				X
68	BIM 4D, 5D, 6D for construction simulation	Design / Construction / Maintena	X	X	X	Road / Rail / /	X	X	X	X	X	All			X	
69	Environmental Life Cycle Assessment: Evaluation of Alternative In	Planning	X			Road / Rail / /	X	X	X	X	X	All		X		
70	Climate impact and energy demand calculation	Planning / Design	X			Road / Airpor	X	X	X	X	X	All Infrastructure				X
71	Sustainable use of construction materials for transport infrastru	Planning and construction phase	X	X		Road / Rail (R	X	X			X	All parts of the road construction, all parts			X	
72	Ecological restoration in areas affected by lineal infrastructures	Design / Construction / Maintena	X	X	X	Road / Rail	X	X			X	Areas with natura	Soils, vegetation, fauna,		X	
73	Bituminous mixture SMA	Construction / Maintenance		X	X	Road / Airpor	X		X		X	Binder course and	Some courses mixtu	X		
74	Making rebar groups in precast pier elements	Design / Construction	X	X		Road / Railwa	X	X			X	Bridge	Pier	X		
75	Low-cost wireless system for dynamic testing of infrastructure, w	Maintenance			X	Road	X					Bridge		X		
76	Monitoring of briges and multi-criteria decision support system	Maintenance			X	Road	X					Bridge			X	
77	Timber bridge monitoring of moisture	Design / Maintenance	X		X	Road / Rail	X	X			X	Bridge	Timber decks, girders, b		X	
78	Use of a lower concrete slab in steel-concrete composite box gird	Design	X			Road / Railwa	X	X			X	Bridge	Deck	X		
79	Use of self compacting concrete in high density reinforced areas	Construction		X		Road / Railav	X	X			X	Bridge	Deck and substructu	X		
80	Use of weathering steel in steel structures	Design	X			Road / Railwa	X	X			X	Bridge	Deck	X		
81	Avoid overlapping of reinforced bars at maximum stress sections	Design	X			Road / Railwa	X	X			X	Bridge	Deck and substructu	X		
82	Avoiding the sliding of elastomeric bearing pads	Design	X			Road / Railwa	X	X			X	Bridge	Bearing	X		

83	Delayed pouring of a concrete closure in bridge widenings	Construction / Maintenance		X	X	Road / Railav	X	X			X	Bridge	Deck	X		
84	Checkerboard concreting in large surfaces	Construction / Maintenance		X	X	Road / Railav	X	X			X	Bridge / Railway S	Slabs	X		
85	Telescopic arm on self-propelled platform for cable tensioning	Construction		X		Road / Railwa	X	X			X	Bridge / Tunnels	Tensioning cables	X		
86	Evaluation of the detection limits for the investigation of strands	Maintenance			X	Road / Rail	X	X				Bridge / Undergrou	Deck, bearing parts	X		
87	Use of lean tools not only for internal gains but also for meeting	Construction / Maintenance		X	X	Road / Railwa	X	X	X	X	X	Bridge, tunnel, pavement, - all			X	
88	Ultrasound tomography on inspection of reinforced and pre-stres	Maintenance			X	Road / Railwa	X	X			X	Bridges	Beams, colums - Concre		X	
89	Use of the gammagraphy technique in the field inspection of rein	Maintenance			X	Road / Railwa	X	X			X	Bridges	Beams, colums - Concre		X	
90	Real-time online Concrete Monitoring of temperature-developmer	Design / Construction / Maintena	X	X		Road / Railwa	X	X			X	Bridges, Tunnels, (	Deck, pylon, inner li	X		
91	Use of micropiles in geotechnical applications (foundation supp	Design / Construction	X	X		Road / Rail /	X	X	X	X	X	Bridges, tunnels, s	Foundation, earth r	X		
92	Use of correct rebar spacers for concrete infrastructures in aggre	Design	X			Road / Airpor	X	X	X	X	X	Concrete structures		X		
93	Aerial inspections using Remote Piloted Aircrafts (RPAs) of bridge	Maintenance			X	Road / Airpor	X	X	X	X	X	Difficults access a	Bridges, tec.			
94	Permeable hard made surfaces for infrastructrue	Design / Construction	X			Road	X					Entire Road	All layers of the pavement p			X
95	Safety considerations in the cross section	Design	X			Road	X					External elements	Verges, ditches, side slo		X	
96	Balanced infraestructure earthworks	Design	X			Road / Railwa	X	X			X	Fillings and cuttin	Fillings, cuttings, ar	X		
97	Adaptive use of Lighting on motorways	Design / Operation	X			Road	X					Lighting			X	
		Tally	**51**	**55**	**44**	**Tally**	**85**	**62**	**28**	**23**	**57**		**Tally**	**48**	**32**	**15**

Table 2: List of best practices

4.1 Best practices and the lifecycle stage

Table 3 and Figure 6 show the spread of best practices across the selected transport infrastructure lifecycle stages. The figure shows that there is a number of practices that apply to several lifecycle stages as well as that there is a good coverage of all stages alike.

	Design	Construction	Maintenance
Number of Practices	51	55	44

Table 3: Spread of practices across the lifecycle stage

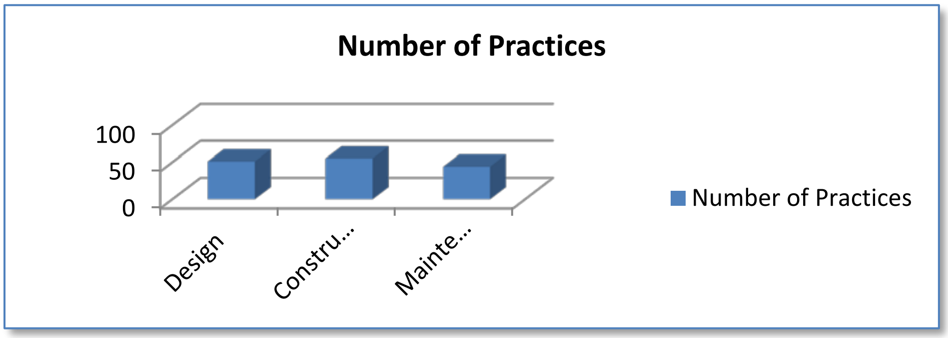


Figure 6: Bar chart showing the spread of practices across the lifecycle stage

4.2 Best practices and type of infrastructure

Table 4 and Figure 7 show the spread of best practices across the selected transport infrastructure types. The figure shows that there is a number of practices that apply to several lifecycle types of infrastructure (multimodal int this context) as well as that there is a good coverage of road and rail. Airport and water have a lower coverage as it seems the number of experts in these areas is lower than in the others.

	Road	Rail	Airport	Water	Multimodal
Number of Practices	85	62	28	23	57

Table 4: Spread of practices across type of infrastructure

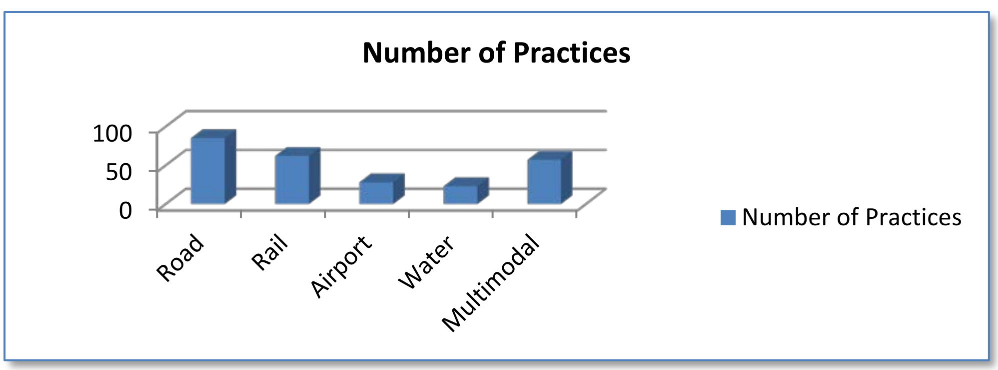
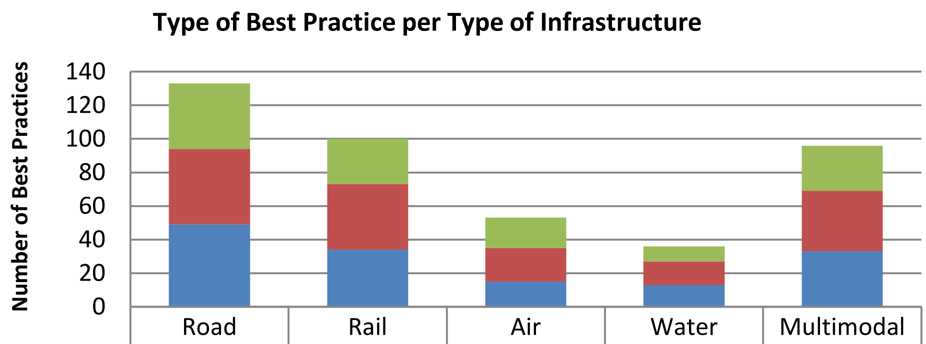


Figure 7: Bar chart showing the spread of practices across type of infrastructure

4.3 Type of Best Practice per Type of Infrastructure

In Figure 8 the number of best practices according to its type (design, construction or maintenance) and to the type of infrastructure where they can be applied are shown. Notice that in some cases one best practice may be applied to more than one lifecycle stage or to more than one type of infrastructure.



	Road	Rail	Air	Water	Multimodal
Maintenance	39	27	18	9	27
Construction	45	39	20	14	36
Design	49	34	15	13	33

Figure 8: Type of Best Practice per Type of Infrastructure

5 Best Practices for Design

5.1 Type of Infrastructure: Road (Design)

5.1.1 Recycled asphalt mixtures with high percentage of reclaimed asphalt pavement (30% and 50%)

Best Practice #6	
Field	**Description**
Title and Keywords	**Recycled asphalt mixtures with high percentage of reclaimed asphalt pavement (30% and 50%)** Keywords: Recycling, reclaimed asphalt pavement, rejuvenator additive, Performance.
Source of best practice	Elevo Group and University of Minho
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	Surface, binder or base layers
Short Description	This practice consists in the production of hot asphalt mixtures with

	incorporation of high quantity of reclaimed asphalt pavement (RAP) (30% to 50% of the final mixture). This mixture is based on a conventional asphalt concrete mixture (AC 14 bin/surf or AC 20 bin/base) with the incorporation of high rates of RAP, also including rejuvenator additives (only in mixtures with higher RAP contents). The function of the rejuvenators is to recover some softness and flexibility of the aged bitumen present in the RAP, providing a better workability and fatigue resistance to the recycled asphalt mixtures. One of the rejuvenators used in this study has organic origin, thus being more sustainable. The incorporation of high percentages of RAP is only possible by correctly treating this material. The separation of RAP material in different fractions and the heating temperatures of each fraction used during mixing have a big influence in the resulting recycled mixtures. The study of the size fraction separation of RAP in two different fractions was made using an industrial classifier. The heating conditions of each fraction used during the mixing process should be different: the fine fraction should be introduced at room temperature and the coarse fraction can be heated at at high temperatures together with the new aggregates. Due to this difference in the preparation of both fractions of RAP, the asphalt plant used to produce these recycled mixtures must be prepared with different lines for introduction of the fine and coarse fractions of RAP.
Success factors	For a successful replication of this technique it is very important the adequate treatment of RAP, including the correct size fraction separation and selection of heating temperatures, and the proper use of rejuvenator additives. The final recycled mixture must show similar or superior performance than that of a conventional asphalt mixture.
Constraints	The high temperatures used to heat the new aggregates and the coarse fraction, in order to compensate the introduction of fine fraction at room temperature, could imply a small increase on the consumption of fuel, and some additional aging of the coarse fraction of RAP.
Main impacts	This technique can be seen as an innovative product that contains in full the basic pillars of sustainability: environmental, economic and social component. At economic level, through the incorporation of 30 to 50% of RAP, which significantly reduces the amount of new material used (aggregates and bitumen) and the final cost of the recycled mixture. In environmental terms, the reuse of RAP reduces the quantity of this material wasted in landfills. The emissions with greenhouse effect are also reduced. The use of an ecological organic rejuvenator, instead of chemical ones typically used, is another envoronmental advantege. Concerning the social component, the reduction of space needed for RAP disposal is one of the advantages of this technique.
Maturity and degree of implementation	About the mixtures studied on that phase a correct formulation in laboratory have been obtained. The analyses of the behavior of that

	type of mixtures in laboratory show that it's possible the implementation in situ however until now hadn't been possible this application.
Key Performance Indicators	The results obtained in laboratory for that type of mixtures give us good indicators about the behavior in situ of that mixtures. The mixtures with rejuvenators present better or similar results in terms of water sensibility and durability than conventional mixtures.
Further information	

5.1.2 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

Best Practice #11	
Field	**Description**
Title and Keywords	***The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction*** Keywords: WMA, asphalt, pavement, energy saving, environmental sustainability.
Source of best practice	Emerging technology all over the world.
Lifecycle stage	Design, Construction and Maintenance.
Type of infrastructure	Multi-modal (Road and Air).
Component of infrastructure	Pavement.
Element of the infrastructure	Asphalt layers.
Short Description	Warm Mix Asphalt (WMA) is a modified asphalt concrete, obtained by using organic (wax), chemical or foaming additives, which can be produced, applied and compacted at lower temperatures (100–140 °C) than Hot Mix Asphalt (HMA). Such increase in workability is generally due to lower binder viscosity at mixing and compaction temperatures or to the reduced friction at the interface between bitumen and aggregates provided by the presence of surfactants which should reduce the surface tension of the asphalt binder acting as an emulsifier and thus increasing lubricity. WMA can be successfully used in all types of asphalt concrete (dense-graded, stone mastic asphalts and porous) for all asphaltic layers prepared with both plain of polymer modified bitumens and subjected to a wide variety of traffic levels (minor roads to major highways).
Success factors	The extensive use of WMA will lead to reduced preparation and compaction temperatures of road asphalt layers allowing considerable reduction of energy consumption and emission of pollutants towards the preservation and protection of natural and working environments.
Constraints	The basic WMA challenge is the production of a pavement mixture characterized by at least the same performance of traditional HMA,

	thus able to assure acceptable in-service mechanical performance and durability. In this sense, mechanical properties of WMA mixes can vary in a large range mainly depending on the amount of additive and the type of WMA technology used. Specific care must be taken based on the type of the technology used (e.g. wax should not have a melting point lower than in-service temperatures to avoid permanent deformations). Generally, the most documented drawbacks related to the reduction of mixing and compaction temperatures are related to greater moisture susceptibility, higher rutting potential, reduced interface shear strength as well as coating and bonding problems. Moreover, uncertainties regarding long-term performance also exist.
Main impacts	The use of WMA leads to environmental benefits as well as to economic/operational advantages. In particular, reduced energy consumption and gas and fume emissions are achieved both in plant and in the field proportionally to the reduction of temperatures towards environment protection and reduced worker exposure. Moreover, lower production costs can be obtained thanks to reduced fuel usage. On the other hand, if WMA are prepared at higher temperatures, they will allow longer hauling distances and/or extended construction periods since they maintain adequate workability at lower temperatures than HMA.
Maturity and degree of implementation	Quite-well established technology in most part of the world but still without extensive and long-term field applications and monitoring. Specific aspect should also be studied in depth such as the interface shear strength between WMA and coating and bonding problems due to lower preparation temperatures.
Key Performance Indicators	
Further information	

5.1.3 Use of base and sub-base soil-cement solution to low traffic roads

Best Practice #13	
Field	**Description**
Title and Keywords	**Use of base and sub-base soil-cement solution to low traffic roads** Keywords: soil treatment, cement, base and sub-base layers, soil-cement
Source of best practice	Current practice in some countries of South America and Africa, namely the Portuguese Oficial Language Countries
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	Base and sub-base layers

Short Description	The transport sector is a key element to many aspects of economic life, with road transport playing a dominant role. The high costs of road infrastructure's construction, maintenance and rehabilitation combined with sustainability concerns of the adopted solutions and environmental impacts minimization, justify the needed optimization and rationalization of both funds and natural resources. For this purpose, and in order to minimize costs throughout the infrastructure lifecycle behaviour without compromising its performance, it is crucial the use of adequate methodologies when choosing each case solution. This I&D project aims the development of new road pavement solutions, mainly for tropical countries, including new bituminous mixtures and hydraulic bound soils, namely soil-cement solutions. Two different constructive methods are evaluated, in order to reduce the costs of construction and minimize the social and environmental impacts: base and sub-base layer stabilized and compacted in one operation (30 cm thickness – 1 layer) versus a solution realized in two operations (15 cm + 15 cm – 2 layers). It is also studied the application of a double surface coating to mitigate the propagation of reflective cracking to bituminous layer. In order to improve the knowledge of this type of solutions, four different road pavement structures are tested over a Full-scale Accelerated Pavement Testing (FAPT), built on these project scope.
Success factors	It is useful in all low traffic roads to improve the bearing capacity of in-situ materials to apply in base and sub-base layers.
Constraints	Not possible apply in all type of soils. Soils with poor characteristics are not contempled in normalizations to treatment with hydraulic binders, namely cement.
Main impacts	The application of soil-cement solution in base and sub-base layers has social environment and economic impacts such us: - Usage of in situ materials or borrow sites near construction site, leading to a cost reduction in transportation of graded aggregates to apply in this layers; - The application of a single layer with 30 cm instead the application of 15 cm + 15 cm solution, results in a more economical solution, if the tests conducted in FAPT reveals similar results for both solutions; With the application of Stress Absorbing Membrane Interlayer to mitigate the propagation of reflective cracking originated by the soil-cement retraction phenomenon to bituminous layers above would increase road infrastructures intervention times (from 3 to 6 years) and costs reductions (around 50%). This study has already concluded that the use of soils with poor properties than the specified in the South Africa Specification could be considered if the laboratorial tests confirm the fulfilment of the requirements of strength specified.

	Two different laboratorial methodologies are suggested to use in European soil and soil cement study: - The linear shrinkage test to substitute the retraction limit test. The last test is no longer used due the prohibition of the use of mercury. The linear shrinkage could be an excellent test to determine this property. - The determination of Initial Consumption of Lime or Initial Consumption of Stabiliser (ICL/ICS) should be implemented in formulation of hydraulically bound materials. With this test is possible determine the approximate content of stabiliser required to the material stabilisation. Furthermore, the South African Pavement Engineering Manual refers a maximum value to ICL/ICS of 3.5% to effective, feasible and economic stabilisation solution.
Maturity and degree of implementation	Very used in some countries, specially in African Portuguese Oficial Language and in South Africa, since the ‘70s. The usage of soil-cement layers have a hystoric of more than 60 years.
Key Performance Indicators	
Further information	

5.1.4 Use of synthetic interlayer reinforcement systems for pavements

Best Practice #15	
Field	**Description**
Title and Keywords	**Use of synthetic interlayer reinforcement systems for pavements** Keywords: synthetic interlayer, bituminous pavements, reinforcement
Source of best practice	Current practice in all Europe. RILEM SIB Committee
Lifecycle stage	Design, Construction and Maintenance
Type of infrastructure	Road and Airport
Component of infrastructure	Pavements
Element of the infrastructure	Bituminous interfaces
Short Description	This practice deals with the use of synthetic interlayer reinforcement systems between bituminous layers. Geosynthetic reinforcements can be placed at the interface of bituminous layers for both new constructions and rehabilitation of existing pavements, in order to improve repeated loading and rutting resistance and to prevent or delay reflective cracking.
Success factors	A number of studies on flexible bituminous pavements have demonstrated that, in general, geosynthetic reinforcement increase the stiffness and rutting resistance of the asphalt concrete pavements and in particular, they provide good performance under repeated loading cycles, especially when placed at the bottom of bound layers, where

	tensile stresses-strains are the highest and can be absorbed by the grid.
Constraints	The presence of an interlayer reinforcement may also hinder the full transmission of horizontal shear stresses between asphalt layers (debonding effect), penalizing the overall efficiency of the pavement system. Care must be used in the design and construction phase. A number of products exist on the market and the behaviour of each should be carefully weighed according to the specific application.
Main impacts	Nowadays, road pavements are subjected to steadily increasing traffic volumes generating accelerated functional and structural distresses that require frequent and expensive maintenance. On the basys of such needs, in recent years practical applications and theoretical studies have proved that the service life of flexible pavements can be extended by installing geosynthetic reinforcements.
Maturity and degree of implementation	Geosynthetic reinforcements are very common through Europe and other countries. Research is being done in order to better understand aspects such as: durability, effectivness of each solution, recyleability.
Key Performance Indicators	
Further information	

5.1.5 Recycled asphalt mixtures with foamed bitumen

Best Practice #22	
Field	**Description**
Title and Keywords	**Recycled asphalt mixtures with foamed bitumen** Keywords: Foamed bitumen, Warm mix asphalt, Recycling
Source of best practice	Elevo Gourp and University of Minho
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	Surface, binder or base layers
Short Description	This practice consists in the production of recycled warm mixtures asphalt with incorporation of high quantity of reclaimed asphalt pavement (RAP) (30% to 50% of the final mixture) and using foamed bitumen technology. The incorporation of high percentages of RAP is only possible by correctly treating this material. The separation of RAP material in different fractions and the heating temperatures of each fraction used during mixing have a big influence in the resulting recycled mixtures. The study of the size fraction separation of RAP in two different fractions was made using an industrial classifier. The heating

	conditions of each fraction used during the mixing process should be different: the fine fraction should be introduced at room temperature and the coarse fraction can be heated at at high temperatures together with the new aggregates. Due to this difference in the preparation of both fractions of RAP, the asphalt plant used to produce these recycled mixtures must be prepared with different lines for introduction of the fine and coarse fractions of RAP.The binder used in the production of this recycled mixture is foamed bitumen. Foamed bitumen is obtained by the introduction of small quantities of water (2 to 3% by weight of binder), under pressure, to hot bitumen (generally between 150 and 180°C) into an expansion chamber. In laboratory, this practice it is only possible using a proper equipment that allows the production of foamed bitumen, this equipment is similar to the plants used in the manufacture of bituminous mixtures, but in a smaller scale. The foamed bitumen process decrease the viscosity of the bitumen used in the production of mixture, during a short period of time, allowing the coat of aggregates with the bitumen at lower temperatures than usual.
Success factors	For a successful replication of this technique it is very important the adequate treatment of RAP, including the correct size fraction separation and selection of heating temperatures, and the proper use of rejuvenator additives. Furthermore, for the production of foamed bitumen it is necessary to have a proper equipment for the production of foamed bitumen (both in lab and in plant). Moreover, all the parameters that influence the production of foamed bitumen must be deeply studied to optimize the final results. The final mixture must show similar or superior performance than a conventional mixture during a short period of time, allowing the coat of aggregates with the bitumen at lower temperatures than usual. The incorporation of RAP normally imply the overheating of the aggregates, on that case and with the application of the foamed bitumen it's possible a significantly reduction in the temperatures and consequently a huge reduction of fuel consumption.
Constraints	The use of foamed bitumen technique involves a great knowledge of all the factors involved. Thus, for different bitumens, in terms of origin or penetration, it is necessary study all these factors (percentage of water, temperature of bitumen, use of foaming additives, among others). In fact, this technique is not yet well known and disclosed, which complicates the study of such solutions.
Main impacts	This technique can be seen as an innovative product that contains in full the basic pillars of sustainability: environmental, economic and social component. At economic level, through the incorporation of 30 to 50% of RAP, which significantly reduces the amount of new material used (aggregates and bitumen). The fact that lower temperatures are used, it is also advantageous, because it allows lower costs in plant, namely the

	fuel used to heat the agregates. In environmental terms, the reuse of RAP reduces the quantity of this material wasted in landfills. Moreover, the fact that allow the production of asphalt mixtures at lower temperatures, allows a reduction in the emission of greenhouse gases. Concerning the social component, the reduction of space needed for RAP disposal is one of the advantages of this technique.
Maturity and degree of implementation	On that phase the tests made in laboratory give us an idea about the most important aspects to the success or failure of that type of mixtures. The company plant is already equipped with the device to the production of foamed bitumen and with two different lines that allows the introduction of the fine and course fration of RAP.
Key Performance Indicators	The use of foamed bitumen to asphalt mixtures evidence the possibility to the production and application in situ of that type of mixtures. However the conditions of production have a lot of influence in the final behavior.
Further information	

