RCA

Reference CCS Architecture

An initiative of the ERTMS users group and the EULYNX consortium

Migration

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Summary

This document demonstrates how the legacy system architectures of infrastructure managers (IMs) shall develop to the defined RCA target system architecture, that consists of onboard train systems and trackside infrastructure.

As part of a large European rail network, national existing Command Control and Signalling (CCS) systems need to be developed further according to the expectation of IMs and their stakeholders concerning network capacity and performance. ERTMS is the basic enabler for further system developments. Modern technology and working processes bring cost reduction by centralisation, digitalisation, modularisation, reduction of trackside assets and using fibre cable instead of copper; the rollout of ERTMS is brought closer by these characteristics. The most important principle is that this migration is driven by standardisation of interfaces between systems, this makes the entire CCS system modular. The process in which systems and their interfaces arrive at the desired future situation is called "migration". The migration of CCS consists of ERTMS, EULYNX and future expansion with so-called 'game changers'.

Rolling stock must at least be equipped with ERTMS functionality; where onboard localisation and train integrity monitoring makes higher ambitions possible.
The target system architecture at the trackside is then described on the basis of a modular framework of systems that comply to RCA. The needs of every IM can be met by choosing configuration plateaus within this framework; the highest plateau fulfils the highest ambition in terms of network capacity and performance.

Migration from the current to the future system architecture has a large number of variables. This document opts for the approach whereby from a strategically chosen ambition for the future, the RCA, based on the target system architecture, is projected to the initial situation. The different European IMs each have a different initial situation with their own system architecture. This is the reason why a different approach is required for each of the IMs. Every IM also has its own business case.

For migration, the train must be "always connected"; an ERTMS implementation is a must. First, the application of Object Controllers prepares the infrastructure for further centralisation and digitalisation of the CCS system. A next step for higher performance of the railway network is the implementation of Automatic Train Operation (ATO) on both trackside and onboard systems. Higher ambitions come within reach when trains can monitor their integrity, this can be realised first with complete trainsets, in a later stage more train types may have this functionality. The highest performance of the railway system comes within reach when also onboard localisation has been developed. All these measures are accompanied by a step-by-step reduction in the number of track-side assets and of course costs.

Developments and roll out programs lead to deployment per IM, typically with geographical or functional segmentation. To prevent permanent diversity in systems, and thereby optimise the business case of European CCS system development, it is recommended to develop so-called open systems from the target system architecture based on jointly defined requirements, where the intellectual property rights of the new systems are with the IMs. Standardisation of interfaces means that suppliers and their systems and innovations must comply with them in order to fit into the standard.

This document will not describe the entire system architecture, but will focus on the differences in architecture that determine migration. What is described in this document can be projected on the situation of each individual IM. On the basis of a comparison of six architecture migrations of IMs, it is shown that European standardisation and migration based on RCA should be further promoted.

1. Migration

1.1. Aim of this document

With the RCA, IMs aim to modernise their CCS systems [1]. This process starts with the existing infrastructure (as built). This document facilitates modernisation by describing the generic design of CCS systems and describing the issues that play a role in the transition to the new configuration of systems using cab signalling. The target configuration is based on the modular RCA reference architecture, which should help the individual strategies of IMs to meet their specific business challenges, i.e., reduce the cost of the CCS system through decomposition, digitalisation and standardisation. Technology innovation can be used in conjunction with modern methods for specification and acceptance. The modular and modern approach based on ERTMS and EULYNX will also make it possible to introduce so-called game changers[1] later when they come within reach for IMs who need to bring their network to a higher level of capacity, reliability, availability and / or safety. With an open approach, market parties can develop new products and systems in competition.

1.2. Migration, definition and scope

1.2.1. Definition

The process of changing the existing system architecture to the target configuration is called “migration”. The target system architecture as used in this document is the RCA architecture that consists of the configuration of the entire CCS system, a combination of different systems configured in different ways, including interfaces. The CCS system consists of systems on both the infrastructure side and the side of the Rolling Stock.

