MAINLINE

MAINtenance, renewal and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts

Collaborative project (Small or medium-scale focused research project)

Theme SST.2011.5.2-6.: Cost-effective improvement of rail transport infrastructure

Deliverable 3.3:

Rail Switches and Crossings. Development of new technologies for replacement

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Abstract of the MAINLINE Project

Growth in demand for rail transportation across Europe is predicted to continue. Much of this growth will have to be accommodated on existing lines that contain old infrastructure. This demand will increase both the rate of deterioration of these elderly assets and the need for shorter line closures for maintenance or renewal interventions. The impact of these interventions must be minimized and will also need to take into account the need for lower economic and environmental impacts. New interventions will need to be developed along with additional tools to inform decision makers about the economic and environmental consequences of different intervention options being considered.

MAINLINE proposes to address all these issues through a series of linked work packages that will target at least €300m per year savings across Europe with a reduced environmental footprint in terms of embodied carbon and other environmental benefits. It will:

- Apply new technologies to extend the life of elderly infrastructure
- Improve degradation and structural models to develop more realistic life cycle cost and safety models
- Investigate new construction methods for the replacement of obsolete infrastructure
- Investigate monitoring techniques to complement or replace existing examination techniques
- Develop management tools to assess whole life environmental and economic impact.

The consortium includes leading railways, contractors, consultants and researchers from across Europe, including from both Eastern Europe and the emerging economies. Partners also bring experience on approaches used in other industry sectors which have relevance to the rail sector. Project benefits will come from keeping existing infrastructure in service through the application of technologies and interventions based on life cycle considerations. Although MAINLINE will focus on certain asset types, the management tools developed will be applicable across a broader asset base.

Partners in the MAINLINE Project

UIC, FR; Network Rail Infrastructure Limited, UK; COWI, DK; SKM, UK; University of Surrey, UK; TWI, UK; University of Minho, PT; Luleå tekniska universitet, SE; Deutsche Bahn, DE; MÁV Magyar Államvasutak Zrt, HU; Universitat Politècnica de Catalunya, ES; Graz University of Technology, AT; TCDD, TR; Damill AB, SE; COMSA EMTE, ES; Trafikverket, SE; SETRA, FR; ARTTIC, FR; Skanska a.s., CZ.

WP3 in the MAINLINE project

The main objectives for WP3 are to:

- investigate new construction methods and logistics for transport that minimize the time and cost required for the replacement of obsolete infrastructure. The focus here is on cost effective and environmentally sound methods that are easy to implement with low impact on the rail traffic and a short down time of the network.
- plan and optimize the construction processes on existing lines where replacement of existing infrastructure is an alternative. The results will help the infrastructure manager to decide for the most favourable measure from technical, environmental or cost demands.
- deliver input regarding data to the development of life cycle cost models and other decision support systems for infrastructure managers. This includes taking into account construction time and logistics, short- and long-term impact on the network.

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Glossary

Abbreviation/ acronym	**Description**
BV	Banverket – former Swedish IM
DB	Deutsche Bahn – German IM
DTS	Dynamic Track Stabilizer
FBW	Flash Butt Welding
FFU	Fibre-reinforced foamed urethane
IM	Infrastructure Manager
JBV	Jernbaneverket – Norwegian IM
MAV	Magyar Államvasutak – Hungarian IM
NR	Network Rail – British IM
ÖBB	Österreichische Bundesbahnen – Austrian IM
RCF	Rolling contact fatigue
SBB	Schweizerische Bundesbahn – Swiss IM
S&C	Switches & crossings
TCDD	Türkiye Cumhuriyeti Devlet Demiryolları – Turkish IM
TRV	Trafikverket – Swedish IM
TSL	Temporary Speed Limitation
TSR	Temporary Speed Restriction
UBM	Under Ballast Mat
URP	Under Rail Pad
USP	Under Sleeper Pad
WP	Work Package

1. Executive Summary

Switches represent a key asset of the railway infrastructure, which must be replaced with higher frequency than plain track given that they have to bear higher stress. There is a wide range of methods being used to replace switches and crossings (S&C), which offer different outputs and installation qualities.

A review of S&C renewal methods across Europe is undertaken in Chapter 4. The study analyses and compares the S&C replacement methods used in eight countries (Spain, Sweden, Germany, Turkey, Hungary, United Kingdom, Czech Republic and Norway) in terms of outputs, resources (labour and machinery) and quality of installation.

Track stiffness variation along the switch has a direct effect on the magnitude of impact loads that cause track deterioration. A study on the measures to adopt in the design and during the renewal of the switches in order to homogenise track stiffness is carried out in Chapter 5.

From the results obtained in Chapter 4 and 5, further improvements on the design and on the logistics of S&C renewals are proposed. This will be the base for the elaboration of the guidelines (Deliverable 3.4) in what regards to switches.

2. Acknowledgements

This present report has been prepared within Work Package WP3 of the MAINLINE project by with the collaboration of the following partners and Infrastructure Managers:

- COMSA (COMSA), Spain
- SKANSKA (SKANSKA), Czech Republic
- Deutsche Bahn AG (DB), Germany
- Magyar Államvasutak (MAV), Hungary
- Türkiye Cumhuriyeti Devlet Demiryollari Isletmesi (TCDD), Turkey
- Trafikverket (TrV), Sweden
- Jernbaneverket (JBV), Norway (outside the project)

3. Introduction

Switches are a fundamental part of the railway infrastructure, given that they enable the creation of a “real” network. Switches are not only placed in the infrastructure to connect different lines, but also to connect parallel tracks of the same line (crossovers) in order to give flexibility to track operation. The operational impact caused by an incident on the track is directly related to the number of crossovers in the line, which evinces their importance for IMs.

Moreover, because of their configuration, turnouts represent a singular point in the track. Compared to plain track, switches have higher track stiffness given that they are provided with altered sleepers dimensions and arrangements, additional rail elements, etc. Furthermore, in relation to the adjacent track, the conditions of the wheel-rail interface vary significantly given the rail geometry discontinuities of the switch. This results in an increase of wheel dynamic loads that deteriorates the switch, especially the crossing nose and blades that receive the impact loads, causing wear, RCF – rolling contact fatigue – and noise.

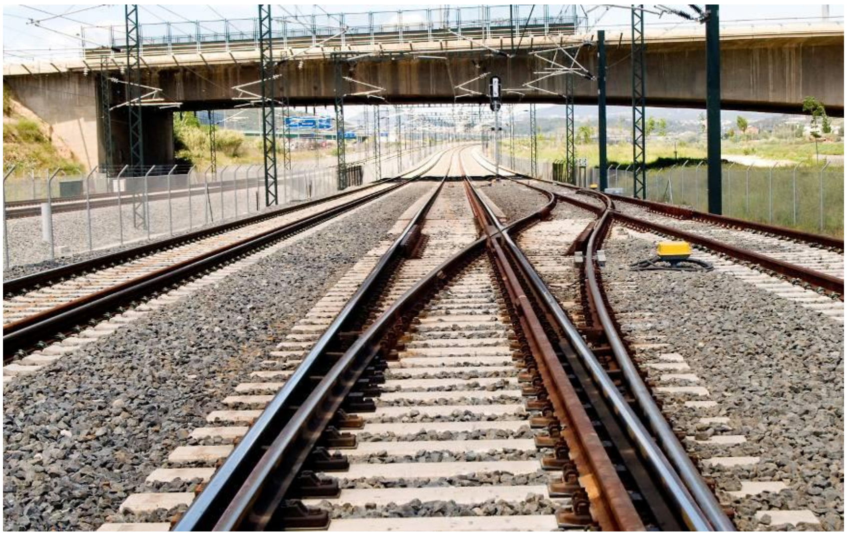


Figure 1. Switch in a dual gauge line in Spain (source: Adif)

Switches must be kept in good condition in order to guarantee an adequate running of the train through switch, and thus, to minimize its degradation by dynamic loads. If not properly maintained, the wheel-rail interface will be negatively affected, which could eventually derive in derailments (e.g. as a result of the wheel impacting a blade that is not correctly coupled to the stock rail or suffers excessive wear).

Because of safety and operational issues, switches are intensively inspected and maintained. Inspection costs account for the 50% of all maintenance costs for switches. In spite of the high investment on maintenance, switches have a lesser lifespan than plain track given that they suffer higher stress. According to B. Lichtberger in [1], the service life of a wooden sleepers S&C is about 20 years in average, while when using concrete sleepers the expected life increases up to 30 years.

Due to the high number of switches being replaced every year (e.g. over 2000 in Germany), efficient methods in terms of cost and time have to be employed to minimize the impact on operations. Moreover, future performance of the new switches depends strongly on the quality of installation.

For this reason, this deliverable aims at analysing the current practice in S&C renewal in Europe in order to achieve two main goals: (i) to identify best practices in switch replacement, that could serve as a reference to all countries and (ii) to point out potential further improvements on the logistics and design of the switches.

The results of this project will be the base of the guidelines that will be elaborated in Deliverable 3.4, in what regards to S&C renewal.

3.1 Sources of information for the review of S&C renewal methods

In order to carry out a complete review of the European practice on switch renewal, the maximum number of countries was intended to be included. The information was mainly gathered through a questionnaire distributed among MAINLINE partners. The questionnaire was agreed by all WP3 partners and was sent to all IMs and contractors involved in the project.

Apart from this, another main source of information regarding the current practice in S&C replacement has been the 6th FP project INNOTRACK, specially the Deliverable 5.4.2 – Final Report on the Logistics of S&C [2].

Finally, information about Norwegian practice was sent by JBV after the presentation of MAINLINE project by DB at the UIC Track Expert Group meeting in January 2014.

Therefore, in this report there can be found the description of the current practice in S&C renewal of the following countries:

- Germany (DB)
- Spain (Comsa)
- Sweden (Banverket/Trafikverket)
- Turkey (TCDD)
- Hungary (MAV)
- Czech Republic (Skanska)
- United Kingdom (NR)
- Norway (JBV)

3.2 D3.3 in the MAINLINE project

Deliverable D3.3 is a report on the activities of Task 3.3, which is described in the MAINLINE DoW as *“Development and improvement of new technologies for replacement“.* The D3.3 report is addressed to the asset maintenance engineers within the railways infrastructure owners or working for consultants and others involved in the planning and design of infrastructure renewal. Along with the “twin deliverable” D3.2 from Task 3.2 regarding replacement of bridges this deliverable is intended to inform the work of Task 3.4 in producing a Guideline to replace railway infrastructure. This Handbook is the final output of work within WP3 and will feed into WP5, Task 5.5, which is to produce the MAINLINE Life Cycle Assessment Tool (LCAT).

Figure 3.1 shows schematically the general organisation of the project into work packages (WPs) and identifies the main interactions.

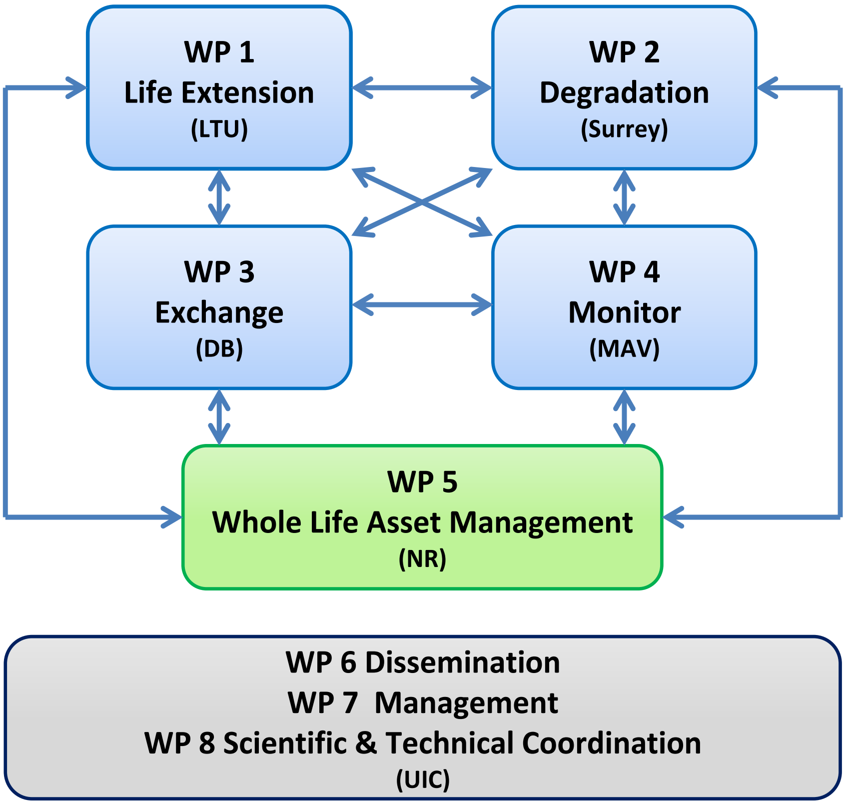


Figure 3-2 General organisation of the project

Part n°	WP3 Partners	Country
1	UNION INTERNATIONALE DES CHEMINS DE FER - UIC	FR
2	NETWORK RAIL INFRASTRUCTURE LTD	UK
3	COWI A/S	DK
8	LULEA TEKNISKA UNIVERSITET	SE
9	DEUTSCHE BAHN	DE
12	TECHNISCHE UNIVERSITAET GRAZ	AT
13	TÜRKIYE CUMHURIYETI DEVLET DEMIRYOLLARI ISLETMESI	TR
15	COMSA	ES
16	TRAFIKVERKET	SE
19	SKANSKA	CZ
20	SINCLAIR KNIGHT MERZ	UK

4. Review of existing methods for S&C replacement

This section aims to give an overview of existing S&C renewal methods that are currently employed across Europe, paying special attention to those offering higher output and track quality.

Different S&C renewal methods will be described and compared in this section, indicating the required resources (labour and plant) and the average output achieved. The results of this analysis, along with the main conclusions outlined in *Chapter 6 – Logistics and design improvements for S&C renewal optimisation*, will be the basis of Deliverable 3.4 – Guidelines for IMs in what regards to S&C replacement.

4.1 Classification of S&C replacement methods

Three main methods for S&C renewal can be identified:

- Assembled in situ
- Pre-assembled in the vicinity of the works
- Modular switch (just in time)

According to DB, the proportions of these three methods is 9% pre-assembled in situ, 90% pre-assembled at the lineside and less than 1% for modular switch. This proportion is very similar to the majority of the countries analysed in the report. Only in some Eastern European countries the proportion of switches assembled in situ is higher. In contrast, Network Rail is the only Infrastructure Manager of the project that uses the modular switch concept with certain frequency.

As a result we can admit that assembly of the S&C adjacent to the worksite is the most common practice across Europe due to the following advantages:

- On acceptance of the S&C at the factory, disassembly, transport and reassembly near the renewal site is relatively straightforward.
- S&C can be constructed near the worksite and installed with minimised disturbance to traffic.
- The quality of the components and installed geometry is known to be good upon commissioning.

However, the use of modular switch concept is expected to grow in some countries given that this method allows a reduction of not only the installation time but can also facilitate significantly the pre-renewal works (no need to negotiate with landowners if there is no available space for the assembly of the new switch) and post-renewal works (less time required for commissioning).

It is important to remark also that in some countries, especially in Eastern Europe, piecemeal is still a common practice (15% is renewed piecemeal, according to [3]). However, piecemeal renewal leads to a lower quality of the switch since S&C units end up with components of varying age and condition.

4.2 Phases of S&C replacement methods

As it was mentioned before, there can be found a wide range of methods for replacing a turnout, nevertheless, all replacement methods follow a similar structure, which can be organized in four main phases.

Pre-renewal works

- Preparation of storage areas
- Transport of replacement components to site
- Pre-assembly of the new switch in the storage area (in case it is required)
- Topography works previous to installation

Removal of the old S&C and site preparation

- Dismantling and removal of the old S&C
- Removal of the upper part or the whole layer of ballast

Installation of new S&C

- Adding of new ballast (and optionally placing of geogrid)
- Laying and assembly of the new switch panels
- Welding or clamping
- Initial track geometry restoration
- Control system commissioning
- Final commissioning and testing
- Dynamic Track Stabiliser (optionally)

Post-renewal activities

- Welding and stress release (if it is not done during the installation phase)
- Final track geometry restoration
- Final inspection and acceptance

This same structure will be used later on in *Section 4.11 Comparison of S&C renewal methods* to compare all methods in terms of resources (workforce and machinery) and output that have been collected in WP3, and that are described here after.

4.3 German practice (DB)

According to DB, around 2000 S&C on average are replaced annually in Germany (in 2013, 2350 switches were replaced while in INNOTRACK project, about 1500 S&C renewals were stated). The switches are supplied by a factory owned by DB Netz and by two other factories in Germany. The latter two factories supply nearly 75% of all the switches.

The criteria to decide which method should be used during the S&C renewal are based on economical aspects, and for that reason the most common method is the **pre-assembling near the site** (90%). Usually there is lineside space available for the pre-assembling of the S&C and track access roads to transport the switch components and machinery. In practically 99% of cases, heavy railway cranes (up to 40 tons) are used for installing the new switch panels on their final position. Other installation systems such as UWG system, excavators or VAIA-Car crane-beam are infrequently used.

Figure 3. Multi-purpose railway crane commonly employed for switch renewal. (Source: DB).

On the contrary, when there are lineside space constraints to the preassembly of the switch, such as in tunnels or embankments, the **modular switch** method is preferred. The modular switch renewal concept accounts for only 1-3% of the total S&C renewals. One of the main reasons of this low use of the modular concept is the reduced number of special tilting wagons available for the transport of switch panels from the factory to the worksite.

DB owns a total of 8 special tilting wagons, known as Weichentransportwagen (WTW). Considering that replacements take place during weekends (52 a year) and that usually 3 WTW are used to transport the total switch, around 100 S&C replacements take place annually with this system (which is consistent with the 1-3% of the total renewals mentioned above).

Figure 4. Tilting wagons used to transport switch panels from factory. (Source: DB).

And finally, around 7 to 9% of S&C renewals are done using the **assembly in situ** method. This method is also very rarely employed given that it requires longer track possession and involves high labour costs.

DB Netz intends to implement “plug and play” techniques in the future to speed up replacement and commissioning of components interfaced with the signalling system (e.g. point motors) by using computerised self-testing.

Usually, DB practice during switch renewal is to clamp the rails during installation and carry out the welding before the line is reopened, which is usually at line speed as long as the ballast has been tamped to restore track geometry. However, in some cases line is opened before the final track geometry restoration is done and temporary speed restrictions (TSR) apply until a certain amount of traffic has passed. The speed limitation depends on the speed of the line and the traffic passage as it can be shown in the figure below:

local speed limit zul v [km/h]	track systems		highest speed allowed [km/h] depending on the traffic passage [t]					
	track with concrete sleepers l≥2,60m	all other systems	≤ 25 000	> 25 000 ≤ 50 000	> 50 000 ≤ 100 000	> 100 000 ≤ 150 000	> 150 000 ≤ 200 000	≥ 200 000
≤ 70	x	x	zul v	zul v	zul v	zul v	zul v	zul v
> 70 ≤ 120	x		**70**	zul v	zul v	zul v	zul v	zul v
> 70 ≤ 120		x	**70**	**70**	zul v	zul v	zul v	zul v
> 120 ≤ 140	x		**90**	zul v	zul v	zul v	zul v	zul v
> 120 ≤ 140		x	**90**	**90**	zul v	zul v	zul v	zul v
> 140 ≤ 160	x		**90**	**140**	**140**	zul v	zul v	zul v
> 140 ≤ 160		x	**90**	**110**	**110**	zul v	zul v	zul v
> 160 ≤ 200	x		**90**	**140**	**140**	zul v	zul v	zul v
> 160 ≤ 200		x	**90**	**110**	**160**	**160**	**160**	zul v
> 200	x		**90**	**140**	**140**	zul v	zul v	zul v

Table 1: Temporary speed limitations in Germany after switch renewal (source: DB).