5.1.6 Asphalt mixtures with foamed bitumen

Best Practice #23	
Field	**Description**
Title and Keywords	**Asphalt mixtures with foamed bitumen** Keywords: Foamed bitumen, Warm mix asphalt
Source of best practice	Elevo Gourp and University of Minho
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	Surface, binder or base layers
Short Description	This practice consists in the production of warm mixtures asphalt (temperatures between 120 and 140°C) using foamed bitumen process. Foamed bitumen is obtained by the introduction of small quantities of water (2 to 3% by weight of binder), under pressure, to hot bitumen (generally between 150 and 180°C) into an expansion chamber. In laboratory, this practice it is only possible using a proper equipment that allows the production of foamed bitumen, this equipment is similar to the plants used in the manufacture of bituminous mixtures, but in a smaller scale. The foamed bitumen process decrease the viscosity of the bitumen used in the production of mixture, during a short period of time, allowing the coat of aggregates with the bitumen at lower temperatures than usual.
Success factors	For a successful replication of this technique it is necessary to have a proper equipment for the production of foamed bitumen (both in lab

	and in plant). Moreover, all the parameters that influence the production of foamed bitumen must be deeply studied to optimize the final results. The final mixture must show similar or superior performance than a conventional mixture, reducing the heating costs and the environmental impact in comparison with hot mix asphalts.
Constraints	The use of foamed bitumen technique involves a great knowledge of all the factors involved. Thus, for different bitumens, in terms of origin or penetration, it is necessary study all these factors (percentage of water, temperature of bitumen, use of foaming additives, among others). In fact, this technique is not yet well known and disclosed, which complicates the study of such solutions.
Main impacts	This technique proves to be innovative especially at environmental and economic levels. The production of mixtures at lower temperatures allows the reduction of greenhouse gases emissions and the reduction of costs in terms of energy used to heat the materials involved in asphalt mixtures producion.
Maturity and degree of implementation	On that phase the tests made in laboratory give us an idea about the most important aspects to the success or failure of that type of mixtures. The production/application in situ of this type of mixture is technically possible once the plant is equipped with a device for production and injection of foamed bitumen in the mixer. The company plant is already equipped with this device.
Key Performance Indicators	The use of foamed bitumen to asphalt mixtures evidence the possibility to the production and application in situ of that type of mixtures. However the conditions of production have a lot of influence in the final behavior.
Further information	

5.1.7 Drainage treatment in outfalls

Best Practice #28	
Field	**Description**
Title and Keywords	Title: Drainage treatment in outfalls Keywords: water flows, outfalls, water treatment
Source of best practice	Roads Standards
Lifecycle stage	Design
Type of infrastructure	Roads
Component of infrastructure	Drainage systems.
Element of the infrastructure	External ditches, ponds, surface and subsurface drainage.
Short Description	The infrastructure produce an effect of increasing the final flows in the outfall to a natural stream, and this flows could be also polluted. It is necessary to treat and store the water before returning to the natural

	system in order to maintain the natural conditions.
Success factors	Channel and size properly the surface drainage to the outfall. Place ponds or other storage and treatment systems before the outfall.
Constraints	Increase the cost of the drainage elements. Increase the manteinace cost. Increase the land requiered for the storage elements.
Main impacts	Less risk of flooding caused by the infraestructure Less environmental impact Better water quallity.
Maturity and degree of implementation	In some contries this kind of drainage solutions are completely implemented.
Key Performance Indicators	
Further information	

5.1.8 Reuse of Mining and other Industrial Wastes materials into pavements

Best Practice #29	
Field	**Description**
Title and Keywords	**Reuse of Mining and other Industrial Wastes materials into pavements** Keywords: Mining Wastes, Industrial Wastes, recycled pavements
Source of best practice	Current practice in some European countries, and in Northern and Central America
Lifecycle stage	Design, Construction and Maintenance
Type of infrastructure	Road, Railway and Airport
Component of infrastructure	Road and Airport Pavement or Railway Sub-ballast
Element of the infrastructure	Bituminous, unbound and hydrically bound layers
Short Description	Mine tailings and Industrial Wastes can be seen as a potential source of materials for the production of building materials that can be adopted in the field of civil infrastructures in general and, in particular, for road applications. Different kind of bituminous mixtures can be produced (hot, warm or cold), unbound and hydraulically bound mixtures. Mining and Industrial Waste can also be used for the production of synthetic aggregates and modular elements (paving blocks, etc.) for mixtures and layers, as well as part of the bonding matrix of synthetic mortars for construction of layers and interlayers.
Success factors	Conversion to the production of construction materials is a viable alternative for the recycling of the millions of tons of mining waste rocks. Reuse of Mining and other Industrial Wastes materials can determine the reduction of materials disposed to landfills with significant benefit from the environmental and economical point of

	view.
Constraints	The safe reuse of this type of waste is still rather limited due to the lack of local regulations and consistent research results. This constraint is strictly linked to each country national regulations and Green Procurement policies. The properties of the final mixture is significantly affected by the quality and kind of waste materials. An ever increasing number of innovative and environmentally friendly recycled waste materials has been launched on the market, and others are still under study, being the step of characterization of the materials of crucial importance.
Main impacts	Reuse of Mining and other Industrial Wastes materials can determine the reduction of materials disposed of in landfills with significant benefit from different points of view. Their re-use has a two-fold environmental benefit, since it saves natural resources such as raw materials, and significantly reduces the volume of materials disposed. At the same time, it implies the reduction in costs related to the purchase of raw material and to the production of recycled mixtures and building materials.
Maturity and degree of implementation	Reuse of Mining and other Industrial Waste materials into pavements is a relatively recent technology. It is widespread in USA and quite common in many European countries, though new kind of solutions and materials are under investigation.
Key Performance Indicators	
Further information	

5.1.9 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

Best Practice #30	
Field	**Description**
Title and Keywords	**Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements** Keywords: Warm Mix Asphalts, Cold Mix Asphalt, bituminous pavements
Source of best practice	Current practice in some countries, specially in Italy, France, Spain and in the USA
Lifecycle stage	Design, Construction and Maintenance
Type of infrastructure	Road, Railway and Airport
Component of infrastructure	Road and Airport Pavement or Railway Sub-ballast
Element of the infrastructure	Bituminous layers
Short Description	Cold Mix Asphalts and Warm Mix Asphalts have gained increasing popularity in the recent ten years for its versatile properties. Compared to the traditional hot technique it is possible to design high-

	performance paving without the addition of heat, with significant reductions in energy consumption and emissions during production and laying. Service performances, durability and recyclability ar not affected.
Success factors	The benefits of using Cold and Warm Mix Asphalt technology are above all the reduction in energy consumption and emissions during production and laying, in addition to the actual possibility of achieving high quality pavement layers. Without the addition of heat it is also possibile increase the amount of Reclaimed Asphalt Pavement (RAP) added for the production of new recycled asphlat mixtures. Specific bituminous products are needed for a successful technology.
Constraints	Main constraints are related with the lack of knowledge within technical staff. Technologies are relatively new, but still, despite the large amount of positive research, their diffusion is still not large. In some cases plant modification is needed. Initial costs may be higher, altough final ones have been proven to be lower.
Main impacts	The main impacts related to Cold and Warm Mix Asphalts technology are connected to the reduction of temperature during the production in plants. This lead to a significant decrease in energy consumption and since the laying is carried out at temperature generally under 150°C, materials can be handled with more flexibility in time. From an ambiental point of view, a substantial reduction in emission during production and laying is recorded. As the production tempearture decrease, it is possible increase the quantity of RAP added in the mixture. Cold Mix Asphalt technology is also commonly used for maintenace due to the speed of the processing time and the whole absence of heat necessary for the production.
Maturity and degree of implementation	Cold and Warm Mix Asphalts are widely used in USA and in many European counties, though new kind of solutions are under investigation to abate constraints.
Key Performance Indicators	
Further information	

5.1.10 Use of End-of-Life Tyres (ELT) rubber into asphalt layers of pavements

Best Practice #32	
Field	**Description**
Title and Keywords	**Use of End-of-Life Tyres (ELT) rubber into asphalt layers of pavements** Keywords: ELT, bituminous pavements, recycled rubber
Source of best practice	Current practice in some countries, specially in Italy and Spain
Lifecycle stage	Design, Construction and Maintenance
Type of infrastructure	Road and Rail
Component of infrastructure	Road Pavement or Railway Sub-ballast
Element of the infrastructure	Bituminous layers
Short Description	This practice deals with the incorporation of grinded (moslty fine)

	rubber from End-of-Life tyres from vehicles. Rubber is recycled from specific plants that are generally linked in a consortium (Ecopneus, Signus, etc). Different kind of bituminous mixtures can be produced (hot, warm or cold) and advantages in terms of durability and environmental impact are recorded.
Success factors	Rubber is not dumped (where still legal) and are not burnt for energy. Intrinsic value of the rubber is reflected inside the bituminous mixture in terms of workability, mechanical resilience and functional aspects such as tyre-pavement noise reduction and friction.
Constraints	Plant production is not significanlty affected as rubber can directly enter in the bitumen as modifier or in the mixture as active filler. Main constraints are related with the control of temperature for plant production, laying and compaction workability. Temperature is also very important for limiting the fumes and odours which are generally one of the main contraints to the use of these practice. Finally, the first constraint is political and comes from the vision of each country national regulations and Green Procurement policies.
Main impacts	Rubber is collected and recycled in a well organized and trained system of Consortium. Value is given to a by-product that becomes a component of bituminous pavements. Materials are also re-recyclable as Reclaimed Asphalt Pavment. The mechanical and durability performance of the bituminous layers is improved and maintenance interventions (and its costs) are reduced. Surface layers can be attributed a strong acoustic performance related to the mixture design.
Maturity and degree of implementation	Asphalt rubber and rubberized asphalts with ELT are widely used in USA and are quite common in Europe, though new kind of solutions are under investigation to abate constraints.
Key Performance Indicators	
Further information	

5.1.11 Recycling Construction and Demolition Waste materials into pavements

Best Practice #33	
Field	**Description**
Title and Keywords	Title: **Recycling Construction and Demolition Waste materials into pavements** Keywords: Construction and Demolition Waste, bituminous pavements, recycled material
Source of best practice	Current practice in most of European countries, and in Northern and Central America
Lifecycle stage	Design, Construction and Maintenance

Type of infrastructure	Road, Railway and Airport
Component of infrastructure	Road Pavement, Railway Sub-ballast and Airport Pavement for base or subbase layers
Element of the infrastructure	Bituminous, unbound and hydrically bound layers
Short Description	This practice deals with the incorporation of Construction and Demolition waste materials into pavement layers and foundations. Different kind of mixtures can be produced: bituminous (hot, warm or cold), unbound and hydaulically bound. Significant economical advantages in terms of costs related to reduction of the use of raw materials and virgin aggregates are recorded.
Success factors	Construction and Demolition Waste materials are not dumped (according the legislation of each country) and substitute raw material within specific mixtures. According to the type of Construction and Demoliton Waste and a certain mix design, it is possible to improve the mechanical and durability properties of mixtures and reduce the costs related to their production.
Constraints	The properties of final mixtures is significantly affected by the quality of the Construction and Demolition Waste materials. Different treatment plants located in different areas will produce different materials: CE marking is needed according to EN 13242, EN 13285 and related standards. There are political constraints related to the vision of each country national regulations and Green Procurement policies.
Main impacts	Economic and enviromental benefits are related to the reduction of use of raw material and virgin aggregates. The presence of Construction and Demolition Waste does not negatively affect the mechanical and durability properties of the final mixture, which on the contrary could be increased.
Maturity and degree of implementation	Very common practice in many European countries. Reclaimed Asphalt Pavement can be considered as part of this practice.
Key Performance Indicators	
Further information	

5.1.12 Intelligent Transport System auditing using road traffic micro-simulation

Best Practice #34	
Field	**Description**
Title and Keywords	Title: **Intelligent Transport System auditing using road traffic micro-simulation** Keywords: ITS, traffic simulation, traffic telematics
Source of best practice	Municipal Council of Wroclaw, Poland; ArsNumerica Group, Poland
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Other: Road Traffic System

Element of the infrastructure	Traffic micro-simulation (dynamic simulation light signalization settings)
Short Description	The main aim of traffic micro-simulation is to use an integrated execution environment to dynamically simulate traffic light phase adjustment on multiple intersections included into the Intelligent Transportation System. Such an environment enables specialists to calibrate the traffic model against any parameters of a single simulation, and can be used to check whether a better performance can be achieved with different parameters. Data Processing Centre, Intelligent Transport System Wroclaw  Source: Municipal Council of Wroclaw The dynamic simulation light signalization settings was developed by the ArsNumerica Group and applied to audit Intelligent Transport System in the city of Wroclaw. The ITS system requires conducting a range of operations covering analytical, design and construction works as well as engineering in the following fields: city transport, environmental protection, telecommunications, IT and automation. Therefore, the traffic micro-simulations prepared by ArsNumerica Group should be seen as one of the factors which improve effectiveness of the Wroclaw ITS system.
Success factors	This example can be replicated in all cities which use Intelligent Transport Systems to copy with traffic disruptions of transport flows, especially when local traffic system consists of many intersections equipped with traffic lights.
Constraints	• Long-standing process of system adaptation to structure of local traffic • Higs costs of infrastructure which provides possibilities for using the traffic micro-simulations and is related to Intelligent Transport System (detection cameras, fibre optic network etc.)
Main impacts	• Reduction of CO_2, pollutants and noise emissions generated by cars which do not have to stop as often as before implementation of the micro-simulations • Improvement of infrastructure capacity and optimization of maintenance costs for all transport modes • Reduction of disruptions of transport flows
Maturity and degree of implementation	Fully implemented on one of the main arteries in the city of Wroclaw – Legnicka Street. It was verified that the integrated execution environment is able to execute to each intersection its micro-program that can dynamically change duration of traffic

	light phases, keeping phases coordination.
Key Performance Indicators	
Further information	• Bazan M. et. al. (2015*), Intelligent Transport System auditing using road traffic micro-simulation*, "Archives of Transport System Telematics", vol. 8 • *The first Intelligent Transport System in Wroclaw (Poland)*, http://www.eltis.org/discover/news/first-intelligent-transport-system-wroclaw-poland-0

5.1.13 Road safety systems for the protection of motorcyclists

Best Practice #36	
Field	**Description**
Title and Keywords	Title: **Road safety systems for the protection of motorcyclists** Keywords: motorcyclists, road safety systems, EN 1317-8
Source of best practice	EN standard EN1317-8 was released recently. Spain and Portugal mostly.
Lifecycle stage	Design, Construction and Maintenance
Type of infrastructure	Road
Component of infrastructure	Safety Systems
Element of the infrastructure	Longitudinal Barriers
Short Description	This practice deals with the installation of road restraint systems specifically designed for the protection of motorcyclists. A European standard exists that deals with real scale testing of continuous and punctual devices.
Success factors	Being road restraint systems designed for cars and trucks the problem of motorcyclists protection has been growing together with the Powered Two Wheelers number. Some types of safety barriers are very aggressive towards motorcyclists. The development of specific products is solving the problem.
Constraints	Main constraints are related to the cost effectivness of the installation of these protections on the road networks. Secondly the installation on existing devices may alter their behaviour when impacted and this can cause legal issues. Local national laws should provide guidance on what and where to install. Only fallen PTW is considered.
Main impacts	Fatalities or serious injuries among motorcyclists are increasing with an opposite trend to car and truck accidents. This is mainly due to the increase of PTWs on the roads. Safety systems, when needed, should be design and installed also for the motorcyclists safety. Regulations for intallation should be given.
Maturity and degree of implementation	A number of products are available on the market. Most of them have been crushed and certified according to EN 1317-8. National regulations and speficications should encompass the installation of these systems.

Key Performance Indicators	
Further information	

5.1.14 Multilayer susitanable tunnel linings

Best Practice #44	
Field	**Description**
Title and Keywords	Title: **Multilayer susitanable tunnel linings** Keywords: tunnel lining, fibres, ceramics, funtionalized surfaces
Source of best practice	Design, Research projects
Lifecycle stage	Construction and maintenence
Type of infrastructure	Road or rail
Component of infrastructure	Tunnel
Element of the infrastructure	Lining
Short Description	It consists in a definitive lining made of various layers effective from the point of view of sustainability and reuse of construction and demolition waste: a structural lining made of sustainable concrete, optimized for structural performances, durability and amount of raw materials required, an adhesive layer and an external covering layer with functionalized surface.
Success factors	No particular limitation, great flexibility, saving of raw materials.
Constraints	Local availability of secondary raw materials with adequate performances.
Main impacts	All the components of the package are inspired by criteria of circular economy, being mainly based on secondary raw materials. The lining can be used as a whole in new constructions or divided in parts for repair and strenghening of existing infrastructures. Performances of the different layers allow saving of raw materials, construction time and increase the service life of the infrastructure, together with its costs for downtime.
Maturity and degree of implementation	There are applications of tunnels with innovative techniques and materials in various EU countries (e.g. Italy, Spain). The usage of recycled aggregates is still limited.
Key Performance Indicators	
Further information	

5.1.15 Non-steel fibers reinforced concrete segments in tunnels

Best Practice #45	
Field	**Description**
Title and Keywords	Title: **Non-steel fibers reinforced concrete segments in tunnels** Keywords: Fiber, segments
Source of best practice	DURADOV R&DProject

Lifecycle stage	Design
Type of infrastructure	Multi-modal
Component of infrastructure	Tunnel
Element of the infrastructure	Segments lining
Short Description	Removal of conventional segment reinforcement into a new one solely reinforced by non steel fibers.
Success factors	Enhance the performance of the segment during handling and installation Obtain higher durability Enhance fire behavior of the segments
Constraints	Unexpected bearing capacity of the syntetic fibers with concrete mix.
Main impacts	Economic benefits Increse of durability,so as to face the high durability requirements (100-150 years) we are been required.
Maturity and degree of implementation	Under development
Key Performance Indicators	
Further information	ITAtech Design Guidance For Precast Fibre Reinforced Concrete Segments-Draft Report

5.1.16 Overburden length

Best Practice #46	
Field	**Description**
Title and Keywords	Title: **Overburden length** Keywords: Overburden
Source of best practice	DRAGADOS
Lifecycle stage	Design and Construction
Type of infrastructure	Multi-modal
Component of infrastructure	Tunnel
Element of the infrastructure	Tunnel alignment
Short Description	Designers assume a minimum overburden length of one diameter. It drives to build a ditch and broadly it must be removed at the end of the works which would produce annoyance to landowners.
Success factors	The cost of the complementary works are directly related to the depth. Therefore it is possible to reduce the construction cost if a minimum if overburden length is not prestablished. By installing micropiles in the entrance of the tunnel is possible to get low overburden.
Constraints	Geotechnical rock mass quality must be optimal to reach low overburden.
Main impacts	Not to prestablish design parameters without stuying the constraints the specific project.

Maturity and degree of implementation	Implementation in different works depending on the designer's approach.
Key Performance Indicators	
Further information	

5.1.17 Performance-based requirements and recommendations for fire safety in road tunnels

Best Practice #47	
Field	**Description**
Title and Keywords.	**Performance-based requirements and recommendations for fire safety in road tunnels** Fire safety, tunnels
Source of best practice	Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2013). Performance-based requirements and recommendations for fire safety in road tunnels (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2012). Funktionsbaserade krav och rekommendationer för brandsäkerhet i vägtunnlar (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2014). Performance-based design of road tunnel fire safety: Proposal of new Swedish framework. *Case Studies in Fire Safety, 1*(0), 18-28. doi: http://dx.doi.org/10.1016/j.csfs.2014.01.002 Ingason, H., Li, Y. Z., & Lönnermark, A. (2015). *Tunnel Fire Dynamics*. New York: Springer.
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Tunnel
Element of the infrastructure	Provision of fire safety
Short Description	A performance-based design guide for road tunnel fire safety derived from Swedish and European regulation is proposed. The overall purpose of the guideline is to protect life, health, property, environment, and key societal functions from fire. The guideline is structured into five key groups of requirements. Each group contains a hybrid of prescriptive requirements, performance-based requirements, and acceptable solutions. Prescriptive requirements must be fulfilled, however, it is the choice of the design team to either adopt the proposed acceptable solutions, or to design alternative solutions by verifying that performance-based requirements are satisfied. A scenario-based risk analysis with several specified input variables and methods is proposed.

Success factors	That responsible authorities acknowledges the design guide. On a case by case basis input parameters and required performance needs to be defined.
Constraints	Current legislation needs to allow for a performance-based design approach. If the regulation is prescriptive and tough, there si no room for safety tradeoffs or alternative solutions.
Main impacts	Functional road tunnel frie safety to a lower cost.
Maturity and degree of implementation	Road tunnel fire safety design is not a well researched area and regulation is working as a straight-jacket to maintain old solutions. Several assumptions and input parameters for designing fire safe road tunnels are uncertain and debatable.
Key Performance Indicators	
Further information	Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2013). Performance-based requirements and recommendations for fire safety in road tunnels (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2012). Funktionsbaserade krav och rekommendationer för brandsäkerhet i vägtunnlar (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2014). Performance-based design of road tunnel fire safety: Proposal of new Swedish framework. *Case Studies in Fire Safety, 1*(0), 18-28. doi: http://dx.doi.org/10.1016/j.csfs.2014.01.002 Ingason, H., Li, Y. Z., & Lönnermark, A. (2015). *Tunnel Fire Dynamics*. New York: Springer.

5.1.18 Replacement of “elephant foot” into more curved sections

Best Practice #48	
Field	**Description**
Title and Keywords	Title: **Replacement of “elephant foot” into more curved sections** Keywords:
Source of best practice	
Lifecycle stage	Design
Type of infrastructure	Multi-model
Component of infrastructure	Tunnel
Element of the infrastructure	Tunnel Section
Short Description	“elephant foot” is a common tunnel section used in soil or soft rock in order to relay the crown loads to the ground at the middle

	of the section. Thereby such loads are withstood by invert support.
Success factors	When the soil bearing capacity is too low to resist loads, with more curved sections it is possible to reduce flexure and tensile stresses, which means reducing the support systems considerably.
Constraints	Wrong conceptual approach.
Main impacts	Overburden excavation up to 15% with "elephant foot" implementation is avoided.
Maturity and degree of implementation	Increasingly implemented.
Key Performance Indicators	
Further information	

5.1.19 Performance-based requirements and recommendations for fire safety in road tunnels

Best Practice #50	
Field	**Description**
Title and Keywords	Performance-based requirements and recommendations for fire safety in road tunnels Fire safety, tunnels
Source of best practice	Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2013). Performance-based requirements and recommendations for fire safety in road tunnels (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2012). Funktionsbaserade krav och rekommendationer för brandsäkerhet i vägtunnlar (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2014). Performance-based design of road tunnel fire safety: Proposal of new Swedish framework. Case Studies in Fire Safety, 1(0), 18-28. doi: http://dx.doi.org/10.1016/j.csfs.2014.01.002 Ingason, H., Li, Y. Z., & Lönnermark, A. (2015). Tunnel Fire Dynamics. New York: Springer.
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Tunnel
Element of the infrastructure	Provision of fire safety
Short Description	A performance-based design guide for road tunnel fire safety derived from Swedish and European regulation is proposed. The overall purpose of the guideline is to protect life, health, property, environment, and key societal functions from fire. The guideline is structured into five key groups of requirements. Each group contains a hybrid of prescriptive requirements, performance-based requirements, and acceptable solutions. Prescriptive

	requirements must be fulfilled, however, it is the choice of the design team to either adopt the proposed acceptable solutions, or to design alternative solutions by verifying that performance-based requirements are satisfied. A scenario-based risk analysis with several specified input variables and methods is proposed.
Success factors	That responsible authorities acknowledges the design guide. On a case by case basis input parameters and required performance needs to be defined.
Constraints	Current legislation needs to allow for a performance-based design approach. If the regulation is prescriptive and tough, there si no room for safety tradeoffs or alternative solutions.
Main impacts	Functional road tunnel frie safety to a lower cost.
Maturity and degree of implementation	Road tunnel fire safety design is not a well researched area and regulation is working as a straight-jacket to maintain old solutions. Several assumptions and input parameters for designing fire safe road tunnels are uncertain and debatable.
Key Performance Indicators	
Further information	Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2013). Performance-based requirements and recommendations for fire safety in road tunnels (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2012). Funktionsbaserade krav och rekommendationer för brandsäkerhet i vägtunnlar (FKR-BV12). Borås, Sweden: SP Technical Research Institute of Sweden. Gehandler, J., Ingason, H., Lönnermark, A., Frantzich, H., & Strömgren, M. (2014). Performance-based design of road tunnel fire safety: Proposal of new Swedish framework. Case Studies in Fire Safety, 1(0), 18-28. doi: http://dx.doi.org/10.1016/j.csfs.2014.01.002 Ingason, H., Li, Y. Z., & Lönnermark, A. (2015). Tunnel Fire Dynamics. New York: Springer.