1.2.2. High-level goal

European IMs recognise that they cannot obtain the best solutions at national level, but need to specify and develop **one international, common, future (simple) framework** to which they can migrate, sooner or later. In this migration **ERTMS is the enabler for further cost reduction** and increase of benefits in the field of CCS. The already mentioned **game changers** cover the remaining needs of railways, these also will act as the starting point for further developments to even more innovative means of transport. Migration includes all CCS systems and related processes. **The combination of open systems**, of which the intellectual property rights are with the IMs, ultimately allows efficiency and capacity increases in the entire railway production through integrated and optimised planning and control. A coordinated migration strategy **prevents complex tuning of too many different individual development programs**, systems, baselines, releases, versions, etc. Figure 1 shows that different developments that run in parallel are connected with each other for the sake of a less complex migration. Simplification is achieved by **limiting the total number of developments** (as is already legally enforced for national ATP systems). Early adopters are essential in the deployment of migration strategies of parts of the RCA concept; they have big influence on the later adopters. It is important to ensure that **sufficient market volume is reached quickly**. Work will be done towards a standard connection for interchangeability of **systems** (e.g., COTS Object Controllers) **from**

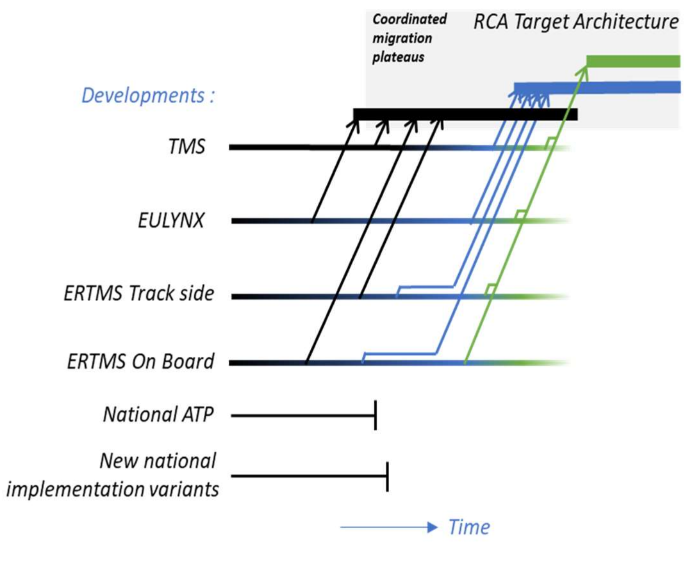


Figure 1 The RCA standard must simplify migration

[1] Game changers are ERTMS Level 3, ATO, train-localisation, new communication infrastructure, etc.

different suppliers, in competition and for different IMs. To achieve an optimum use of investments, systems should be able to fit into the target architecture. In combination with this, IMs and suppliers need to **spend their scarce resources on developments that realise their business cases**; modifications to legacy systems with limited returns then receive a lower priority. This makes it possible for **suppliers to better anticipate developments** to achieve the target architecture. Migration offers IMs and suppliers more certainty for investments in developments in the direction of the target system architecture and offers the benefits in guaranteeing aftercare and back-orders for fewer configurations.

1.2.3. Scope

This document focuses on the CCS infrastructure system architecture of the IMs (Chapter 5). Because trains have to be equipped with ERTMS in advance of making significant changes to the infrastructure, the CCS of the vehicles (interoperability) is considered in RCA (Chapter 4). This document will not describe the entire system architecture, but will focus on the differences in architecture that determine migration.

At TMS level, implementation of the production plan is within the scope; the production planning is out of scope. The interface from a central system to the trackside assets, i.e., the communication between the CCS system and the trackside devices, is in scope of the migration. The trackside assets such as points, level crossings, national ATP, etc., are out of scope. Out of scope of the migration described in this document are other (non-CCS) systems of vehicles. The related power supply is seen as an IM responsibility and is out of scope of the migration described in this document.