4.4 Spanish practice (COMSA)

The most common S&C replacement method employed in Spain is the **pre-assembled on site method** (95%). The assembled in situ method is only a valid option if the switch must be built in a new line or line is closed for several days for track works.

The system used for the renewal of the switch depends strongly on the dimensions and weight of the switch (or of the panels into which the switch is divided). Additionally to the dimensions and weight, quality of installation is also a decision-making driver in some cases, such as in high speed lines. In Spain there are mainly three different methods for replacement: **portal cranes** (Geismar-Fasseta), **crane-beam or special crane systems** (Vaiacar or Desec), and **rail/road excavators**.

The use of **excavators** is the most common method in **conventional lines**, since it is usually the most economical. To remove the old switch and to install the new switch, two hi-rail excavators are used. When there is a parallel track, the hi-rail excavators run over it from the storage area till the location of the switch renewal. Given that their load capacity is between 5 and 8 tones, and also to minimize the deflection during transport, the switch is usually divided in three panels: switch panel, closure panel and crossing panel.

Figure 5. Installation of new switches in segments by rail-road excavators (source: COMSA).

Apart from the excavators, **crane-beam systems** are also used in the Spanish **conventional rail network** but very occasionally, due to the fact they incur usually in a higher cost. They could also be used in high speed lines, but given that the lengths of the switch can be over 60 m and its weight higher than 60 tonnes, the use of two crane-beam systems attached (tandem)would be required. However, as it will be described further on, in these cases the solution of portal cranes, such as Fasseta solution, is preferred.

Figure 6. Installation of a switch with VAIACAR crane-beam system. COMSA.

The installation of a switch in a **high-speed line** is treated differently from that of a conventional one, since the dimensions and weight are much higher but also because of the complexity of the switch. In comparison to the 30-50 m length of a common switch for conventional lines, switches allowing speeds on the deviated line higher than 200 km/h can have up to 175 m in total and weight over 200 t.

They are usually divided in three segments (switch panel, closure panel and crossing panel). For a typical high-speed switch, these are the characteristics of weight and length of the different panels:

SWITCH	PANEL	LENGTH (M)	WEIGHT (T)
TG 0,020	*SWITCH*	63	63,8
	CLOSURE	62	78
	CROSSING	49	70,4
TG 0,03125	*SWITCH*	54,6	53,9
	CLOSURE	54	62,9
	CROSSING	21,3	34,1

Table 2: Length and weight of the three panels into which two common high-speed switches are divided for transport and installation (source: COMSA).

As a consequence, even if they are divided in three parts, crane-beam systems or excavators cannot bear with them. The solution employed in these cases is the **portal crane system** (Geismar-Fasseta in the case of Spain).

Figure 7. Installation of a switch panel by portal cranes. (source: COMSA).

This system is composed of a set of completely independent machines which lays pre-assembled points or crossings in one or more sections depending on its length. This machine loads and unloads the points or crossings, moves them laterally or longitudinally and installs them (on existing or new track). The system’s versatility means that it can be used during track replacement works.

It has to be said that given that the installation of these high standard switches in the Spanish network has been quite recent (less than 15 years), this system has been only used for building up the new switch, but not for replacing an existing switch. However, the methodology for the renewal will be essentially the same.

COMSA practice is to clamp the rails during installation and to weld them just after the first restoration of the switch geometry, once the topographic team has checked that the switch is in its correct position. The line is reopened with a temporary speed restriction, usually between 50 and 80 km, until 200.000 tonnes have passed. Then, the final track geometry restoration can be done.

4.5 Swedish practice (Banverket/Trafikverket)

The most common method for S&C renewal in Sweden is the pre-assembled S&C method. In this case switch components are transported by trackside access road, the switch is pre-assembled at the vicinity of the works and installation is carried out by means of a railway crane (such as the **Kirow crane**).

Figure 8. Installation of a switch using the Kirow crane (source: Balfour Beaty).

The number of switches replaced each year in Sweden is about 40. There are not big differences between the activities done in a replacement of a switch in a conventional line and in a high speed line. The activities are mainly the same, however different track closure times apply.

Modular switch is not a common method in Sweden, however, as stated in INNOTRACK project, Banverket is planning to start using the “modular switch” to speed up replacement and commissioning of components using computerised self-testing.

The Banverket practice is to always replace the complete layer of ballast (which usually has a thickness of 30 cm). The welding of the 12 or 16 welds (depending on how the switch is divided) is done by 2 workers for 2-3 days, depending on track closing times.

After the renewal of the switch there is a speed limitation of 70 km/h, that is applied until 100.000 tones have passed by (usually 3 days in a normal line). One or two weeks after the renewal, a second tamping is done to bring the switch into its final position.

4.6 Czech practice (Skanska)

Every year, around 200 or 300 switches are replaced in Czech Republic. The most common method employed in Czech Republic is the **pre-assembled S&C** method (95% for mainline tracks). And the installation is usually done by either **DESEC crane-beam** system or **railway cranes** (EDK 300/5 and Kirow crane). If national standards allow it, the renewal is often done with **rail-road excavators** given that even though it involves usually more labour, is the cheapest practice as far as Eastern Europe is concerned.

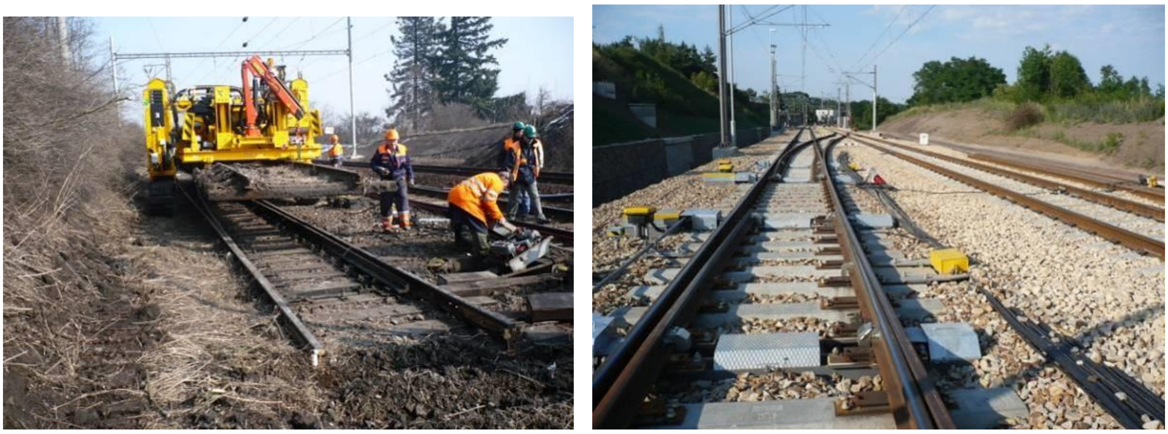


Figure 9. Replacement of a switch using Desec system (source: Skanska).

At the moment, tilting wagons are not used in Czech republic, and as a consequence, the modular concept cannot be fully implemented. Notwithstanding this, in some cases a partial modular switch method is used in combination with the pre-assembled method.

If clearance of the line permits it, some of the switch panels can be transported with flatbed wagons directly from the factory. However, there are other switch panels, such as the crossing panel, that must be pre-assembled in the lineside and later transported to the site by means of railway cranes.

The combination of pre-assembled and modular methods permits to reduce the need of space near the worksite for the assembly of the switch and to increase the output of the renewal. However the feasibility of using the flatbed wagons to transport switch panels strongly depends on the dimensions of the panels and the loading gauge of the line.

Furthermore, when the switch is situated in a secondary line, piecemeal renewal is also a common practice, given that it is the cheapest solution. Only the worn-out parts are replaced and they are either refurbished in the workshop and re-installed or replaced by new parts. For partial replacement of S&C the excavators can be used as it is the most economical method for these works.

In what regards to the handing of the switch during transport and installation, there is a Czech standard (SZDC S3/1) that regulates how the switch should be supported during transport (minimum number of handling points, location of the handling points, etc.) in order to minimize deformations of the switch panels. The norm also defines storage conditions of the switch, such as that the maximum number of levels of storage is three.

Usually, after the installation of the switch, a speed limitation is imposed, which usually last for a week.

4.7 Hungarian practice (MAV)

The majority of the replacement of switches and crossings in Hungary is done using the pre-assembled method. One method of installation of the switch employed by MAV is the **UWG system**. The UWG system is used to remove the old S&C and to install the new one, as shown in the figures below.

Figure 10. Replacement of a switch using Geismar UWG system (source MAV)

If time is not a big constraint, the preferred solution is to assemble the new switch on the spot. Before assembling the new switch, the old switch in stripped in situ and it is removed in pieces.

Moreover, as stated by Skanska, piecemeal renewal is also a common practice in Hungary in lines with low traffic. It usually refers to the replacement of half switch, the crossing, the wing or guide rails, sleepers or ballast. Although in some cases this is considered maintenance and not renewal.

The Hungarian network contains about 13000 turnouts. Around 70% of the switches in Hungary are made of wooden sleepers and the most common switches have a total length between 30 and 55 m.

The renewal of common switch with wooden sleepers (such as the 54 XIII with 28 m of length) may include or not the renewal of the ballast layer. Nevertheless, for high standard switches such as 54 800, that uses concrete sleepers, the renewal of the ballast layer is mandatory. This results in different track closure times for different types of switches.

In most cases, the current practice is to impose a temporary speed restriction of 60 km/h after installation for two days. Then, the allowed speed is increased in steps of 40 km/h every 24 hours.

4.8 Turkish practice (TCDD)

There are about 7600 switches in the Turkish network, which are replaced at a rate of 200-300 per year. About one third of the switches have been replaced during the last 10 years.

In Turkey, the common practice is the **pre-assembly** of the switches in the vicinity of the worksite and the installation by **road cranes or excavators**. The cranes that are usually employed are road cranes that are placed on the side of the track and that are able to lift the switch panels. Depending on the type of the switch and the location of the cranes, it would be necessary to use one or two cranes to lift one switch panel.

Figure 11. Replacement of a switch using road cranes (source: TCDD).

In cases where the access of the cranes by road is not possible, rail-road excavators or the crane-beam of Vaiacar are used.

The renewal time of a switch depends on the type of sleepers used in the switch. The renewal of switches with wooden sleepers usually takes two or three hours less than switches with concrete sleepers.

To avoid speed limitations after the installation of the switches, the Dynamic Track Stabiliser is used, which equals the effect of 50.000-75.000 tonnes of traffic.

TCDD counts with four tilting wagons that are used to transport 1:9 190 switches (about 27.7 m of length) in two parts. The usage of modular concept of switch replacement is about 1% in Turkey. The availability of the wagons and the distance between the factory of TCDD in Ankara and the worksite led to this low use of the method.

Recently, TCDD has constructed a bigger tilting wagon (28 m-long) that is able to transport the 1:9 190 switches as one single panel. The tilting wagon is currently under testing for validation.

Figure 12. TCDD tilting wagon for switch panel transport (source: TCDD).

TCDD aims at implementing the modular switch concept in order to increase the efficiency of the renewal.

4.9 British practice (Network Rail)

Network rail renews about 340 switches per annum. The majority of S&C units and half-sets currently used in renewals of Network Rail infrastructure are manufactured off-site and then assembled for quality purposes at the site of the manufacture, prior to dismantling and re-assembling at the site. Transport of S&C components to site is undertaken by rail or road. Conventional S&C renewal usually requires large areas adjacent to the renewal site for assembly of S&C, which, if the land is not owned by the IM, can inconvenience the landowners and introduce the need for the IM to negotiate with them to gain access to use the land.

The work activities undertaken to plan and undertake S&C renewals vary according to the speed and type of switch, and the geographic location, however they correspond to the phases established in 4.2.

During the last decade, Network Rail has been improving its switch renewal method in order to increase outputs and reduce costs. These improvements have come, in part, from the use of the modular concept.

The British rail network has a particularity that hindered during years the development of the modular switch concept, and that is its constricted loading gauge. As it can be seen in the figure below, UK gauge W6 (maximum width of 3.7 m) is much reduced in comparison to UIC gauge G2 (4.4 m), and this made difficult the transport of all switch panels.

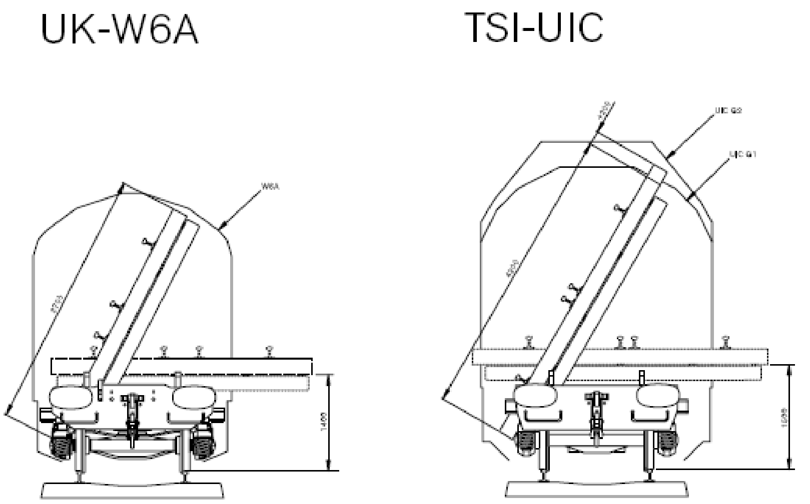


Figure 13. Comparison of loading gauge UK-W6A and TSI-UIC (source: Kranunion).

To overcome this difficulty two measures were required. On one hand, the design of the switches was modified. Previous long bearers of the switch were segmented (split bearers) to allow transport on the narrow W6A gauge. And on the other hand, tailored tilting wagons were manufactured.

A part from this, NR has also developed a load fixing and handling system to make easier, quicker and safer the loading and unloading of the panel.

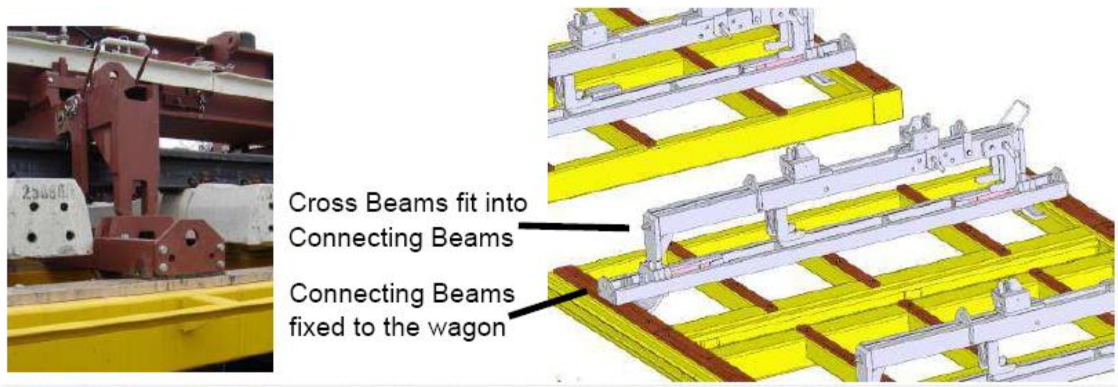


Figure 14. Fixing and handling system developed by NR (source: Kranunion).

Moreover, additional savings of time are achieved by using a specialized machine for ballast removal, which is known as automated ballast collector, and by reducing the time for commissioning the switch.

All these improvements resulted in a drastical reduction of the total renewal time. According to the article written by NR in the International Rail Journal in 2007, the use of modular S&C would allow NR to reduce the average track possession time for installing a traditional crossover from 52 hours to 21h in a weekend possession or a 4x8h night possessions over a weekend or mid-week. For a single turnout, NR aimed at carrying the renewal in only 8 hours.

Targets and timescale for modular S&C system

Targets 2006-07	Mk 1 Modular		Modular & tilting wagons		
	Now	End of Dec 2008	End of Oct 2009	End of April 2010	End of April 2011
Time saving (%)	0	40	55	70	80
Turnout time (hours)	37	21	12	10	8
Crossover time (hours)	54	27	21	16	2x8
Complex time (hours)	76	TBA	TBA	TBA	TBA

Figure 15. Track possession times depending on the level of implementation of the modular switch (source: International Rail Journal).

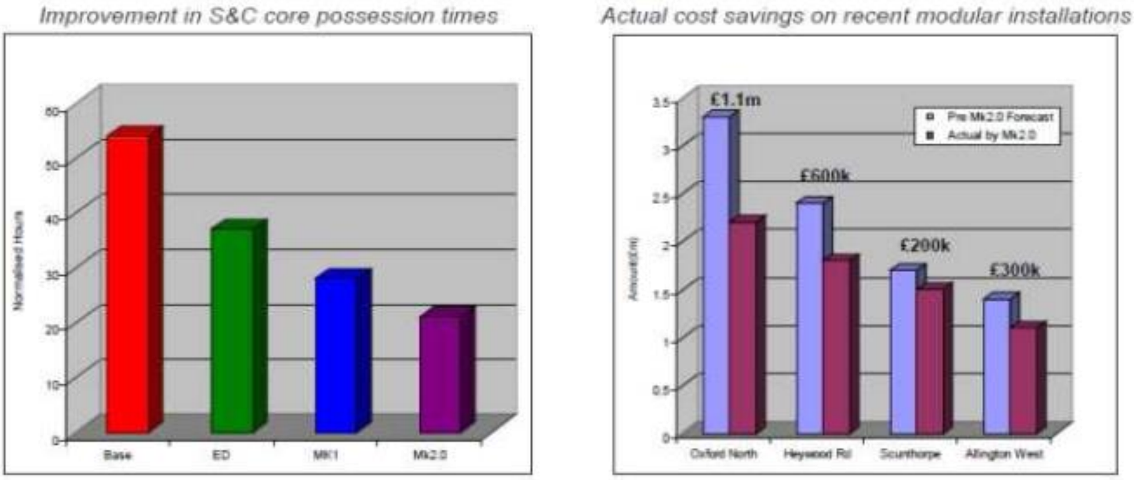


Figure 16. Reduction of track possession times and actual costs incurred in different switch renewals (source: Kranunion).

According to INNOTRACK project, in 2014 Network Rail would replace 75% of the switches using the modular concept. In 2008, NR ordered 26 tilting wagons that were delivered during 2009 and 2010. At the end of 2010, more than 64 switches had been replaced using the tilting wagons.