5.1.20 Control of Road Tunnel Ventilation Systems

Best Practice #51	
Field	**Description**
Title and Keywords	**Control of Road Tunnel Ventilation Systems** Keywords: Tunnel ventilation; Ventilation control; Pollution control; Fire safety
Source of best practice	Currently applied to the Mont Blanc Tunnel
Lifecycle stage	Design; maintenance
Type of infrastructure	Road
Component of infrastructure	Tunnel

Element of the infrastructure	Ventilation system
Short Description	The practice proposed consists of three steps **1.** Local measurement of the flow in the tunnel under scrutiny using steady and traveling anemometer rakes **2.** Creation and calibration of a one dimensional numerical model of the fluid-dynamics of the tunnel and its ventilation system **3.** Development of an ad hoc control system
Success factors	The technology proposed can be applied to all road tunnel with an active ventilation system (e.g., a Jet Fan system)
Constraints	There no specific constraints
Main impacts	Faster response and increased safety in case of a fire event; improved air quality in ordinary operative configurations by the control of air pollution levels.
Maturity and degree of implementation	Recently applied to the Mont Blanc Tunnel: replicable, adaptable
Key Performance Indicators	Time spent by the airflow in the tunnel to reach the desired flow conditions in a fire accident configuration; pollution levels in every possible atmospheric condition
Further information	References: – P Levoni, D Angeli, E Stalio, E Agnani, GS Barozzi, and M Cipollone. Fluid-dynamic characterisation of the Mont Blanc tunnel by multi-point airflow measurements. Tunnelling and Underground Space Technology, 48:110–122, 2015 – P. Levoni, A. Scorcioni, D. Angeli, E. Stalio, G.S. Barozzi, and M. Cipollone. T.A.L.P.A.: an innovative facility for continuous longitudinal airflow profile acquisition in tunnels. In Proceedings of the 30th U.I.T. National Heat Transfer Conference, Bologna, Italy, pages 325–330. Società Editrice Esculapio, 2012 Contacts: Dr. Enrico Stalio: enrico.stalio@unimore.it Dr. Paolo Levoni: paolo.levoni@mimesis.eu Dr. Diego Angeli: diego.angeli@unimore.it

5.1.21 Distance between twin tunnels

Best Practice #52	
Field	**Description**
Title and Keywords	Title: **Distance between twin tunnels** Keywords: Twin tunnel
Source of best practice	DRAGADOS
Lifecycle stage	Design and Construction
Type of infrastructure	Multi-modal
Component of infrastructure	Tunnel
Element of the infrastructure	Tunnel alignment
Short Description	It is wrongly assumed that distance between twin tunnel must be

	at least two diameters. This assumption is due to the fact that the ground pile between tunnels must withstand the redistribution of ground tensions during the excavation of the second tunnel. However it is possible to design the lining of the second tunnel so it can bear the groung loads without affecting the first excavated tunnel.
Success factors	It is possible to reduce the distance between tunnel to the minimum. The two diameters distance solution does not lead to an overcost in the tunnel construction. Nevertheless, by reducing such distance, cross passages can be much shorter or even don't exist (binocular tunnel).
Constraints	It is neccesary to design a proper lining with bearing capacity in order to minimize the twin tunnel distance.
Main impacts	Reduce or even eliminate cross passages.
Maturity and degree of implementation	Implementation in works depending on the designer's approach.
Key Performance Indicators	
Further information	

5.1.22 Cathodic Protection for Cutter Soil Mix retaining walls

Best Practice #53	
Field	**Description**
Title and Keywords.	**Cathodic Protection for Cutter Soil Mix retaining walls** Retaining wall, cathodic protection
Source of best practice	TNO Delft, The Netherlands
Lifecycle stage	Design, and Maintenance.
Type of infrastructure	Road, Rail, Water,
Component of infrastructure	Tunnel and Underpasses
Element of the infrastructure	Vertical retaining walls
Short Description	Corrosion mittigation of bearing profiles in Cutter Soil Mix (CSM) walls through a Cathodic Protection system.
Success factors	Generally applicable
Constraints	None
Main impacts	Allows a reliable application, specifically for long service life, of concepts for which assesment of crack width is beyond the state of the art.
Maturity and degree of implementation	Sucessfully applied
Key Performance Indicators	
Further information	BAM Infraconsult, TNO

5.1.23 Dimensioning of the typical cross section with an horizon year of traffic.

Best Practice #56	
Field	**Description**
Title and Keywords	Title: **Dimensioning of the typical cross section with an horizon year of traffic.** Keywords:Traffic flows, typical cross section, length of structures.
Source of best practice	Roads standards
Lifecycle stage	Planning and Design
Type of infrastructure	Roads
Component of infrastructure	Typical cross sections in a road.
Element of the infrastructure	Elements in a typical cross section sized by traffic flows (number of lanes, thickness of pavement, length of structures over and under the road…)
Short Description	Size roadway systems at a level of service that allow some flexibility in the future and consider to design some elements (structures, central reserve…) to allow additional lanes in case they will be needed in future.
Success factors	Good traffic studies and forecasts. Economical stability in terms of stability in traffic growth and development.
Constraints	It is necessary to anticipate the investment to the need. Increase the right of way acquisition. Incertain traffic studies based on future economical stability.
Main impacts	Economical cost reduction in the future if it is needed to widen the road. Social impact reduction if it is needed to widen the road (no right of way acquisition, no new areas of work….).
Maturity and degree of implementation	It is quite common that projects foresee a wide central reserve or longer structures that allow a new lane if it is foreseen in the traffic study of the project.
Key Performance Indicators	
Further information	

5.1.24 Standardization of viaducts for infrastructure crossings

Best Practice #57	
Field	**Description**
Title and Keywords.	**Standardization of viaducts for infrastructure crossings**
Source of best practice	Master thesis of Delft University of Technology, The Netherlands, in cooperation with BAM
Lifecycle stage	Design and Construction
Type of infrastructure	Road, Rail, Water,
Component of infrastructure	Viaducts

Element of the infrastructure	Deckstructures of viaducts and abutments
Short Description	Decision model to obtain the optimum solution in relation to functional requirements and boundary condition
Success factors	Focus on: Optimization of concept, reduction of risk, and minimization of manhours for design
Constraints	non
Main impacts	See success factors
Maturity and degree of implementation	In use at BAM
Key Performance Indicators	.
Further information	Library Delft University, BAM Infraconsult

5.1.25 Gdansk Urban Transport Project (IIIC stage) – Multimodal Hub Platform Design

Best Practice #59	
Field	**Description**
Title and Keywords	Title: **Gdansk Urban Transport Project (IIIC stage) – Multimodal Hub Platform Design** Keywords: multimodal hub, platforms, transport integration
Source of best practice	Municipal Council of Gdansk, Poland
Lifecycle stage	Design
Type of infrastructure	Multimodal
Component of infrastructure	Multimodal hubs
Element of the infrastructure	Platforms with surrounding infrastructure (stairs, lifts, pavements, passenger information system)
Short Description	This table discusses specificity of platforms located in three multi-modal hubs which were constructed as part of Gdansk Urban Transport Project (IIIC stage): “Jasien”, “Kielpinek” and “Bretowo”. Each platform is accessible for people with physical disabilities and includes other solution which improve attractiveness of low-emission public transport: • Stairs and lifts guaranteeing comfortable connections between tram, bus and suburban train stops • Quick and easy access to bicycle parking which is dedicated for passengers and located in close proximity of the platforms • Quick and easy access to car parking which is also dedicated for passengers and located in close proximity of the platforms (except the “Kielpinek” hub) • Electronic passenger information system • Platform height adapted to parameters of vehicle doors Additionally, the “Bretowo” multi-modal hub offers one common platform, where “door to door” transfers are available.

	 **Multi-modal hub “Bretowo”, source: http://phototrans.eu**  **Multi-modal hub “Bretowo”, source: Gazeta Baltycka**  **Multi-modal hub “Jasien”, source: Gazeta Baltycka** Described infrastructure is an integral part of Gdansk investment activity aimed at improvement of urban mobility (daily/urban mobility) with particular emphasis on electric transport as part of the concept of electromobility (trams and low/zero-emission buses which reduce CO^2 emission and encourage to use public transport).
Success factors	This example can be replicated in all investment avtivities aimed at integration of various types of public transportation, when at least two transport modes have to be well connected to enable fast and effective passenger flows.
Constraints	• Low availability of space which can be used for creation of effective connections between various transport modes • Reluctance of passengers to transfers between various transport modes (passengers prefer direct connections)

	• Lack of tariff integration between various operators
Main impacts	Platforms constructed as a part of the Gdansk Urban Transport Project (IIIC stage) can be seen as a good example of solutions aimed at optimising design of multi-modal hubs and terminals for passengers. Described infrastructure: • Allows to integration of low emission buses, trams and suburban train systems • Improves the quality of sustainable modes and 'mobility as a service' • Provides more efficient passenger flow • Improves accessibility of public transport
Maturity and degree of implementation	Task finished and fully implemented. It is excepted that it will improve attractiveness of local public transport, as in the case of previous stages of Gdansk Urban Transport Project which resulted in increase in the number of public transport passangers from 147 million in 2009 to over 168 million in 2013.
Key Performance Indicators	
Further information	http://www.gdansk.pl/urzad/mobile,512,31022.html (only in Polish)

5.1.26 Good coordination between vertical and horizontal alignment

Best Practice #60	
Field	**Description**
Title and Keywords	Title: **Good coordination between vertical and horizontal alignment.** Keywords:Horizontal and vertical alignment, sight stopping distance, drainage, safety.
Source of best practice	Roads standards
Lifecycle stage	Design
Type of infrastructure	Roads
Component of infrastructure	Alignment and typical cross section.
Element of the infrastructure	Typical cross section and surface course in pavements.
Short Description	Good coordination between vertical and horizontal alignment to improve sight stopping distance and also in terms of drainage in the carriageway (vertical alignment without low points and small gradients in rollovers).
Success factors	Good sight stopping distance analysis taking into account all the elements in the cross section for the design speed.
Constraints	To improve the sight stoping distance sometimes it is needed widening the clear zone in the cross section. This means higher quanties of earthworks. To improve the alignment in terms of carriageway drainage sometimes means alignment restriction that can affect to the earthworks balance.

	Increase the economical cost.
Main impacts	Safety improvement.
Maturity and degree of implementation	It is quite common to perform a visibility check but sometimes it does not include all the real obstructions in the cross section (barriers, structures…) In some countries it is necessary to do a water level study in rollovers to avoid hydroplaning.
Key Performance Indicators	
Further information	

5.1.27 Infrastructure Lifecycle Management

Best Practice #61	
Field	**Description**
Title and Keywords	Title: **Infrastructure Lifecycle Management** Keywords: BIM, Infrastructures lifecycle, Efficiency & Quality improvements.
Source of best practice	Ferrovial Agroman
Lifecycle stage	Design, Construction & Maintenance.
Type of infrastructure	All types of infrastructure
Component of infrastructure	The infrastructure as a whole.
Element of the infrastructure	The infrastructure as a whole.
Short Description	The inovative working philosophy, based on BIM, boosts collaboration and effective information management. This approach also involves clients, subcontractors, consultants, etc.
Success factors	The implementation of the new working model has improved the way the company manages the information and consequently the consecution of measurable impacts.
Constraints	Constraints are mainly related to the level of implementation of BIM in the projects.
Main impacts	Design stage: - Improving the understanding of clients requirements - Full stakeholders engagement - Running clash detection for spatial coordination between disciplines. - Design optimization. Construction stage: - Minimising H&S risks - 4D modelling. Improved construction programme planning - Field management - Quantity take-offs to optimise cost control (5D) Maintenance stage: - Verifying and complying with client requirements and

	standards - Deliver, log and archive information more efficiently - Building familiarisation and training
Maturity and degree of implementation	Implemented in the U.K. and in progress in other countries such as Spain.
Key Performance Indicators	As the model involves the whole project, we can use the general KPIs of the project and monitor their evolution after the implementation of ILM.
Further information	Ferrovial Agroman internal procedure

5.1.28 MEAT (Most Economically Attractive Tender) stategy in Tenders

Best Practice #62	
Field	**Description**
Title and Keywords.	**MEAT (most economically attractive tender) stategy in Tenders**
Source of best practice	Dutch state department for transportation
Lifecycle stage	Design,
Type of infrastructure	Road, Rail, Air, Water, Multi-modal.
Component of infrastructure	All
Element of the infrastructure	All
Short Description	Value creation components added to cost optimization of infrastructure tenders. Cost and value as basis for contract award
Success factors	Value identification and appraisal by Clients
Constraints	MEAT aspects should be SMART
Main impacts	Optimum approach of specific value aspects, in combination with cost optimization
Maturity and degree of implementation	In use
Key Performance Indicators	
Further information	BAM Infraconsult, Rijkswaterstaat, Prorail

5.1.29 Performance Based Design

Best Practice #63	
Field	**Description**
Title and Keywords.	**Performance Based Design**
Source of best practice	Contract Documents in Civil Engineering
Lifecycle stage	Design, Construction and Maintenance.
Type of infrastructure	Road, Rail, Air, Water, Multi-modal.
Component of infrastructure	Integral Project
Element of the infrastructure	See avove

Short Description	Performance Based requirements in stead of Deemed to Satisfy requirements as basis for design, construction and maintenance
Success factors	SMART definition of the Functional Requirements
Constraints	Adequate and reliable analysis tools and the criteria.
Main impacts	Optimum match betweem the concept and the intended purpose
Maturity and degree of implementation	Applied in Civil Engineering projects
Key Performance Indicators	
Further information	BAM Infraconsult

5.1.30 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

Best Practice #64	
Field	**Description**
Title and Keywords	Title: **Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures.** Keywords: BIM, 3D, 4D , Planning, Infrastructures
Source of best practice	Current practice during last 30 years. High growht during last 10 years.
Lifecycle stage	Design, Construction & Maintenance
Type of infrastructure	All
Component of infrastructure	All
Element of the infrastructure	All
Short Description	4D Techniques allow the Virtual Construction of the infrastructure. Risk in construction can be reduced, the use of resources can be optimized, different alternatives can be easily evaluated…
Success factors	It is useful in all type of infrastructure. The Virtual Construction can be developed using different comercial softwares.
Constraints	It is important to develop the 3D model only to the level that the current step of the project needs. Interoperability between different softwares could be a real constraint.
Main impacts	Simplify the real construction of any type of infrastructure.
Maturity and degree of implementation	It had been used for years, but nowadays construction authorities of differents countries are developing legal regulations.
Key Performance Indicators	
Further information	

5.1.31 Wearables

Best Practice #67	
Field	**Description**

Title and Keywords	Title: **Wearables** Keywords: Warning presence, bitcoins, Smart-glasses, H&S
Source of best practice	Ferrovial Agroman and other stakeholders
Lifecycle stage	Construction
Type of infrastructure	All types of infrastructure
Component of infrastructure	The infrastructure as a whole
Element of the infrastructure	The infrastructure as a whole
Short Description	Wearables is a initiative which main objective corresponds to the definition of strategies to boost the use of wearables (smart-glasses, bracelets, etc.) in order to improve the performance and experience of professionals in the worksite. This initiative is focused on diverse aspects such as H&S, clash detection, use of AR, communications, etc.
Success factors	The implementation of these technologies is expected to improve many general aspects in projects independently of the location. This is especially relevant for a multinational company, because the use of wearables can save some barriers such as cultural differences, language, specific ways to understand some processes, etc.
Constraints	Nowadays the main constraint identified corresponds to the lack of connectivity to the different networks (due to the location of the worksite, its characteristics, etc.).
Main impacts	Improvement of the productivity and quality of our products and services, the safety on our worksites while we are able to reduce the barriers that the globalization implies.
Maturity and degree of implementation	In the context fo the initiative, we are internaly developing different technologies, internally or as a part of a consortium, related to wearables. For example, some of the projects we are currently developing are: 1. **Warning Presence of People (WPP)** (Ferrovial Agroman project) Safety system designed to avoid collisions on site. It consists of a device with an acoustic and light alarm system in the machine's cab and another wearable one attached to the clothing of operators working outside, both being interconnected. If either of the devices comes close to the other and there is risk of collision, the system activates the alarm. 2. **Project ACCEPT** (H2020 project) Assistant for quality check during construction execution processes for energy-efficient buildings. The assistant will run

	on Smart Glasses and unobtrusively guide workers during the construction (on site).
Key Performance Indicators	As the idea is related to the improvement of the whole project, we expect to use the general KPIs of the project and monitor their evolution after the implementation of the wearables.
Further information	You can find further information in the website http://accept-project.com/

5.1.32 BIM 4D, 5D, 6D for construction simulation

Best Practice #68	
Field	**Description**
Title and Keywords.	**BIM 4D, 5D, 6D for construction simulation**
Source of best practice	Further development of 3D techniques
Lifecycle stage	Design, Construction and Maintenance.
Type of infrastructure	Road, Rail, Air, Water, Multi-modal.
Component of infrastructure	Integral all components
Element of the infrastructure	See above
Short Description	3D Model extended with Time and Cost to simulate consequences of Concepts and the realization thereof in relation to Cost and Time. 6D extension to demonstate compliance with requirements
Success factors	Virtual construction attitude
Constraints	Application does require a revision of the traditional roles of the diciplines in construction
Main impacts	Optimum solution and reduction of risk
Maturity and degree of implementation	5D in operation, 6 D under development
Key Performance Indicators	Indicators according to the definition of the RMMTI model that help to assess the efficiency of the described practice.
Further information	BAM Infraconsult, The Netherlands

5.1.33 Environmental Life Cycle Assessment: Evaluation of Alternative Infrastructural Solutions Associated With Each Transport Case

Best Practice #69	
Field	**Description**
Title and Keywords	Environmental Life Cycle Assessment: Evaluation of Alternative Infrastructural Solutions Associated With Each Transport Case. Keywords: life cycle assessment (LCA), transport infrastructure, environmentally friendly.
Source of best practice	The information will be collected from various sources. For

	the existing technology the most recent version of ecoinvent database will be used (ecoinvent database is the most comprehensive commercial database regarding the environmental concerns). However, for the innovative solutions that information could not be obtained from the ecoinvent database, the information is required to be collected and compiled on an LCA software tool with help of the consortiums who are claiming for their best practices. In addition, ISO Standard 14040, EN 15978 Standard and EN 15804 Standard are used as guidelines to structure the work in a systematic way. N.B. One should be highlighted regarding the collection of data from the consortiums is that this works is not against the confidentiality of information. Instead, it aims to bring a more transparent and structured assessment regarding each environmental claim corresponding to the best practice. Moreover, through a non-discloser agreement, it will be strived to encrypt the merit of technology.
Lifecycle stage	Early planning
Type of infrastructure	Road, Rail, Air, Water, Multi-modal.
Component of infrastructure	This work can cover all components corresponding to each type of transport infrastructure.
Element of the infrastructure	This work can cover all elements corresponding to each component of the transport infrastructure.
Short Description	Challenges regarding design-build-renovate-maintain transport infrastructure vary from one place to another. These changes can be due to different climatic conditions, land topologies, traffic distributions etc. that influence the pertinent choices with diverse magnitudes. This at the end results to have different transport infrastructural solutions for each case. In addition, the transport infrastructures are natural resource intensive and put a burden on the environment as well as the economy. Understanding of environmental impacts of alternative transport infrastructural solutions (for each case) may help decision makers to backcast and have a better systematic overview over the environmental performances of the alternative solutions for each case over a long-term analysis periods. Hence, it is important to know what the environmental performance of the best current transport infrastructural solution is as long as it is fulfilling the economic and technical performance criteria over a long-term analysis periods. This helps to have a broad overview of the impacts associated with alternative decisions before reaching to the conclusion of

	designing and consecutive stages.
Success factors	This work has a possitive success factor due to declaring the environmental claims and the environmental performance for each transport solution linked to each case. Correpondingly, this work can be considered as the "environmental indicator" in order to measure the transport solutions in the planning stage before reaching to the investment and design phase.
Constraints	Environmental life cycle assessment is a very data intensive study that requires reliable data especially from producers for new technologies and materials in order to deliver a satisfactory work.
Main impacts	This work delivers an understanding over the environmental impacts associated with alternative transport solution corresponding to each transport case.
Maturity and degree of implementation	Environmental life cycle assessment is a well-established and widely used methodology due to the increased awareness of importance of environmental stewardship. The LCA analysis quantifies and evaluates potential environmental impacts associated with product systems over a defined life cycle. And, it assists in finding critical stages and/or processes (hot spots) to better understand and address the impacts.
Key Performance Indicators	Selection of the environmental indicators will be based on the EN 15804 standard. The prescribed impact assessment consists of seven impact categories named: Depletion of abiotic resources-elements (kg Sb equiv.), Depletion of abiotic resources-fossil fuels (MJ, net calorific value), Acidification for soil and water (kg SO_2 equiv.), Ozone Depletion (kg CFC 11 equiv.), Global Warming (kg CO_2 equiv.), Eutrophication (kg $(PO_4)^{3-}$ equiv.), Photochemical ozone creation (kg Ethene equiv.).
Further information	Chalmer University of Technology Civil and Environmental Engineering Building Technology bijan.adl-zarrabi@chalmers.se babake@chalmers.se holger.wallbaum@chalmers.se

5.1.34 Climate impact and energy demand calculation

Best Practice #70	
Field	**Description**
Title and Keywords.	**LCA, climate impact, energy use, infra structure, calculator**
Source of best practice	Swedish Transport Administration, Klimatkalkyl 3.0

	Language Swedish http://www.trafikverket.se/contentassets/eacf8784f0b341c4a4198d40eb620134/klimatkalkyl_v3_150826.xlsm
Lifecycle stage	Landscaping, construction and use
Type of infrastructure	Roads, rail ways, tunnels, constructions, equipment steel and electricity
Component of infrastructure	The entire road and rail construction
Element of the infrastructure	
Short Description	Characterization values for climate impact and energy demand are transparent and have references. Data represent mostly Swedish conditions. There is also a table for Reference Service Life for different constructions Quantify the infrastructure and the calculator quantify climate impact and energy demand.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	Can now be use for rough estimate of different infra structure scenarios in early stage planning. The database is not so specific but broad.
Key Performance Indicators	
Further information	

5.1.35 Sustainable use of construction materials for transport infrastructure

Best Practice #71	
Field	**Description**
Title and Keywords	**Sustainable use of construction materials for transport infrastructure** Primary aggregates, secondary sources, mass balance
Source of best practice	Current practice in Norway and Sweden, Switzerland etc. But still many gaps. See below!
Lifecycle stage	Planning and construction phase
Type of infrastructure	Road or tunnels, railway ballast etc when constructed in/with rocks
Component of infrastructure	All parts of the road construction, all parts below the rails, concrete lining etc in tunnelling
Element of the infrastructure	See above
Short Description	Transition to usage of materials along the infrastructure is a key to sustainable material supply
Success factors	Beforehand knowledge about the rock quality and suitability for different areas such as concrete, wearing coarse… Knowledge

	about differences in materials testing when the material comes from small sized sampling (e.g. drill cores) versus a crushing plant. Stock piling possibilities.
Constraints	Primarily logistics, time constraints and stockpile locations, especially in urban construction
Main impacts	All materials extracted during construction are used for the construction itself. Extra materials/aggregates come from secondary sources. This leads to a very low environmental impact.
Maturity and degree of implementation	Used in several pilots. Standard for open road and railway construction in Sweden, not for tunnelling.
Key Performance Indicators	
Further information	

5.1.36 Ecological restoration in areas affected by lineal infrastructures and mining sites

Best Practice #72	
Field	**Description**
Title and Keywords	Title: **Ecological restoration in areas affected by lineal infrastructures and mining sites** Keywords: ecological restoration, sustainability
Source of best practice	R&D projects for more than 12 years in Spain and abroad, with a strength collaboration among industry (construction groups) and universities. Some successful experiences on sites in Spain and Latin America.
Lifecycle stage	Design, Construction and Maintenance.
Type of infrastructure	Mining sites, linear infrastructures (roads, rails),
Component of infrastructure	Areas with natural vegetation, degraded areas or new-built areas such as roadslopes, recreational areas, riverine areas, man-made created ponds, etc.
Element of the infrastructure	Soils, vegetation, fauna, landscape
Short Description	Site-specific analysis and identification of the main ecological processes altered at the site as a consequence of the construction project. Performance of an analytical site-specific diagnosis to stablish the main objectives of the restoration project. The most accurate and adapted to site technologies are applied to reach specific objectives.
Success factors	Correct diagnosis and time, since restoration of degraded areas is a time-consuming process.
Constraints	New disturbance sources in the area, weather conditions, incorrect diagnosis of the main disturbance sources and their effects on ecological processes.
Main impacts	Economic advantages since both execution and maintenace

	costs are reduced. Ecological and landscape advantages, as a result of : • better environmental integration of degraded areas • enchancement of ecosistem services • biodiversity increase
Maturity and degree of implementation	This practices have had an important development in the last 10 years, counting already on some specialists all around the world, thus they are not yet commonly adopted.
Key Performance Indicators	Biodiversity indexes, erosion indexes, water pollution indexes, soil quality indexes.
Further information	"Restauración ecológica de áreas afectadas por infraestructuras del transporte. Bases científicas para soluciones técnicas". Fundación Biodiversidad. 2011.