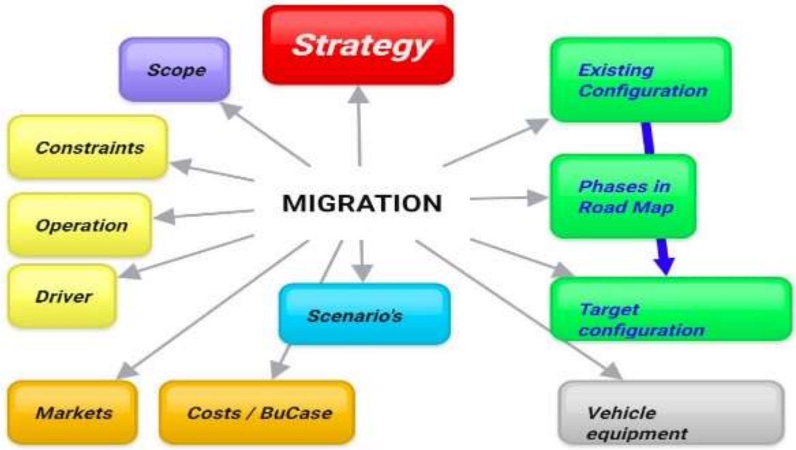


Figure 2 Migration context

When considering the migration of the CCS architecture, many variables must be taken into account (Figure 2). Depending on specific drivers, constraints or operational use, many migration scenarios are possible. Variables should be analysed per IM and should lead to their requirements for migration. By understanding the requirements, the migration scenarios, architectural decisions and choice of applying baselines can be understood. Each of the scenarios has consequences for development and rollout, and therefore for the costs. The business case for IMs to purchase more products from different market parties must justify the investments for technical developments for the strategy for a more standardised system landscape. That is why this document combines the scope described above with the variables, scenarios and consequences. The comparison between architecture migrations of different IMs in this document is intended to promote European standardisation and migration.

An entire mind map is given in Annex 2 (as a table) and Annex 3 (as a graphic).

1.3. Order of migration

In the migration to ERTMS, both the infrastructure and the onboard train equipment must be converted, fast or slow. If an integral sector-wide strategy is chosen, a moment can be seized to implement ERTMS in the existing network as the new standard and alongside renewal of existing equipment.

RCA is founded on radio-based ETCS, i.e., all trains are equipped with ERTMS. This is in line with the business case that states that the infrastructure should not be provided with double systems because equipping rolling stock is less costly than equipping many kilometres of track with multiple systems. This order of migration minimises the integral costs of RUs and IMs and accelerates the benefits.

Therefore rolling stock will be equipped (possibly temporarily) with double systems (ERTMS + STM[2]) to prevent double systems in the infrastructure.

The upgrade of trains with train integrity / onboard localisation and ATO is not required for the start of the migration to the RCA. The benefits on capacity and reduced LCC costs will increase when more trains will be equipped with ATO and improved localisation (e.g., train integrity or onboard localisation). The localisation migration is addressed in Chapter 4.

[2] With an STM, ERTMS trains can run on both ERTMS track sections and track sections with existing legacy (Class B) train-protection systems.

2. Variables

2.1. Constraints

RCA is based on radio-based ERTMS. This means that without migration to radio-based ETCS, migration to the target situation of the infrastructure is impossible. This determines the most important limitation: development and roll-out of ERTMS is a must, without which the goals are impossible to achieve.

A second constraint concerns availability of the network during migration. Given the extensive use of the network of many IMs, scenarios that limit the operational use of the infrastructure during the migration period shall be avoided: “Big bangs” have many disadvantages. This means that migration could take place stepwise; examples of architecture migrations of different IMs are described in Chapter 6.

2.2. Operational use

The application of successive baselines and releases of subsystems within the system landscape must be considered. These are related to the specific rollout of successive projects within IMs.

The current operation of the infrastructure must be taken into account when migrating to the target configuration. At the moment that in a certain migration step the change is made from, e.g., legacy signalling to radio-based ETCS the operational use changes considerably. This change, which may vary in detail for each of the IMs, must also be taken into account. At the start of the migration process, a large part of the signalling infrastructure of IMs consists of legacy systems. However, important migration steps have already been taken on specific parts of the European network where ERTMS is applied. Existing investments, as long as they are not obsolete, must be protected when presenting scenarios for further migration.