In what regards to other issues of the renewal, it should be said that NR recommends carrying out the maximum number of welds during track possession (always complying with the minimal requirements). Otherwise the joints are clamped, and welded later.

After the installation of the switch, a speed limitation of 80 km/h is usually fixed for 14 days. Next to this period of speed limitation, the remaining welds are executed and the geometry of the switch is brought to its final position.

4.10 Description of S&C renewal methods

From the description of each country practice, the following renewal methods could be identified.

4.10.1 Pre-assembled S&C renewal with excavators

The use of excavators is a common method in many countries (such in Spain, Eastern Europe, etc.), since it is usually the most economical. To remove the old switch and to install the new switch, two hi-rail excavators are used. When there is a parallel track, the hi-rail excavators run over it from the storage area till the location of the switch renewal. Given that their load capacity is between 5 and 8 tones, and also to minimize the deflection during transport, the switch is usually divided in three segments: switch, closing and crossing panels.

Figure 17. Installation of new switches in segments by rail-road excavators (source: COMSA).

Excavators have the advantage that they are low cost, widely available and very versatile. By changing the end of its arm, the excavator is able to carry out several tasks (from transporting the switch panel to removing the old ballast layer).

Nevertheless, the use of excavator for switch handling is not recommended since the switch panels can suffer excessive deformations. For this reason, other machinery more specialized to handle switches is recommended. Moreover, the S&C renewal with excavators usually requires more labour, and for that reason is usually used in countries where wages are low.

Furthermore, rail-road excavators are often employed for other tasks than switch panel transportation. They can be used for the replacement of the long bearers, installation of some parts of the S&C (e.g. check rail), etc.

4.10.2 Pre-assembled S&C renewal using cranes

There can be found a wide variety of cranes that can be used during a switch renewal. Cranes can be classified by:

- **Lifting capacity**: is the main feature of the crane, given that it determines if the crane can handle the switch in one piece or if it has to be divided in several panels. The lifting capacity depends strongly on the extension of the boom of the crane. Lifting capacities from cranes commonly used for switch renewals may vary from 40 to 160 tones. On the other hand, the cranes are able to extend their arms so as to reach objects up to 20 m away from the crane. An example of how varies the lifting capacity with the extension of the arm is shown in the following figure:

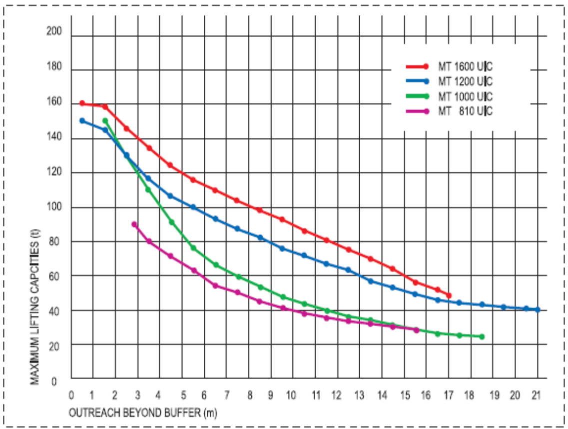


Figure 18. Variation of lifting capacity with boom extension (source: Kranunion).

- **Railway or road cranes**: railway cranes refer usually to cranes installed on bogies that are able to move along the track. These type of cranes offer much more flexibility than road cranes, which can only access the worksite if there is trackside road access.

- **Handling of the switch**: the switch has to be handled in a way that it does not suffer excessive deformations. Cranes can lift the switch panels by using a special beam that suspends the panel at several points or they just can lift the switch at only two points. The latter should be avoided if the panel has a considerable length, given that it will result in undue deflections during transport.

Figure 19. Different handling systems for switch renewals (source: Kranunion and TCDD).

In some cases, due to the high weight of some switches, two cranes have to be used simultaneously (as shown in Figure 18).

A clear advantage of using crane for switch laying when compared to excavators is that, if provided with the longitudinal beam, the switch is lifted by multiple points, achieving a better quality of installation.

Another advantage of using cranes is that they can perform several tasks apart from switch laying; they are also used for track laying and for accident service (e.g. removal of carriages after a derailment). For this reason, IMs tend to own several of these cranes, which makes them available for switch renewals.

4.10.3 Pre-assembled S&C renewal using crane-beam system

Crane-beam systems could also be included in the crane group described before, however, it presents some significant differences from railway cranes such as the Kirow Multitask cranes, and for that reason they are described separately.

Crane-beam systems are composed by two cranes supported by caterpillars that allow them to move on the ground, although some systems can also be provided with special wheels to run over the track. The two cranes support a metallic beam that serves to give stability to the system and to lift and place the switch. Depending on the system, the caterpillars are able to rotate 90 degrees, which can be very convenient when the new switch has been pre-assembled at the side of the old switch.

Figure 20. Transportation of a switch with the DESEC system (source: DESEC).

The speed at which the crane-beam systems can move is very reduced, around 1 to 5 km/h. Hence, they are not recommended if there is a relevant distance between the pre-assembled new switch and the installation area. However, some systems allow to be pushed by a rail/road vehicle.

The lift capacity of crane-beam systems can vary significantly depending on the system. A typical range of admissible load is between 30 and 60 tones. On the other hand, the admissible length of the switch varies also from 35 to 50 m. In some cases, two crane-beams can work together to install a complete switch.

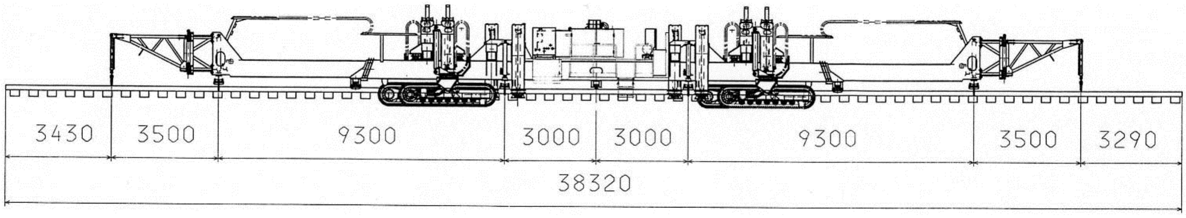


Figure 21. Drawing of Desec crane-beam system (source: Desec).

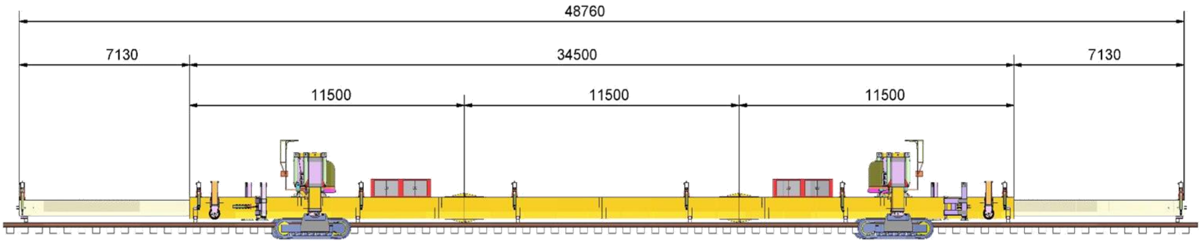


Figure 22. Drawing of Vaicar crane-beam system (source: Vaicar).

Crane-beams also offer the advantage of handling properly the switch, by supporting the switch at several points avoiding the bending or sag. They can be remotely controlled and thus, the labour can be reduced.

Some of the crane-beams, such as DESEC TL, can be transported by rail on flatbed wagons, as shown in the figure below.

Figure 23. Desec TL being transported by platform wagons (source: Desec).

As a disadvantage, this type of machines is very specific and usually expensive, so they are not as widely available as cranes or excavators.

4.10.4 Pre-assembled S&C renewal using Geismar UWG switch laying system

The UWG system can be used for dismantling the old switch and for laying new pre-assembled S&C without the need of dividing the switch into several panels. The UWG laying system consists of:

- Self-propelled **hydraulic jacks PUM** or portal cranes, designed for lifting and lowering the assembled S&C. Each jack is controlled by one operator.
- **Trolley MWT** that is hydraulically controlled from PUM, which is designed to transport the assembled S&C.
- **Auxiliary track** and connecting ramps with the adjacent track.

Method of dismantling of S&C:

- The PUM jacks are situated along the pre-assembled switch and they lift it.
- An auxiliary track is placed under the switch and connected to adjacent track via ramps.
- MWT trolleys run on the auxiliary track below the old switch until they are at the same position than the PUM jacks.
- PUM jacks lower its arms until the old switch and themselves are loaded on the MWT trolleys.
- The entire system is towed away from the site and if necessary the auxiliary rail is removed
- On arrival to the unloading site, jacks lift again the S&C, MWT trolleys move from below the switch and jacks lower the switch until it is on the ground.

Figure 24. PUM jacks and MTW trolleys during switch renewal (source: Geismar).

The installation of the new switch is performed in reverse order.

- The new S&C is pre-assembled directly on the track. Using the ramps, the PUM jacks move along the switch and lift it. In the event that the new switch is pre-assembled close to the line, the lifting jacks transfer it to track by successive lateral displacements.
- The MTW trolleys move under the S&C until they are just below the jacks.
- PUM jacks and the pre-assembled switch are loaded on the trolleys which move the entire system to the installation site.
- PUM jacks lift again the pre-assembled switch. The trolleys move away from the installation site.

- Finally, PUM jacks lay the S&C on its final position, and then, move away from the installation site.

The PUM jacks lift the switches by means of clamps that grip the rail head on one side. These clamps can rotate for 180 degrees so that the rails can be held both ways - inside and outside. In addition to the clamps, two locking chains are placed on each side of the jack and therefore the lifted load cannot fall down.

The trolleys are equipped with stool, which can be shifted from the central axis. This enables to avoid obstacles during transport (signalling, platforms, etc.). During the installation it is possible to shift S&C by lifting jacks in the transverse direction. This ensures the accuracy of laying.

The main advantage of this system is that the switch can be removed or installed entirely, without the need of dividing it into panels. Thanks to its modular concept, it is able to handle switches from various lengths and weights, by adding or removing more jacks and trolleys. This implies that the pre-assembled switch can be welded before the installation, assuring that there will be no traffic over clamped rails.

Moreover, this system guarantees a correct handling of the switch given that it is supported by several points.

On the other hand, this system has two main disadvantages:

- It is a very specific machinery with higher investment costs.
- The UWG systems requires of one operator to control each PUM jack. This result in an increase of labour costs, but also the synchronisation of the jacks is human dependent.

4.10.5 Pre-assembled S&C renewal using Geismar- Fasseta portal cranes

The Geismar-Fasseta system could be seen as an evolution of the UWG system. It is composed by several portal cranes (also called PEM jacks) that are able to move in a synchronised way (they are radio controlled). Each crane is provided by two wheels that allow them to circulate over the rails (of the track or of the switch to be transported) and by two lateral arms that can be deployed to support the crane onto the ballast. Each portal crane has a self-propelled trolley associated (LEM trolley), that can run over the track, and which transports the switch until its final location.

In the next figure, the drawings of the cranes and the trolleys are shown:

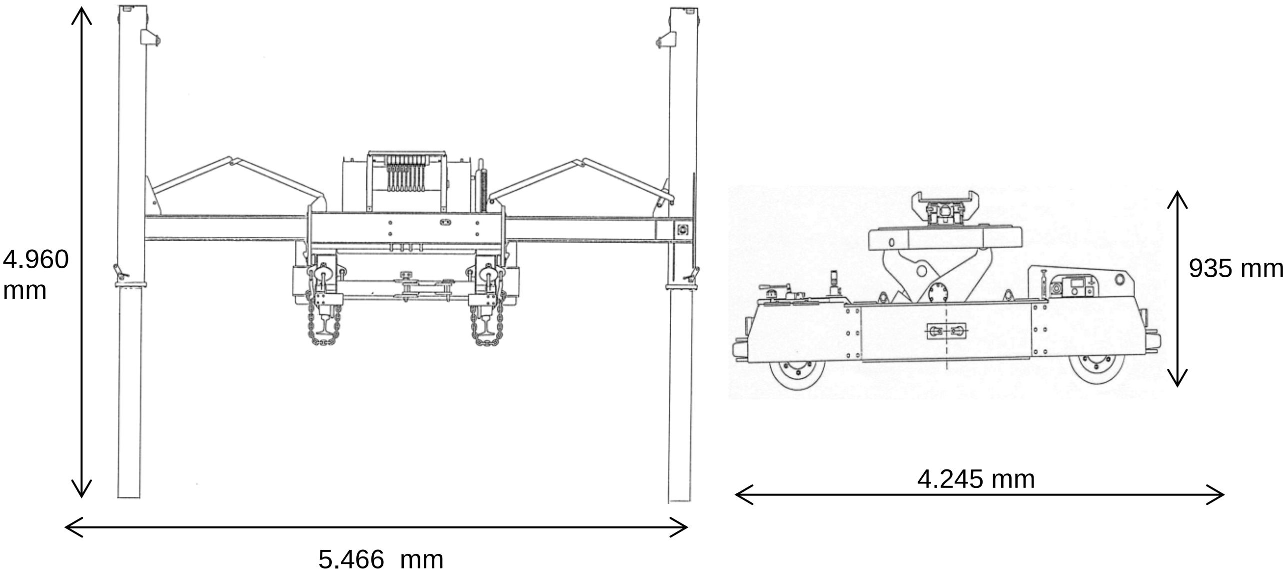


Figure 25. Drawing of a portal crane and its associated self-propelled trolley (source: Geismar-Fasseta).

The number of portal cranes to be used depends on the length and the weight of the panel that is being transported, and the maximum allowed deflection. Each gantry/trolley combination is able to handle a 20 tonne load. In practice, the distance between independent cranes is usually between 10 and 15 m, which means that for the transport of one HS switch panel, from 3 to 7 of them are required.

The installation process of a switch panel using the Geismar-Fassetta system can be summarized in the following steps:

- Firstly, the portal cranes and the self-propelled trolleys are unloaded by an excavator from the train platforms, where they are transported, and distributed along the switch segment.
- The switch panel is lifted in a synchronized way by the portal cranes that are supported by their lateral arms onto the ballast.
- The self-propelled trolleys move by radiocontrol until they are under the portal cranes, which retrieve their lateral arms. This way, both the portal cranes and the switch rest totally on the trolleys.
- The trolleys take the switch to the installation location, where the portal cranes extend again their lateral arms to support the switch and to release the trolleys, which move out under the switch.
- Next, the auxiliary rails placed in the installation area to allow the access of the trolleys are removed by excavators, and the switch is laid by the portal cranes.
- Once the switch is in its right position, the portal cranes are loaded again onto the train platforms by an excavator, which moves them back to the spot in the line where the remaining pre-assembled switch panels are placed.

Figure 26. Photos of the installation of a high-speed switch with Geismar-Fasseta system. (source: COMSA).

For the installation of a complete high-speed switch about 1 day (8 hours) is required, and it can involve up to 18 workers. The duration of each activity is summarized in the following table:

	Installation of auxiliary rails so diplorys can access to installation area	Positioning of the portal cranes and motorised diplorys	Lift of the switch segment and unloading onto diplorys	Transporting switch segment to the installation area	Move out of the diplorys and unloading of the switch	Loading of the cranes onto the train platforms
ARRIVALOF CRANES AND DIPLORYS + INSTALLATION OF PANEL 1		30 min	15 min	15 to 30 min	30 a 45 min	15 min
	DURATION: ~ *2 h*					
INSTALLATION OF PANEL 2	30 min	15 min	15 min	15 to 30 min	30 a 45 min	15 min
	DURATION: ~ 2,5 h					
INSTALLATION OF PANEL 3 + DEPARTURE OF CRANES AND DIPLORYS	30 min	15 min	15 min	15 to 30 min	30 a 45 min	30 min
	DURATION: ~ 3 h					

Table 3: Steps and duration of the S&C renewal using Geismar-Fasseta system (source: COMSA).

4.10.6 Modular S&C

Modular S&C or just-in-time method usually refers to the fact the S&C units are assembled at the factory as the whole unit, or in 2 or 3 large parts, and then transported to the renewal site using specialised wagons during the renewal works. The S&C units are then transferred directly from the tilting wagons to their final position as complete assemblies, thus maintaining the geometric quality of the S&C. Railway cranes, crane-beam systems or portal cranes can be used for the switch unloading from the tilting wagons and laying of the switch on its final position.

The implementation of the modular switch concept can result in significant savings of time and resources if compared with the pre-assembled systems. These savings are explained here below:

- Pre-renewal works: there is a significant time and cost savings incurred through the need to assemble the S&C unit once only at the factory. This avoids the time and labour required for the pre-assembly of the switch but also the need of negotiation with landowners if there is no lineside space available.

- Delivery and installation: delivery of the S&C panel can be made directly and just-in-time from the factory to the site in one train operation. The transfer of the panels from the wagons to its final position is made by railway cranes, and it is faster than for pre-assembled methods given that transport distance tends to be shorter.

- Commissioning and temporary speed restrictions: installation of the S&C panel in one piece ensures that the geometry and quality installed in the controlled environment of the factory are maintained as far as possible, resulting in time and cost savings from not having to fettle the S&C panel once installed. Moreover, there is also the belief that TSR could be avoided given that the quality of the installation is higher.

- Maintenance of post-installation quality: On the assumption again that the installation quality is improved in relation to pre-assembled methods, the subsequent rate of deterioration of the S&C panel in terms of track geometry and component condition is reduced.

Furthermore, along with the implementation of the modular switches, IMs tend to introduce other improvements to the switch renewal such as the use of the automated ballast collector or the use of an improved handling system of the switch to facilitate the lifting of the panel from the tilting wagon by the crane. These improvements result in further reductions of costs and labour.

In view of these advantages, many IMs have bought or constructed several tilting wagons in order to implement the modular concept in their switch renewals. However, except for SBB and NR, the employment of the modular switch method is very low in comparison with the pre-assembled method. This could be explained mainly because the number of tilting wagons owned by the IMs is limited, and hence, the number of switches replaced with this technique is very small compared to the total number of replacements. For instance, the number of tilting wagons owned by DB is about 6 or 8 wagons, while the total number of switches replaced per annum in Germany is around 2000.

The reasons why many IMs are not planning on buying new tilting wagons are:
- The investment cost of buying new tilting wagons is high.
- The pre-assembled method is a proven and straight-forward method that delivers a good quality of installation.
- Some of the time and resources benefits of the modular switch are based on a better quality of installation, while many IMs think that the quality is similar to that achieved with the pre-assembled method.
- The feasibility of delivering just-in-time the switch panels from the factory depends on the distance between the worksite and the S&C assembly factory. For that reason, in some cases, the modular switch is not an efficient method.

According to this, many IMs limit the use of their tilting wagons to those cases where trackside access road does not exist, there are lineside space constraints for the switch preassembly or they have to meet a very short track possession time.

On the other hand, SBB and later NR, made an important investment on tilting wagons in order to increase the output and to reduce costs, given that both track possession costs and labour costs are very high.