5.1.37 Making rebar groups in precast pier elements

Best Practice #74	
Field	**Description**
Title and Keywords	Title: **Making rebar groups in precast pier elements** Keywords: precast pier, rebar groups
Source of best practice	Precast concrete industry
Lifecycle stage	Design and construction
Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Pier
Short Description	Forming rebar groups of vertical reinforcement in order to ease the connection between the precast main pier member and the pier cap and/or the foundation
Success factors	This measure helps to connect elements when erecting precast piers. The whole operation is carried out in a shorter time reducing connection problems
Constraints	Limitations included on Standards in relation with maximum distances between bars must be met
Main impacts	This practice eases erection procedures and helps to carry out operations safely and on time
Maturity and degree of implementation	Widely used in precast concrete industry
Key Performance Indicators	-
Further information	-

5.1.38 Timber bridge monitoring of moisture

Best Practice #77	
Field	**Description**

Title and Keywords	Title: **Timber bridge monitoring of moisture** Keywords: timber bridge, monitoring, wooden/glulam deck
Source of best practice	SP Technical Research Institute of Sweden
Lifecycle stage	Design and maintenance
Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Timber decks, girders, beams, columns, railings, arches
Short Description	SP Monitor is a measuring service from SP for monitoring moisture in wooden structures. It is a simple and affordable solution for control and monitoring of moisture in bridge elements of wood. It is a long-term, well-tested and scalable system for both the manual measurement on site and an online measuring service for monitoring over time. SP Monitor is available as a standard accessory to new bridges and can be installed in the timber bridge factory for the measurements that are within the maintenance plan. SP Monitor can also be easily retrofitted in-situ to meet the need for accurate moisture measurement in already constructed bridges, to improve the quality of the measurements carried out at the main inspections or for follow-up of completed repairs or maintenance.
Success factors	SP Monitor is in its simplest form completely passive with no electronics and components that require protected environment, maintenance or power supply. The sensors are expected to work during the life of the bridge. The measurements are based on well proven and widely accepted measurement techniques. Sensors are calibrated, and measurements give proper correction for temperature and wood in construction (pine, spruce etc).
Constraints	It is a small additional investment cost, and there is a low cost of making a measurement.
Main impacts	It is essential to measure the moisture in timber bridges correctly because moisture is the main threat to the long term durability. The expected service life for timber bridges is strongly linked to avoiding high moisture in the construction. The monitoring systems must be reliable with quality assured moisture measurements and database management. Better control can give longer service life for the bridges.
Maturity and degree of implementation	SP Monitor has been in operation since 2008 and is currently used by researchers, construction companies, timber bridge manufacturers, the Road Adminsitration and property companies, mainly in Sweden.
Key Performance Indicators	
Further information	

5.1.39 Use of a lower concrete slab in steel-concrete composite box girders (also called “double composite action”)

Best Practice #78	
Field	**Description**
Title and Keywords	**Use of a lower concrete slab in steel-concrete composite box girders (also called “double composite action”).** Keywords: double composite action, lower slab, composite box girder
Source of best practice	Current practice in some countries, specially in Spain
Lifecycle stage	Design
Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Deck
Short Description	It consists in a concrete slab located directly on the lower plate of the steel box girder and connected to it by stud (shear connectors). Longitudinally, it is situated in zones near the pier bearing sections, i.e. the negative bending moment zones. Cast-in-place of the lower slab is easy as it needs no formwork, because it is poured directly on the lower plate of the steel box.
Success factors	It is useful in all composite steel-concrete box girders with al least 1 pier (otherwise, ther is no negative bending moment).
Constraints	It is not so efficient in case of very narrow box girders, where there is no enough wide space to place the concrete required area. Usually the lower slab reaches a high compression stress (much more than the upper slab), so it is necessary to use a relatively high compressive strength concrete. It requires to add a step in the bridge construction process, because it is necessary to make the lower slab after the steel structure is completed and before casting the upper slab. It increases the weight of the structure (but not too much).
Main impacts	The lower slab allows to resist a part of the compression due to bending moment by mean of concrete instead of steel; the box girder lower plate can be thinner so it results in an important saving of money because it is much less expensive to resist compression by concrete. Other effect is to lower the gravity center of the box section, so there is a larger part of the webs in tension instead of compression, making the cross section more compact, allowing bigger stresses in the webs (getting more efficiency) and increasing the ductility of the structure.
Maturity and degree of implementation	Very used in some countries, specially in Spain, since the ‘70s
Key Performance Indicators	
Further information	

5.1.40 Use of weathering steel in steel structures

Best Practice #80	
Field	**Description**
Title and Keywords	**Use of weathering steel in steel structures** Keywords: Weathering steel
Source of best practice	-
Lifecycle stage	Design
Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Deck
Short Description	Use of weathering steel in beams, girders and trusses of steel and composite bridge decks instead of painted steel
Success factors	It is useful generally, but specially in cases where maintenance works are difficult
Constraints	It is not suitable in places near the sea (5 km or less) or in industrial atmosphere. It is not so advantageous in box girders because inner surfaces must be coated.
Main impacts	There is no need for maintenance of weathering steel outer surfaces because they need no paint protection, so open structures (e.g. I-beams) don´t need to be coated. Closed elements as truss box members neither need to be coated if they are sealed.
Maturity and degree of implementation	Very used in many countries since a long time
Key Performance Indicators	-
Further information	-

5.1.41 Avoid overlapping of reinforced bars at maximum stress sections

Best Practice #81	
Field	**Description**
Title and Keywords	**Avoid overlapping of reinforced bars at maximum stress sections** Keywords: overlapping, reinforced bars
Source of best practice	-
Lifecycle stage	Design
Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Deck & Subestructure
Short Description	Avoid overlapping of reinforced bars at maximum stress sections

Success factors	Move possible weakness sources to non critical sections
Constraints	It could be in conflict with optimizing the brealdown of the reinforcement
Main impacts	Reducing the risk and impact of a deficient overlapping, preserving the safety factors required by the local and national regulations
Maturity and degree of implementation	Commonly applied world wide
Key Performance Indicators	-
Further information	-

5.1.42 Avoiding the sliding of elastomeric bearing pads

Best Practice #82	
Field	**Description**
Title and Keywords	**Avoiding the sliding of elastomeric bearing pads** Keywords: sliding, elastomeric bearing pads
Source of best practice	Current practice in some countries
Lifecycle stage	Design
Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Bearings
Short Description	The sliding of elastomeric bearing pads is the movement of the bearing due to the fact that the horizontal force is greater than the friction between the bearing and its top and bottom contact surfaces. It is considered a minimum stress of 3 MPa to avoid sliding with permanent loads. The possible causes to explain the sliding in bearings are: the variation in the theoretical coefficient of friction, the variation in the estimated value of the forces involved, the overdimension of bearings, deviations from the type of bearing specified in the design, defects in the support surfaces and the failure to regularize slopes. Some actions can be taken to solve the sliding of bearings: bonded bearings with an epoxy resin binder, use bearings with vulcanised anchor steel plates with welded or bolted anchors, use bearings with checkered steel sheets vulcanised onto the upper and lower pad surface or arrangement of physical elements of steel or concrete to block the sliding.
Success factors	It is important to prevent sliding in order to avoid the complete loss of bearings which would change the distribution of loads

	and the stresses in the different elements of the structure.
Constraints	All the solutions to avoid the silding of bearings mean an increase of costs and a more difficulty during the construction. Some solutions can complicate the future replacement of bearings.
Main impacts	Preventing the sliding of bearings will avoid the bearings have to be relocated and spread out the replacement of bearings.
Maturity and degree of implementation	Very used in some countries
Key Performance Indicators	
Further information	

5.1.43 Real-time online Concrete Monitoring of temperature-development and strength-development based on state of the art maturity method and modern communication technology

Best Practice #90	
Field	**Description**
Title and Keywords	Title: **Real-time online Concrete Monitoring of temperature-development and strength-development based on state of the art maturity method and modern communication technology** Keywords: real-time monitoring, concrete strength and temperature, increase quality and lifetime of infrastructure, optimize construction process, reduce costs and increase speed by high quality, increase sustainability of infrastructure, increase safety
Source of best practice	1. cut and cover tunnel construction 2. mining type tunnel 3. bridge pylon 4. bridge deck
Lifecycle stage	Design – Construction – Maintenance
Type of infrastructure	Roads and Railroads
Component of infrastructure	Bridges, Tunnels, Concrete Topping of roads
Element of the infrastructure	Deck, pylon, inner line of Tunnel
Short Description	Real-time monitoring of concrete works like this: - measuring the concrete temperature development in the concrete on site - data evaluation – calculation of the concrete strength by using the maturity method (de Vree or Saul..) by using a calibration of the used concrete - using the data of temperature and strength for determination of striking time of formwork, time for finishing curing – reduce cracks, for quality management by storing the data in a BIM system
Success factors	The will and the power to realize the way to optimize the

	construction process
Constraints	If there is no interest and persons which are responsible to work with the measured concrete data for quality management and optimization of the construction process there will less worth by using concrete monitoring. The benefit of the data is depending by the use of the data.
Main impacts	Here are the main impacts for infrastructure from planning, construction and maintenance: **Bridges:** Increase speed for climbing for pylons, right estimation for the time of pre-stressing, optimize the curing – prevention of terminal cracks **Tunnel:** Increase cycle time, monitoring of temperature to prevent termal cracks **Road concrete topping**: Optimize cycle time and curing time **General:** increase Quality and sustainability by using data in BIM systems, reduce CO2 by reduction of cement
Maturity and degree of implementation	Well established in the Netherlands and Belgium and starts to establish in Germany, Austria, UK….., the use of the maturity calculation is defined in the EN 13670, In overseas the maturity method is also high established in northern America ASTM C 1074-04
Key Performance Indicators	
Further information	- CONFIRMATION OF REAL TIME CONCRETE STRENGTH IN CONSTRUCTION PROJECTS (11 CCC Congress 2015/Austria) - REALTIME MONITORING OF HYDRATION TEMPERATURE-AND COMPRESSIVE-STRENGTH-DEVELOPMENT OF CONCRETE (Bridge Conference Wisla 2015)

5.1.44 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

Best Practice #91	
Field	**Description**
Title and Keywords	Title: **Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)**. Keywords: micropile, foundation, grout, slope stabilization.
Source of best practice	International codes, standards and publications. For example, in Spain, "Guía de Ejecución de Micropilotes". In USA "FHWA Micropile Design and Construction".
Lifecycle stage	Design, Construction.
Type of infrastructure	Multi-modal.
Component of infrastructure	Bridges, tunnels, slopes, embankments.
Element of the infrastructure	Foundation, earth reinforcement.

Short Description	A micropile is a small-diameter (typically less than 300 mm), drilled and grouted non-displacement pile that is typically reinforced. A micropile is constructed by drilling a borehole, placing steel reinforcement, and grouting the hole. Micropiles can withstand relatively significant axial loads and moderate lateral loads, and may be considered a substitute for conventional driven piles or drilled shafts or as one component in a composite soil/pile mass, depending upon the design concept employed. Micropiles are installed by methods that cause minimal disturbance to adjacent structures, soil, and the environment.
Success factors	Micropiles may be succesful under the following project-specific limitations: • project has restricted access or is located in a remote area. • required support system needs to be in close pile proximity to existing structures. • ground and drilling conditions are difficult. • pile driving would result in soil liquefaction. • vibration or noise needs to be minimized. • hazardous or contaminated spoil material will be generated during construction. • adaptation of support system to existing structure is required.
Constraints	Vertical micropiles may be limited in lateral capacity and cost effectiveness. The ability of micropiles to be installed on an incline, however, significantly enhances their lateral capacity. Because of their high slenderness ratio (length/diameter), micropiles may not be acceptable for conventional seismic retrofitting applications in areas where liquefaction may occur due to concerns of buckling resulting from loss of lateral support. Specialized drilling equipment is often required to install the micropiles from within existing basement or other limited headroom facilities.
Main impacts	Micropiles can be installed where access is restrictive and in all soil types and ground conditions. Micropiles can be installed at any angle below the horizontal using the same type of equipment used for the installation of ground anchors and for grouting projects. Since the installation procedure causes minimal vibration and noise and can be used in conditions of low headroom, micropiles are often used to underpin existing structures. Micropile structural capacities rely on high-capacity steel elements to resist most or the entire applied load. These steel elements may occupy as much as one-half of the drillhole cross section of cast-in-place drilled or non-displacement piles. The

	special drilling and grouting methods used in micropile installation allow for high grout/ground bond values along the grout/ground interface. The grout transfers the load through friction from the reinforcement to the ground in the micropile bond zone in a manner similar to that of ground anchors.
Maturity and degree of implementation	Well known technique widespread all around the world.
Key Performance Indicators	Load testing. The maximum verification test load will usually be 2.0 to 2.5 times the design axial (compression or tension) load. For lateral load tests, tests are performed to 2.0 times the design lateral load.
Further information	• FHWA (2000), "Micropile Design and Construction Guidelines Implementation Manual". Report No. FHWA-SA-97-070. • Guía para el Proyecto y Ejecución de Micropilotes en Obras de Carretera. Ministerio de Fomento (2005). • Bustamante, M. (1986): «Un método para el cálculo de los anclajes y de los micropilotes inyectados».

5.1.45 Use of correct rebar spacers for concrete infrastructures in aggressive environment

Best Practice #92	
Field	**Description**
Title and Keywords	Title: **Use of correct rebar spacers for concrete infrastructures in aggressive environment** Keywords: Rebar spacer, Concrete cover, Durability
Source of best practice	Current practice in some countries
Lifecycle stage	Design
Type of infrastructure	Multi
Component of infrastructure	Concrete structure
Element of the infrastructure	All
Short Description	A rebar spacer is a device that secures the correct concrete cover to the reinforcing steel or "rebar" in reinforced concrete structures as the rebar is assembled in place prior to the final concrete pour. The rebar spacers are left in place and become a permanent part of the structure. The rebar spacer and its interface to the surrounding concrete is a possible weak spot with regard to the durability of the structure. To obtain high durability of concrete infrastructures it is recommeded to use non-corrosive rebar spacers of high quality and good bond to the surrounding concrete. This is mainly done by use of high quality concrete spacers. Plastic has generally a significant higher coefficient of thermal expansion than that of concrete, and when the concrete temperature first increases in the plastic phase and secondly decreases in the hardened phase, it results in a

	separation between the plastic rebar spacers and the poured concrete, creating a free passage for corrosive agents to reach the steel reinforcement from the environment.
Success factors	The optimum rebar spacer is easily mounted, have sufficient load-bearing capacity, maintains its position during casting to ensure correct cover, is less permeable than the concrete, and leaves no gap in the interface between the rebar spacer and the surrounding concrete.
Constraints	The geometry and the surface roughness of the concrete rebar spacer is important to avoid bad casting joints between the spacer and the sorrounding concrete. Vertical oriented faces should be omitted to avoid creation of permanent gaps from bleeding water and setting of the concrete. In general, point shaped rebar spacers should be preferred to linear rebar spacers. Furthermore, it is important that the rebar spacer is proven to be less permeable than the surrounding concrete.
Main impacts	Correct use of appropriate rebar spacers ensures correct concrete cover and high durability of the concrete infrastructure.
Maturity and degree of implementation	Normally used to day in large infrastructure projects including bridges, tunnels and harbours.
Key Performance Indicators	
Further information	BS 7973-1:2001: Spacers and chairs for steel reinforcement and their specification. Product performance requirements

5.1.46 Permeable hard made surfaces for infrastructure

Best Practice #94	
Field	**Description**
Title and Keywords.	**Permeable hard made surfaces for infrastructure**
Source of best practice	BRRI (Belgium), Interpave (UK), SP, VTI (Finland), CBI, VTT www.greenurbansystems.eu (most parts in Swedish) http://www.vtt.fi/sites/class/en (most parts in Finnish) http://www.paving.org.uk/commercial/permeable.php (in English)
Lifecycle stage	Design and Construction, water retention capacity
Type of infrastructure	Roads, (today not those with the haviest loads)
Component of infrastructure	The entire road construction, including wearing coarse
Element of the infrastructure	See above. i.e. not only permeable asphalt but all layers beneath
Short Description	Construction of resilient hard made surfaces for handing traffic and stormwater
Success factors	Nordic climats as well as continental climate due to differences in winter maintnance and use of studded tyres, anti skid gravel

	etc.
Constraints	Mainly knowledge. Partly maintenance. Not sufficient knowledge about frequency of maintenance.
Main impacts	Open roads despite heavy rainfall. Less stress on standard water pipes. Less impact on waste water systems. Less costs due to flooding.
Maturity and degree of implementation	Already exists in several places in Belgium. 1% of all hard made surfaces. In Norden not on a regula basis. Demos will be built 2016.
Key Performance Indicators	
Further information	See references We develop a free webbased dimensioning programme for the construction

5.1.47 Safety considerations in the cross section

Best Practice #95	
Field	**Description**
Title and Keywords	Title: **Safety considerations in the cross section** Keywords:side and central reserve slopes, verges width, safety barriers
Source of best practice	Roads Standards
Lifecycle stage	Design
Type of infrastructure	Roads
Component of infrastructure	External elements in the cross section away from the carriageway
Element of the infrastructure	Verges, ditches, side slopes, cuttings and fillings slopes
Short Description	Analysis of the cross section in terms of safety in case of accident. Find alternatives solutions to safety barriers and do a cost-benefit evaluation.
Success factors	Evaluation of the safety in the infraestructure in terms of economical cost.
Constraints	Land occupation value. Wider sections increase the earthworks quantities (filling and cutting) and also the environmental impact and economical costs.
Main impacts	Improve safety, decrease the damage in case of accident. Wider sections that place obstacles far fron the carriageway and increase sight stopping distance.
Maturity and degree of implementation	There are some issues that are taking into account as safety slopes in verges and ditches but the barrier is mostly the alternative selected because of the economical cost.

Key Performance Indicators	
Further information	

5.1.48 Balanced infraestructure earthworks

Best Practice #96	
Field	**Description**
Title and Keywords	Title: **Balanced infraestructure earthworks** Keywords:Horizontal and vertical alignment, earthworks quantities, cross sections and reuse of materials.
Source of best practice	
Lifecycle stage	Design
Type of infrastructure	Roads and railways
Component of infrastructure	Fillings and cuttings
Element of the infrastructure	Fillings, cuttings, and pavements
Short Description	Design an infraestructure with earthworks balanced, trying to reuse the material that it are excavated, and balance the cutting and filling quantities required. Take into account horizontal and vertical alignment, posibilities in the cross section (slopes, verges width, safety clear zones…) and tecniques to reuse the materials availables.
Success factors	Good Knowledge about the type of materials that are along the scheme and if there are suitable for construction.
Constraints	The ground level sometimes does not allow to balance the earthworks (f.e.In flat areas mainly fillings). Projects sometimes are through areas with materials that are not suitable for construction (mainly for layers with high requirements….). Right of way
Main impacts	Less environmental impact. No borrow pits, no areas for materials disposal, less material transportation therefore less contamination. Less economical cost.
Maturity and degree of implementation	It is quite common that construction projects look for earthworks balance but sometimes the corridor is fixed by the right of way without taking into account the geotecnical conditions in the first stages of the design. When the corridor is fixed it is not so easy to balance the earthworks and have the best materials.
Key Performance Indicators	
Further information	

5.1.49 Adaptive use of Lighting on motorways

Best Practice #97	
Field	**Description**
Title and Keywords.	**Adaptive use of Lighting on motorways**
Source of best practice	Dutch state department of transportation
Lifecycle stage	Design,
Type of infrastructure	Road,
Component of infrastructure	Roas infrastructure as a whole
Element of the infrastructure	lighting
Short Description	Full automatic adaptation of lighting intensity relative to actual traffic volume
Success factors	Awareness of the potential
Constraints	none
Main impacts	Energy saving without compromising traffic safety
Maturity and degree of implementation	In use
Key Performance Indicators	
Further information	Rijkswaterstaat, The Netherlands

5.2 Type of Infrastructure: Rail (Design)

5.2.1 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

5.2.2 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

5.2.3 Use of End-of-Life Tyres (ELT) rubber into asphalt layers of pavements

See Section 5.1.10 (BP #32).

5.2.4 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

5.2.5 Multilayer susitanable tunnel linings

See Section 5.1.14 (BP #44).

5.2.6 Non-steel fibers reinforced concrete segments in tunnels

See Section 5.1.15 (BP #45).

5.2.7 Overburden length

See Section 5.1.16 (BP #46).

5.2.8 Replacement of "elephant foot" into more curved sections

See Section 5.1.18 (BP #48).

5.2.9 5.1.19 Performance-based requirements and recommendations for fire safety in road tunnels

See Section 5.1.19 (BP #50).

5.2.10 Distance between twin tunnels

See Section 5.1.21 (BP #52).

5.2.11 Cathodic Protection for Cutter Soil Mix retaining walls

See Section 5.1.22 (BP #53).

5.2.12 Method for the installation of slab tracks in twin tube tunnels

Best Practice #54	
Field	**Description**
Title and Keywords	Title: **Method for the installation of slab tracks in twin tube tunnels** Keywords: slab tracks, auxiliary track, railway, assembly.
Source of best practice	Current practice in some countries, specially in Spain
Lifecycle stage	Design and Construction
Type of infrastructure	Railways
Component of infrastructure	Tunnels
Element of the infrastructure	Track on a slab of concrete
Short Description	Method for the installation of slab tracks in tunnels, in particular tracks on a slab of concrete, with the optimized design and execution characteristics, and substantially increased performance compared to the normal known methods. The method includes a succession of phases executed in order, with the help of an auxiliary track, consisting of the design of the construction section, the construction of the railway yards, assembly of the auxiliary track form the evacuation platform, execution of the foundation base, assembly of the track in slabs, transitions from slab track, ballast track and placement of long bars and welding.
Success factors	The slab track guarantee the correct positioning of each one of the elements that make up the track, such as the rails and

	sleepers, keeping the geometric parameters unchanged over time, and on the other hand, require less maintenance work than traditional tracks, which thus allows the intervention times to be reduced and, consequently, increases the operating availability of the infrastructure.
Constraints	The criteria for their construction are much more demanding than those of traditional track, as they require greater precision in so far as refers to the levelling, alignment and track width, as any subsequent correction of possible mistakes is very expensive.
Main impacts	The slab track can either have embedded rails, that is, the rail is introduced onto the inside of a channel made in the concrete slab, in such a way that the rail is supported along its entire length with the resulting reduction of stress and a better distribution of the loads, both static and dynamic, or with the rail assembled on sleepers.
Maturity and degree of implementation	Very used by the company in several countries.
Key Performance Indicators	Process optimization, cost optimization
Further information	www.fcccco.es

5.2.13 Standardization of viaducts for infrastructure crossings

See Section 5.1.24 (BP #57).

5.2.14 Gdansk Urban Transport Project (IIIC stage) – Multimodal Hub Platform Design

See Section 5.1.25 (BP #59).

5.2.15 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

5.2.16 MEAT (Most Economically Attractive Tender) stategy in Tenders

See Section 5.1.28 (BP #62).

5.2.17 Performance Based Design

See Section 5.1.29 (BP #63).

5.2.18 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

5.2.19 Wearables

See Section 5.1.31 (BP #67).

5.2.20 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

5.2.21 Environmental Life Cycle Assessment: Evaluation of Alternative Infrastructural Solutions Associated With Each Transport Case

See Section 5.1.33 (BP #69).

5.2.22 Climate impact and energy demand calculation

See Section 5.1.34 (BP #70).

5.2.23 Sustainable use of construction materials for transport infrastructure

See Section 5.1.35 (BP #71).