2.3. Drivers

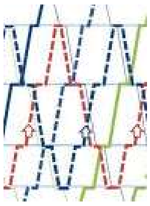
Strategic drivers of individual IMs determine which systems must be migrated. They support the acquisition of exchangeable, upgradeable CCS components from different suppliers. The strategies of the individual IMs are the most important factors for migration. Obsolescence of existing equipment or higher requirements for capacity, reliability, availability and / or safety are drivers for migration. An already planned project or program can also be such a driver for a step in the migration process.

In this document the most important drivers for the IMs (shown below with a limited number of symbols) will be related to the corresponding system functions in the migration.

The railway infrastructure **life cycle cost will be reduced** when renewing the signalling system architecture following the RCA standard. Cost reduction is reached by centralisation, digitalisation, reduction of trackside assets (copper cable, train detection and signals) and remote control over longer distance by using fibre cable; besides saving money this has environmental advantages. Reduction of life cycle cost of object controllers by diagnostics (easier recovery) and easy exchangeability of systems of multiple suppliers. Methodical approaches such as the use of (semi-) formal methods prevent costs from being incurred due to uncertainties in specifying, contradictions and hidden assumptions in engineering and configuration efforts. A new system architecture makes a modular approach possible and also enables hardware and software independency. Further cost reduction is reached by increased competition and reduction of dependency on suppliers.

RAMS performance is largely determined by an adequate system architecture (with provisions for maintenance and management, forms of redundancy, in combination with a specific safety approach, etc.). Reducing the number of trackside assets means fewer degraded situations, with consequences for trains, people and processes; on balance, that means an increase in availability.

Safety is the common thread when it comes to system migration of signalling. Simplicity in design with thoughtful incorporation of safety functions into the individual standard modules leads to “thin”, affordable and safe systems. Supervision of all movements (i.e., less manual procedures) increases safety.



Capacity improvements comes through optimising block sections and configuration by appropriate ERTMS design. The highest network capacity is reached with ERTMS trains equipped with onboard localisation and train integrity monitoring (TIM); with virtual train detection, trackside train detection (TTD) can be limited. As long as it cannot be guaranteed that unfitted trains no longer occur, TTD must be maintained, with a negative effect on network capacity and costs. In all cases ATO improves network capacity, it can also improve operation in degraded situations. Higher levels of ATO, beyond Grade of Automation 2, mean the dependency on the train driver is removed.

3. RCA target system architecture

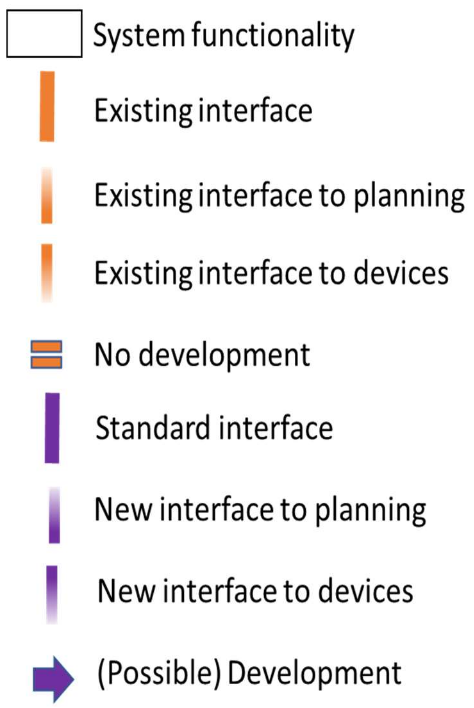


Figure 3 Symbols used

3.1. Uniform symbols used

This document structures the terminology and concepts of migration at different European IMs. The symbols used in this document are not used in documents from IMs yet. This prevents unintended conflicts with these and other documents and it is envisaged that each IM can project its own situation onto the one described here. For these unified symbols that are used, see Figure 3.