Tilting wagons are tailored to meet every network requirement. For example, in UK, tilting wagons had to adapt to narrow W6 gauges. The dimensions of the tilting wagons deck however are usually between 3.7 and 4.4m of width, allowing the transport of entire switches with up to 4.8 m-long sleepers and without dismantling the driving equipment. The deck length is usually between 22.5 and 28 m, while the maximum load of the panel is usually about 30 tonnes. Some tilting wagons also allow a lateral displacement of the loading platform from 0.5 m up to 1.2 m, to avoid any interface with adjacent track.

Conventional tilting wagons are able to transport EW 900 to EW 300 switches in three panels, while for smaller switches, such as the SBB type 185, two wagons are enough.

Figure 27. Transportation of the switch panels by the special wagon (source: Network Rail).

It should be also stated, that in some countries that do not count with tilting wagons, they apply partially the modular switch concept by transporting the switch panels in flat-bed wagons. Due to gauge restrictions, this usually means that only the closure panel can be transported, while the rest of the panels have to be pre-assembled as usual. However, this depends on the dimensions of the switch and the gauge restrictions. This hybrid method is used in some cases in Czech Republic. The RES platform wagons used are shown below.

Figure 28. RES flatbed wagons own by CD for switch panel transport (source: CD).

4.10.7 Mechanized ballast collection and special ballast wagons

As said before, mechanized ballast collection is used in combination with the modular concept in UK or Switzerland in order to achieve higher outputs. One well-known automated ballast collector is the W+ machine from SERSA. This is a new machine designed for achieving a high output in the ballast renewal. The W+ machine has an excavation capacity of up to 250 m3/h and an excavation width of over 8 m.

The W+ machine is provided with an impeller, which is specially designed to excavate ballast beds. The maximum excavation depth is 1300 mm from top of sleeper.

The W+ machine usually works together with a REINER+ machine, which works as a ballast cleaner. The old ballast is transferred from the W+ to the REINER by conveyor belts, and the cleaned ballast follows the opposite direction. The cleaned ballast is fed into the adjustable-height ballast silo which discharges it into the trackbed via the foundation compactor. Therefore, excavation and compaction are carried out in a single continuous working operation.

Furthermore, the old ballast collected can be transferred to the AVES wagons, also from SERSA, which are provided of bogies and crawlers to be able to operate in and outside of the track. They provide also a high output, but their use is more justified for track renewal than for a switch renewal, given that the amount of ballast to be removed is not that important.

Figure 29. W+ machine working during a switch renewal (source: Sersa).

Figure 30. AVES wagons during a switch renewal (source: Sersa).

4.11 Comparison of S&C renewal methods

In this section, methods described in *4.10 Description of S&C renewal methods* are compared in terms of their output and resources (labour and machinery). According to the several stages of the renewal, that are considered as common to all methods, tables including duration of works, labour and machinery required are presented in *4.11.2 Comparative summarizing tables*.

However in first place, given that the conditions of a renewal may vary enormously, it is required to explain which have been the assumptions considered for the comparative analysis (*4.12.1 General assumptions*). In this sense, the activities composing each renewal phase are also described with the aim of stating clearly for what the output and resources included in the *4.11.2* are accounting.

Finally, in 4.12.3 Conclusions, the relevant outcomes coming from the comparison of the methods, not only in terms of output and resources but also in terms of quality are presented.

4.11.1 General assumptions

As it was mentioned before, the boundary conditions of two different S&C renewal works may vary drastically. The availability of road access or a storage area in the vicinity of the works can make the renewal much easier and quicker. For each renewal phase, the assumptions considered will be explained. Nevertheless, there are other general considerations that affect the whole process that are described next.

The type of switch has a big influence on the duration of the works. In this case, a conventional switch used in lines with speeds between 140 and 200 km/h has been considered. Usually this kind of switches has around 40-50 m of length and about 40 t.

Another important issue is the type of track possession considered. The works can be done during a non-stop track possession during a weekend or during night shifts of usually 8 hours. If night shifts are considered, the effective working time is about 4,5 h of the total 8 hours. In the case of pre-renewal and post-renewal activities, since they are done outside of the long track possession, the duration of the works have been considered as night shifts. On the contrary, for the renewal activities (renewal phases B and C), a continuous process has been considered and the duration of the works refers to effective working hours.

Moreover, during the development of the renewal phases *B – Removal of the old switch* and *C – Installation of the new switch*, there are work activities that do not require all the labour that are on site. However, since all labour has to be on site to carry out the critical activities, we can consider that they are present for the whole track possession.

A. Pre-renewal activities

Pre-renewal activities refer to the preparation work that has to be done before the removal of the old turnout. It covers the selection and preparation of the storage area, the transport of the materials required (both components of the switch and auxiliary equipment for the renewal), the (pre-)assembly of the new switch and the topographic surveying works

A.1 Preparation of storage areas + A.2 Transport of materials

The first step of a renewal is the selection and preparation of a storage area next to the site. In many cases, there is not any possible storage area in the line premises and negotiation with local land-owners is required. Once the storage is is ready, the materials for the assembly of the switch, machinery and small equipment (generators, temporary lighting, etc.) are transported.

In this study, it is assumed that there is a road access to the storage area, and that materials are transported by road, meaning that there is no traffic disruption.

The duration of these two activities is one shift (8 hours) for all methods. The use of the Modular S&C should incur in a reduction of the preparation of the storage area and transport of the material given that the major part of the switch components are not transported. However, given that other materials such as temporary lighting and other small plant are equally required, the same duration of the works has been considered. However, it has been stated a reduction of the machinery is required.

The output and labour required has also been considered as common for all methods.

A.3 Assembly of the new S&C in panels in the storage area

Turnouts are assembled at the factory, with all parts being marked to denote their correct position. Then, they are disassembled in parts to be delivered to site (the degree of disassembly depends on the method of installation) in the case of the pre-assembled method. Once the components of the switch are transported to the storage area, the switch is re-assembled (usually in three panels: switch, closure and crossing panels).

This activity is not required for the Modular S&C given that the complete switch is transported during the renewal works. For the rest of methods, output and resources are the same: a crew of 6 workers plus 2 for safety during two shifts of 8 hours. Only an excavator is considered as required machinery (the small tools are not considered).

A.4 Topographic works previous to installation

Previous to the beginning of the renewal works, a topographic surveying must be done in order to mark the topographic reference points that will be used during the installation of the new switch (in order to be sure that it is positioned in its right position).

This activity is done for all methods and the duration and resources allocated for it are the same. Two topographers plus two people for safety during one night shift (8 hours). Only topographic equipment is required for this activity.

B. Removal of the old switch and site preparation

The beginning of the track possession for the renewal starts with the dismantling of the old switch. This phase covers the removal of the old switch and the old ballast layer. In some cases, only the upper part of the ballast layer is removed, instead of removing the whole ballast layer (of usually 30-35 cm). When possible, outputs for both options are presented.

B.1 Dismantling of the old switch and site preparation + B.2a Removal of the upper part of ballast layer

The work included in B1 refers not only to the dismantling of the switch but also of the signalling equipment and point machines. The switch is disconnected from the adjacent track and then moved out of the track. Usually the switch is cut in thirds to facilitate the transport. The labour and output of these tasks depend on the method used (crane, excavators, etc.)

In some cases, instead of undertaking the renewal of the whole layer of ballast, only the upper part is removed (down to the lower level of the switch). This is usually done by a front loader or an excavator. As a consequence, the amount of old ballast is not very important and a train with hopper wagons is not required. In this case, the ballast is put by the front loader/excavator onto a rail/road dumper truck that takes the old ballast to the storage area.

Nevertheless, in some countries, such as in UK or Sweden, the renewal of the whole ballast layer is compulsory.

B.1 Dismantling of the old switch and site preparation + B.2b Removal of whole ballast layer

The activity B1 covers the same work described before (it is independent from the renewal of the whole ballast layer or not). The renewal of the ballast layer, as previously said, is compulsory for some administrations. If the complete layer of old ballast is removed, which usually accounts for 35 cm, the amount of old ballast generated usually implies the use of a ballast hopper train. The same train that has hopper wagons to receive the old ballast, will have also other hopper wagons that carry the new ballast to be used in work activity *C.1 Adding new ballast*.

The removal of the old ballast is usually done with front loader or excavators, which will pour the ballast on the hopper wagons. After the removal of the ballast, the layer and subgrade layer is levelled with a grader and compacted with a roller.

However, NR employs a special machine, called *Automated ballast collector*, which improves the output of the ballast removal (it removes the old ballast, adds recycled ballast and compacts the soil). In some cases, specialised wagons for ballast transport, such as AVES wagons, are also used to achieve a better output.

C. Installation of the new switch

C.1 Adding new ballast

The new ballast is added from the hopper wagons of the ballast train (which is usually the same train used to collect the old ballast). Then, the ballast layer is compacted using a roller.

C.2 Laying and assembly of the new switch panels + C.3a Clamping / C.3b Welding and stressing + C.4 Initial track geometry restoration + C.5 Control system commissioning + C.6 Final commissioning and testing + C.7 Dynamic Track Stabiliser

Once the ballast layer is ready, the switch panels are laid down according to the method used (excavators, cranes, etc.) –*C2*-. In some cases, where there are long concrete bearers that impose problems to the laying methods, such as cranes, they have to be placed in situ with the aid of excavators. However, in this study it has been considered that short independent bearers are used or if there are long bearers, they can be lifted, transported and laid down with the switch laying method.

The three panels in which the switch is usually divided are connected (clamped or welded) –*C3*-, which usually results in 12 or 16 joints. In many cases, the panels are clamped provisionally till they are welded during night shifts in the post-renewal phase, given that there is not enough time to carry out the welds during track possession. Some IMs, such as NR, only consider the option of welding during track possession. Welding is usually aluminothermic welding, although NR is also studying the possibility to use FBW.

Next, a first restoration of geometry is done by an S&C tamping machine –*C4*-. This is followed by the commissioning of the S&C drive and its reconnection and interfacing with the signalling system –*C5*-. In this work activity, the lubrication of the switch mechanism as well as the adjustment of the switch throw rail and locking mechanisms are included.

Finally, the switch is tested and inspected to be sure that it complies with the national requirements and then accepted –*C6*-.

Even though a first restoration of the geometry of the switch is done, temporal speed restriction usually applies. With the aim to increase the imposed speed restriction or even to avoid it, Dynamic Track Stabiliser could be used. TCDD was the only organisation that acknowledged its use –C7-.

D. Post-renewal activities

Once the appropriate number of tonnes has passed by the switch and the ballast is properly consolidated, the speed restriction can be removed and the final track restoration can be done. The welding of the switch is usually done in the previous night shift. The final step of the renewal is the final commissioning and testing to the switch.

The use of modular S&C has the potential to avoid a second track geometry restoration, and therefore it has not been considered in this chapter.

Moreover, for TCDD, given that the DTS is used, no further work apart from the welding is required (there is no need for a second track geometry restoration).

Since the long track possession has finished, it is considered that the works are done in night shifts of 8 hours. However, according to SKANSKA, the long possession in Czech Republic lasts until the second track restoration. This means that the post-renewal activities in the case of Skanska should be in fact included in renewal phase *C – Installation of the new switch* (it is however included in renewal phase D to be consistent with the rest). For this reason, the duration of the works only for Skanska are stated in effective working hours. In what regards to labour and machinery required, since these activities are included in the long track possession they are the same as in renewal phase C. The time required for this renewal phase for Skanska is 7 working hours.

D.1 Welding and stress release

This work activity covers the welding required to connect the S&C panels between them and the switch with the adjacent track. It also includes the re-stressing of the rail.

D.2 Final track geometry restoration + D.3 Final inspection and acceptance

This work activity refers to the final positioning of the switch, which involves the tamping of the switch and the shaping of the ballast. Once the switch is positioned, it is inspected and tested (including drive adjustment) which leads to the acceptance of the switch and the finalisation of the renewal. In some cases, previous to the tamping of the switch, additional ballast is added and a ballast train is required. However, in this study, if further ballast is required it will be placed rather “manually”, and no ballast train is required.

4.11.2 Comparative summarizing tables

TIME AND RESOURCES REQUIRED ACCORDING TO METHOD USED	**PRE-ASSEMBLED S&C**							**MODULAR S&C**
	Crane	**Excavators**	**Crane**	**Crane**	**Excavators**	**Indep. cranes (UWG system)**	**Crane-beam (DESEC)**	
	DB	TCDD	JBV	TRV	COMSA	MAV	SKANSKA	NR
A. PRE-RENEWAL WORKS								
A.1 Preparation of storage areas	1 shift (8h)							
A.2 Transport of materials								
A.3 Assembly of the new switch in panels in the storage area	2 shift (16h)							
A.4 Topographic works previous to installation	1 shift (8h)							
TOTAL HOURS	*A1+A2+ A3+A4* **32h**	*A1+A2+ A3+A4* **32h**	*A1+A2+ A3+A4* **32h**	*A1+A2+ A3+A4* **32h**	*A1+A2+ A3+A4* **32h**	*A1+A2+ A3+A4* **32h**	*A1+A2+ A3+A4* **32h**	*A1+A2+ A3+A4* **16h**
WORK FORCE	*A1+A2* **2 + 2 (safety)** *A3* **6 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**	*A1+A2* **2 + 2 (safety)** *A3* **6 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**	*A1+A2* **2 + 2 (safety)** *A3* **6 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**	*A1+A2* **2 + 2 (safety)** *A3* **6 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**	*A1+A2* **2 + 2 (safety)** *A3* **6 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**	*A1+A2* **2 + 2 (safety)** *A3* **6 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**	*A1+A2* **2 + 2 (safety)** *A3* **6 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**	*A1+A2* **2 + 2 (safety)** *A4* **2 (topography) + 2 (safety)**
MACHINERY REQUIRED	*A1* **- Excavator - Dump truck** *A2* **-2 vehicles (van)** *A3* **- Excavator** *A4* **-Topographic equipment**	*A1* **- Excavator - Dump truck** *A2* **-2 vehicles (van)** *A3* **- Excavator** *A4* **-Topographic equipment**	*A1* **- Excavator - Dump truck** *A2* **-2 vehicles (van)** *A3* **- Excavator** *A4* **-Topographic equipment**	*A1* **- Excavator - Dump truck** *A2* **-2 vehicles (van)** *A3* **- Excavator** *A4* **-Topographic equipment**	*A1* **- Excavator - Dump truck** *A2* **-2 vehicles (van)** *A3* **- Excavator** *A4* **-Topographic equipment**	*A1* **- Excavator - Dump truck** *A2* **-2 vehicles (van)** *A3* **- Excavator** *A4* **-Topographic equipment**	*A1* **- Excavator - Dump truck** *A2* **-2 vehicles (van)** *A3* **- Excavator** *A4* **-Topographic equipment**	*A1+A3* **-Excavator - Dump truck** *A2* **-One vehicle** *A4* **-Topographic equipment**

TIME AND RESOURCES REQUIRED ACCORDING TO METHOD USED	**PRE-ASSEMBLED S&C**							**MODULAR S&C**
	Crane	**Excavators**	**Crane**	**Crane**	**Excavators**	**Indep. cranes (UWG system)**	**Crane-beam (DESEC)**	
	DB	TCDD	JBV	TRV	COMSA	MAV	SKANSKA	NR
B. REMOVAL OF THE OLD SWITCH AND SITE PREPARATION *(Beginning of track possession)*								
B.1 Dismantling of the old switch (including dismantling of signalling and points machines) + ***B.2a Removal of upper part of the ballast layer***		3/4 working hours (wooden/ concrete sleepers)	4 working hours		3 working hours		5 working hours	
B.1 Dismantling of the old switch (including dismantling of signalling and points machines) + ***B.2b Removal of complete layer of old ballast***	4 working hours	4/5 working hours (wooden/ concrete sleepers)	6 working hours	2 shifts (16 h) / 9 working hours	6 working hours	4 working hours	9 working hours	1 shift (8h) / 4,5 working hours
TOTAL HOURS	*B1+B2b* **4h**	*B1+B2a* **3/4h (w/c)** *B1+B2b* **4/5h (w/c)**	*B1+B2a* **4h** *B1+B2b* **6h**	*B1+B2b* **9h**	*B1+B2a* **3h** *B1+B2b* **6h**	*B1+B2b* **4h**	*B1+B2a* **5h** *B1+B2b* **9h**	*B1+B2b* **4,5h**
WORK FORCE	*B1+B2b* **10 + 4 (safety) + 2(signalling)**	*B1+B2a/B2b* **10 +2 (safety) + 2(signalling)**	*B1+B2a/B2b* **5 +2 (safety) + 2 (signalling)**	*B1+B2a/B2b* **8 + 3 (safety) + 3 (signalling)**	*B1+B2a/B2b* **10 +2 (safety) + 2(signalling)**	*B1+B2a/B2b* **13 +2 (safety) + 2(signalling)**	*B1+B2a/B2b* **10 +2 (safety) + 4(signalling)**	*B1+B2b* **6 + 4 (safety) + 2 (signalling)**
MACHINERY REQUIRED	*B1* **- Crane** *B2b* **- Excavator** **- Front loader** **-Dump truck** **- Grader (optional)** **- Roller** **-Hopper wagons+loco**	*B1* **- 2 Excavators** *B2a+B2b* **- Excavator** **- Front loader** **-Dump truck** *Only for B2b* **- Grader (optional)** **- Roller** **-Hopper wagons+loco**	*B1* **- Mobile Crane** *B2a+B2b* **- Front loader** **- Dump truck**	*B1* **- Kirow Crane** *B2b* **- Excavator** **- Front loader** **-Dump truck** **- Grader (optional)** **- Roller** **-Hopper wagons+loco**	*B1* **-2 Rail/Road excavators** *B2a+B2b* **- Front loader** **- Excavator** *Only for B2a* **- Dump truck** *Only for B2b* **- Hopper wagons+loco** **-Roller**	*B1* **- Geismar UWG system** **- Flatbed wagons + loco (for UWG transport)** *B2b* **- Excavator** **- Hopper wagons+loco / dump truck** **-Roller**	*B1* **- Crane-beam (** **- Special bogies or flat wagons + loco (for Desec transport)** *B2a+B2b* **- Front loader** **- Excavator** **- Hopper wagons+loco** Only for *B2b* **- Grader** **-Roller**	*B1* **- Kirow Crane** *B2b* **- Automated ballast collector** **- Hopper wagons+loco** **-Grader** **-Roller**