5.2.24 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

5.2.25 Making rebar groups in precast pier elements

See Section 5.1.37 (BP #74).

5.2.26 Timber bridge monitoring of moisture

See Section 5.1.38 (BP #77).

5.2.27 Use of a lower concrete slab in steel-concrete composite box girders (also called "double composite action")

See Section 5.1.39 (BP #78).

5.2.28 Use of weathering steel in steel structures

See Section 5.1.40 (BP #80).

5.2.29 Avoid overlapping of reinforced bars at maximum stress sections

See Section 5.1.41 (BP #81).

5.2.30 Avoiding the sliding of elastomeric bearing pads

See Section 5.1.42 (BP #82).

5.2.31 Real-time online Concrete Monitoring of temperature-development and strength-development based on state of the art maturity method and modern communication technology

See Section 5.1.43 (BP #90).

5.2.32 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

5.2.33 Use of correct rebar spacers for concrete infrastructures in aggressive environment

See Section 5.1.45 (BP #92).

5.2.34 Balanced infraestructure earthworks

See Section 5.1.48 (BP #96).

5.3 Type of Infrastructure: Air (Design)

5.3.1 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

5.3.2 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

5.3.3 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

5.3.4 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

5.3.5 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

5.3.6 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

5.3.7 MEAT (Most Economically Attractive Tender) stategy in Tenders

See Section 5.1.28 (BP #62).

5.3.8 Performance Based Design

See Section 5.1.29 (BP #63).

5.3.9 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

5.3.10 Wearables

See Section 5.1.31 (BP #67).

5.3.11 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

5.3.12 Environmental Life Cycle Assessment: Evaluation of Alternative Infrastructural Solutions Associated With Each Transport Case

See Section 5.1.33 (BP #69).

5.3.13 5.1.34 Climate impact and energy demand calculation

See Section 5.1.34 (BP #70).

5.3.14 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

5.3.15 Use of correct rebar spacers for concrete infrastructures in aggressive environment

See Section 5.1.45 (BP #92).

5.4 Type of Infrastructure: Water (Design)

5.4.1 Use of concrete bulky armor units for breakwaters with enhanced face to face fitting behavior

Best Practice #35	
Field	**Description**

Title and Keywords	Title: **Use of concrete bulky armor units for breakwaters with enhanced face to face fitting behavior** Keywords: Bulky units, Armor unit, Breakwater armor elements
Source of best practice	Some breakwaters in Spain and other countries constructed in the last 5 years.
Lifecycle stage	Design and construction
Type of infrastructure	Breakwaters, harbors, ports
Component of infrastructure	Rubble mound breakwaters
Element of the infrastructure	Armor layers
Short Description	Concrete armor units (CAU´s) are widely used as armor elements in breakwaters when natural quarry stones are not available (in size or quantity). Hydraulic stability has to be assessed and depends on the shape of the elements. Massive elements (cubes) have low stability and face to face fitting and interlocking elements have high structural requirements and size limitation. New bulky elements with high hydraulic stability and industrial construction advantages have been developed and proven in Spain and other countries.
Success factors	Low strength requirements and high manufacturing and placing performance allow for great economic savings. The easy and flexible placing pattern make more realistic and adjusted the wave attack response to the tested design. Concrete consumption is 50% less than massive units like cubes. No size limitation is established.
Constraints	Slender units have less consumption of concrete than these new bulky elements, though they also have more constructive constraints and fragility associated risks.
Main impacts	Schedule, quantities and manufacturing facilities are improved due to the armor unit advantages in all these factors.
Maturity and degree of implementation	Already proven in several projects in Spain and North of Africa in the last 5 years.
Key Performance Indicators	
Further information	An example of this kind of new bulky elements: www.cubipod.com

5.4.2 Cathodic Protection for Cutter Soil Mix retaining walls

See Section 5.1.22 (BP #53).

5.4.3 Standardization of viaducts for infrastructure crossings

See Section 5.1.24 (BP #57).

5.4.4 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

5.4.5 MEAT (Most Economically Attractive Tender) stategy in Tenders

See Section 5.1.28 (BP #62).

5.4.6 Performance Based Design

See Section 5.1.29 (BP #63).

5.4.7 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

5.4.8 Wearables

See Section 5.1.31 (BP #67).

5.4.9 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

5.4.10 Environmental Life Cycle Assessment: Evaluation of Alternative Infrastructural Solutions Associated With Each Transport Case

See Section 5.1.33 (BP #69).

5.4.11 Climate impact and energy demand calculation

See Section 5.1.34 (BP #70).

5.4.12 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

5.4.13 Use of correct rebar spacers for concrete infrastructures in aggressive environment

See Section 5.1.45 (BP #92).

5.5 Type of Infrastructure: Multi-modal (Design)

This section provides a list of practices for construction of transport infrastructure which are multi-modal. In this context, multi-modal means that the practice can be applied to more than one type of infrastructure.

5.5.1 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

5.5.2 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

5.5.3 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

5.5.4 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

5.5.5 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

5.5.6 Lattice girder in tunnels

See Section 6.1.22 (BP #43).

5.5.7 Multilayer susitanable tunnel linings

See Section 5.1.14 (BP #44).

5.5.8 Non-steel fibers reinforced concrete segments in tunnels

See Section 5.1.15 (BP #45).

5.5.9 5.1.16 Overburden length

See Section 5.1.16 (BP #46).

5.5.10 Replacement of “elephant foot” into more curved sections

See Section 5.1.18 (BP #48).

5.5.11 5.1.19 Performance-based requirements and recommendations for fire safety in road tunnels

See Section 5.1.19 (BP #50).

5.5.12 Distance between twin tunnels

See Section 5.1.21 (BP #52).

5.5.13 Cathodic Protection for Cutter Soil Mix retaining walls

See Section 5.1.22 (BP #53).

5.5.14 Gdansk Urban Transport Project (IIIC stage) – Multimodal Hub Platform Design

See Section 5.1.25 (BP #59).

5.5.15 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

5.5.16 MEAT (Most Economically Attractive Tender) stategy in Tenders

See Section 5.1.28 (BP #62).

5.5.17 Performance Based Design

See Section 5.1.29 (BP #63).

5.5.18 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

5.5.19 Wearables

See Section 5.1.31 (BP #67).

5.5.20 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

5.5.21 Environmental Life Cycle Assessment: Evaluation of Alternative Infrastructural Solutions Associated With Each Transport Case

See Section 5.1.33 (BP #69).

5.5.22 Climate impact and energy demand calculation

See Section 5.1.34 (BP #70).

5.5.23 Sustainable use of construction materials for transport infrastructure

See Section 5.1.35 (BP #71).

5.5.24 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

5.5.25 Making rebar groups in precast pier elements

See Section 5.1.37 (BP #74).

5.5.26 Timber bridge monitoring of moisture

See Section 5.1.38 (BP #77).

5.5.27 Use of a lower concrete slab in steel-concrete composite box girders (also called "double composite action")

See Section 5.1.39 (BP #78).

5.5.28 Use of weathering steel in steel structures

See Section 5.1.40 (BP #80).

5.5.29 Avoid overlapping of reinforced bars at maximum stress sections

See Section 5.1.41 (BP #81).

5.5.30 Avoiding the sliding of elastomeric bearing pads

See Section 5.1.42 (BP #82).

5.5.31 Real-time online Concrete Monitoring of temperature-development and strength-development based on state of the art maturity method and modern communication technology

See Section 5.1.43 (BP #90).

5.5.32 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

5.5.33 Use of correct rebar spacers for concrete infrastructures in aggressive environment

See Section 5.1.45 (BP #92).

5.5.34 Balanced infraestructure earthworks

See Section 5.1.48 (BP #96).

6 Best Practices for Construction

6.1 Type of Infrastructure: Road (Construction)

6.1.1 Foamed bitumen stabilization

Best Practice #1	
Field	**Description**
Title and Keywords.	Title: **Foamed bitumen stabilization** Keywords: cold recycling, foamed bitumen, pavement rehabilitation
Source of best practice	Current practice in several countries including Slovenia
Lifecycle stage	Construction or Maintenance.
Type of infrastructure	Road
Component of infrastructure	pavement
Element of the infrastructure	Stabilized layer
Short Description	In situ rehabilitation of pavement damaged due to use of the frost suceptible unbound materials or inadequate bearing capacity of the existing pavement due to the increase of traffic load.
Success factors	Analysis of current pavement materials is needed. On basis of the existing materials properties and pavement structure, a mix design for foamed bitumen rehabilitation is prepared.
Constraints	It is not efficient in cases of city roads and roads with many drainge shafts or where level of the road can not be changed (many driveways, intersections, …)
Main impacts	Performance of the pavement is increased by use of the existing materials (environmental benefits). It is cost effective and quicker in comparison to the classical rehabilitation.
Maturity and degree of implementation	Widely used.
Key Performance Indicators	
Further information	

6.1.2 Improved self-propelled machine for roadway surface construction

Best Practice #2	
Field	**Description**
Title and Keywords	Title: **Improved self-propelled machine for roadway surface construction** Keywords: Soil/cement/pre-cracking machine
Source of best practice	Current practice in some countries, mainly in Spain
Lifecycle stage	Construction

Type of infrastructure	Road
Component of infrastructure	pavement
Element of the infrastructure	Road surface
Short Description	Self-propelled pre-cracking machine for roadway surface pavements in construction. The machine has portal frame with ends mounted on two self-propelled caterpillars, and chassis storing emulsion heating and injection system, hydraulic section and electricity-generating switchboard. A movable carriage, moving longitudinally on portal frame, has striker pin for performing vertical slide cutting operation and emulsion injection valve associated with emulsion heating and injection system. The machine forms fissures on cemented ground or highway, and injects compact emulsions into fissures without moving on highway surface and spoiling finished surface of highway.
Success factors	It operates with a low cost of implementation and operation and a speed equivalent to that of the spreader in all cases, while can effect both transversely and longitudinally cut.
Constraints	
Main impacts	This machine allows carry out cracks in soil-cement before compacting in order to avoid later cracking on that firm are induced. It moves through the outer region to the soil cement by the shoulder areas remaining on both sides of the trace, without spoiling its surface finish. No impact negatively on the IRI *(International Roughness Index)* It does not modify the soil cement in the surrounding area of the joint.
Maturity and degree of implementation	Very used by the company in several countries, mainly in Spain.
Key Performance Indicators	Surface finish, cracks perpendicular and parallel to the axis of the road.
Further information	www.fcccco.es

6.1.3 Innovative geosynthetics for aspahlt layers reinforcement

Best Practice #3	
Field	**Description**
Title and Keywords	Title: ***Innovative geosynthetics for aspahlt layers reinforcement***. Keywords: interlayer, grids, composite materials, reinforcement, cracking resistance, pavement.
Source of best practice	Emerging technology in several countries.
Lifecycle stage	Construction and Maintenance
Type of infrastructure	Multi-modal (Road and Air)
Component of infrastructure	Pavement
Element of the infrastructure	Asphalt layers.

Short Description	Asphalt layer reinforcement with geosynthetics can be considered one of the most effective pavement construction and rehabilitation technique since it is demonstrated that geosynthetics, when appropriately chosen and correctly installed at the interface of bituminous layers, are able to improve the mechanical properties of pavements against cracking due to repeated loading and reflective phenomena. A wide range of products can be classified as asphalt layer reinforcements fulfilling one or more of the following functions inside the pavement: providing enhanced tensile resistance, assuring stress absorbing interlayer, establihing waterproofing barrier.
Success factors	Asphalt layers reinforcement with geosynthetics can allow a noticeable enhancement of pavement service life for both new and rehabilitated pavements avoiding technical and economical disavantages for road users and administrators due to frequent and ineffective maintenance.
Constraints	The main constratint related to the use of geosynthetics for asphalt pavement reinfrocement is that the presence of an interlayer reinforcement may also hinder the full transmission of horizontal shear stress between asphalt layers, reducing the overall efficiency of the pavement system. This debonding effect can compromise the structural improvement provided by the reinforcement. Thus, the application of reinforcing materials close to the road surface should be carefully designed as a function of predicted stresses and strains at the interface. Moreover, costs of such materials are not negligible even if it can be demonstrated that, when correctly chosen and applied, the reinforcement is a highly cost-effective solution based on life cycle analysis. Finally, a still existing challenge is the right field installation of reinforcements. In fact, depending on the product, there could be difficulties in keeping the mesh flat during the laying of the upper layer with the paver machine and, in the case of wrong installation, the reinforcement might not work as expected, making its use ineffective from a technical and economic point of view.
Main impacts	Geosynthetics can be used for asphalt pavement reinforcement as a cost-effective tool for increasing service life of new and rehabilitated pavements avoiding frequent and inefficacious maintenance. This will lead to cost savings in the long term period and improved serviceability of infrastructures for road users. Alternatively, the use of geosynthetic reinforcement, if properly designed, can allow the reduction of thicknesses of asphalt layers leading to structures with equivalent or even

	enhanced structural behaviour at the same or even lower construction cost.
Maturity and degree of implementation	Geosynthetic reinforcement is becoming a standard construction and rehabilitation technique to improve the performance of bituminous pavements even if asphalt reinforcement with geosynthetics is still an important subject of debate due to the above-mentioned constraints. Moreover, there is the need of developing tools that can be used for the mechanistic-empirical design of reinforced pavements to demonstrated the structural benefits provided by the geosytnthetics.
Key Performance Indicators	
Further information	

6.1.4 Reducing the noise from roads

Best Practice #7	
Field	**Description**
Title and Keywords.	**Reducing the noise from roads**.
Source of best practice	
Lifecycle stage	Construction
Type of infrastructure	Road
Component of infrastructure	pavement.
Element of the infrastructure	pavement.
Short Description	In the Nordic countries the road pavement has a more rugged surface in order to resist the wear from the studded tyres. This results in excess noise. There are other surface pavements available which have shown good results. One such example is the highway E4 outside Husqvarna in Sweden. However, such roads requires more maintenace.
Success factors	
Constraints	
Main impacts	Reduction of noise.
Maturity and degree of implementation	
Key Performance Indicators	
Further information	

6.1.5 Road materials made with high RAP (Reclaimed Asphalt Pavement) aggregate content, in hot and cold mix recycling

Best Practice #8	
Field	**Description**
Title and Keywords	Title: ***Road materials made with high RAP (Reclaimed Asphalt Pavement) aggregate content, in hot and cold mix recycling.***

	Keywords: cold in-place recycling, reclaimed asphalt, environemental sustainability, foamed bitumen.
Source of best practice	Strategic topic in developed countries.
Lifecycle stage	Construction and Maintenance.
Type of infrastructure	Multi-modal (Road and Air).
Component of infrastructure	Pavement.
Element of the infrastructure	Subbase, base and surface layers.
Short Description	Reclaimed Asphalt Pavement (RAP) is a material that derive from pavement milling when is necessary to maintain or to re-pave the old pavement. This material is destinated to the waste dump or to the bituminous mixes plant, as "black aggregate". The bituminous mixes production methods with RAP are two: hot recycling (RAP is heated in light mode, to not oxidize the binder, and it is added as aggregate in the new bituminous mixtures) or cold recycling (the rap is mixed with foamed bitumen or bitumen emulsion with other aggregates at ambient temperature). Both these methods permit the rap recycling in site or in plant.
Success factors	Recycling of material detinated to the waste dump. Charcteristics improvement of bituminous mixes (also with additives that can to better performances of the binder contained in the rap).
Constraints	The RAP contains a percentage of bitumen. It need to take into account this for two reason: 1) when it is calculated the new binder amount in the bituminous mixes; 2) the binder contained in the RAP particles is oxidized due to aging suffered durign service life (this fact negatively affects final properties of recycled mixtures).
Main impacts	Less confinement in waste dump and less use of virgin aggregates (from quarry). Less construction costs and environmental impacts.
Maturity and degree of implementation	The technology of RAP use is born about from the 1980, and nowadays has reached a certain maturiry degree. The new challenge is to recycle a large amount of RAP in the bituminous mixtures also assuring higher performance.
Key Performance Indicators	
Further information	

6.1.6 Solar energy harvesting applied to road pavements

Best Practice #9	
Field	**Description**
Title and Keywords	Title: ***Solar energy harvesting applied to road pavements***

	Keywords: road pavement, energy harvesting, heat transfer.
Source of best practice	Strategic topic in current research and application.
Lifecycle stage	Construction and Maintenance.
Type of infrastructure	Road.
Component of infrastructure	Pavement.
Element of the infrastructure	Entire pavement.
Short Description	The topic concerns the use of optimized integrated technologies in road pavement construction, in order to save thermal energy required for heating buildings, using the thermal characteristics of road pavements. In particular, pavements should become less worm during summer thanks to the extraction of the absorbed heat, which can be used as renewable heat energy for the surrounding environment (buildings) during winter. To this aim, asphalt solar collectors (to be studied) can be installed within the pavement during both road construction and maintenance. Underground thermal energy storage is a key technology for the successful and economically feasible implementation of such a system.
Success factors	Harvesting heat from an asphalt pavement means exploiting a renewable energy resource (otherwise lost), extending the life of the pavement (lower temperature leads to less aging and permanent deformation) and reducing the Urban Heat Island (systematically higher temperatures in an urban environment). This will lead to an increased environment protection and cost savings.
Constraints	Only a few small projects have been monitored in detail. More large-scale demonstration field projects are required in order to precisely document the benefits of energy harvesting technologies on thermal comfort and energy consumption but also the effectiveness and suitability of the technology.
Main impacts	The main impacts of heat harvesting technologies will refer to the growing need for “low energy” buildings due to economic and environmental issues. In this sense, thermally optimized solutions for pavements able to reuse absorbed heat are of strategic importance for environment protection (saving and reusing a huge amount of solar energy otherwise lost) and cost savings, aiming towards sustainable development at urban scale.
Maturity and degree of implementation	The idea of using the heat collected by pavements to harvest energy dates back to 1979. Nowadays, there are companies marketing hydronic pavement systems for ice/snow-melting purposes and/or for space heating of nearby buildings, thanks to underground thermal energy storage systems. However, more numerical simulations and experimental validation studies are

	necessary.
Key Performance Indicators	
Further information	

6.1.7 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

Best Practice #10	
Field	**Description**
Title and Keywords	Title: ***The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability*** Keywords: road, recycling, marginal materials, artificial aggregate, environmental sustainability.
Source of best practice	Strategic topic in current research and application.
Lifecycle stage	Construction and Maintenance.
Type of infrastructure	Multi-modal (Road, Railway and Air).
Component of infrastructure	Pavement.
Element of the infrastructure	Bound and unbound layers.
Short Description	The transport infrastructure construction with marginal materials in total or partial substitution of virgin aggregates (coming from quarry) is today a compulsory solution in order to reduce wastes for dumping. These are industrial by-products and secondary material coming from different places: manufacturing cycle (e.g. steel slags, foundry sand, ecc.), recycling cycle (e.g. glass, reclaimed apshalt pavement, ecc.), ecc. These materials are recycled in bituminous or concrete mixes but require a careful mix design. They can be used in different layers: foundation, road base, base course or wearing course, railway embankments, according to their performances.
Success factors	The use of marginal materials solves two types of problem: the saving of natural and virgin aggregate and the reduction of waste dumping. Sometimes the masrginal aggregates possess mechanical propertiers better than the natural ones.
Constraints	Today each country has fixed different rules and technical standards in order to determine the maximum amount and type of materials to be used, according to their leaching characteristics. The marginal materials contain sometimes heavy metals which can become dangerous when they have a contact with water. This material often possess high densities, and it can lead to

	enhanced trasportation costs.
Main impacts	The re-use of these materials gives the possibility to limit wastes production and consequent pollution; moreover, a lower amount of natural aggregates should be extracted (with reduction of territory consumption). Furthermore, many marginal material allow better performances of the final product (bituminous and/or concrete mixes).
Maturity and degree of implementation	The use of recycling in trasport infrastructure construction started in poor countries and has been developed, in the last 30 years, all over the world. It can be a strategic solution for the future. However, a lot of materials have not been investigated yet and their potentialities are unknown. Rules for a correct use are lacking.
Key Performance Indicators	
Further information	

6.1.8 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

6.1.9 Thin polymeric trafficable waterproofing for bridge deck or multi-level car park paving

Best Practice #12	
Field	**Description**
Title and Keywords	Title: ***Thin polymeric trafficable waterproofing for bridge deck or multi-level car park paving*** Keywords: waterproof, pavement, synthetic resin, bridge deck, multi-level car park
Source of best practice	Established practice in some countries, particularly in USA.
Lifecycle stage	Construction and Maintenance.
Type of infrastructure	Road.
Component of infrastructure	Pavement.
Element of the infrastructure	Surface layers.
Short Description	Bridges and multi-level car park are structures subjected to different stresses, owed to their structure as well as external loading. Therefore, they require specific pavements, different from those usually laid on the ground. In fact, the deck (brigde or multi-level car park) is formed by a concrete slab that has a very high stiffness if compared with a normal soil (whose mechanical properties are lower). Pavements can be made with synthetic binders and aggregate; unlike traditional asphalt concrete road pavements, they provide, at the same time, a trafficable, safe and comfortable

	surfacing and a waterproofing of the underlying structure.
Success factors	These polymeric pavements, depending on the coating method, have good surface characteristics and good mechanical properties, resisting the simultaneous action of chemical agents and freeze/thaw cycles.
Constraints	Mixtures with polymeric binder have expansion properties different from concrete; therefore, it is better to construct thin pavements (between 5 and 10 millimetres) in order to reduce stresses between pavement and concrete.
Main impacts	The synthetic mortars have good mechanical characteristics (flexibility, strenght, and low deformation), guaranteeing a good adhesion to the concrete support (also after freeze/thaw cycles) and a good capacity to resist chemical action of de-icing salts (ensuring protection to the deck). These coatings guarantee faster laying time than similar products with a bituminous matrix, because they do not need heat to be laid and harden at ambient temperature and, unlike a rigid pavement, do not require specific equipment for the application. Other advantages are: the possibility of eliminating joints (the material possesses good elasticity), the lower weight of the pavement on the deck (due to the reduced layer thickness); the possibility of applying the products under different ambient temperatures; ease of pavement maintenance.
Maturity and degree of implementation	Common pratice in USA in the second part of 20th century, not often used in Europe; now it is possible to study new materials to improve the constraints related to the use of old ones.
Key Performance Indicators	
Further information	

6.1.10 Use of nanomaterials in the improvement of rheological and mechanical performance of bituminous mixtures for pavement construction.

Best Practice #14	
Field	**Description**
Title and Keywords	Title: ***Use of nanomaterials in the improvement of rheological and mechanical performance of bituminous mixtures for pavement construction.*** Keywords: nanomaterials, binders, rejuvenators, anti-icing, rheological characterization.
Source of best practice	Cutting edge technology in pavement engineering.
Lifecycle stage	Construction and Maintenance.
Type of infrastructure	Multi-modal (Road and Air).