3.2. Top-level requirements

Cost reduction is a main goal. This is reached by reduction of trackside assets combined with standardisation, maybe the most dominant cost factor for IMs. The reasons behind standardisation are increased competition combined with reduction of dependency on suppliers, where the intellectual Property Rights are at the side of the IMs. **An important principle is that standardisation is driven by standardisation of open interfaces.** ERTMS and EULYNX are typical examples of this. **Another principle is that the ability to migrate the infrastructure is determined by (first) equipping the rolling stock** with systems for radio-based ETCS and additional functionality that make the reduction of trackside assets possible. Equipping rolling stock with safety systems is directly related to European and national regulations.

3.3. RCA architecture, onboard and trackside

3.3.1. Trackside configurations

To achieve the high-level objective, **one target reference system architecture** for both track- and train-side has been established [2]. Different migration plateaus can be realised. A plateau represents a relatively stable state of the architecture.

Any plateau before the final one can be a goal for some IMs. For a certain network segment the IM can stay on a certain plateau for a certain period. In this period an IM may have to wait for synchronisation in equipping trackside and onboard systems, or this choice is given by its business model, being the decided scope of certain projects. When migrating from the legacy situation to this target architecture, fast or slow migration is possible with (big or small) steps in development and rollout. Plateau 1 is the non-regret move of introducing object controllers to improve the capability for a next migration step. Plateau 2 is for the IM who needs to keep its interlocking / RBC configuration[3] but needs to have ATO, and also wants to stay upgradable to the next plateau. The maximum benefit comes with the highest ambitions: Plateau 3 and 4, RCA.

[3] For possible configurations see Section 5.3.1.

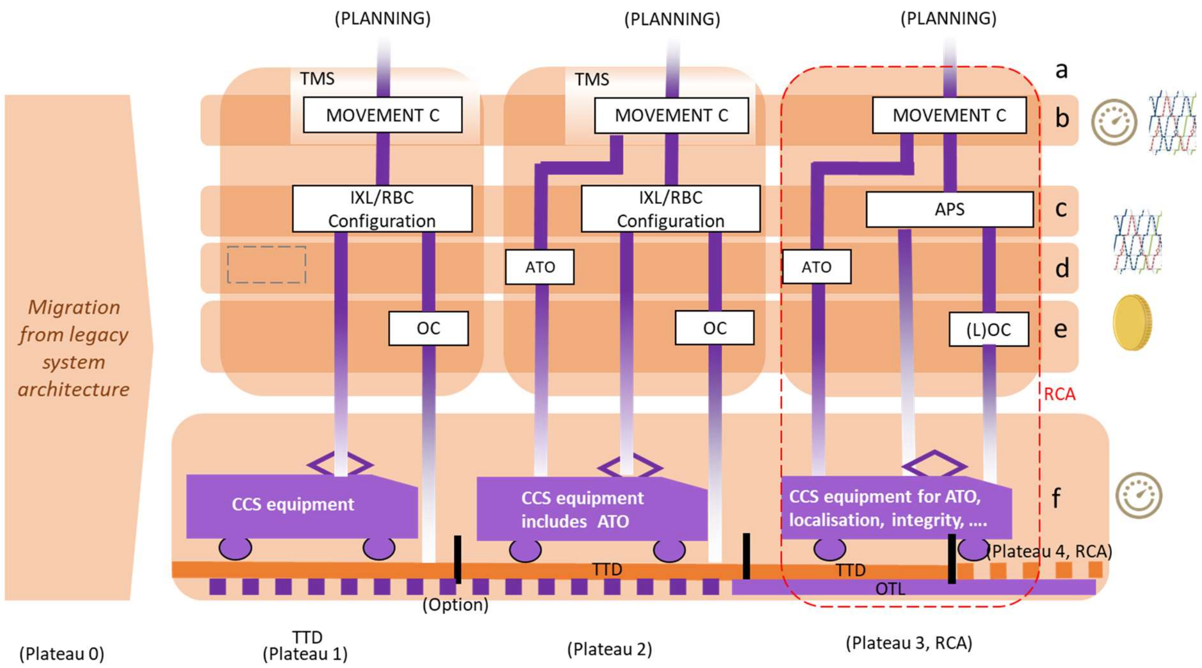


Figure 4 Plateaus and option, leading to the target architecture RCA

In Figure 4 the demonstrated choices within the same reference architecture are:

Plateau 1	Basic application of ERTMS trackside and rolling stock, applying Object Controllers may bring **reduction of costs**; optimisation in TMS / planning systems.
Plateau 2	Basic application including ATO and / or Object Controllers; ATO or interface standardisation to trackside devices can be applied completely independently of each other. This plateau leads to **higher performance and use of network capacity and / or lower life cycle costs**.
RCA, Plateau 3	The optimal configuration includes onboard localisation and integrity monitoring without application of TTD systems. This plateau brings **the highest performance and network capacity and performance.**
RCA, Plateau 4	Track side train detection can be taken away when all trains are equipped with onboard localisation or integrity monitoring. If it can't be guaranteed that only equipped rolling stock occurs, TTD can't be omitted. This plateau allows to reduce the trackside assets costs. See Section 4.2.
Option	Mixed application of positioning technology (TTD and/or onboard localisation) can be combined with any of the plateaus (Hybrid Level 3 or LSL). This allows to already achieve the capacity benefits of the higher plateaus for equipped trains with this plateau. Retaining a level of TTD also provides a robust recovery in degraded situations.

The symbols used in Figure 4 are a simplification of the detailed RCA architecture overview with a number of levels of different system functionality. The relationship between these is shown in Annex 1. This Annex also shows the relation to generic functions like Data Preparation, Diagnostics and Monitoring of assets. The symbols better match the variety of situations that now occur with different IMs. Now it becomes possible to set up migration scenarios from the current situation to the target[4], projected on more than one IM. Related to this, in Figure 4 the following so-called layers can be distinguished, for standardisation these interfaces are relevant:

a. Interface with Planning (Planning itself is out of scope RCA);
b. Movement Control;
   Migration of TMS;
c. Safety Control (APS = Advanced Protection System);
   Migration of interlocking / RBC configurations to Data Centres (APS);
d. ATO;
e. Device Control (vehicle supervisor or vehicle locator, object controller (L)OC);
   Migration like ERTMS and EULYNX and future game changers;
f. Interface with Devices (vehicle or object as actors or sensors are out of scope RCA);
   Migration from GSM-R to FRMCS and to exchangeability of devices from different suppliers.

3.3.2. Onboard configurations

RCA is a part of the entire railway system. CCS equipment on trains does not belong to the IM but must be considered when looking at migration of the trackside. A complete solution however includes the vehicles, this determines the business model of the Railway Undertaking (RU). With every migration step in the infrastructure, different CCS configurations of the onboard equipment can be combined (an example is given in Annex 4). For each configuration / scenario the RU can map the (business) economic benefits of migration on the vehicle side for a given functionality of the infrastructure. This makes it possible to identify and map the consequences of certain (technical) migration steps in terms of costs and revenues for the infrastructure manager, vehicle owners and at the societal level. This provides interesting background information for the decision-making process. Functionalities can be added as desired, for example for innovative technologies.

In this context it is important to mention OCORA (Open CCS On-board Reference Architecture) [3]. The target of OCORA is a modular architecture for the CCS functionality on the vehicle that strongly reduces the costs and workloads for upgrades and extensions including homologation.

[4] The target architecture for the individual IMs may include necessary inexpensive solutions for interfacing to existing systems; this protects existing investments and saves resources for later stages. This means: do not start with the current state and then working further ahead; such incremental development will not offer an optimal solution and will lead to a less efficient national collection of solutions. But start with the target state in mind and reason back from the target.

3.4. Change the signalling atlas by segmentation

The resulting target reference system architecture shall be applied on the national networks, depending on the performance requirements of IM stakeholders for certain locations. Infrastructure deployment segmentation is constrained by onboard deployment and driven by renewal needs and benefits. See Figure 5. If it becomes necessary to migrate the entire network of the country, a limited number of segments (1, 2, ...) is obtained (examples: clipping the map of Denmark, Norway in one program). A study by DB compared the consequences of geographical segmentation. Some assessed aspects were: costs concerning management, suppliers and interfaces, duration of migration and consequences for procurement and competition. A further more or less functional subdivision per network corridor is used by ProRail. Combinations are possible, but a conflict can arise if earlier choices in segmentation prove to be in conflict with later insights.