<table>
<tr><th rowspan="3">TIME AND RESOURCES REQUIRED ACCORDING TO METHOD USED</th><th colspan="7">PRE-ASSEMBLED S&C</th><th rowspan="2">MODULAR S&C</th></tr>
<tr><th>Crane</th><th>Excavators</th><th>Crane</th><th>Crane</th><th>Excavators</th><th>Indep. cranes (UWG system)</th><th>Crane-beam (DESEC)</th></tr>
<tr><th>DB</th><th>TCDD</th><th>JBV</th><th>TRV</th><th>COMSA</th><th>MAV</th><th>SKANSKA</th><th>NR</th></tr>
<tr><td colspan="9">C. INSTALLATION OF THE NEW SWITCH</td></tr>
<tr><td>C.1 Placing geogrid and adding new ballast</td><td rowspan="2">4 working hours</td><td>1 working hours (no geo.)</td><td>4 working hours</td><td rowspan="5">2 shifts (16 h) / 9 working hours (C1+C2+C4+C5)
+
2 shifts (16 h) / 9 working hours (C3b)</td><td>4 working hours</td><td>4 working hours</td><td>6 working hours</td><td rowspan="5">1 shift (8h) / 4,5 working hours (C1+C2+C4+C5)
+
2 shifts (16 h) / 9 working hours (C3b)</td></tr>
<tr><td>C.2 Laying and assembly of the new switch panels +
C.3a Clamping</td><td rowspan="3">5/6 working hours (w/c) (C2+C3a+C4)
or
10/11 working hours (w/c) (C2+C3b+C4)</td><td rowspan="3">5 working hours (C2+C3a+C4)</td><td rowspan="3">5 working hours (C2+C3a+C4)</td><td rowspan="5">5 working hours (C2+C3a+C4+C5+C6)</td><td rowspan="3">5 working hours (C2+C3a+C4)</td></tr>
<tr><td>C.2 Laying and assembly of the new switch panels +
C.3b Welding and stressing</td><td></td></tr>
<tr><td>C.4 Initial track geometry restoration</td><td rowspan="3">3 working hours</td></tr>
<tr><td>C.5 Control system commissioning</td><td>2 working hours</td><td rowspan="2">24 working hours</td><td rowspan="2">3 working hours</td><td rowspan="2">3 working hours</td></tr>
<tr><td>C.6 Final commissioning and testing</td><td>1 working hours</td><td>3 working hours</td><td>3 working hours</td></tr>
<tr><td>C.7 Dynamic Track Stabilizer</td><td></td><td>15 minutes</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>TOTAL HOURS</td><td>C1+C2+C3a+C4+C5+C6
7 h</td><td>C1+C2+C3a+C4
6/7 h (w/c)
C1+C2+C3b+C4
11/12 h (w/c)
C5+C6+C7
3,25 h</td><td>C1+C2+C3a+C4+C5
9 h
C6
24 h</td><td>C1+C2+C3b+C4+C5
18 h
C6
3 h</td><td>C1+C2+C3a+C4
9 h
C5+C6
3 h</td><td>C1+C2+C3a+C4+C5+C6
9 h</td><td>C1+C2+C3a+C4
11 h
C5+C6
3 h</td><td>C1+C2+C3b+C4+C5
13,5 h
C6
3 h</td></tr>
<tr><td>WORK FORCE</td><td>C1+C2+C3a+C5+C6+C7
10 +2 (safety) + 2(signalling)
C6
1 (permanent way engineer)</td><td>C1+C2+C3a+C5+C6+C7
10 +2 (safety) + 2(signalling) +1 (permanent way engineer)</td><td>C1+C2+C3a+C4+C5+C6
8 +1 (safety) + 4 (signalling)</td><td>C1+C2+C3b+C4+C5
10 + 3 (safety) + 5 (signalling) +2 (welding)
C6
2 (permanent way engineers)</td><td>C1+C2+C3a+C4+C5+C6
10 +2 (safety) + 2(signalling) +1 (permanent way engineer)</td><td>C1+C2+C3a+C4+C5+C6
12 +2 (safety) + 2(signalling) + 1 (permanent engineer)</td><td>C1+C2+C3a+C4+C5+C6
10 +2 (safety) + 4(signalling)</td><td>C1+C2+C3b+C4+C5
6 + 3 (safety) + 3 (signalling) +2 (welding)
C6
2 (permanent way engineers)</td></tr>
</table>

TIME AND RESOURCES REQUIRED ACCORDING TO METHOD USED	**PRE-ASSEMBLED S&C**							**MODULAR S&C**
	Crane	**Excavators**	**Crane**	**Crane**	**Excavators**	**Indep. cranes (UWG system)**	**Crane-beam (DESEC)**	
	DB	TCDD	JBV	TRV	COMSA	MAV	SKANSKA	NR
MACHINERY REQUIRED	*C1* **- Hopper wagons+loco (for new ballast)** **- Front loader** **- Roller** *C2* **- Mobile Crane** *C4* **- S&C tamping machine** **- Regulator (optional)** **- Topographic equipment**	*C1* **- Hopper wagons+loco[5] (for new ballast)** **- Grader** **- Roller** *C2* **- 2 Excavators** *C4* **- S&C tamping machine** **- Ballast regulator** **- Topographic equipment** *C7* **- DTS**	*C1* **- Hopper wagons+loco (for new ballast)** **- Front loader** **- Roller** *C2* **- Mobile Crane** *C4* **- S&C tamping machine** **- Regulator (optional)** **- Topographic equipment**	*C1* **- Hopper wagons+loco (for new ballast)** **- Front loader** **- Roller** *C2* **- Mobile Crane** *C4* **- S&C tamping machine** **- Regulator (optional)** **- Topographic equipment**	*C1* **- Hopper wagons+loco[5] (for new ballast)** **- Front loader** **-Roller** *C2* **- 2 Rail/Road excavators** *C4* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment**	*C1* **- Hopper wagons+loco[5] (for new ballast)** **- Front loader** **-Roller** *C2* **- Geismar UWG system** **- Flatbed wagons + loco (for UWG transport)** *C4* **- S&C Tamper** **-Topographic equipment**	*C1* **- Hopper wagons+loco[5] (for new ballast)** **- Front loader** **-Roller** *C2* **- Crane-beam (Desec)** **- Special bogies or flat wagons + loco (for Desec transport)** *C4* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment**	*C1* **- Hopper wagons+loco (for new ballast)** **- Front loader** **- Roller** *C2* **- Tilting wagons + loco** **- Kirow Crane** *C4* **- S&C tamping machine** **- Regulator (optional)** **- Topographic equipment**

TIME AND RESOURCES REQUIRED ACCORDING TO METHOD USED	**PRE-ASSEMBLED S&C**							**MODULAR S&C**
	Crane	**Excavators**	**Crane**	**Crane**	**Excavators**	**Indep. cranes (UWG system)**	**Crane-beam (DESEC)**	
	DB	TCDD	JBV	TRV	COMSA	MAV	SKANSKA	NR
D. POST-RENEWAL ACTIVITES *(Opening of the line with temporary speed restriction)*								
D.1 Welding and stress release (5)	1 shift (8 hours)	1 shift (8 hours)	3 shifts (21 hours)		1 shift (8 hours)	1 shift (8 hours)	7 working hours (8)	
D.2 Final track restoration	1 shift (8 hours)		1 shift (8 hours)	1 shift (8 hours)	1 shift (8 hours)	1 shift (8 hours)		1 shift (8 hours)
D.3 Final inspection and acceptance		1 hour inspect. during 7 days						
TOTAL HOURS	*D1+D2+D3* **16h**	*D1+D2+D3* **15h**	*D1+D2+D3* **29h**	*D2+D3* **8h**	*D1+D2+D3* **16h**	*D1+D2+D3* **16h**	*D1+D2+D3* **7h**	*D2+D3* **8h**
WORK FORCE	*D1* **4 (welders) + 2 (safety)** *D2+D3* **- 2 (topograph) + 2 (safety) + 2 (perman. way engineers)**	*D1* **4 (welders) + 2 (safety)** *D3* **- 1 (permanent way engineer)**	*D1* **2 (welders) + 1 (safety)** *D2+D3* **- 2 (topograph) + 1 (safety) + 1 (perman. way engineer)**	*D2+D3* **- 2 (topograph) + 2 (safety) + 2 (perman. way engineers)**	*D1* **4 (welders) + 2 (safety)** *D2+D3* **- 2 (topograph) + 2 (safety) + 2 (perman. way engineers)**	*D1* **4 (welders) + 2 (safety)** *D2+D3* **- 2 (topograph) + 2 (safety) + 2 (perman. way engineers)**	*D1+D2+D3* **10 +2 (safety) + 4(signalling) + 2 (topograph) + 4 (welders))**	*D2+D3* **- 2 (topograph) + 2 (safety) + 2 (perman. way engineers)**
MACHINERY REQUIRED	*D2* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment**	*D2* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment**	*D2* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment**	*D2* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment**	*D2* **- S&C Tamper** **-Topographic equipment)**	*D2* **- S&C Tamper** **-Topographic equipment**	*D2* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment - Hopper wagons+loco(5)**	*D2* **- S&C Tamper** **-Ballast regulator** **-Topographic equipment**

4.11.3 Results of the comparative analysis

Prior to analysing and comparing the several methods described before, it is important to stress out that even though some assumptions were made in section 4.11.1 to establish similar working conditions for every method, there are still issues that make the comparison between methods complex. As an example, some S&C renewal method may require different amount of labour or/and offer different output in two different countries, since the specifications and regulations to be followed are country-dependent. In consequence, countries where specifications are more demanding (e.g. in terms of safety, quality checks after the installation, etc.) require further resources and are more time consuming.

Another important constraint that is country-related is the length of the track possession. As described in 4.11.1 we have considered a weekend-long track possession for phase B. Removal of the old switch and site preparation and phase *C. Installation of the new switch*. However, in many cases the track possession in considerably less and as a result, for instance, welding is not done during the track possession but some days later.

Taking this into consideration, the comparison between S&C replacing methods per renewal phase is presented below.

Comparison of methods per renewal phase

Phase A. Pre-renewal works

Given that worksite conditions and accessibility has been considered the same for all cases, there are not significant differences in work force, machinery or output between the pre-assembled methods.

Nevertheless, there is a remarkable difference between modular and pre-assembled methods and that is that the former does not require the assembly of the new switch in the vicinity of the works. This results in not only a reduction of time, labour and machinery but also avoids any conflict with land-owners in case there is no space for the S&C assembly.

Phase B. Removal of the old switch and site preparation

There are not significant differences between pre-assembled methods. The time required for the dismantling of the old switch and removal of the complete layer of ballast is about 5-6 hours in average. SKANSKA stated a longer time (9 hours) given that it accounts for the time required for the train with the Desec crane to arrive and to unload the Desec crane from the flatbed wagons.

On the other hand, only 4,5 hours have been considered for the modular switch method. But this is due to the fact that an automated ballast collector has been considered, which could also be used in the other methods.

In what regards to work force, there can be seen some differences between methods that in some cases could result from country particularities. In this sense, JBV (Norway) stated a low number of workers in comparison with the rest of methods. Given the high wages in Norway, the number of workers can be reduced to the strictly necessary ones in order to optimize the cost of the S&C replacement. On the other side, MAV (Hungary) reported a higher number of workers given that the Geismar UWG system requires more labour than other methods. On average, for pre-assembled methods, IMs allocate 10 workers, plus two for safety and two for signalling. In contrast, for the modular switch method, only 6 workers are required, plus two for signalling and four for safety.

Machinery required depends of course on the method. Excavators, cranes (such as Kirow-crane or Desec crane) or UWG machine have been reported. In some cases, the train required for their transport to the worksite has been considered. In the rest, they are supposed to reach the worksite by road.

Phase C. Installation of the new switch

The data reported by IMs/partners for this renewal phase is organized in several ways, which makes the comparison complex. Moreover, the decision of welding or clamping temporarily the switch has an important effect on the total duration of this phase. For this reason, the methods are compared for one or several tasks, but not for the whole renewal phase.

For the activity *C1. Placing the geogrid (optional) and adding new ballast*, the majority of partners/IMs stated 4 hours for pre-assembled methods. In the case of modular switch, the time is not defined specifically for this task, but it is much less.

After the laying and assembly of the switch panels, the most common practice is to joint them by clamping in order to minimize the duration of the track possession (then, panels are welded some days after the track possession has finalized –renewal phase D-). The average time required for activities C2+C3+C4 (including the laying and assembly of the switch, clamping and the initial track geometry restoration) is 5 hours.

However, in some cases welding of panels is performed directly, instead of clamping, which is preferred by most of IMs. Time required for welding varies between 6 hours (TCDD) and 9 hours (NR and TRV), but if depends of course on the number of workers (welders) considered.

Activities *C5 Control system commissioning* and *C6 Final commissioning and inspection* take 3 hours on average. However, JBV stated 24 hours for these tasks. The duration of these tasks depends also on the specifications of each country.

Furthermore, only TCDD has reported the use of the Dynamic Track Stabilizer (DTS). According to TCDD, the time required for it is only 15 minutes and it avoids the establishment of TSR (temporary speed restrictions).

Work force allocated to renewal phase C is similar to that reported on renewal phase B, since both phases take place during the track possession. A total of 10 workers plus 2 for safety and 2 for signalling have been considered as an average. However, several partners have stated a higher number of signalling workers (up to 5 signalling workers) given that signalling works can be very time consuming. These differences may be derived from considering different types of switches, with different needs for signalling re-commissioning.

A total of 6 workers plus four for safety and two for signalling have been considered for the modular switch method, which is significantly less than the pre-assembled methods.

Phase D. Post-renewal activities

Most of IMs reported that welding activities take place during night shifts some days after the installation of the new switch (e.g. MÁV carry out welding in a maximum of three days after the installation). In those cases, welding is performed by 4 welders during a single night shift of 8 hours. However, other IMs (such as JBV) stated that welding takes up to 2 or 3 nights, but employing less labour (2 welders).

On the other hand, SKANSKA preferably extends track possession to carry out the welding and final track restoration altogether, which requires 7 hours instead of two night shifts (about 9 working hours). This, however, depends on the feasibility of extending track possession.

Most of IMs declared that the final geometry restoration and the final inspection are carried out during one single night shift of 8 hours. In contrast, TCDD does not perform a second track geometry restoration and inspection is carried out by a single permanent way engineer that inspects daily the switch for an hour, during one week.

General conclusions

In general terms, outputs and labour are similar between pre-assembled methods. The total working hours for removal and installation of the new switch (phase B and C) is about 20 hours, that if added the extra time for travel to site, set up and withdrawal of the personnel and machinery results in nearly the 30 hours reported in INNOTRACK project for Trafikverket and Network Rail. For this reason, a full weekend track possession is usually required for a switch replacement.

However, there are indeed differences between pre-assembled S&C replacing methods and that are described here-below:

- The use of specific machinery, such as UWG system or Desec crane, usually requires transport by rail. This results in higher non-productive set-up and withdrawal time (given to unloading and loading of the machine from/to the train, transfer time of the train, etc.) and resources (e.g. an additional train) than excavators or conventional cranes.
- On the other side, specific machinery for switch laying, such as UWG system, Desec TL-1200 or TL-2000 or Kirow crane, supports the switch panels at several points and transport carefully, which avoids excessive deflections or stress on the switch that may occur when using excavators or road cranes.
- The UWG systems requires higher workforce than the rest of methods (3 more workers than the average), given that every portal crane used for switch laying is controlled by one worker.

In relation to pre-assembled S&C replacing methods, the modular switch method allows a significant reduction of labour and duration of works according to information provided by

Network Rail. The total time for the renewal can be reduced up to the half compared to conventional systems and labour can be reduced from 16 to 12 workers. This reduction of labour and working time takes place during:

- Pre-renewal phase: Pre-assembled methods require two shifts for the assembly of the switch panels, while modular switch are assembled only once at the factory.
- Removal of the old switch: the reduction of time and labour comes in this case from the employment of an automated ballast collection machine, which offers higher output for the removal of the old ballast layer than the conventional methods. However, this system is independent from modular switch method and hence, can be used in combination with any replacing method.
- Installation of the new switch: by using the tilting wagons and an S&C specialized crane (such as Kirow or Desec crane) the installation of the new switch can be done in half time than the conventional systems (1 shift instead of 2 shifts, according to INNOTRACK project). Additional savings of time can steam from quicker signalling recommissioning and inspection and acceptance of the switch.
- Post-renewal works: it has not been considered here, but NR reported that it may allow a sooner restoration of commercial speed (shorter TSL) in comparison to other replacement methods.

On the other hand, the use of the modular switch requires additional specific machinery, such as tilting wagons or automated ballast collector that on one hand, increases the cost of machinery, and on the other, depends on its availability.

Furthermore, there are additional conclusions coming from the comparison of methods that are worth to comment:

- Many IMs do not consider the option of removing only the upper part of the old ballast layer, given that the removal of the complete layer is mandatory. This is due to the belief that a good condition of the support layers is required for a good future performance of the switch.
- Most of IMs prefer to carry out welding, instead of clamping, during the track possession. However, the total possession time is commonly not enough to allow all the welding to be done. In this case, most of IMs recommend to undertake as much welds as possible during the possession and carry out the remaining as soon as possible (e.g. MAV considers a maximum of three days to carry out all the welds).
- The type of sleeper has an effect on the total output during the renewal. An additional hour for the removal of the old switch and another for the installation of the new switch are required when using concrete sleepers in comparison to replacement of switches with wooden sleepers.
- TCDD is the only company using Dynamic Track Stabilizer (DTS) in order to avoid Temporary Speed Limitation (TSL). Moreover, there is no secondary track geometry restoration required.

4.12 Conclusions of the comparison of S&C replacement methods

From the description of each country practice, the following renewal methods were identified:

Pre-assembly S&C replacing methods:

- Excavators
- Road cranes
- Railway cranes (such as Kirow crane)
- Crane-beam systems (such as Desec TL1200 or TL 200 cranes)
- Portal cranes (UWG system or Fasseta system)

Modular switch method:

- Tilting wagons + automated ballast collector + specialized crane (Kirow or Desec)

The main advantages and disadvantages of each method are explained here-below:

- **S&C replacement using excavators**: they represent usually the cheapest and more flexible option, given that the machinery is widely available, low cost and very versatile (rail/road excavators can transport the switch and later remove the old ballast by just replacing the tool at the end of the arm). For this reason this method is commonly employed in many countries, such as that of Eastern Europe, Spain, Turkey, etc. However, lifting and transport of switches by excavators can induce high stress and deformation of the switch that can affect their installation and future performance. This is why their use is not recommended for high-standard switches.

- **Road cranes**: the use of road cranes presents very similar advantages and disadvantages to excavators. However, since they cannot circulate on the track, they can only be used when road access to the installation site is possible. Moreover, they need free space near the switch installation to place the road crane. Distance between the available space for crane positioning and worksite is critical to decide whether to use or not road crane system.

- **Railway cranes**: the most important benefit of the use of specialized railway cranes, such as Kirow crane, in comparison to excavators or road cranes is that the switch is more carefully handled and exposed to lower stress and deformations. It is because of that, that many IMs use these systems as the preferred solution. They are more expensive than conventional cranes or excavators and they are able to run also on rails. Moreover, given that they are also used by IMs for other purposes (such as accidental service), IMs use to count with several of these cranes. Thus, they are usually more available for switch renewal than other specialized systems such as the tilting wagons or the crane-beam systems.

- **Crane-beam systems**: similar to railway cranes, they offer a good quality of installation due to a careful handling of the switch. The main benefit of this system is that it allows the switch to be transported entirely, without the need of dividing it into panels. This allows the welding to be done during the pre-assembling, avoiding the high stress on the rail due to the passage of trains when switch panels are provisionally clamped. On the other hand, the use of specialized cranes, such as Desec TL 1200/TL 2000, is more expensive than conventional cranes or excavators and usually requires an additional train or special vehicle for their transportation.

- **Portal cranes**: similarly to Kirow or Desec TL cranes, UWG portal cranes are able to support the switch at several points and to transport and install the switch correctly without excessive deformations. As disadvantages, UWG system requires higher workforce than other systems, given that each portal crane is controlled by one person. In this sense, Fasseta system represents an evolution of UWG system, since one person can remotely control all portal cranes. Fasseta system is used for installing high speed switches given that it is able to transport longer switches than Kirow or Desec cranes.