Component of infrastructure	Pavement.
Element of the infrastructure	Asphalt layers.
Short Description	The bituminous materials (mastics, binders and mixes) are used in different civil engineering works to realize road and airport pavements, but bituminous mixtures' behavoiur is affected by mastics characteristics. Traditionally, the mastics are the union of filler and binder. The filler is the finest aggregate, classified as material passing almost completely to the 0.063 mm sieve. Recently the use of nanomaterials replacing the aggregate filler in the bituminous mixes started. Nanomaterials are artificial products and it is possible to select time by time the better characteristics, able to give better performances to mastics and bituminous mixes (e.g. rutting or fatigue better resistance).
Success factors	Carbon-nanotubes can provide a better resistance to rutting and a better resistance to thermal cracking. The nanoclay and nanoceramics can provide a binder viscosity increase, improving rutting and fatigue resistance of bituminous mixtures. The bituminous mixtures composed by binders modified with nanomaterial have characteristics and performances higher than traditional ones (e.g. higher modulus stiffness, higher rutting and fatigue resistance).
Constraints	Only few nanomaterials are able to give improved behaviour to bituminous mixes. These materials have neen studied: carbon nanotubes, nanoclay (silicates or aluminasilicates), nanoceramics and oxides. A constraint is the actual high cost of such materials.
Main impacts	The use of nanomaterials usually increases durability of construction products. Bituminous mastics have higher fatigue resistance and lower permanent deformation. Nanomaterials also provide a greater stability to the mixtures, improve adhesion between binder/mastic and aggregate, increase cohesion. Asphalt mixtures prepared with nanomaterials can be able to allow longer service life avoiding frequent and expensive road maintenance.
Maturity and degree of implementation	The use of nanomaterials in asphalt mixtures is a quite recent technique and it is an emerging promising technology.
Key Performance Indicators	
Further information	

6.1.11 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

6.1.12 New road pavement materials for hindering the Urban Heat Island impact and safeguarding human health

Best Practice #17	
Field	**Description**
Title and Keywords	Title: ***New road pavement materials for hindering the Urban Heat Island impact and safeguarding human health*** Keywords: road pavement, Urban Heat Island, health, albedo, climate.
Source of best practice	Strategic topic in current research and application.
Lifecycle stage	Construction and Maintenance.
Type of infrastructure	Road.
Component of infrastructure	Pavement.
Element of the infrastructure	Bituminous and cement bound layers.
Short Description	Urban Heat Island (UHI) is defined as the development of systematically higher temperatures in an urban environment due to high absorption of solar radiation, human activities heat, decreased thermal losses, pollution and energy consumption, etc. In this context, road pavements are considered one of the major contributors to the development of UHIs due to their wide surface as well as their aptitude to absorb solar radiation and transfer heat. In fact, pavement surfacings are mainly built with asphalt mixes (black coloured), which generally have high solar heat absorbency. For this reason it is desirable to build cold pavements mainly adjusting their albedo to solar radiation and the thermal emissivity, by means an optimization of coatings without compromising usual mechanical and functional properties.
Success factors	The reduction of UHI is becoming of strategic importance for human health and environment protection, aiming towards an increased sustainable development at urban scale.
Constraints	Possible constraints are related to the possibility of achieving efficient and durable solutions able to guarantee, at the same time, the usual mechanical and functional properties required to pavements (safety, comfort and structural intergrity). In fact, widespread use of innovative solutions is often hindered by repercussions on the mechanical and functional characteristics of the materiasl (skid resistance, durability, etc.). Morevore, the effective field applicability, from a technical and economical point of view, should be investigated.
Main impacts	The mitigation of UHI is mainly based on the enhancement of themal properties of road materials, oriented to an effective improvement of the environmental conditions. The mitigation of UHI implies positive influences on human health, a noticeable

	reduction in energy consumption of buildings, lower energy consumption for cooling purposes, lower emission and generation of urban pollutants and better impacts on the overall ecological footprint.
Maturity and degree of implementation	Some prototype solutions are cited in literature with conflicting results; deeper studies and applications are required.
Key Performance Indicators	
Further information	

6.1.13 The use of fibers for the improvement of the resistant of bituminous mixtures

Best Practice #18	
Field	**Description**
Title and Keywords	Title: **The use of fibers for the improvement of the resistant of bituminous mixtures** Keywords: Fibers, bituminous mixtures, pavements, roads, ports
Source of best practice	Current practice in some countries all over the world
Lifecycle stage	Construction
Type of infrastructure	Road, rail, ports and airports
Component of infrastructure	Pavement/Bituminous subballast
Element of the infrastructure	Bituminous mixture
Short Description	It consists in the addition of fibers to the manufacture of bituminous mixtures. These additives are incorporated with the aggrregates toghether, and after that, the bitumen is incorporated to aglomerate the material. The fibers are dispersed in all the volume of materials providing a tridimensional network which can distribute the stresses generated in the material and increase its internal cohesion.
Success factors	The bituminous mixuture design should be carried out attending to the volume and type of fibers added. It is necessary to use fibers that do not absorb bitumen to avoid the increment of this material (that could rise the production cost of the mixture). In addition, it is necessary to use fibers that had a good adherence to the bitumen (if not the effect could be opposite to that pursuit, as many weak points will be created inside the mixture).
Constraints	It is difficult to guarantee a good distributuion of the fibers in the mixture, specially when they are produced in higher volumes. The addition of fibers could also reduce the workability of the mixtures, and therefore, it is necessary to pay special attention on its manufacture and compaction.
Main impacts	The addition of fibers can be a good solution to improve the mechanical resistance of bituminous mixtures placed on road,

	airport or ports pavements. Whit a low investment, it can provide a more durable material that could reduce the reahbilitation costs related to these infrastructures.
Maturity and degree of implementation	This technique is commonly used in many european countries to improve the resistance of asphalt mixtures and to decrease its desintegration.
Key Performance Indicators	
Further information	

6.1.14 Foamed asphalt for the production of warm mix asphalt

Best Practice #19	
Field	**Description**
Title and Keywords	Title: **Foamed asphalt for the production of warm mix asphalt** Keywords: Foamed asphalt, warm mix asphalt
Source of best practice	Current practice in some countries, specially in EE.UU
Lifecycle stage	Construction
Type of infrastructure	Road, railway, airport, port
Component of infrastructure	Pavement/ bituminous subballast
Element of the infrastructure	Bituminous mixture
Short Description	It consist in foamming the bitumen before its use in the manufacture of bituminous mixtures. For this purpose, the hot binder (over 100 °C) is introduced in a chamber, where water is injected. When the water contact the bitumen begins to evaporate, creating a foaming process in the binder that allow for the increase of its specific surface.
Success factors	It is very useful and can save lot of environmental and economical resources, in asphalt mixtures manufactured with traditional binders, and when the production is high.
Constraints	To apply this technique is necessary to make some modification to the traditional batch plants used for the manufacture of the bituminous mixtures.
Main impacts	By foaming the bitumen is posible to obtain a material with a higher specific surface and therefore, it is not needed an increase in their temperature to ensure the wetting of the aggregates during the manufacture of bituminous mixtures. This effect allows for a considerable reduction of the temperature of compaction of asphalt mixes, which is related to a decrease in the fuel consumption of the plant, as well as to the reduction of the contaminant emmision to the atmosphere. In addition, the occupational safety of the workers is also improved as they use a

	product not as hot at traditional asphalt mixes.
Maturity and degree of implementation	Very used in EE.UU (around 85% of the warm mix asphalt are manufactured using this technology, and around 35% of the total mixtures used in EE.UU are warm mix asphalt).
Key Performance Indicators	
Further information	

6.1.15 Tire crumb rubber modified asphalt for pavements

Best Practice #20	
Field	**Description**
Title and Keywords	Title: **Tire crumb rubber modified asphalt for pavements** Keywords: tire, rubber, asphalt, pavements
Source of best practice	Current practice in some countries all over the world
Lifecycle stage	Construction
Type of infrastructure	Roads and Railway
Component of infrastructure	Pavement, Superinfrastructure and Substructure of the track
Element of the infrastructure	Bituminous mixture, Ballast and Subballast
Short Description	It consists of adding crumb rubber from waste tires into the asphalt mixtures for its application in the construction or rehabilitation of pavements for roads and for its application as a replacement of the granular ballast and subballast in railway tracks. Depending on the characteristics of the rubber particles and the percentage used, it can be employed as an additive or to replace part of the natural aggregates to work as elastic components.
Success factors	The incorporation of rubber particles into the asphalt mixtures allows for higher damping capacity of these materials and higher resistance due to the elastic characteristics of rubber. In addition, this allows for the improvement of the quality and mechanical performance of asphalt mixtures, obtaining a high performance material.
Constraints	Depending on the characteristics of the tire rubber particles and the quantity incorporated to the asphalt mixture, this solution can lead to the degradation of some essential properties of the material such as the bonding resistance between aggregates and bitumen, and therefore, some problems such as higher susceptibility to water action can take place.
Main impacts	This solution allows for the reduction of the accummulation of an abundant waste material (end-of-life tires) at the same time that a high performance asphalt mixture can be obtain with mechanical

	behaviour comparable (or even higher) to that presented for mixtures with modified bitumens with polymers (whose main disadvantage is its high price), and therefore, lower costs can be achieved during the manufacturing of asphalt mixtures.
Maturity and degree of implementation	The use of asphalt mixtures modified with tire crumb rubber is a solution that has been widely used in different countries, and then it is becoming a common solution for its application in pavements for roads and bituminous layers for railway tracks.
Key Performance Indicators	
Further information	

6.1.16 Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)

Best Practice #21	
Field	**Description**
Title and Keywords	Title: **Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)** Keywords: Asphalt, RAP
Source of best practice	Current practice in some countries all over the world
Lifecycle stage	Construction/Maintenance
Type of infrastructure	Roads and Railway
Component of infrastructure	Pavement, Superinfrastructure and Substructure of the track
Element of the infrastructure	Bituminous mixture, Ballast and Subballast
Short Description	It consists of manufacturing new asphalt mixtures by using reclaimed asphalt mixtures that are recovered from deteriorated pavements. Different percentajes of RAP (reclaimed asphalt pavements) can be used for the manufacturing of asphalt mixtures as well as different temperatures of manufacturing, using then diverse techniques and binders (bitumen, emulsion, etc.) in order to obtain a material with appropriate properties for its application in pavements for roads and in railway tracks. In addition, depending on the characteristics of the RAP, this material can be used as black aggregates to replace part of the natural aggregates in the new asphalt mixture, or even the RAP can be used as aggregates with bitumen, and therefore, the quantity of binder for the new mixture can be also reduced.
Success factors	This solution allows for the reduction of the consumption of natural resources (aggregates, bitumen,…) at the same time that the accumulation of this waste material is avoided.
Constraints	Asphalt mixtures including RAP usually present lower mechanical performance than that recorded for conventional asphalt mixtures, and then, more investigations are required to improve the behaviour of this type of mixtures.

Main impacts	This solution allows for important reduction of environmental and economic costs associated with the manufacturing of asphalt mixture.
Maturity and degree of implementation	This solutions has been widely used in different countries by using "low" percentages of RAP. Nowadays, the objective is to develop asphalt mixtures incorporing high quantity of RAP without reducing its mechanical performance for its application in roads and railways.
Key Performance Indicators	
Further information	

6.1.17 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

6.1.18 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

6.1.19 Use of End-of-Life Tyres (ELT) rubber into asphalt layers of pavements

See Section 5.1.10 (BP #32).

6.1.20 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

6.1.21 Road safety systems for the protection of motorcyclists

See Section 5.1.13 (BP #36).

6.1.22 Lattice girder in tunnels

Best Practice #43	
Field	**Description**
Title and Keywords	Title: **Lattice girder in tunnels** Keywords: Steel channel
Source of best practice	Some successful applications in different work sites
Lifecycle stage	Construction
Type of infrastructure	Multi-modal
Component of infrastructure	Tunnel
Element of the infrastructure	Tunnel support
Short Description	Aplication of linked steel channels instead of conventional ones

	(TH or HEB sections) in the tunnel support. The steel channel aim is to withstand the flexure moment due to the ground pressure, whilst shotcrete or wire support are placed to face the compressions.
Success factors	Unlikely the TH section channels, the linked steel channels work as truly concrete reinforcement so there is no discontinuity. Lighter than TH or HEB sections. Quicker to assembly Better finish.
Constraints	
Main impacts	Lighter than TH or HEB sections. Quicker to assembly Better finish.
Maturity and degree of implementation	Implementation in works depending on the designer's approach.
Key Performance Indicators	
Further information	DRAGADOS

6.1.23 Multilayer susitanable tunnel linings

See Section 5.1.14 (BP #44).

6.1.24 5.1.16 Overburden length

See Section 5.1.16 (BP #46).

6.1.25 Shotcrete reinforced by steel and synthetic fibers

Best Practice #49	
Field	**Description**
Title and Keywords	Title: **Shotcrete reinforced by steel and synthetic fibers** Keywords:Shotcrete, steel fibers
Source of best practice	ITAtech Design Guidance For Precast Fibre Reinforced Concrete Segments-Draft Report
Lifecycle stage	Construction
Type of infrastructure	Multi-modal
Component of infrastructure	Tunnel
Element of the infrastructure	Tunnel support
Short Description	Sustitution of wire support element into shotcrete reinforced by steel fibers.
Success factors	Economic benefits. Reduce the work cycle, which means decrease the deadline of works, so reduce the work cost.

Constraints	It is necessary an exhaustive control of the shotcrete placed in work. Proper mix of fibers with shotcrete, using if necessary stabilizer or setting retarders and accelerators. Attention to shotcrete releases of the crown.
Main impacts	Economic benefits. Reduce the work cycle, which means decrease the deadline of works, so reduce the construction cost.
Maturity and degree of implementation	Implemented in several works
Key Performance Indicators	
Further information	ITAtech Design Guidance For Precast Fibre Reinforced Concrete Segments-Draft Report

6.1.26 Distance between twin tunnels

See Section 5.1.21 (BP #52).

6.1.27 Tunneling by means of hydroshields or mixshields

Best Practice #55	
Field	**Description**
Title and Keywords	**Tunneling by means of hydroshields or mixshields** Keywords: tunneling, hydroshield, mixshield, bentoair.
Source of best practice	Tunnels around the world where the ground is specially very permeable and high contents of granular solids and high pressure.
Lifecycle stage	Construction
Type of infrastructure	Multi-modal
Component of infrastructure	Tunnels with reinforced concrete segments.
Element of the infrastructure	Excavation and lining.
Short Description	The hydroshield or mixshield is a type of tunnel boring machine (TBM) capable of excavating grounds with high content of granular materials, highly permeable and where hydrostatic pressure could reach up to 16 bar.
Success factors	Safety and stability for surrounding structures. The control and steadiness of the excavating face is so tight that settlements on the top are nearly zero.
Constraints	Grounds with high content of clay reduce the performance rate considerably, although it will never stop the advance. In most cases, the slurry treatment plant stablishes the maximum capacity. Potencial discomfort during production phase to the neigborhood. More expensive in comparison to a bridge.
Main impacts	Zero impacts to surrounding structures because the settlements

	are insignificant. For crossing rivers or areas close to the sea, a bridge constrains the gauge.
Maturity and degree of implementation	This technology is being applied for a long time by TBM manufacturers from Germany or Japan in worldwide projects, with successful manufacturing TBMs upto 15 meters diameter.
Key Performance Indicators	
Further information	OHL's Tecno Magazine #85. Article: "Twin tunnel under the navigation channel of the Vistula River".

6.1.28 Standardization of viaducts for infrastructure crossings

See Section 5.1.24(BP #57).

6.1.29 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

6.1.30 Performance Based Design

See Section 5.1.29 (BP #63).

6.1.31 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

6.1.32 Use of techniques of Work Study in Construction activities

Best Practice #65	
Field	**Description**
Title and Keywords	Title: **Use of techniques of Work Study in Construction activities.** Keywords: Work study, Method study, Work measurement
Source of best practice	Use of these techniques in Industrial processes.
Lifecycle stage	Construction
Type of infrastructure	All
Component of infrastructure	All
Element of the infrastructure	All
Short Description	The use of techniques of Work Study in Construction activities make increase the percentage of ensure their compliance in schedule, quality and economic terms.
Success factors	It is usefull in all kind of construction activities.

Constraints	It is needed a previous period of training before taking advantage of it use.
Main impacts	Productivity in construction activities increases. You make a better use of the needed resources to complete the production works.
Maturity and degree of implementation	It's use is standarized in industrial processes all over the world. In construction processes it's use has been increasing for the last 40 years.
Key Performance Indicators	
Further information	

6.1.33 Use of Time-Chainage or Time-Location Management for Planning the construction of all type of Infrastructures

Best Practice #66	
Field	**Description**
Title and Keywords	Title: **Use of Time-Chainage or Time-Location Management for Planning the construction of all type of Infrastructures** Keywords: Time Location Management, Planning, Infrastructures
Source of best practice	Current practice all around the world, specially in linear infrastructures.
Lifecycle stage	Construction
Type of infrastructure	All
Component of infrastructure	All
Element of the infrastructure	All
Short Description	Time Location Management makes easy to undestand the traditional Gantt Chart planning to workers involved in the production proccess, because of it's visual representation. It allowes to use a new type of resource: Location.
Success factors	It is useful in a lot of different type of infrastructure. The interoperability between Gantt Chart and Time Location Diagram is automatic today using differents comercial software.
Constraints	It is not so efficient when it is necessary to show a huge number of activities, which complicate the visual representation.
Main impacts	Simplify the planning visualitation of any type of infrastructure.
Maturity and degree of implementation	
Key Performance Indicators	
Further information	

6.1.34 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

6.1.35 Sustainable use of construction materials for transport infrastructure

See Section 5.1.35 (BP #71).

6.1.36 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

6.1.37 Bituminous mixture SMA

Best Practice #73	
Field	**Description**
Title and Keywords	**Bituminous mixture SMA**
Source of best practice	In use in several countries included Spain, iniciated in Germany in 1968.
Lifecycle stage	Construction / Maintenance
Type of infrastructure	Paved surfaces (roads, airports, urban roads, etc.)
Component of infrastructure	Binder course and/or sourface course
Element of the infrastructure	Some courses mixture component
Short Description	Asphalt bituminous mixture with a high amount of thick aggregates and a high amount of asphalt (6.6-7.2%) that is manufactured and poured with the conventional system. It can be used in any paved surface.
Success factors	It is specially indicated with high traffic levels, in high performance surface courses and as a crack-resistance material.
Constraints	There are not known constraints
Main impacts	The SMA mixture is more expensive to install at first but more economic in a medium to long term as it has a longer durability. By reducing the maintenance actuations, the environmental footprint is reduced, for which it can be used in strictly environmentaly regulated places. As a surface course, it has a good texture, comfortable and safe for the user, that reduces the noise compared to traditional mixtures.
Maturity and degree of implementation	Increment of its use in Spain in the last 8 to 10 years.
Key Performance Indicators	Fatigue resistant mixture, more durable with a better crack-resistance and good superficial characteristics.
Further information	www.proyectosma.eu

6.1.38 Making rebar groups in precast pier elements

See Section 5.1.37 (BP #74).

6.1.39 Use of self compacting concrete in high density reinforced areas

Best Practice #79	
Field	**Description**
Title and Keywords	Title: **Use of self compacting concrete in high density reinforced areas** Keywords: self compacting concrete, reinforcement, high density
Source of best practice	Development of new technologies for concrete mixes (cement, additives,…).
Lifecycle stage	Construction
Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Deck & Subestructure
Short Description	Use of self compacting concrete in high density reinforced areas to avoid problems during concreting and at the end holes or zones with no concrete or deficient quality of the concrete
Success factors	Feasibility of concreting high density reinforced areas reducing the risk of deficient quality of the concrete, presence of voids or holes and deficient surface finishings.
Constraints	The cost of the concrete is higher, and so could happen with the formwork (higher pressures during concreting). It might be difficult or more complex to achieve high concrete strengths.
Main impacts	Reducing the risk and impact of a deficient concreting and the presence of voids, holes or zones with no concrete or deficient quality of the surface finishings.
Maturity and degree of implementation	5 to 10 years.
Key Performance Indicators	Surface finishings.
Further information	-

6.1.40 Delayed pouring of a concrete closure in bridge widenings

Best Practice #83	
Field	**Description**
Title and Keywords	Title: **Delayed pouring of a concrete closure in bridge widenings** Keywords: closure pour, differential deflection
Source of best practice	Guide for Widening Highway Bridges (ACI 345.2R-98) Bridge Memo to Designers. (CALTRANS)
Lifecycle stage	Construction/Maintenance

Type of infrastructure	Road or rail
Component of infrastructure	Bridge
Element of the infrastructure	Deck
Short Description	Use of a delayed closure pour to complete the attachment between new and existing structure.
Success factors	It is useful in general, but specially in cast-in-place concrete decks, medium/large spans and/or large overhangs in the cross section, where live load deflection gap could be larger or where prestress shortening could have a bigger effect in the existing deck
Constraints	It could affect the widening schedule, specially in cast-in-place structures where closure pouring should wait more unless falsework removal could be delayed
Main impacts	Delaying this connection pouring until the end of the whole widening process reduces deflection gaps between new and existing deck and minimizes existing traffic effects in the new structure
Maturity and degree of implementation	Widely used in many countries for a long time
Key Performance Indicators	-
Further information	Detailed information in Section 9.3 of Bridge Memo to Designers (CALTRANS) and Chapter 3 of Guide for Widening Highway Bridges (ACI 345.2R-98)

6.1.41 Checkerboard concreting in large surfaces

Best Practice #84	
Field	**Description**
Title and Keywords	Title: **Checkerboard concreting in large surfaces** Keywords: concrete, big Weight, segments, erection, lift-off
Source of best practice	-
Lifecycle stage	Construction
Type of infrastructure	Road or rail
Component of infrastructure	Bridges, railway stations
Element of the infrastructure	Slabs
Short Description	Concreting has to be done in two stages. Firstly checkerboard concrete is carried out and at the second stage the slab is completed. There has to be at least one month between both stages.
Success factors	Instead of concreting the whole surface it is recommended to concrete in checkerboard shape in order to allow shrinkage deformations and reduce tension stress in concrete.
Constraints	Performance of this work is reduced because concrete in two

	stages is required.
Main impacts	The steel reinforced needed in the slab is reduced and the cracking control is improved.
Maturity and degree of implementation	Widely used at big surface slabs.
Key Performance Indicators	-
Further information	-

6.1.42 Telescopic arm on self-propelled platform for cable tensioning

Best Practice #85	
Field	**Description**
Title and Keywords	Title: **Telescopic arm on self-propelled platform for cable tensioning** Keywords: cable tensioning, segment, telescopic arm
Source of best practice	Spain
Lifecycle stage	Construction
Type of infrastructure	Rail, Road
Component of infrastructure	Bridge, tunnels
Element of the infrastructure	Tensioning cables
Short Description	Telescopic arm, mounted on a self-propelled platform, intended for tensioning cables in locations with difficult access and limited space.
Success factors	Selfpropelled character; Positioning and guidance provided by the boom arm.
Constraints	
Main impacts	The telescopic arm, by virtue of the possibilities of incorporating rotation, a load can be positioned close to the system, within certain action. Being a self-propelled machine, you may move forward or backward and changes direction with its front axle, allowing you to achieve any desired positioning. All actuators and motors are hydraulic type, powered by a hydraulic power unit provided with electric motor, which gives the whole unlimited autonomy provided there is a power source nearby. Eliminating any possibility of fuming inside the spaces where you are going to work.
Maturity and degree of implementation	Very used by the company in several countries, mainly in Spain.
Key Performance Indicators	Areas to difficult to access, restricted space, 360° rotations
Further information	www.fcccco.es

6.1.43 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

Best Practice #87	
Field	**Description**
Title and Keywords.	Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.
Source of best practice	NCC
Lifecycle stage	Construction (Maintenance)
Type of infrastructure	Road, Rail, Air, Water, Multi-modal - all
Component of infrastructure	Bridge, tunnel, pavement, - all
Element of the infrastructure	N/A
Short Description	In order to meeting the demands of urbanisation, construction projects are often carried out in densly populated urban areas. Lean construction has been proposed as a mean to meet the demands of increasing the productivity of the sector. But, lean usually focuses on the internal processes on site and on the production processes. However, in order to meet increasing societal demands (noise reduction, mobility, accessibility etc), it is necessary that also the neighborhood is taken into account when planning and executing construction. Moreover, due to more stakeholders are becoming involved throughout the projects and prolonging the acceptance phase, the society feels a need to become even strikter on how a site can affect the neighborhood surrounding. More information can be found in http://publications.lib.chalmers.se/records/fulltext/161189.pdf and in http://publications.lib.chalmers.se/records/fulltext/220530/220530.pdf
Success factors	Understanding the effects on the society when a temporary site is introduced into the neighborhood. This is a way to win contracts especially when MEAT contracts are awarded.
Constraints	Most effective in urban construction
Main impacts	increased safety, reduction of disturbance, less noise, added customer value etc.
Maturity and degree of implementation	It is technically feasible, replicable, adaptable but requires a thorough understanding of the needs of society and also the business model of the company may need adaptions.
Key Performance Indicators	-
Further information	See above

6.1.44 Real-time online Concrete Monitoring of temperature-development and strength-development based on state of the art maturity method and modern communication technology

See Section 5.1.43 (BP #90).

6.1.45 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

6.2 Type of Infrastructure: Rail (Construction)

6.2.1 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

See Section 6.1.7 (BP #10).

6.2.2 The use of fibers for the improvement of the resistant of bituminous mixtures

See Section 6.1.13 (BP #18).

6.2.3 Foamed asphalt for the production of warm mix asphalt

See Section 6.1.14 (BP #19).

6.2.4 Tire crumb rubber modified asphalt for pavements

See Section 6.1.15 (BP #20).

6.2.5 Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)

See Section 6.1.16 (BP #21).

6.2.6 Method for the installation of railway tracks of ballast, without an auxiliary track

Best Practice #26	
Field	**Description**
Title and Keywords	Title: **Method for the installation of railway tracks of ballast, without an auxiliary track** Keywords: railway tracks, ballast bed, auxiliary track.