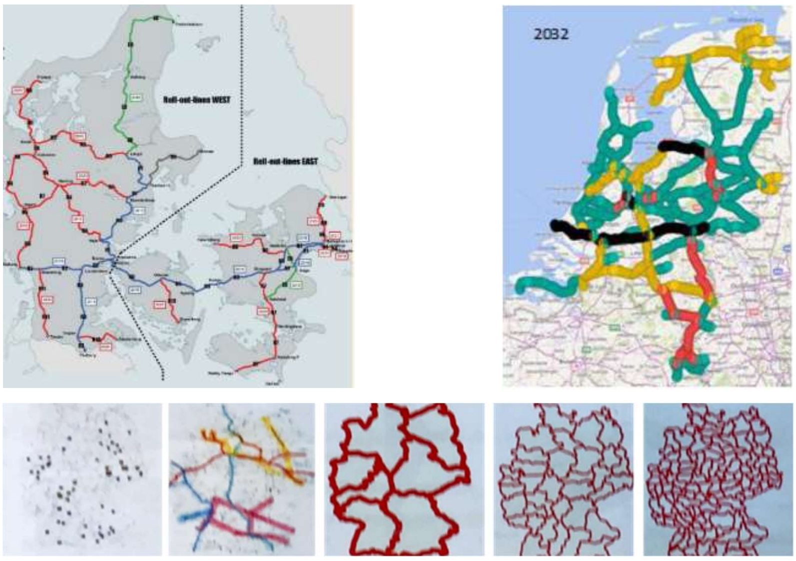


Figure 5 Different ways of segmentation

In the following table, an example is given for a national application. The subdivision used in the table is arbitrary. The relationship between the geographical subdivision with the procurement approach is obvious.

		Plateau 0	Plateau 1	Plateau 2	Plateau 3	Plateau 4	Option
Legacy	Starting situation	+					
Standard	Level 2		+				+
High capacity	With ATO			+	+		+
Very high capacity	With ATO and onboard localisation			+	+	+	+
Mixed equipped trains	With ATO and onboard localisation			+	+	+	+
Only fully equipped trains	Highest performance, RCA					+	+

Table 1: Segmented application of target architecture (example)

4. Migration of CCS onboard

4.1. Conditions for migration

Determining the accurate information on the position of the complete train (in signalling terms: train vacancy detection) is an essential signalling function. With legacy technology, train positions are determined by train detection equipment along the track, information on the position of the train is defined per section or block. In the approach to migration the starting point should be to be able to run all variants of legally accepted trains.

The potential of ERTMS is currently restricted whilst the onboard equipment is unable to determine the position of the whole train. In this situation, hard boundaries of blocks or sections need to be provided by train detection systems. When this constraint is removed and the onboard can determine and report the position of the whole train, a higher utilisation of infrastructure becomes possible. This also has a benefit in enabling a reduction in the amount of TTD required which provides a significant cost benefit for the IM.

The influence of the IM on the migration of the onboard CCS on the railway undertaking is limited. In Europe, the ownership of onboard ERTMS equipment is not normally the responsibility of the IM. When drawing up the migration strategy for RCA, therefore, the use of both ERTMS equipped and unequipped trains has to be taken into account. The change of use is addressed in the national roll-out programs. In some countries, many trains are equipped already with ERTMS, in some this process is starting. These are the reasons that for the RCA migration strategy, every IM will have to choose the migration approach on this aspect.

A migration step is accompanied by system developments and installation of equipment, for the IM and / or for the owner of the rolling stock (see Section 3.2.2.). Such a step is only taken if ERTMS or new functionality, such as that provided by the game changers, is added. The associated investments and withdrawals for operation must then be accompanied by clear benefits. Such a migration step, e.g., with a certain baseline which is fully usable for a particular IM, can serve as the basis for further development or change.