- **Modular switch**: compared to pre-assembled S&C methods, the modular switch method is able to reduce significantly the total track possession, especially if combined with other innovative technologies such as the automated ballast collector. It also has the benefit of avoiding conflicts with landowners given that this method does not require additional space for the pre-assembly of the switch. On the contrary, the modular switch requires the use of tilting wagons which are not always available due to their high costs. Moreover, the distance between the factory where the switch is assembled and the installation site plays a key role when deciding the suitability of this method. In what regards to quality, this method offers similar quality as specialized cranes or portal cranes.

The advantages and benefits of these methods are summarized in the following table:

	Output (duration of track possession; total S&C duration)	**Need of lineside space** (for S&C pre-assembly)	**Availability of the system** (is the machinery required widely available? Is its use extended?)	**Labour** (number of workers required for installation)	**Machinery Cost** (cost related to the use of machinery)	**Quality of installation** (is the switch carefully handled during transport and installation?)
Excavators	++	+	+++	+	+++	+
Road Cranes	++	+	+++	+	+++	+
Railway cranes (Kirow,etc.)	++	+	++	++	++	+++
Crane-beam systems (Desec TL1200, VAIACAR, etc.)	++	+	+	++	++	+++
Portal Cranes (UWG, Fasseta, etc.)	++	+	+	+ (UWG) +++ (Fasseta)	++	+++
Modular switch	+++	+++	+	+++	+	+++

+++ Excellent performance

++ Average performance

+ Poor performance

5. Solutions to homogenize track stiffness in switches

During the last decade, there has been an increasing awareness of the important role that track stiffness has in track behaviour and hence, in maintenance works. Sudden variations of track stiffness result in high dynamic loads that lead to track degradation (development of RCF defects, differential track settlement, etc). As track deterioration process starts, the variations of wheel/rail interaction forces increase of magnitude, which turns into an intensification of track deterioration rate.

In comparison to plain track, turnouts represent a stiffer section due to the existence of a higher number of rails, longer and heavier sleepers, etc. Furthermore, there is also a variation in track stiffness (and mass) along the switch, given that within the switch there are sleepers with different lengths and properties (hollow sleepers) as well as other stiffening components, such as the frog, the check rails or the wing rails.

There is a long list of studies, such as those carried out by Andersson and Dahlberg, Zarembski and Zhu [4,5,6,7], that analyse and quantify how track stiffness affects dynamic impact loads.

Andersson and Dahlberg [4] investigated, by use of a numerical model, the load impact at the crossing nose when a wheel moves (at the frog) from the wing rail to the nose. Their article concluded that the severity of the load impact depends on variations of track stiffness, variations of mass distribution, and geometric irregularities at the crossing.

In order to avoid, or minimize, this impact load, a suitable transition arrangement is envisaged. To do that, firstly it is important to understand and quantify how the track stiffness varies along the turnout.

The first change of track stiffness happens at the transition point between the stock rail sleepers and the heavier turnout sleepers located at the beginning of the switch panel. The latter contains also hollow steel sleepers, to allocate ancillary systems, and the inclusion of the switch rails, which themselves have a varying inertia from the switch toes to the switch heels, that leads also to a stiffness variation.

In the closure panel, there is a continuous increase of bearer's lengths, also affecting track stiffness. And finally in the crossing panel, the existing of the frog, wing rails and check rails increase noticeably the inertia of the panel. Also, at some point, there is a change of long bearers to independent short sleepers, that can be placed eccentrically, which may lead to track torsion.

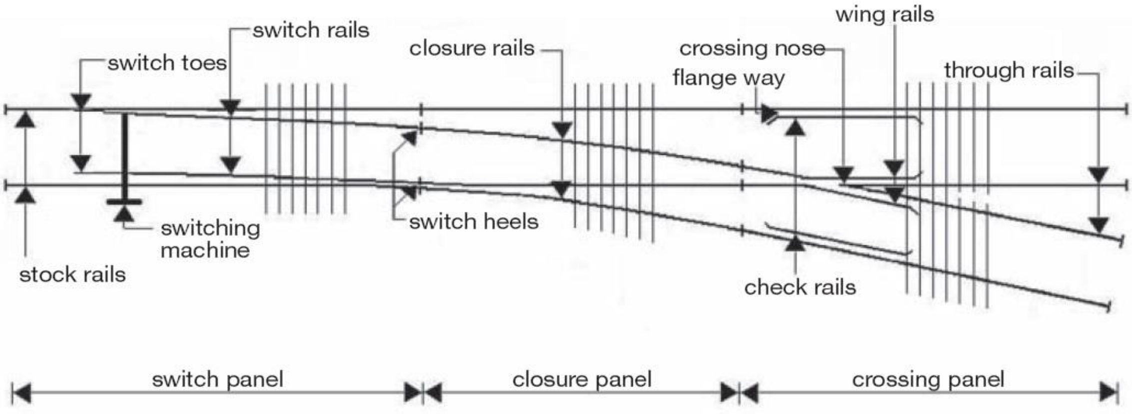


Figure 31. Components of a standard turnout (source: [8]).

Figure 31 shows the stiffness variation along UIC 60-500 switch in Germany, measured in INNOTRACK project by the RSMV car from Banverket. Switch panel shows stiffness of 70 KN/mm while other panels have about 90 KN/mm. The low values of stiffness in the switch are due to the use of soft pads (30 KN/mm). The adjacent track was provided with stiff pads (600 KN/mm) and thus, overall stiffness is about 170 KN/mm.

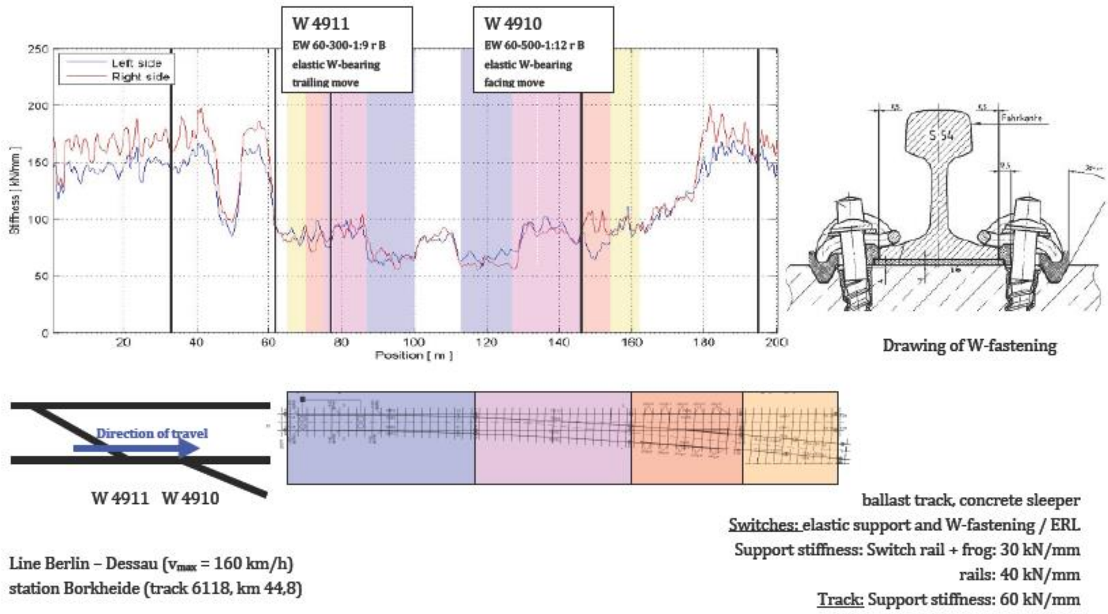


Figure 32. Results of stiffness measuring with RSMV in Berlin-Dessau line (source: INNOTRACK).

The solutions that have recently been studied and/or tested to homogenize the track stiffness within the switch and in the transition with the plain track are described here-after. Nonetheless, before describing them, two important research works carried out in recent years in this field should be mentioned.

On one hand, UIC undertook a comprehensive work specially on USP and UBM that is summarized in the following leaflets/reports:

• UIC-Report “Under Sleeper Pads I/05/U/440” and annexes [9]

• UIC-Report “Under Ballast Mats (UBM): Insertion Loss” [10]

• UIC-Report “RENVIB II, Phase 3, Task E: Guideline for Vibration Mitigation” [11]

And on the other hand, several reports of the RIVAS project have been used to access a broad range of knowledge. Some of the UIC reports will be reviewed to include the new developments carried out in the RIVAS project.

5.1 Soft under rail pads (URP)

The use of soft (under) rail pads – URP – to reduce the stiffness of the switch, especially under the crossing nose has been studied and tested in real conditions in many occasions.

In [12], V.L. Markine et al. concluded that by reducing the rail pad stiffness (from 500 KN/mm to 85 KN/mm) the impact load at the crossing could be reduced to a 20% of the original impact load. In fact, soft rail pads were identified in this study as the most efficient way to reduce impact load when compared to USP or ballast mats.

In the field test carried out by Palsson and Nielsen [13], the effect of track stiffness on wheel-rail contact forces was analysed. Track stiffness was measured using the rolling stiffness measurement vehicle (RSMV) and the contact forces were measured by an instrumented wheelset mounted in a freight car. The results showed that soft rail pads were able to reduce contact force, both in the thought route and diverging route.

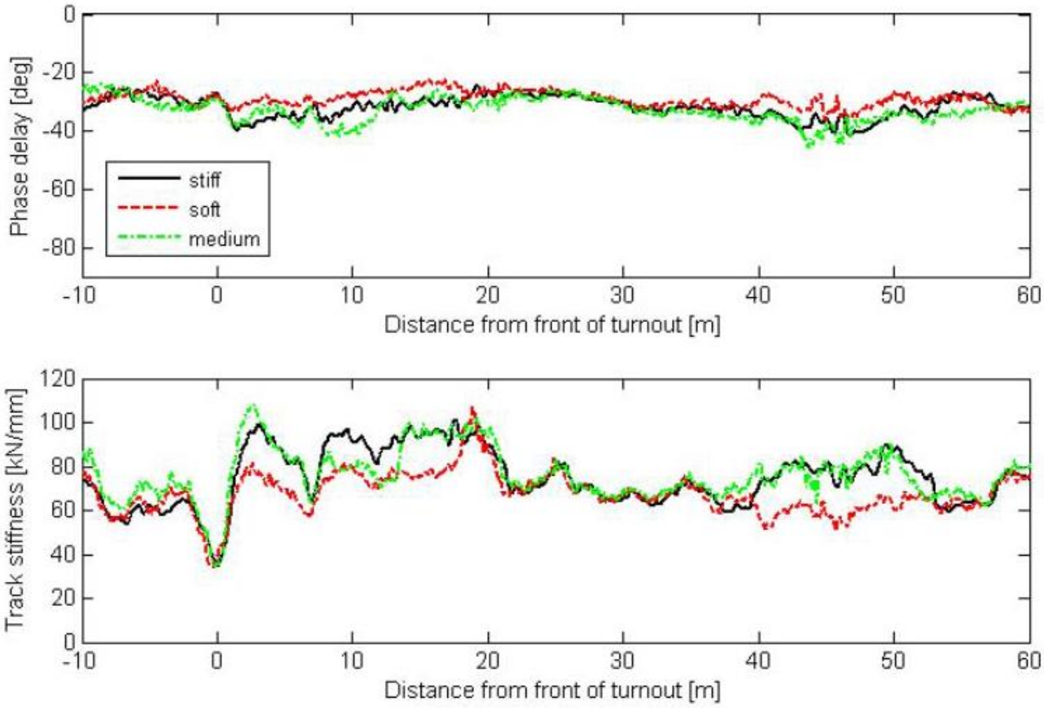


Figure 33. Effect of stiff, medium and soft rail pads in track stiffness variation along a switch (source:[13])

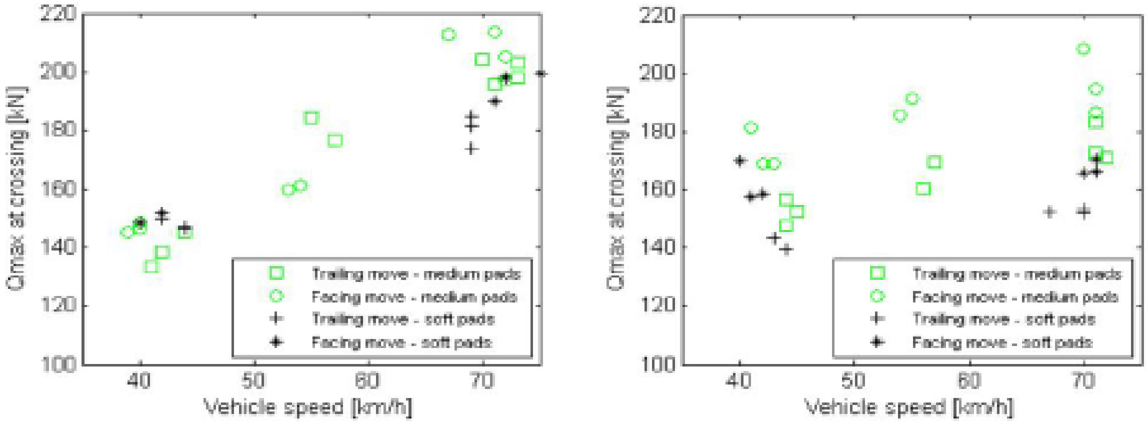


Figure 34. Effect of medium and soft rail pads on maximum vertical wheel-rail contact forces at the crossing in diverging route (left) and through route (right) (source: [13])

Similar tests were carried out during INNOTRACK project in Sweden in 2009. The wheel-rail contact forces for a conventional switch (60E1-760-1:15 switch) was measured using standard rail pads (120 KN/mm) and soft rail pads (80 KN/mm). The following figures show the results obtained in the tests:

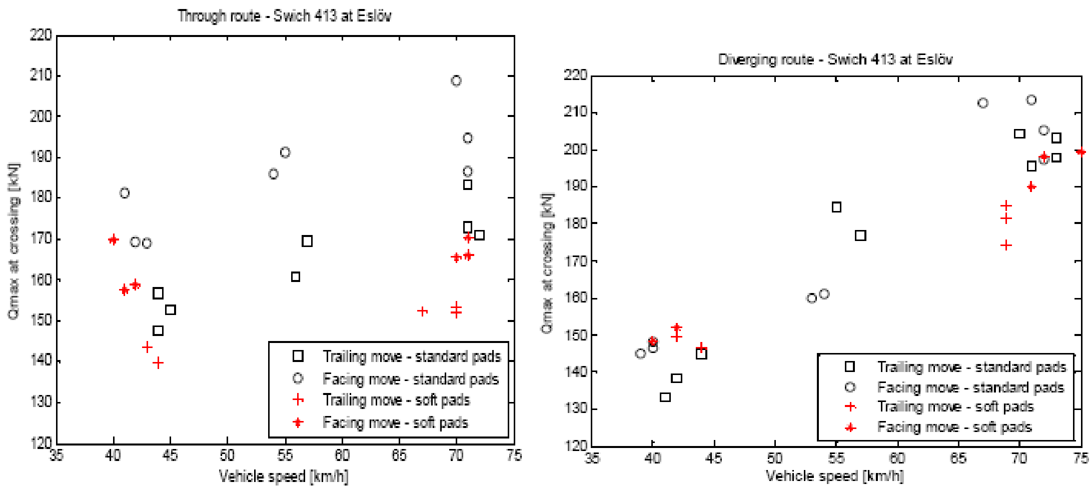


Figure 35. Effect of standard and soft rail pads on maximum vertical wheel-rail contact forces at the crossing in diverging route (right) and through route (left) (source: [14]).

According to the studies and experimental tests carried out up to present, the use of soft rail pads positively contributes to the homogenization of track stiffness along the switch and to minimize impact load.

The use of different soft pads with varying stiffness was also analysed in some studies in order to further minimize track stiffness variation along the switch. By placing stiffer rail pads starting from some distance before the front of the turnout and softer rail pads close to the switch heel, INNOTRACK project was able to reduce to just 8% the track stiffness variation along the switch.

5.2 Elastic ribbed baseplates

Elastic ribbed baseplates are used to provide higher elasticity to plain track and switches either in ballasted and slab track. The rigidity of the baseplates must be tailored to meet the specific requirements of each case, being the speed of the line one of the critical parameters. Lines with speeds over 200 km/h require very elastic baseplates, while other lines with low speed allowance are provided with stiffer systems (usually common rail pads).

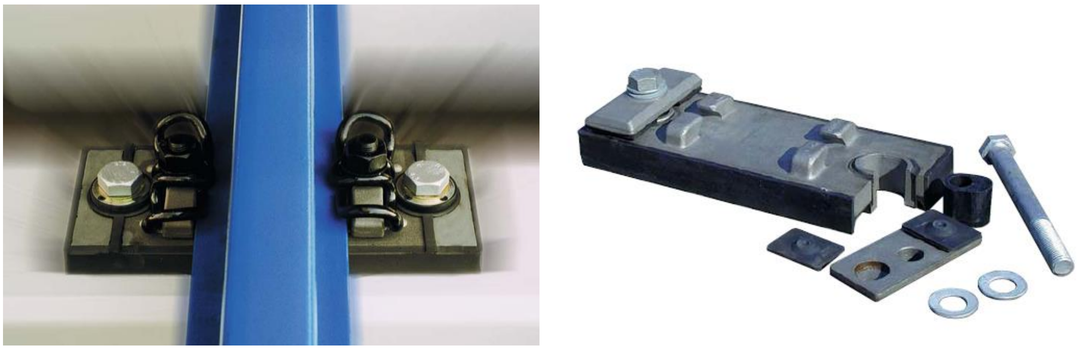


Figure 36. Elastic ribbed baseplates (source: Voest-Alpine).

Depending also on the stiffness requirements for the turnout, elastic ribbed baseplates can be used only in the area of the set of switches and frog area or in the whole switch. When average track rigidity (85 KN/mm) is desired, medium elasticity baseplates (about 30 KN/mm) should be used only at the switch and frog area, while the rest of the switch is equipped with elastic rail pads, just as in the plain track.

In contrast, if a very elastic switch (around 65 KN/mm) is envisaged, a more elastic baseplate (around 17.5 KN/mm) should be used in the totality of the turnout. In this case, additional transition areas before and after the switch must be created to adapt the stiffness to the adjacent track stiffness.

For systems in slab track, the turnout is also generally provided with the low elasticity baseplates (17.5 KN/mm). However, here the elastic transitions in front and behind the turnout are omitted.

In what regards to the scientific literature review, Zhu [7,15] mounted elastic slide base plates under the switch rail to reduce the contact force. The reduction was experimentally and numerically studied (see Figures below).