Source of best practice	Current practice in some countries, specially in Spain
Lifecycle stage	Construction
Type of infrastructure	Rail
Component of infrastructure	Railways
Element of the infrastructure	Railway tracks on ballast
Short Description	A method for installing railway tracks onto ballast beds avoiding the need for installing any type of auxiliary track. The method comprises successive stages to be carried out after having located the sleepers onto the ballast bed, consisting of fixing and laying of a pair of rails from a mini train, for the transport of the rails with the fastening and traction of same up to their complete uploading, the operation being guided by means of a discharge wagon; supporting the rails on rollers for the longitudinal movement thereof; cutting, squaring and fixing the adjacent needs to the consecutive rails; raising the rail with the help of a crane, and removing the rollers; partial fastening of the track and place3ment of the rollers for the next cycle, and removing the tractor from the mini train, and the final fastening of the rails.
Success factors	Provides an optimised method for the installation of railway tracks on ballast, by means of which the need for the installation, assembly or use of any auxiliary track is eliminated, and in addition is built on the basis of a reduced number of external devices: a discharge (unloading) wagon, a tractor device, and a predetermined number of slide elements for the rails (rollers).
Constraints	
Main impacts	The installation method allows the rails of the railway to be unloaded and positioned by cycles with a predetermined length, with a net increase in performance compared to the conventional methods thanks to the substantial increase in the number of cycles per production day.
Maturity and degree of implementation	Very used by the company in several countries, mainly in Spain.
Key Performance Indicators	Process optimization, cost optimization
Further information	www.fcccco.es

6.2.7 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

6.2.8 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

6.2.9 Use of End-of-Life Tyres (ELT) rubber into asphalt layers of pavements

See Section 5.1.10 (BP #32).

6.2.10 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

6.2.11 Elastic elements in railway structures

Best Practice #37	
Field	**Description**
Title and Keywords	Title: **Elastic elements in railway structures** Keywords: pads, under-ballast mats, under-sleeper pads, railway
Source of best practice	Current practice in some countries all over the world
Lifecycle stage	Construction/Maintenance
Type of infrastructure	Railway
Component of infrastructure	Sleeper, ballast
Element of the infrastructure	Pads, under-ballast mats, under-sleeper pads
Short Description	It consists in the incorporation of elastic elements to the railway structure, in order to improve its stiffness and to disminish the impacts caused by the pass of the trains. These elastic elements can be placed between the rail and the sleeper (pads, which is the most common use), under the sleeper, or as a continious mat under the ballast.
Success factors	The stiffness of these materials could play a very important role on the mechanical behaviour of the railway structure. Therefore, it is necessary to select this stiffness according to the global resistance of the other components (bearing capacity of the foundation, typw of sleeper, thickness of the ballast layer, type of train load supported, etc.). In addition, the place where these elements are introudec is very important. It is more advisable to use them over the ballast layer (pads and under-sleeper pads), because of the risk of high settlement caused by ballast vibration and reorganization.
Constraints	If the stiffness or type of elastic elements selected is not accurate for the railway structure, it can provide more drawbacks than advantages to their mechanical response. Because of this fact it is necessary to study the interaction of these elements with the rest of the structure, before its use in a real railroad.
Main impacts	The use of these elements could considerably reduce the investments done in railway rehabilitation such as ballast tamping. In addition, it can also positively affect the energy

	consumption in the train advance, as it improve the resistance provided by the structure.
Maturity and degree of implementation	This technique is commonly used in many european countries, specially in high speed train railways.
Key Performance Indicators	
Further information	

6.2.12 Asphalt mixtures for its application in railway tracks

Best Practice #38	
Field	**Description**
Title and Keywords	Title: **Asphalt mixtures for its application in railway tracks** Keywords: Asphalt, railways
Source of best practice	Current practice in some countries all over the world, specially USA, France, Italy and Japon.
Lifecycle stage	Construction
Type of infrastructure	Railway
Component of infrastructure	Substructure of the track
Element of the infrastructure	Ballast, Sub-ballast
Short Description	It consists of using asphalt mixtures to replace conventional granular layers such as ballast and sub-ballast, commonly used in High-Speed railway tracks. It is common to employ a dense asphalt mixture with maximum aggregate size betweem 22-32 mm, and it can be used directly under the sleepers (as a bituminous slab for a ballastless track); or under the ballast (as a bituminous sub-ballast); or the asphalt mixtures can be used to replace both components (ballast and sub-ballast).
Success factors	When high performance asphalt mixtures are used, this solution allows for the reduction of the settlement of the railway track, and then its maintenance requeriments are reduced. In addition, this allows for a higher quiality track with longer service life.
Constraints	If the design of the asphalt mixture is not appropriate and its mechanical behaviour under the expected service conditions (punching stress, permeability capacity,..) is not adequate, the maintenance costs can be highly increased. In addition, the use of this solution leads to a more rigid infrastructure that can cause the increase in the overloads when trains passing, and then, further investigations are required. Besides, the initial constructive costs are higher than those for the traditional railway track.
Main impacts	This solution can lead to important reduction in maintenance

	frequency, and then, maintenance costs. At the same time, a higher quaility system of transportation is obtained with longer service life.
Maturity and degree of implementation	The use of bituminous subballast is a solution that is becoming common in some countries, but in the case of using asphalt as a slab to replace the ballast is a solutions that required to be developed.
Key Performance Indicators	
Further information	

6.2.13 High output sleepers aligment machine

Best Practice #40	
Field	**Description**
Title and Keywords	Title: **High output sleepers aligment machine** Keywords:aligment, sleepers.
Source of best practice	Practice in some countries, Spanish Thecnology
Lifecycle stage	Construction and maintenance (renewal).
Type of infrastructure	Rail
Component of infrastructure	Track
Element of the infrastructure	Sleepers
Short Description	Once the track is pre installed, 166 or167 sleepers should be installed per every 100 m. Alignment is need to carry out this task. A sleeper high output aligment machine is used for this job which is able of aligning 10 sleeper units at a time.
Success factors	It can be used in every rail worksite where a sleeper replacement is needed.
Constraints	
Main impacts	Improve the preformance and the quality of the works.
Maturity and degree of implementation	Very used in Spain.
Key Performance Indicators	
Further information	VIAS

6.2.14 Unloading of Long Welded Rail (LWD) through a provisional Track

Best Practice #41	
Field	**Description**
Title and Keywords	Title: **Unloading of Long Welded Rail (LWD) through a provisional Track.** Keywords:Long Welded Rail, provisional track.

Source of best practice	Practice in some countries, specially in Spain
Lifecycle stage	Construction and maintenance (renewal).
Type of infrastructure	Rail
Component of infrastructure	Track
Element of the infrastructure	Rail
Short Description	The construction methodology, for double track, consists on the construction of a provisional track on a first layer of ballast used to lay the rail for the parallel track, and on the main one in a second phase. Then the position of the sleepers and the rail are realised while the provisional track is disassembled, hereafter the parallel track is assembled as the main one. Before definitively spreading the missing ballast, the sleepers are repositioned by a high output aligment machine. Then tamping and leveling operations are done before welding, finally track stressing and final welds are performed.
Success factors	
Constraints	The construction and disassembly of the provisional track.
Main impacts	
Maturity and degree of implementation	Very used in Spain.
Key Performance Indicators	
Further information	VIAS

6.2.15 Unloading of Long Welded Rail (LWD) with a high output gantry

Best Practice #42	
Field	**Description**
Title and Keywords	Title: **Unloading of Long Welded Rail (LWD) with a high output gantry**. Keywords:Long Welded Rail, High Output Gantry
Source of best practice	Practice in some countries, specially in Spain
Lifecycle stage	Construction.
Type of infrastructure	Rail
Component of infrastructure	Track
Element of the infrastructure	Rail
Short Description	The construction methodology, for double track, consist on, first, positioning of the sleepers on the first layer of ballast (40% of total volume), unloading of long welded rails through several rollers installed in advance, using a high output gantry wich is able to pull from 5 or 6 consecutive joined LWD. This means that

	1,3 to 1,6 km of rail are layed in each movement. After this and using this assembled track, the distribution of the LWR for the parallel track is carried out, finally positioning the sleepers and the rail. Before the spread of the missing ballast the sleepers are repositioned by a high output aligment machine. Then tamping and leveling operations are done before welding, finally track stressing and final welds are done.
Success factors	Proper technique for new layouts or tracks duplications.
Constraints	Usefull method if the sleepers can be positioned in advance before the unloading of the rail.
Main impacts	Improve in performance of around 40%.
Maturity and degree of implementation	Very used in Spain.
Key Performance Indicators	
Further information	VIAS

6.2.16 Lattice girder in tunnels

See Section 6.1.22 (BP #43).

6.2.17 Multilayer susitanable tunnel linings

See Section 5.1.14 (BP #44).

6.2.18 Overburden length

See Section 5.1.16 (BP #46).

6.2.19 Shotcrete reinforced by steel and synthetic fibers

See Section 6.1.25 (BP #49).

6.2.20 Distance between twin tunnels

See Section 5.1.21 (BP #52).

6.2.21 Method for the installation of slab tracks in twin tube tunnels

See Section 5.2.12 (BP #54).

6.2.22 Tunneling by means of hydroshields or mixshields

See Section 6.1.27 (BP #55).

6.2.23 Standardization of viaducts for infrastructure crossings

See Section 5.1.24 (BP #57).

6.2.24 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

6.2.25 Performance Based Design

See Section 5.1.29 (BP #63).

6.2.26 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

6.2.27 Use of techniques of Work Study in Construction activities

See Section 6.1.32 (BP #65).

6.2.28 6.1.33 Use of Time-Chainage or Time-Location Management for Planning the construction of all type of Infrastructures

See Section 6.1.33 (BP #66).

6.2.29 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

6.2.30 Sustainable use of construction materials for transport infrastructure

See Section 5.1.35 (BP #71).

6.2.31 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

6.2.32 Making rebar groups in precast pier elements

See Section 5.1.37 (BP #74).

6.2.33 Use of self compacting concrete in high density reinforced areas

See Section 6.1.39 (BP #79).

6.2.34 Delayed pouring of a concrete closure in bridge widenings

See Section 6.1.40 (BP #83).

6.2.35 Checkerboard concreting in large surfaces

See Section 6.1.41 (BP #84).

6.2.36 Telescopic arm on self-propelled platform for cable tensioning

See Section 6.1.42 (BP #85).

6.2.37 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

6.2.38 Real-time online Concrete Monitoring of temperature-development and strength-development based on state of the art maturity method and modern communication technology

See Section 5.1.43 (BP #90).

6.2.39 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

6.3 Type of Infrastructure: Air (Construction)

6.3.1 Innovative geosynthetics for aspahlt layers reinforcement

See Section 6.1.3 (BP #3).

6.3.2 Road materials made with high RAP (Reclaimed Asphalt Pavement) aggregate content, in hot and cold mix recycling

See Section 6.1.5 (BP #8).

6.3.3 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

See Section 6.1.7 (BP #10).

6.3.4 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

6.3.5 Use of nanomaterials in the improvement of rheological and mechanical performance of bituminous mixtures for pavement construction

See Section 6.1.10 (BP #14).

6.3.6 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

6.3.7 The use of fibers for the improvement of the resistant of bituminous mixtures

See Section 6.1.13 (BP #18).

6.3.8 Foamed asphalt for the production of warm mix asphalt

See Section 6.1.14 (BP #19).

6.3.9 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

6.3.10 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

6.3.11 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

6.3.12 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

6.3.13 Performance Based Design

See Section 5.1.29 (BP #63).

6.3.14 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

6.3.15 Use of techniques of Work Study in Construction activities

See Section 6.1.32 (BP #65).

6.3.16 6.1.33 Use of Time-Chainage or Time-Location Management for Planning the construction of all type of Infrastructures

See Section 6.1.33 (BP #66).

6.3.17 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

6.3.18 Bituminous mixture SMA

See Section 6.1.37 (BP #73).

6.3.19 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

6.3.20 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

6.4 Type of Infrastructure: Water (Construction)

6.4.1 The use of fibers for the improvement of the resistant of bituminous mixtures

See Section 6.1.13 (BP #18).

6.4.2 Foamed asphalt for the production of warm mix asphalt

See Section 6.1.14 (BP #19).

6.4.3 Low reflection structure on the sides of caisson-type quay walls.

Best Practice #24	
Field	**Description**

Title and Keywords	Title: **Low reflection structure on the sides of caisson-type quay walls.** Keywords: maritime infrastructures, floating caisson, caisson shaft
Source of best practice	Current practice in some countries, mainly in Spain
Lifecycle stage	Cosntruction
Type of infrastructure	Maritime infraestructure
Component of infrastructure	Precast reinforced concrete caissons
Element of the infrastructure	caisson shaft
Short Description	Modifications of a Caisson structure in order to provide a lower reflection coefficient
Success factors	Improvements in operational conditions of quays, wharves and navigation channels, lower impact on adjacent beaches
Constraints	Difficulties in construction, extra cost
Main impacts	Operational conditions
Maturity and degree of implementation	Very used by the company in several countries
Key Performance Indicators	Coefficient of reflection, cost
Further information	www.fcccco.es

6.4.4 Use of concrete floating caissons in gravity quays construction with floating facilities

Best Practice #25	
Field	**Description**
Title and Keywords	Title: **Use of concrete floating caissons in gravity quays construction with floating facilities** Keywords: Concrete caisson, floating caisson
Source of best practice	Current practice in some countries, like Spain or Italy
Lifecycle stage	Construction
Type of infrastructure	Harbors, ports
Component of infrastructure	Quay walls
Element of the infrastructure	Infrastructure of the quay
Short Description	Concrete floating caisson is a common typology of gravity structures for harbour construction. It is a reinforced concrete parallelepiped box with a bottom slab and a multicelular shaft that, once constructed, allows it to float in the water. In this way, it can be easily moved to its final position and sunk by using water ballast. Due to their great dimensions and weight, caissons are difficult to handle on land once constructed, so floating facilities can be used

	to solve this problem. Special facilities with a floating platform make easy the construction of the slab and shaft with sliding formwork.
Success factors	This technology avoids great extension of surface for the caisson construction facility on land, and launching operation of the caisson is included in the construction stage. Another key factor is that the facility doesn't need earth movements on land and huge installation expenses and it´s very easy to move, so short number of caissons are easy to manufacture with small fixed expenses.
Constraints	It is necessary to have a quay line with enough draught for the facility. If no quay line is available, offshore installation is possible, but concrete supply has to be solved in a continuous way. Reinforcement corrosion could be considered as a problem, but chloride penetrations have been demonstrated to be equal in fresh water cured structures, even with early immersion in marine water.
Main impacts	Construction process leads to slightly different load cases and resistance factors. Some additives and special concrete mixes must be defined for it.
Maturity and degree of implementation	It´s the method mainly used for the last 40 years in Spain and other countries like Italy for gravity quays construction.
Key Performance Indicators	
Further information	

6.4.5 Use of concrete bulky armor units for breakwaters with enhanced face to face fitting behavior

See Section 5.4.1 (BP#35).

6.4.6 Standardization of viaducts for infrastructure crossings

See Section 5.1.24 (BP #57).

6.4.7 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

6.4.8 Performance Based Design

See Section 5.1.29 (BP #63).

6.4.9 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

6.4.10 Use of techniques of Work Study in Construction activities

See Section 6.1.32 (BP #65).

6.4.11 6.1.33 Use of Time-Chainage or Time-Location Management for Planning the construction of all type of Infrastructures

See Section 6.1.33 (BP #66).

6.4.12 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

6.4.13 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

6.4.14 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

6.5 Type of Infrastructure: Multi-modal (Construction)

6.5.1 Innovative geosynthetics for aspahlt layers reinforcement

See Section 6.1.3 (BP #3).

6.5.2 Road materials made with high RAP (Reclaimed Asphalt Pavement) aggregate content, in hot and cold mix recycling

See Section 6.1.5 (BP #8).

6.5.3 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

See Section 6.1.7 (BP #10).

6.5.4 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

6.5.5 Use of nanomaterials in the improvement of rheological and mechanical performance of bituminous mixtures for pavement construction

See Section 6.1.10 (BP #14).

6.5.6 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

6.5.7 The use of fibers for the improvement of the resistant of bituminous mixtures

See Section 6.1.13 (BP #18).

6.5.8 Foamed asphalt for the production of warm mix asphalt

See Section 6.1.14 (BP #19).

6.5.9 Tire crumb rubber modified asphalt for pavements

See Section 6.1.15 (BP #20).

6.5.10 Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)

See Section 6.1.16 (BP #21).

6.5.11 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

6.5.12 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

6.5.13 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

6.5.14 Lattice girder in tunnels

See Section 6.1.22 (BP #43).

6.5.15 Multilayer susitanable tunnel linings

See Section 5.1.14 (BP #44).

6.5.16 Overburden length

See Section 5.1.16 (BP #46).

6.5.17 Shotcrete reinforced by steel and synthetic fibers

See Section 6.1.25 (BP #49).

6.5.18 Distance between twin tunnels

See Section 5.1.21 (BP #52).

6.5.19 Tunneling by means of hydroshields or mixshields

See Section 6.1.27 (BP #55).

6.5.20 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

6.5.21 Performance Based Design

See Section 5.1.29 (BP #63).

6.5.22 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

6.5.23 Use of techniques of Work Study in Construction activities

See Section 6.1.32 (BP #65).

6.5.24 6.1.33 Use of Time-Chainage or Time-Location Management for Planning the construction of all type of Infrastructures

See Section 6.1.33 (BP #66).

6.5.25 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

6.5.26 Sustainable use of construction materials for transport infrastructure

See Section 5.1.35 (BP #71).

6.5.27 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

6.5.28 Bituminous mixture SMA

See Section 6.1.37 (BP #73).

6.5.29 Making rebar groups in precast pier elements

See Section 5.1.37 (BP #74).

6.5.30 Use of self compacting concrete in high density reinforced areas

See Section 6.1.39 (BP #79).

6.5.31 Delayed pouring of a concrete closure in bridge widenings

See Section 6.1.40 (BP #83).

6.5.32 Checkerboard concreting in large surfaces

See Section 6.1.41 (BP #84).

6.5.33 Telescopic arm on self-propelled platform for cable tensioning

See Section 6.1.42 (BP #85).

6.5.34 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

6.5.35 Real-time online Concrete Monitoring of temperature-development and strength-development based on state of the art maturity method and modern communication technology

See Section 5.1.43 (BP #90).

6.5.36 Use of micropiles in geotechnical applications (foundation support, slope stabilization, earth retention…)

See Section 5.1.44 (BP #91).

7 Best Practices for Maintenance

7.1 Type of Infrastructure: Road (Maintenance)

7.1.1 Foamed bitumen stabilization

See Section 6.1.1 (BP #1).

7.1.2 Innovative geosynthetics for aspahlt layers reinforcement

See Section 6.1.3 (BP #3).

7.1.3 Nonintrusive monitoring of pavements

Best Practice #4	
Field	**Description**
Title and Keywords.	**Nonintrusive monitoring of pavements** keywords: road inspection, embedded sensors, high speed measurements, big data
Source of best practice	GEOCISA, … ECSEL-JU
Lifecycle stage	Maintenance
Type of infrastructure	Road
Component of infrastructure	pavement
Element of the infrastructure	Pavement
Short Description	Road inspections are often carried out by static measurements or slow moving vehicles. Due to the cost and hindrance, the measurement frequency is maintained as low as possible. New techniques with (wireless) embedded sensors and/or vehicle mounted sensors which can operate at traffic speed may provide for a continuous flow of pavement inspection data. Even if the accuracy were less, a statistical treatment of the obtained data could provide valueable information for pavement management and maintenance planning.
Success factors	unified measurement criteria, open data
Constraints	cooperation needed from third parties
Main impacts	It is foreseen that cars are equipped with ever more sensors in the developments towards autonomous driving. A data interchange between pavement and cars (v.v.) can be beneficial to both.
Maturity and degree of implementation	Several isolated tests have been done with embedded sensors in cars and pavements. An integrated solution and open data format is to be developped.
Key Performance Indicators	?

Further information	wvanbijsterveld@geocisa.com

7.1.4 Pavement Management Systems for preventive maintenance

Best Practice #5	
Field	**Description**
Title and Keywords.	**Pavement Management Systems for preventive maintenance**
Source of best practice	GEOCISA, http://www.wcpam2017.com/
Lifecycle stage	Maintenance
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	Pavement, including subgrade.
Short Description	A pavement management systems is an interactive database, optionally with GIS features, which stores relevant data on the pavement section and the measurements and assessments performed on each road section. By means of experience based algorithms, the evolution of key performance indicators can be predicted and different maintenance strategies can be simulated and evaluated.
Success factors	Consistent data acquisition
Constraints	Extreme events (weather, over load) or lack of data.
Main impacts	Timely maintenance interventions ensure a suitable level of quaility, safety and comfort, and reduce the time and cost involved with bigger repairs or reconstruction.
Maturity and degree of implementation	Technically feasible and implemented at different levels. The methodology is adaptable to other modes and could be improved by more active data acquisition techniques (embedded sensors, big data).
Key Performance Indicators	
Further information	wvanbijsterveld@geocisa.com

7.1.5 Road materials made with high RAP (Reclaimed Asphalt Pavement) aggregate content, in hot and cold mix recycling

See Section 6.1.5 (BP #8).

7.1.6 Solar energy harvesting applied to road pavements

See Section 6.1.6 (BP #9).

7.1.7 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

See Section 6.1.7 (BP #10).

7.1.8 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

7.1.9 Thin polymeric trafficable waterproofing for bridge deck or multi-level car park paving

See Section 6.1.9 (BP #12).

7.1.10 Use of nanomaterials in the improvement of rheological and mechanical performance of bituminous mixtures for pavement construction

See Section 6.1.10 (BP #14).

7.1.11 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

7.1.12 Very thin asphalt overlay

Best Practice #16	
Field	**Description**
Title and Keywords	Title: **Very thin asphalt overlay** Keywords: bituminous mixtures, pavements, roads, ports
Source of best practice	Current practice in some countries all over the world
Lifecycle stage	Maintenance
Type of infrastructure	Road, ports and airports
Component of infrastructure	Pavement
Element of the infrastructure	Bituminous mixture
Short Description	It consists in the manufacture of an asphalt mixture with a very small size aggregate (maximum nominal size of 8-10 mm), with a very resistant and cohesive mastic, and an open mineral skeleton in order to provie a good macro-texture (to improve the adherence). This mixture is used as a very thin overlay (1-2 cm) in the rehabilitation of deteriorated pavements.
Success factors	It is necessary to use an aggregete with good properties (resistance) and a high adhesion to the binder. In the same way, it

	is interesting to use a considerable high dosage of polymer modified binder (over 5%). The filler/bitumen relationship should be between 1.1-1.3, in order to ensure a good cohesion of the mixture, and to guarantee a minimum of voids (macrotexture). It is necessary to use a good tack coat (with an abundant modified emulsion over the deteriorated pavement), in order to ensure the good bonding of the very thin laryer.
Constraints	It is difficult to extend and compact this type of mixtures. It is necessary to use precise spreaders, in order to ensure a homogeneous regularity of the layer. If the tack coat is not well spreaded, it can induce the failure of the layer trough its dettachment.
Main impacts	This technique alow for the rehabilitation of pavements with a low consumption of natural resources. In addition, the rehabilitation process is faster, and it could be very useful in places where the pavement cannot be regrown.
Maturity and degree of implementation	This technique is commonly used in many european countries to rehabilitate their pavements (specially in bridges or cities, where the pavement cannot be regrown).
Key Performance Indicators	
Further information	

7.1.13 New road pavement materials for hindering the Urban Heat Island impact and safeguarding human health

See Section 6.1.12 (BP #17).

7.1.14 Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)

See Section 6.1.16 (BP #21).

7.1.15 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

7.1.16 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

7.1.17 Managed lanes in Texas

Best Practice #31	
Field	**Description**

Title and Keywords	Managed lanes in Texas
Source of best practice	Cintra- Ferrovial
Lifecycle stage	Concession
Type of infrastructure	Toll road
Component of infrastructure	Toll lanes
Element of the infrastructure	Toll lanes
Short Description	Concessions which include the maintenance and improvement of toll-free existing lanes on both highways, and the construction of extra lanes boasting barrier-free electronic tolling with variable toll rates depending on the congestion levels of the highways. "It is an innovative system: toll lanes whose pricing is managed in real time according to traffic occupancy and speed
Success factors	Ability to innovate and to offer the client solutions to make the project viable.
Constraints	The main challenge faced was acquiring the land needed to build the extra lanes. In Texas private property is highly protected, so the process is complex and very bureaucratic.
Main impacts	Managed lanes will be the solution for many highly congested urban areas in the U.S. and several states such as Florida, California and Texas have projects at the development or implementation stage.
Maturity and degree of implementation	Completed
Key Performance Indicators	
Further information	http://www.ferrovial.com/en/press-room/news/highway-the-future-cintra-promotes-its-first-managed-lanes-texas/

7.1.18 Use of End-of-Life Tyres (ELT) rubber into asphalt layers of pavements

See Section 5.1.10 (BP #32).