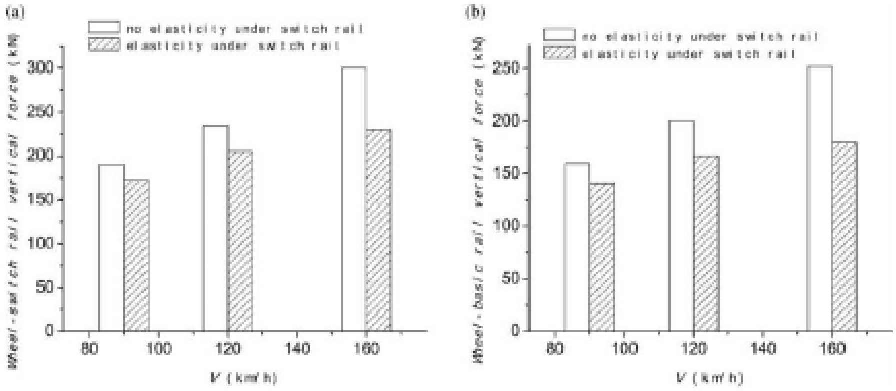


Fig. 4 (a) Wheel–switch rail vertical force. (b) Wheel–stock rail vertical force

Figure 2.26: Reduction of contact force using elasticity under switch rail

Table 2 Experimental comparison after the switch rail is laid elastically

		After the switch rail is laid elastically		Before the switch rail is laid elastically	
Test items	Test position	Freight train	Passenger train	Freight train	Passenger train
Wheel–rail vertical force (kN)	Stock rail	197	172	213	194
	Front switch rail	150	130	175	137
	Stock rail	104	182	133	203
Rail acceleration (g)	Front switch rail	97	240	140	298
	Stock rail	94	106	144	150
Slide base plate acceleration (g)	Anterior switch rail	125	240	155	298
	Middle switch rail	123	148	146	200

Table 2.1: Experimental results – introduction of elasticity under switch rail

Figure 37. Reduction of contact force using elastic baseplates (source: [7,15])

5.3 Under Sleeper Pads (USP)

Under Sleeper Pads (USP) are elastomeric elements placed under the sleepers that provide higher elasticity to the track. As a result of diminishing track bedding modulus, there is an increase of the load distribution, which reduces the stress applied onto the ballast and hence, its deterioration. This loading-distribution effect does not only imply that a higher number of sleepers are involved in the load transmission but also the effective area of sleeper applying the load is increased, avoiding hollow areas under the sleepers.

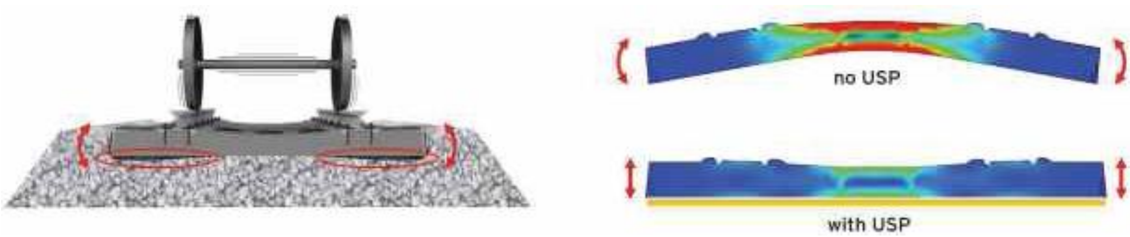


Figure 38. Load distribution effect on sleepers (source: Getzner)

As a result of reducing the contact pressure of the sleeper and the ballast, there is a deceleration of ballast degradation and therefore, track geometry deterioration. Nevertheless, USPs have also other advantages. By using USP, there is an increase of lateral resistance and a reduction of the vibration level transmitted to the ground.

According to the UIC project – Under Sleeper Pads [9], the main reasons that led IMs to use USP are:

- Reduction of long pitch corrugation in tight radius curves.
- Substitution for under ballast mats to reduce noise and vibrations
- Less maintenance, stretching or tamping intervention periods
- Reduction of ballast depth
- Reduction of rail and sleeper stresses, better load distribution
- Improvement of track geometry
- Improvement of track stability
- Reduction in whole life costs, especially with heavier loading of tracks

Regarding turnouts, USPs can be used to smooth track stiffness variations within the switch. To achieve a correct homogenization of track stiffness along the switch, several USP with different degrees of elasticity should be employed.

In [8], H. Loy carried out an analysis of a standard turnout provided or not with USP, which was modelled using the Finite Elements Method. In the figure presented below, there can be one of the main outcomes of his analysis: the rail deflection of a switch without USP, with only with type of USP and using different types of USP.

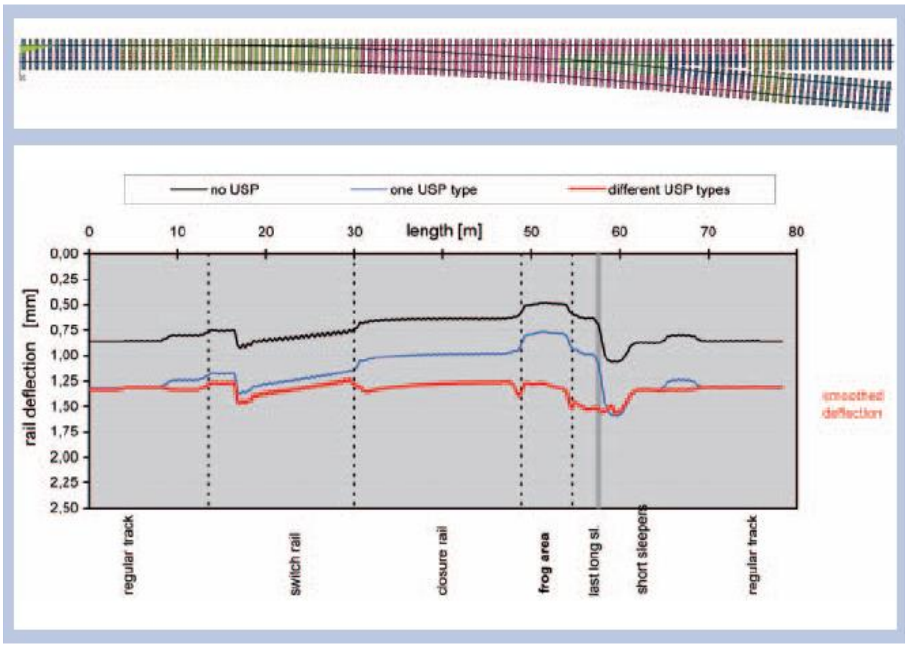


Figure 39. Comparison of rail deflection patterns with optimized track using different USP along the turnout (source:[8]).

By using USP there is an increase of rail deflection, as expected. However, when providing all sleepers with the same USP the differences in rail deflections becomes more important. On the other hand, by customizing the stiffness of USP to the different parts of the switch, the stiffness variation can be drastically smoothed up.

Additionally to the homogenization of track stiffness, USPs also permits to reduce rail seat force by 10-20%, as it can be seen in the following figure.

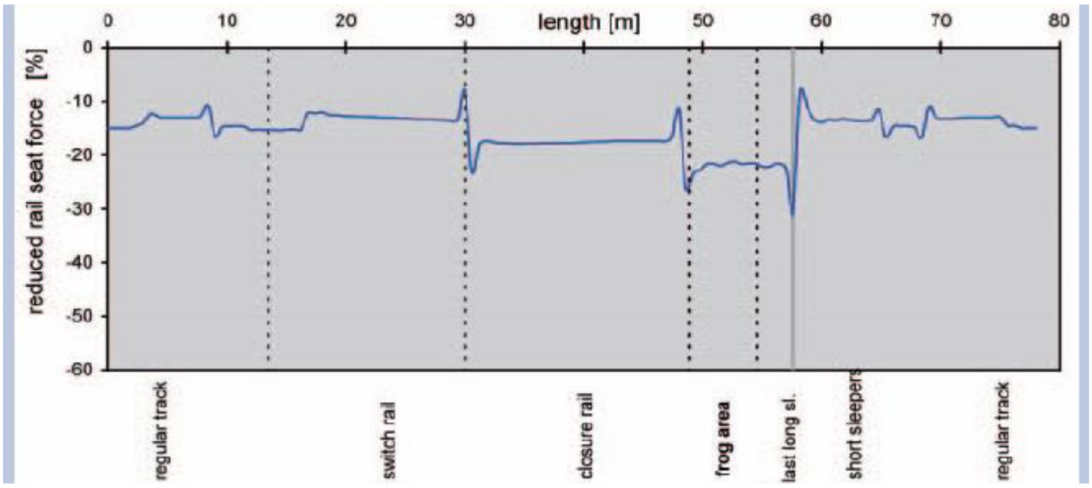


Figure 40. Reduction of rail seat forces along the turnout with optimized solution (source: [8])

V.L. Markine in [12] affirmed that the effect of USP in reducing impact loads on the crossing nose is limited, but they have a clear positive effect on reducing the forces on the sleepers and ballast. By reducing the forces applied to the ballast, the degradation rate of the turnout geometry is also diminished.

During the last years, numerous field tests have been carried out to validate the benefits of USP in switches. According to the UIC project – Under Sleeper Pads [9], the following IMs have successfully applied USP sleepers on their networks (SNCF, SBB, NSB, DSB, ProRail, ADIF, MAV, DB and ÖBB).

From all of them, Austria is the country with more experience in using USP. In Austria, turnouts with USP were firstly installed in 2002 and measurements have shown a reduction of vibrations in the 40Hz-50Hz frequency range. Until 2007, 87 turnouts were installed on the ÖBB network using USPs [15].

The ÖBB experience in switches with USPs demonstrates that there has been a substantial reduction of track subsidence of turnouts with rigid crossing frogs (offering similar results to turnouts with moveable crossing frogs [8]). The positive experiences with USP in turnouts have led to the development of a standardized design for the Austrian Federal Railways.

SBB has been using USP (Cstat = 0.22 N/mm3) over the past few years as a countermeasure for vibration, however, in [15] it is stated that even though it has been tested in some occasions, the assessment of its effect has never been concluding. More tests are planned in SBB in the upcoming years to validate it. The need of new methods to assess the vibration effect on switches, such as to use axle box acceleration, was raised in RIVAS project and should be further studied.

Additional tests were carried in Germany and Belgium to analyse the effect of USP in turnouts. The tests carried out in Testelt (Belgium) showed a significant increase of insertion loss due to USP [8].

As a conclusion, USP represents a valid solution to tune track elasticity in turnouts and thus, to reduce track stiffness variations. SBB and ÖBB have been using them in turnouts for several years. However, their efficiency in vibration attenuation is difficult to measure. In general, hard USPs are preferred over soft USPs. Although according to [8], different USP with different stiffness have to be used to achieve the best results in track stiffness homogenization.

5.4 Under Ballast Mats (UBM)

Given that ballast mats are also employed to provide a higher elasticity to the track, it can be also regarded as a system to homogenise track stiffness such as softer rail pads or USP.

The use of UBM in switches has been studied and tested in several occasions, but with less frequency than soft rail pads and USP. Markine et al.[12] studied the effect of UBM on dynamic wheel/rail forces acting in the crossing nose and pointed out there is almost no effect.

However, even if UBM may not be efficient to reduce impact load and wear on the crossing nose, they are used also as a mechanism to reduce vibration. In this sense, SBB has realised several field tests in order to assess the contribution of UBM to vibration attenuation in switches.

The tests carried out in Rubigen [15] showed that placing a UBM under the switch improves the insertion loss for lower frequencies but is inefficient at the higher frequencies. The effect of UBM in vibration attenuation in the switch and adjacent track was also analysed, showing the effectiveness of the UBM in the switch is lower than in the adjacent track.

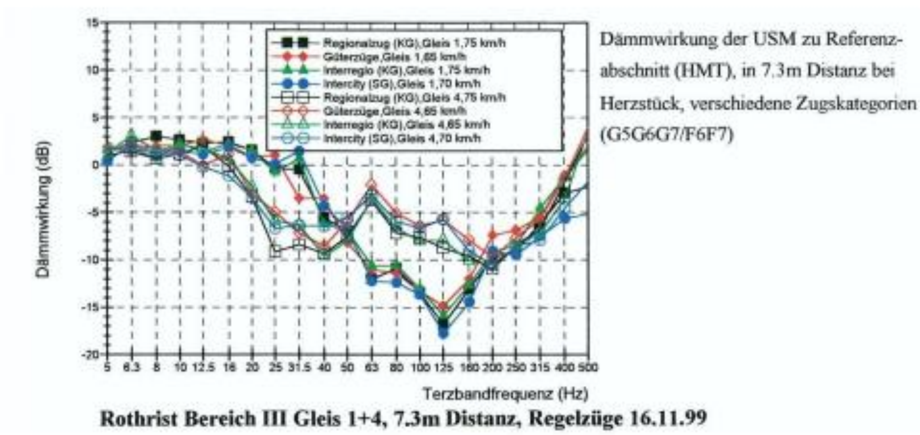


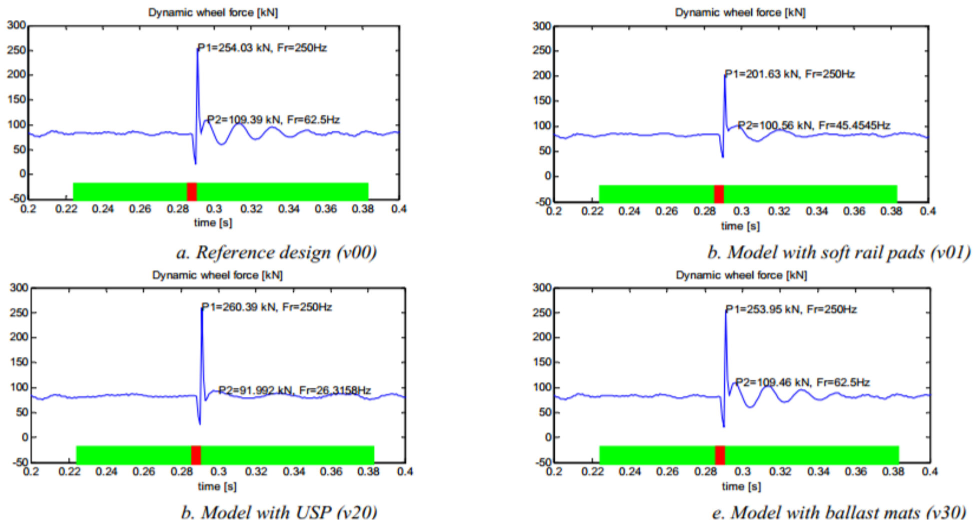
Figure 41. Measures of insertion loss of UBM in SBB network. Results for adjacent track -filled signs-, results for turnouts – unfilled signs-. (source: [15])

Few studies were found tackling the use of under ballast mats in switches with the aim of reducing contact force. From the technical reports analysed, it can be concluded that UBM are not efficient for reducing impact load but they offer vibration mitigation for lower frequencies. However, the assessment of the benefits of using ballast mats in turnouts require of further studies and experimental tests.

5.5 Comparison and combination of URP, USP and UBM solutions

In comparison with under ballast mats, soft (under) rail pads and under sleeper pads are believed to have a higher effect on reducing impact load on the crossings. In [12], the amplitude of the impact load (quantified by P1 and P2 forces) of a conventional switch was compared with turnouts provided with soft URP (variant v01), USP (variant v02) and UBM (variant v03). The results parameters used in the model and the results are summarized in the following table and figure.

Elastisity parameter variation							
Train speed 140 km/h							
Variant	**K_{pad} [MN/m]**	**C_{pad} [kNs/m]**	**M_{sl} [kg/m]**	**K_{usp} [kN/m^3]**	**K_{bm} [kN/m^3]**	**P_1 [kN]**	**P_2 [kN]**
v00	3032	29	120	-	-	254.03	109.39
v01	40	29	120	-	-	**201.63**	**101.03**
v20	3032	29	120	0.05	-	260.39	93.59
v30	3032	29	120	-	0.03	253.95	109.46



a. Reference design (v00) *b. Model with soft rail pads (v01)*

b. Model with USP (v20) *e. Model with ballast mats (v30)*

Figure 42. Analysis of the effectiveness of URP, USP and UBM (source: [12].)

From the figure above, it can be deduced that soft rail pads are the most efficient system to reduce impact load, while UBM has a very little effect on wheel impact loads. Soft rail pads are able to reduce significantly the P1 force (by 20%), which is related to rail damage (RCF). On contrast, USP offers the highest reduction for the P2 force, which is related to sleepers and ballast damage. On the other hand, [15] states that in terms of vibration attenuation, both mitigation measures offer similar performance.

Furthermore, the possibility of combining both soft rail pads and USP to reach higher reductions of wheel impact loads was raised. In this sense, V.L. Markine studied a combined solution and concluded that the dynamic loads on the rail, sleepers and ballast could be further reduced.

Also in INNOTRACK project, the use of rail pads and USP was also studied to reduce track stiffness variation. The study affirmed that by combining under sleeper pads and soft rail pads with varying stiffness along the switch, wear index could be reduced up to 80%.

To sum up, according to the information collected, soft rail pads are the most efficient system to minimize track stiffness variation and hence, impact load on the crossing, while UBM has a very little effect. The combined use of rail pads and USP can bring additional benefits, and it should be considered. However, the stiffness of rail pads and USP should be revised if used together. Also, further studies should be carried out with USP to validate its results.

5.6 Reinforcement of subgrade/ballast layer

Experience has demonstrated that an adequate preparation and compaction of the subgrade and ballast layer before the installation of the new switch is fundamental to guarantee a good future performance of the switch. Uneven ballast compaction can result in differential settlement of the switch which means an increase of impact loads.

Geosynthetics or geogrids are usually placed on top of the subgrade layer with the aim of increasing track stability (i.e. reducing track settlement). This is achieved thanks to the bonding mechanism that is created between the geosynthetic and the soil, which increases the shear strength of the soil. Geogrids also have other functions such as filtration, drainage or separation that avoids the contamination of ballast or sub ballast layers.

Geosynthetics have been studied and tested in multiple occasions, such as in INNOTRACK or SMARTRAIL projects. And its effectiveness to minimize track settlement in plain track and in transition zones has been proved in several field tests.

Nevertheless, J. Kawn [16] concluded in this thesis based on laboratory and field tests that in spite of halving the track deterioration rate, the geogrid reinforcement has very little influence on the trackbed stiffness as the grid is utilised principally to limit the accumulation of plastic strain rather than resilient strains.

According to what has been exposed, geogrids are not able to homogenise track stiffness variation along the switch. However, they can contribute to minimize track settlement, which can be useful since it avoids the impact load caused by differential settlement of the switch.

On the other hand, ballast stiffness has also been studied in some projects, such as in [15]. Ballast stiffness is a parameter difficult to quantify due to its granularity and can vary considerably between one switch to the next. These differences could be due to difference in the intrinsic parameters of the ballast, such as the size, compaction or density of the grains. Lower values of ballast stiffness are recommended to avoid vibration amplifications of the switch.

5.7 Reinforced wooden/light sleepers

Switches made of wood sleepers offer a better dynamic behaviour than switches using concrete sleepers, because the latter are stiffer.

This statement is confirmed by V.L. Markine, who in his study [12] stated that employing light sleepers will have a similar effect as using USP. Light sleepers in combination with soft rail pads allows to reduce dynamic force P1 (responsible for RCF related damage of rails) over 20 %. The use of light sleepers also allows a reduction of the dynamic forces of rails, but by increasing the forces acting on the sleepers. The strength of the sleepers should be enough to resist this increase of forces.