7.1.19 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

7.1.20 Road safety systems for the protection of motorcyclists

See Section 5.1.13 (BP #36).

7.1.21 Multilayer susitanable tunnel linings

See Section 5.1.14 (BP #44).

7.1.22 Control of Road Tunnel Ventilation Systems

See Section 5.1.20 (BP #51).

7.1.23 Cathodic Protection for Cutter Soil Mix retaining walls

See Section 5.1.22 (BP #53).

7.1.24 Maintenance of transport infrastructures using predictive techniques

Best Practice #58	
Field	**Description**
Title and Keywords	**Maintenance of transport infrastructures using predictive techniques**. Keywords: vibration analysis, non destructive test, infrastructure maintenance
Source of best practice	Predictive techniques are increasingly finding applications for the assessment of equipment, structures, etc.
Lifecycle stage	Maintenance
Type of infrastructure	Multimodal
Component of infrastructure	
Element of the infrastructure	
Short Description	Unscheduled maintenance means extra costs and unavailability. Application of equipment condition monitoring and predictive maintenance technologies can reduce these losses and prevent accidents. Techniques like vibration analysis, infrared thermography and, in general, non-destructive tests may be applied to evaluate the performance of the equipment, structures, etc.
Success factors	The use of these technologies is increasing as the result of the development of new instrumentation.
Constraints	Lack of trained technicians.
Main impacts	A reliable methods of evaluate the condition of assets, focussing in loss prevention and cost effective with short term results.
Maturity and degree of implementation	
Key Performance Indicators	
Further information	

7.1.25 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

7.1.26 Performance Based Design

See Section 5.1.29 (BP #63).

7.1.27 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

7.1.28 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

7.1.29 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

7.1.30 Bituminous mixture SMA

See Section 6.1.37 (BP #73).

7.1.31 Low-cost wireless system for dynamic testing of infrastructure, with automatic location based on image processing

Best Practice #75	
Field	**Description**
Title and Keywords	Title: **Low-cost wireless system for dynamic testing of infrastructure, with automatic location based on image processing** Keywords: monitoring sensors, structural damage
Source of best practice	Current practice in some countries
Lifecycle stage	Maintenance. Monitoring of structures
Type of infrastructure	Road
Component of infrastructure	Bridge
Element of the infrastructure	The whole infrastructure.
Short Description	Early detection of any defect in the infrastructure. A low-cost wireless system with automatic location-finding based on image processing for dynamic infrastructure testing, that avoids the precise positioning of the sensors by being based on wireless devices provided with low-cost monitored cameras, enabling the relative position of the sensors in relation to a known point to be obtained by means of the image processing.
Success factors	Early detection of any defect capable of producing loss of rigidity and thus evaluated in updated form the safety and reliability of

	structures. Minimize not only the annual repair costs, but also avoid prolonged periods of time that may represent a higher economic cost.
Constraints	
Main impacts	This system prevents the precise placement of monitoring sensors of structures, since due to the automatic location based in the image processing, the exact point where each sensor is located, it will be known.
Maturity and degree of implementation	Very used by the company in several countries, mainly in Spain.
Key Performance Indicators	Process optimization, cost optimization
Further information	www.fcccco.es

7.1.32 Monitoring of briges and multi-criteria decision support system

Best Practice #76	
Field	**Description**
Title and Keywords.	Title: **Monitoring of briges and multi-criteria decision support system** Keywords: bridge, road, monitoring, damage, inspection
Source of best practice	DARS, DRSI, ZRMK
Lifecycle stage	Maintenance
Type of infrastructure	Road
Component of infrastructure	Bridge
Element of the infrastructure	All elements of bridge
Short Description	The management of bridge network on Slovenian roads with a multi-criteria decision support system. It enables storage of bridges statuses data and from there forms a priority list of bridges in need of remediation. On technical part the priority list is developed based on observed damage while on financial part the basis is extent of remedial works needed, influence on network performance and expected deterioration. Remedial works are prescribed depending upon bridge network condition and annually available financial resources. In addition, financial aspect enables projection of the necessary financial resources to maintain the network status for the five-year period. Effects of multiple parameters of influence upon the speed of deterioration are considered. geographical coverage: roads and highways under the domain of state (in Slovenia)

Success factors	It can be used by operators of network with similar objects (roads, rails…)
Constraints	Operators with large set of bridges to monitor and maintain.
Main impacts	economic benefits of investing into most damaged bridges/parts (acting before deterioration leads to major reconstructions), control over structural safety
Maturity and degree of implementation	It is in use for decade and gradually upgraded. It's technically feasible and replicable. It could be adaptable to different structures (like railway bridges, retaining walls etc.).
Key Performance Indicators	
Further information	www.gi-zrmk.si

7.1.33 Timber bridge monitoring of moisture

See Section 5.1.38 (BP #77).

7.1.34 Delayed pouring of a concrete closure in bridge widenings

See Section 6.1.40 (BP #83).

7.1.35 Checkerboard concreting in large surfaces

See Section 6.1.41 (BP #84).

7.1.36 Evaluation of the detection limits for the investigation of strands using the magnetic leakage field method

Best Practice #86	
Field	**Description**
Title and Keywords	Title: **Evaluation of the detection limits for the investigation of strands using the magnetic leakage field method** Keywords: prestressed steel, non-destructive investigation, bridge inspection, magnetic leakage field method, reinforcement evaluation
Source of best practice	MPA University of Stuttgart. 16th European Bridge Conference 23th to 25st June 2015, Edinburgh, Scotland
Lifecycle stage	Maintenance
Type of infrastructure	Road or rail
Component of infrastructure	Bridge, underground car park
Element of the infrastructure	Deck, bearing parts
Short Description	The magnetic leakage measurement method is useful for the non-destructive investigation of the integrity of tendons using in prestressed concrete members. It is based on the fact, that ruptures or sudden changes of the cross sections of the prestressing steels can be detected by characteristic magnetic anomalies. Due to the

	fact, that all ferromagnetic elements of the reinforcement cause magnetic signals, these anomalies also can be obtained by using several techniques of the magnetization and the signal analysis. The measuring of the remanence magnetic leakage field led in combination with numerical methods to a satisfying suppression of unwanted signals of the mild reinforcement.
Success factors	Ruptures of prestressing steels of pretensioned concrete members can be detected with a good reliability. In case of tensioning steels, which are arranged as a bundle, the detection limit becomes severely limited due to the fact, that the adjacent intact steels cause a considerable attenuation of the signal of a rupture.
Constraints	In case of tensioning steels, which are arranged as a bundle, the detection limit becomes severely limited due to the fact, that the adjacent intact steels cause a considerable attenuation of the signal of a rupture.
Main impacts	With the results of the magnetic leakage field measurements, the limits for the detection of prestressing steel fractures on real structures can be appreciated much better. This increase the safety of the components of the infrastructure. The economic and environmental benefits is based on the fact, that the measured elements can mostly be used much longer.
Maturity and degree of implementation	Very used in whole europe, since the '90s
Key Performance Indicators	
Further information	Schreiner M., Sawade G., Steinfeld B.: *Evaluation of the detection limits for the investigation of strands using the magnetic leakage field method*, proceedings of the 16th European Bridge Conference, Edinburgh, 2015. Contact details: Jürgen Frick, MPA University Stuttgart, juergen.frick@mpa.uni-stuttgart.de Michael Schreiner, MPA University Stuttgart Frank Lehmann, MPA University Stuttgart

7.1.37 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

7.1.38 Ultrasound tomography on inspection of reinforced and pre-stressed concrete structures

Best Practice #88	
Field	**Description**
Title and Keywords	Title: **Ultrasound tomography on inspection of reinforced and pre-stressed concrete structures**. Keywords: ultrasound tomography, inspection, non-destructive tests, concrete, pathology, survey.
Source of best practice	Practice under development in some countries, namely in Portugal

	R&D project - "REABET" - promoted by TEIXEIRA DUARTE - Fincanced by QREN
Lifecycle stage	Maintenance
Type of infrastructure	Roads, rails
Component of infrastructure	Bridges
Element of the infrastructure	Beams, colums - Concrete structural elements
Short Description	The ultrasonic tomography is an innovative and non-destructive technique used to obtain images of the interior of the concrete based on the detection of contrast and density through ultrasound, using a special tomograph with a set of ultrasound transducers in a matrix arrangement. The results obtained are post-processes to obtain tomography images in every 3D plan, identifying pathologies (segregation, voids, etc), rebars, pre-stress cables and other elements and singularities.
Success factors	Ultrasound tomography is a non-destructive technique and allows identifying elements and defects deep within concrete elements.
Constraints	The main constraint of the technique is the lack of suppliers of this type of equipment and the fact that the dedicated software is not open source.
Main impacts	Ultrasound tomography technique may be used to identify and locate defects/flaws and rebars/cables in depth with higher accuracy and within a higher depth than current non-destructive techniques. The visualisation of the results in 3-D images allows a fast and comprehensive interpretation of results, unlike most alternative techniques.
Maturity and degree of implementation	The technique may already be applied although it is still being developed to establish a better interpretation of obtained images.
Key Performance Indicators	
Further information	

7.1.39 Use of the gammagraphy technique in the field inspection of reinforced and prestressed concrete structural elements

Best Practice #89	
Field	**Description**
Title and Keywords	Title: **Use of the gammagraphy technique in the field inspection of reinforced and prestressed concrete structural elements**. Keywords: gamagraphy, inspection, non-destructive tests, concrete, pathology, survey.
Source of best practice	Practice under development in some countries, namely in Portugal R&D project - "REABET" - promoted by TEIXEIRA DUARTE - Fincanced by QREN

Lifecycle stage	Maintenance
Type of infrastructure	Roads, rails
Component of infrastructure	Bridge
Element of the infrastructure	Beems, colums - Concrete structural elements.
Short Description	Gamagraphy consists of a non-destructive inspection technique where the structure is irradiated with gamma radiation and the results obtained are shown as images similar to X-rays, which can be treated with computer software tools, allowing obtaining three-dimensional colour profiles, identifying pathologies (segregation, voids, etc), rebars, pre-stress cables and other elements and singularities.
Success factors	Gamagraphy is a non-destructive technique and allows identifying elements and defects deep within concrete elements.
Constraints	The main constraint regarding gamagraphy technique is the need to evacuate the are in turn during the tests because of the radioactivity. In thicker concrete elements, each gamagraphy image may require up to 20-30 minutes to be obtained.
Main impacts	Gamagraphy technique may be used to identify and precisely locate defects/flaws and rebars/cables in depth with higher accuracy than current non-destructive techniques. The visualisation of the results in 3-D images allows a fast and comprehensive interpretation of results, unlike most alternative techniques.
Maturity and degree of implementation	The technique may already be applied although it is still being developed to establish a better interpretation of obtained images.
Key Performance Indicators	
Further information	

7.1.40 Aerial inspections using RPAs of bridges and other difficult access areas in infrastructures

Best Practice #93	
Field	**Description**
Title and Keywords	**Aerial inspections using RPAs of bridges and other difficult access areas in infrastructures**. Keywords: aerial inspection, remote piloted aircraft, infraestructure maintenance
Source of best practice	RPAs are increasingly finding uses in civil applications.
Lifecycle stage	Maintenance
Type of infrastructure	Multimodal
Component of infrastructure	Difficult access areas
Element of the infrastructure	Bridge structures, etc.
Short Description	RPAs have been used widely by military purposes, however also have been shown to have many civilian uses, such as in agriculture,

	movies, etc. This proposal is referred to technical inspection in infrastructures. In this field there are still many possibilities to be discovered.
Success factors	The ease with which RPAs can be used and the labor efficiency because does not require flight personnel.
Constraints	In Spain, the laws do not allow the RPAs flights in urban areas and only can fly with day light.
Main impacts	The remote surveillance allows immense possibilities in difficult access technical inspections without the associated safety concerns of piloted aircrafts and neither environmental issues like noise and emissions. It is a technology with a high potential of employ generation in the next years as well.
Maturity and degree of implementation	
Key Performance Indicators	
Further information	

7.2 Type of Infrastructure: Rail (Maintenance)

7.2.1 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

See Section 6.1.7 (BP 10).

7.2.2 Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)

See Section 6.1.16 (BP 21).

7.2.3 Reducing noise from the rail

Best Practice #27	
Field	**Description**
Title and Keywords.	**Reducing noise from the rail**.
Source of best practice	
Lifecycle stage	Maintenance.
Type of infrastructure	Rail
Component of infrastructure	Rail and waggons
Element of the infrastructure	
Short Description	Rail waggons carrying gods are usually equipped with brakes directly on the wheels. This results in more noise due to uneven surfaces of the rail. This can be avoided by changing brakes but

	also regular maintenace and grinding of the rails
Success factors	
Constraints	
Main impacts	Noise reduction
Maturity and degree of implementation	
Key Performance Indicators	
Further information	

7.2.4 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

7.2.5 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

7.2.6 Use of End-of-Life Tyres (ELT) rubber into asphalt layers of pavements

See Section 5.1.10 (BP #32).

7.2.7 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

7.2.8 Elastic elements in railway structures

See Section 6.2.11 (BP #37).

7.2.9 Stone-blowing process for the maintenance of railway tracks

Best Practice #39	
Field	**Description**
Title and Keywords	Title: **Stone-blowing process for the maintenance of railway tracks** Keywords: Stone-blowing, maintenance, railway
Source of best practice	Practice in United Kingdom and some experiences in USA
Lifecycle stage	Maintenance
Type of infrastructure	Railway
Component of infrastructure	Superstructure of the track
Element of the infrastructure	Ballast
Short Description	It consists of incorporing small stones between the sleeper and the ballast surface (under the sleeper) in order to fill the gap

	between both components when the settlement of the track takes place and the system rail-sleeper must be lift to restore the geometry of the track. The small stones (mainly with size between 12 mm and 20 mm) are blown under the sleeper when it is lift to recover the original possition, and therefore, it is not needed the tamping process to dilate the ballast layer to recover the geometry.
Success factors	Due to the trains passing, the settlement of the ballast layer takes place and some maintenance tasks are required to restore the geometry of the track. Commonly, a tamping process is applied to dilate the ballast layer. However, the track quickly settles again due to the fact that this process only dilate the granular layer (obtaining then a weaker layer). Nonetheless, the stone-blowing process allows for the restoration of the geometry by incorporing small stones under the sleeper without altering the ballast layer, and therefore, it does not settle quickly since its level of compaction is not altered.
Constraints	The stone-blowing process is still being developed, and then more investigations are required to define the main factor of the process in order to reduce the irregularities along the track that can take place after this maintenance task. In addition, it is necessary to adapt the machinery used in maintenance tasks in order to carry out this process, or even it is needed to acquire new machinery such as the stoneblower
Main impacts	The use of this technique could reduce the maitenance frequency since it is possible to reduce considerably the settlement ratio after this process. In addition, it is possible to increase the durability of the ballast layer since less maintenance tasks are required at the same time that the degradation of the particles is reduced during the task in comparison with the conventional process (tamping).
Maturity and degree of implementation	This technique is usually used in United Kingdom, but deeper studies are required in order to improve the quality of the track after the maintenance by using this process.
Key Performance Indicators	
Further information	

7.2.10 High output sleepers aligment machine

See Section 6.2.13 (BP #40).

7.2.11 Unloading of Long Welded Rail (LWD) through a provisional Track

See Section 6.2.14 (BP #41).

7.2.12 Multilayer sussitanable tunnel linings

See Section 5.1.14 (BP #44).

7.2.13 Cathodic Protection for Cutter Soil Mix retaining walls

See Section 5.1.22 (BP #53).

7.2.14 Maintenance of transport infrastructures using predictive techniques

See Section 7.1.23 (BP #58).

7.2.15 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

7.2.16 Performance Based Design

See Section 5.1.29 (BP #63).

7.2.17 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

7.2.18 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

7.2.19 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

7.2.20 Timber bridge monitoring of moisture

See Section 5.1.38 (BP #77).

7.2.21 Delayed pouring of a concrete closure in bridge widenings

See Section 6.1.40 (BP #83).

7.2.22 Checkerboard concreting in large surfaces

See Section 6.1.41 (BP #84).

7.2.23 7.1.35 Evaluation of the detection limits for the investigation of strands using the magnetic leakage field method

See Section 7.1.35 (BP #86).

7.2.24 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

7.2.25 Ultrasound tomography on inspection of reinforced and pre-stressed concrete structures

See Section 7.1.37 (BP #88).

7.2.26 Use of the gammagraphy technique in the field inspection of reinforced and prestressed concrete structural elements

See Section 7.1.38 (BP #89).

7.2.27 Aerial inspections using RPAs of bridges and other difficult access areas in infrastructures

See Section 7.1.39 (BP #93).

7.3 Type of Infrastructure: Air (Maintenance)

7.3.1 Innovative geosynthetics for aspahlt layers reinforcement

See Section 6.1.3 (BP #3).

7.3.2 Road materials made with high RAP (Reclaimed Asphalt Pavement) aggregate content, in hot and cold mix recycling

See Section 6.1.5 (BP #8).

7.3.3 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

See Section 6.1.7 (BP #10).

7.3.4 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

7.3.5 Use of nanomaterials in the improvement of rheological and mechanical performance of bituminous mixtures for pavement construction

See Section 6.1.10 (BP #14).

7.3.6 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

7.3.7 Very thin asphalt overlay

See Section 7.1.12. (BP #16).

7.3.8 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

7.3.9 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

7.3.10 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

7.3.11 Maintenance of transport infrastructures using predictive techniques

See Section 7.1.23 (BP #58).

7.3.12 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

7.3.13 Performance Based Design

See Section 5.1.29 (BP #63).

7.3.14 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

7.3.15 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

7.3.16 Bituminous mixture SMA

See Section 6.1.37 (BP #73).

7.3.17 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

7.3.18 Aerial inspections using RPAs of bridges and other difficult access areas in infrastructures

See Section 7.1.39 (BP #93).

7.4 Type of Infrastructure: Water (Maintenance)

7.4.1 Very thin asphalt overlay

See Section 7.1.12. (BP #16).

7.4.2 Cathodic Protection for Cutter Soil Mix retaining walls

See Section 5.1.22 (BP #53).

7.4.3 Maintenance of transport infrastructures using predictive techniques

See Section 7.1.23 (BP #58).

7.4.4 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

7.4.5 Performance Based Design

See Section 5.1.29 (BP #63).

7.4.6 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

7.4.7 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

7.4.8 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

7.4.9 Aerial inspections using RPAs of bridges and other difficult access areas in infrastructures

See Section 7.1.39 (BP #93).

7.5 Type of Infrastructure: Multi-modal (Maintenance)

7.5.1 Innovative geosynthetics for aspahlt layers reinforcement

See Section 6.1.3 (BP #3).

7.5.2 Road materials made with high RAP (Reclaimed Asphalt Pavement) aggregate content, in hot and cold mix recycling

See Section 6.1.5 (BP #8).

7.5.3 The use of marginal materials (by-products and secondary materials) in transport infrastructure construction for enhancing mechanical performances and environmental sustainability

See Section 6.1.7 (BP #10).

7.5.4 The use of warm mix asphalt in flexible pavement for energy saving and environmental impact reduction

See Section 5.1.2. (BP #11).

7.5.5 Use of nanomaterials in the improvement of rheological and mechanical performance of bituminous mixtures for pavement construction

See Section 6.1.10 (BP #14).

7.5.6 Use of synthetic interlayer reinforcement systems for pavements

See Section 5.1.4. (BP #15).

7.5.7 Very thin asphalt overlay

See Section 7.1.12. (BP #16).

7.5.8 Asphalt mixtures incorporing RAP (reclaimed asphalt pavement)

See Section 6.1.16 (BP #21).

7.5.9 Reuse of Mining and other Industrial Wastes materials into pavements

See Section 5.1.8 (BP #29).

7.5.10 Use of Warm Mix and Cold Mix Asphalts for bituminous layers of pavements

See Section 5.1.9 (BP #30).

7.5.11 Recycling Construction and Demolition Waste materials into pavements

See Section 5.1.11 (BP #33).

7.5.12 Multilayer susitanable tunnel linings

See Section 5.1.14 (BP #44).

7.5.13 Cathodic Protection for Cutter Soil Mix retaining walls

See Section 5.1.22 (BP #53).

7.5.14 Maintenance of transport infrastructures using predictive techniques

See Section 7.1.23 (BP #58).

7.5.15 Infrastructure Lifecycle Management

See Section 5.1.27 (BP #61).

7.5.16 Performance Based Design

See Section 5.1.29 (BP #63).

7.5.17 Use of 4D techniques for Planning the Virtual Construction of all type of Infrastructures

See Section 5.1.30 (BP #64).

7.5.18 BIM 4D, 5D, 6D for construction simulation

See Section 5.1.32 (BP #68).

7.5.19 Ecological restoration in areas affected by lineal infrastructures and mining sites

See Section 5.1.36 (BP #72).

7.5.20 Bituminous mixture SMA

See Section 6.1.37 (BP #73).

7.5.21 Timber bridge monitoring of moisture

See Section 5.1.38 (BP #77).

7.5.22 Delayed pouring of a concrete closure in bridge widenings

See Section 6.1.40 (BP #83).

7.5.23 Checkerboard concreting in large surfaces

See Section 6.1.41 (BP #84).

7.5.24 Use of lean tools not only for internal gains but also for meeting societal demands, avoidance of annoyance, etc.

See Section 6.1.43 (BP #87).

7.5.25 Ultrasound tomography on inspection of reinforced and pre-stressed concrete structures

See Section 7.1.37 (BP #88).

7.5.26 Use of the gammagraphy technique in the field inspection of reinforced and prestressed concrete structural elements

See Section 7.1.38 (BP #89).

7.5.27 Aerial inspections using RPAs of bridges and other difficult access areas in infrastructures

See Section 7.1.39 (BP #93).

8 Next Steps

In order to make full use of the information contained in this document for the subsequent tasks of the REFINET CSA (e.g. SIP), the next steps need to be taken:

- The collected best practices identified need to be further clustered into groups that represent strategic areas of knowledge for the SIP. For instance the best practices in this document provide information about those which are suitable for the Infrastructure Type "Road", Component type "Pavement", Element type "bituminous mixture".

- The classification can be used for:
  - Identify best practices where the practice is well developed and undertaken by the industry and there is no remaining potential for innovation.
  - Identify best practices where the practice is well developed and undertaken by the industry but there is still potential for innovation as there might still be constraints to be removed to take advantage of the full benefits of the practice.
  - Detecting gaps, areas of lack of knowledge where research still needs to be developed. With the information contained in this document this item is more difficult to achieve as it was explained the list can't be exhaustive. However the identified gap can be researched to either learn there are mature best practices in the area or lack of knowledge and need of research.
- The previous items jointly with the information delivered in D3.4 provide a basis for Strategic Planning in the area of Transport Infrastructure.
- Notice that this work should also be continued by the Infrastructure and Mobility Committee of the ECTP and the ENCORD Work Group on Transport Infrastructure.
- Finally, the best practice template provides a field for KPIs to be further completed with the KPIs from the RMMTI model once these are finally consolidated.

9 CONCLUSIONS

Deliverable "D3.2 Best practices in design, building and maintenance of transport infrastructures" due in month 12 compiles a non-exhaustive collection of best practices that are already being applied in design, construction and maintenance of transport infrastructure. The deliverable contributes to the achievement of the project Objective "2) Defining the REFINET vision". So consequently, the deliverable assists in setting the basis to define how the multimodal European transport infrastructure network of the future should be and the R&I demands to evolve the current European transport networks according to this vision of the best practices currently applied in the industry of Transport Infrastructure.

To provide these Best Practices collection a pragmatic (industrial) approach has been taken, basing the work in direct experience of experts from the industry and the academia. Different information sources and organisations have been consulted and workshops organised to select the best practices in design and construction of new transport infrastructures and maintenance of the existing ones.

For each of the best practices, relevant information regarding scenario defining the context of application, short description of the best practice, main impacts, constraints of application, maturity and current level of dissemination have been collected.