To achieve lighter sleepers two options are presented. Wood sleepers treated with a specific coating to extend its durability and synthetic sleepers. The use of light sleepers also has benefits for the logistics of S&C renewal. A complete description of synthetic sleepers can be found in the next chapter.

6. Logistics and design improvements for S&C renewal optimisation

From the comparative analysis of S&C replacement methods carried out in chapter 4 and the track stiffness analysis undertaken in chapter 5, the following recommendations and ideas for further developments for S&C replacement were deduced.

6.1 Modular switch concept

According to the comparative analysis of replacement methods carried out in chapter 4, the employment of the **modular switch has the potential to halve the total duration of works**, compared to a conventional replacement. This saving of time comes from the fact that the (a) switch is assembled only once at the factory and it is transported, even with the driving devices, just in time to the installation time; (b) the transfer of the switch from the wagon to its final position is faster and (c) commissioning can be done also faster. This results not only in a significant **reduction of track possession and labour costs**, but also **avoids** the need of **negotiations with landowners** in case there is no lineside space for switch assembly.

Furthermore, the implementation of the modular concept for switch renewals often implies a **re-design of the complete renewal process**. The benefits from using tilting wagons are combined with further improvements of the renewal, such as the use of automated ballast collection or the implementation of faster commissioning procedures (such as computerised self-testing of the signalling systems).

In some cases, the use of tilting wagons for switch transport also implies the re-design of the switch. For example, **long bearers can be split** in order to be able to respect loading gauges during the switch transport.

Finally it should be said that the modular switch method has three big constraints:

- Many IMs count with a reduced number of tilting wagons due to their high investment costs, which makes them not as widely available as railway cranes.
- The feasibility of the method depends on the distance between the assembly factory and the worksite.
- Pre-assembly method is quite straight-forward and it is proven for years, which makes some IMs reticent to not consider it as the preferred method for switch renewal. Moreover, quality of installation is similar to that achieved with the modular method.

For these reasons, many IMs use the modular switch method for those cases where trackside access road does not exist, there are lineside space constraints for the switch preassembly or there is a very short track possession time.

To solve the lack of tilting wagons, a **hybrid modular-preassembled** approach could be used. In some cases, some of the switch panels can be transported with flatbed wagons, while the rest are assembled at the lineside of the works. This allows a reduction of the space, labour and time required for the assembly of the switch panels.

6.2 Automated ballast collector

As referred above, the automated ballast collector can be used to increase the efficiency of the ballast layer removal and site preparation. This system is used mainly in combination with the modular switch method, in order to carry out the renewal in the minimum time. However, it could offer the same reduction of time and labour needs when used with the pre-assembled method.

An example of an automated ballast collector is the W+ machine from SERSA. This machine is able to remove the ballast layer and if necessary subgrade layers (maximum excavation depth of 1,3 m) by means of an impeller. Additionally, the W+ counts with a foundation compactor, in order to carry out both the excavation and compaction in one single continuous working operation.

If required, the automated ballast collector can be combined with a ballast cleaning machine in order to recover ballast from the excavated layer and re-use it in the new layer along with new ballast aggregates.

6.3 Methods to minimize varying track stiffness along the switch

Along with geometry optimisation of the switch, the optimisation of track stiffness in a switch can lead to a reduction of dynamic forces, which turns into a better performance switch with less maintenance needs.

The optimisation of the geometry of the switch to minimize dynamic forces on switches has been studied in many occasions, such as in INNOTRACK or RIVAS projects, and design improvements have been proposed. Many of these studies concluded that the effect of track geometry variations in the amplitude of impact load is predominant over the effect of track stiffness variation.

Notwithstanding this, track stiffness variation has a relevant effect on wheel impact loads and for this reason it is studied in this report. According to INNOTRACK, track stiffness values can vary up to 30% within the switch and up to 70% between the switch and the adjacent track.

From the analysis carried out in chapter 5 we can conclude that:

- Numerous studies agree that normal contact forces can be significantly reduced by optimising track stiffness.

- Lowering the track stiffness by means of soft rail pads or USP, especially in switch and crossing panels, helps to homogenise track stiffness and to lower impact loads, and thus, to reduce overall track deterioration (frog, rail, ballast, etc.). However, the softening of the support conditions should be limited to avoid fatigue of the rail foot caused by bending.

- Soft rail pads have been studied in multiple occasions and have proved that they contribute positively to the homogenization of track stiffness and to the reduction of impact loads.

- USP has been used extensively by SBB and ÖBB to minimize vibration and track degradation. However, their effectiveness has been difficult to assess in the field test carried out in Switzerland. Generally, hard USP are preferred.

- Ballast mats have been considered suitable to mitigate attenuation but they have little effect on track stiffness.

- Comparative analysis of soft pads, USP and UBM has been done. Placing soft rail pads seems to be the most efficient way to reduce track stiffness variation, while UBM have a much reduced effect. USPs also seem to contribute to the homogenization of track stiffness along the switch and furthermore, they are able to reduce significantly the loads applied onto the ballast, reducing track settlement. Soft rail pads can be used in combination with USP to further minimize track stiffness variation. The comparative analysis carried out by [17] is summarized in the figure below:

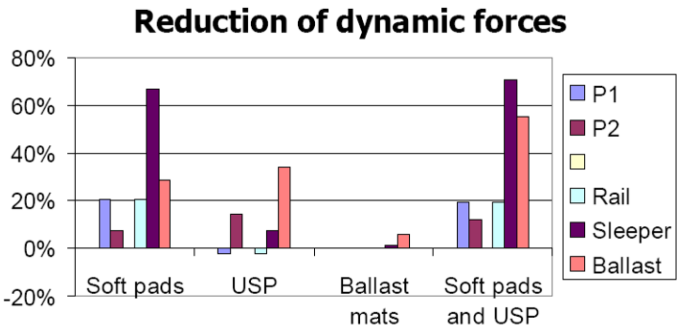


Figure 43. Reduction of dynamic forces using soft pads, USP and ballast mats (source: [12]).

- Elastic ribbed baseplates have also been described as a measure to minimize track stiffness variation. According to [6], depending on the speed of the train, contact forces can be reduced from 10 to 30% by using elastic ribbed baseplates. However, very little technical literature has been found.

- Geosynthetics are able to increase the bearing capacity of the subgrade and thus, to reduce track settlement. However, they have little effect on track stiffness. Use of geogrids can be beneficial to avoid the increase of impact load due to differential track settlement.

- The use of light sleepers seems to have a positive effect on track dynamic behaviour. A complete description of synthetic sleepers can be found in the next section, given that they offer benefits also for the logistics of S&C renewal.

As a final comment, it should be said that the modelling of a switch and the interaction wheel-rail phenomena is very complex given the high number of parameters that intervene, and therefore models tend to be simplistic. Moreover, studies only refer to vertical track stiffness, while lateral stiffness, mainly for the diverging track, should also be addressed.

6.4 Lighter S&C

As reported by TCDD, switches with wood sleepers are quicker to replace than the ones with concrete sleepers. In effect, the use of lightweight switches will allow the cranes to lift longer panels, making the renewal more efficient. Moreover, as mentioned in Section 5, the use of lighter sleepers can contribute to minimize dynamic forces acting on the switch, especially if they have to bear high axle loads. That is the reason why wooden sleepers are often used in switches, even though the adjacent track is provided with concrete sleepers.

However, wooden sleepers deteriorate quickly with time, especially under aggressive environmental conditions. In view of the problems of wooden sleepers, the use of **synthetic sleepers** that are resilient to extreme weather conditions and have a similar weight as wooden sleepers could be a good alternative to concrete sleepers.

Figure 44. Synthetic sleepers used in switches (source: Sekisui).

The best-known synthetic sleepers are the FFU (fibre-reinforced foamed urethane) sleepers, which is a material based on polyurethane reinforced with oriented glass fibres. FFU synthetic sleepers are manufactured using a pultrusion-extrusion process. The main benefits of these sleepers are:

- They offer similar weight as wooden sleepers (about 740 kg/m3), which permits easier handling than concrete sleepers and lower dead weight for bridges.

- They are resilient against weathering and are not affected by greases, lubricants or other chemicals used on railways. They offer long lifespan even under aggressive weather conditions, multiplying by three or more the expected life of beech sleepers.

- They provide higher mechanical properties than wood sleepers. Their bending resistance almost doubles that of wooden sleepers, the maximum static load at the centre of the sleeper is three times more, the screw extraction resistance increases considerably, as well as the impact load resistance, etc.

- They offer a very high electrical resistance which makes it convenient for switches. Values for R33 electrical resistance are about 72 KΩ while the minimum required is 5 KΩ.

- They accept existing fastening systems and screws and they can be handled with the same machinery used for conventional sleepers.

- The dimensions of the sleepers can be tailored to meet any requirements. As they are industrially produced, they can be produced with accurate mm precision. This is very convenient for curves with gradients, because sleepers can vary their thickness, or when low height sleepers are required.

- They can be easily repaired and they are recyclable.

These benefits make them suitable for not only turnouts under heavy loads, but also for bridges. In effect, a LCC analysis was performed by TU Graz using a curve bridge as a reference. For the analysis it was considered that the use of FFU sleepers allowed a 20% reduction of labour needs and a lifespan of 50 years. The outcome of the LCC showed that FFU synthetic sleepers could be used as a standard solution at Austrian wage levels and interest rate of 3%. The initial capital outlay for creating the track superstructure of bridges using FFU sleepers is in the range of 1.35 to 1.55 times what it would be if natural wood were to be used.

FFU synthetic sleepers have been used extensively in Shinkanshen lines in Japan since 1985. For example, in the Tokyo-Osaka high speed line, all switches and steel bridges are provided with synthetic sleepers.

In Europe, the first application of FFU sleepers dates back to 2004, in Wien. The German Federal Railway Authority (Eisenbahn-Bundesamt, EBA) approved their use in July 2009, after a complete serial of tests carried out by TU Munich. Since then, DB has used them in several switches (five in Munich and one in Hamburg from 2009 to 2011) and also for the renewal of the timbers of the 64.2 m long Gobe Vils bridge (Neumarkt St Veit – Landhsut line). The Austrian Federal Railways (ÖBB) tested also FFU sleepers on a number of bridges in 2010.

Figure 45. Installed FFU sleepers on a switch in Hamburg (source: Sekisui).

6.5 Quality of installation

The quality of the installation is critical for the future performance of the switch and therefore, special attention has to be paid to it. Current common practice for switch renewal (pre-assembly method) provides high quality of installation. The use of the modular concept is expected to bring additional quality. The quality of the installation will improve based on the fact that the switch is assembled at the factory with a controlled environment and does not depend on lineside conditions and because the transport distance between the tilting wagons and the installation site tends to be shorter than the distance between the pre-assembly space and the installation site. However, some IMs declared that similar quality is achieved by both methods.

Increasing the quality of installation could permit a faster commissioning of the switch, but only if this leads IMs to rely more on the installation method, meaning a reduction of the number of checks required for the acceptance of the switch.

The way the switch is handled is fundamental to assure a good quality of the installation. Switch panels have to be lifted in a way that they do not suffer undue deformations and thus, stress. There are national standards, such as the SZDC S3/1 in Czech Republic, where the conditions of the handling (number of supporting points, etc.) of the switch during transport and installation are fixed.

In the majority of the methods described in this report, the switches are handled properly by means of railway cranes, crane-beam systems and portal cranes systems since they suspend the panel from multiple points. However, when using excavators or road cranes, panels are usually lifted by only two points, which is only admissible if the switch panels are short.

Another issue to be taken into consideration to achieve a good quality of installation is when the welds are done. In those cases where welding is carried out after the switch has been put into operation, the passing of vehicles over the fishplated rail joints induces high stress to the rails and the position of the adjacent sleepers can change due to impact stress.

For this reason, most IMs recommend to carry out the welds before any traffic passes over the switch. This could be achieved by using specialized cranes that are able to transport and install the complete switch (so the welds can be done during the preassembly prior to transport) or by allocating more time for welding during the weekend possession (by reducing the time required for other activities, such as ballast removal by using, for instance, an automated ballast collector).

6.6 Use of DTS after switch installation

During the analysis carried out in Chapter 4 it was concluded that the use of Dynamic Track Stabiliser after the switch renewal was not a common practice. Only TCDD declared that DTS was usually applied after installation because it allows to increase the temporary speed restriction (TSR) after the installation of the switch, and in some cases, to even avoid the imposition of any speed restriction.

As also seen in Chapter 4, TSR can last for up to a week, with the subsequent impact on the operations. The use of DTS after switch installation should be analysed in order to prove that its use can reduce drastically the speed limit after renewal.

6.7 Reinforcement of subgrade/ballast layer

As stated in many technical publications, the support condition of the switch is critical for the future performance of the switch. A weak supporting layer can lead to excessive and differential settlement of the switch which will result in high maintenance costs. Moreover, this differential settlement will increase the effect of dynamic actions on the switch, incurring in even higher maintenance needs.

To avoid this problem, most of IMs oblige to remove the complete layer of ballast during the renewal works and to prepare and compact the subgrade layer. However, the removal of only the upper part of the ballast layer is also a common practice in certain countries when the switch being replaced is not in a main line.

With the aim of providing a competent support and to decelerate the deterioration rate of ballast layer, the inclusion of geogrids under the ballast layer could be used. Geogrids are able to minimize track settlement and thus, avoid differential track settlement.

7. Conclusion

A review of the S&C renewal methods used across Europe was undertaken based on the information provided by four IMs (DB, JBV, MAV, TCDD) and two contractors (COMSA and SKANKSA). Information for United Kingdom (NR) and Sweden (BV/TRV) was obtained from INNOTRACK project.

According to the information provided by partners, the **pre-assembled method is the most common method for S&C renewal**. The installation of the switch panels can be done by means of excavators, road cranes, railway cranes (such as Kirow crane), crane-beam systems (such as DESEC or VAIACAR cranes) or portal crane system (such as UWG or Geismar-Fasseta system). Outputs and required labour and machinery for each method are defined in chapter 4.

On the other hand, the results of the comparative analysis showed that the employment of the **modular switch concept has the potential to halve the total duration of works**, compared to a conventional replacement. This saving of time comes from the fact that the (a) switch is assembled only once at the factory and it is transported, even with the driving devices, just in time to the installation time; (b) the transfer of the switch from the wagon to its final position is faster and (c) commissioning can be done also faster . This results not only in a significant **reduction of track possession and labour costs**, but also **avoids** the need of **negotiations with landowners** in case there is no lineside space for switch assembly.

However, the spread of the use of the modular switch method is limited by the following factors:

- Many IMs count with a reduced number of tilting wagons due to its high investment costs, which makes them not as widely available as railway cranes.
- The feasibility of the method depends on the distance between the assembly factory and the worksite.
- Pre-assembly method is quite straight-forward and it is proven for years, which makes some IMs reticent to not consider it as the preferred method for switch renewal. Moreover, quality of installation is similar to that achieved with the modular method.

For these reasons, many IMs use the modular switch method for those cases when trackside access road does not exist, when there are lineside space constraints for the switch preassembly or when there is a very short track possession time.

From the analysis of the S&C methods, the following recommendations/ideas for further development were identified:

- **Automated ballast collector**: Used usually in combination with the modular switch method, the automated ballast collector can be used to increase the efficiency of the ballast layer removal and site preparation. However, it could offer the same reduction of time and labour needs when used with the pre-assembled method.

- **Lightweight synthetic sleepers**: The use of lighter sleepers facilitates the renewal works and has also a positive effect in track stiffness homogenization. FFU sleepers offer a similar weight to wooden sleepers but with improved mechanical properties, higher resistance against weathering and provides excellent electrical insulation. They have been used in turnouts and bridges in Japan since decades and some tests have been carried out in Germany and Austria.

- **Higher quality of installation**: Current common practice for switch renewal provides satisfactory quality of installation. The use of the modular concept is expected to bring additional quality, but this statement is not acknowledged by all IMs. By increasing the quality of installation, the commissioning of the switch could be faster. Two activities of the renewal having influence on the installation quality have been studied: the handling of the switch and the clamping/welding. A correct handling of the switch is fundamental to avoid undue deformations and stress, which is usually the case. On the other hand, welding should be done instead of provisional clamping to avoid high stress at the end of the rails caused by passing vehicles over the fishplated joints. Recommendations for these two topics are included in chapter 6.

- **Use of DTS**: Only TCDD declared that DTS is used as common practice after switch renewal, given that it allows to increase the temporary speed restriction (TSR), and in some cases, to even avoid the imposition of any speed restriction. The use of DTS should be analysed in order to prove its effectiveness to increase speed limit after renewal.

- **Reinforced subgrade/ballast layer by using geogrids**: Support condition of the switch is crucial to guarantee a good future performance of the switch. For this reason, most of IMs oblige to remove the complete layer of ballast during the renewal works and to prepare and compact the subgrade layer. The inclusion of geosynthetics contributes to the reduction of track settlement, avoiding differential track settlement that will incur in higher impact loads and hence, track deterioration.

- **Hybrid modular**-preassembled method: To solve the lack of tilting wagons, a hybrid modular-preassembled approach could be used. In some cases, some of the switch panels can be transported with flatbed wagons, while the rest are assembled at the lineside of the works. This allows a reduction of the space, labour and time required for the assembly of the switch panels.

In what regards to track stiffness, the study carried out in chapter 5 concluded that the **optimisation of track stiffness in the switch can lead to a significant reduction of contact force**s, extending the lifespan of the switch.

Soft rail pads and USP has been identified as the most effective way to minimize track stiffness variation, while UBM or geosynthetics have a very big effect. By combining both systems further homogenization of stiffness could be achieved.

As a final conclusion, it should be said that in some cases, such in UK, the implementation of the modular concept for switch renewals comes along with a **re-design of the complete renewal process**. The benefits from using tilting wagons are combined with other improvements of the renewal, such as the automated ballast collector described above.

However, there are other improvements that have not been included in the deliverable because of the lack of information that should be analysed. Examples of these improvements are the development of computerised self-testing of the signalling systems to speed up commissioning or the deployment of “lean” engineering throughout the process.

Added value of the research

There can be found in the technical literature several studies that compare the different S&C replacement methods, but only in general terms. However, the review of methods developed in this deliverable means a **step forward** in this field given that detailed and accurate information is attributed to each method in terms of labour, machinery and outputs.

This comparison at the **European level** (including countries from all parts of the continent: Sweden, Turkey, Spain, UK, etc.) has three important results:

- It enables the different Infrastructure Managers and industry all around Europe to discover not only **new methods**, but **new techniques and tools** used in other countries with the same method that **offer better results**. This also leads to the identification of potential developments that could bring further improvements to the replacement of turnouts.

- It represents a **handy and reliable document** to IMs and contractors to identify the most suitable method for each case.

- It gives **recommendations for the quality of the installation** in order to minimize the future needs of maintenance. This is **especially relevant for some Eastern European countries** that usually employ methods that deliver poor quality (specially due to an incorrect handling of the switch), which results in high maintenance costs.

As a conclusion, this Deliverable gives European IMs and contractors the opportunity **to increase the overall cost-efficiency of the renewal, to minimize the impact of operations and to increase the safety of the workers**.

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