4.2. Equipment for migration

Two areas of development are dominant to reach this target: the precise onboard localisation of a train and the accurate information of train integrity. As the development of these technologies progresses, decisions can be made about equipping rolling stock, experiences with this technology can increase and the remaining risks become (more) known, then it is possible to gradually switch from TTD to advanced onboard positioning functionality.

Before all trains can report integrity (complete trainsets, cargo trains, trains on secondary lines, international passenger trains, etc.) and are equipped with onboard localisation assuring the location for the whole train, new systems have to be developed and implemented on a large scale. Such a situation comes closer to a more “perfect concept”, but both technology and regulations (e.g., TSI) have to be adapted.

A migration concept is needed to allow both the trackside and train side RCA architecture to be used for trains which are able to report location and those which are not able to report location. That is why concepts for mixed application of positioning technology are developed (option described in Section 3.3.1). These concepts are close to Level 2 and allow the use of accurate position information where able to be provided for trains. However, TTD is used for trains without onboard localisation or integrity. This concept is also important for degraded situations, to keep traffic on a busy network moving in case of disruption. When more and more trains are able to report integrity and the complete train location, the amount of train detection can be minimised to a level required for safety and support of unequipped trains. Then, the most optimal concept comes within reach.

On the trackside, the CCS system consists of several subsystems. At a certain step in the migration process, those subsystems may have to deal with both legacy unequipped trains and ERTMS-equipped trains. With a next step in functionality, a train can report its integrity and a train is equipped with onboard localisation assuring the position for the whole train. For this step, interoperability requirements and compatibility shall be taken into account. This, in combination with safety and degraded modes, determines the extent to which IMs can get rid of trackside assets. This means that in the migration strategy, the presence of the following types of wagons and trains has to be taken into account (see Figure 6):

- Legacy wagons and trains, not equipped with ERTMS; TTD normally needed;
- ERTMS-equipped trains, meeting baselines without onboard localisation and/or train integrity functionality; TTD needed;
- ERTMS equipped trains, equipment reports integrity (e.g., cargo trains, international trains) or are equipped with onboard localisation assuring the location for the whole train; so-called onboard train localisation (OTL). OTL is mandatory if no TTD is available.

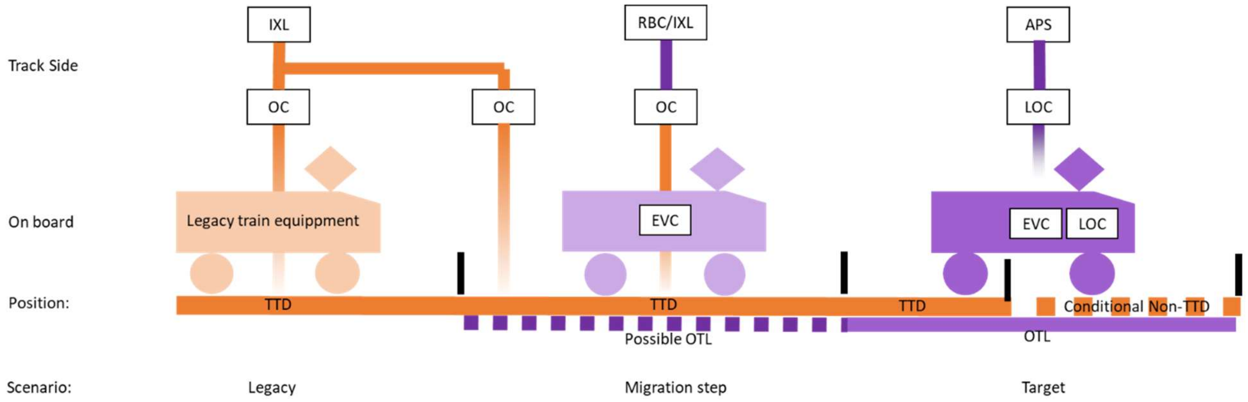


Figure 6 Different needs for train position

4.3. Typical implementation examples

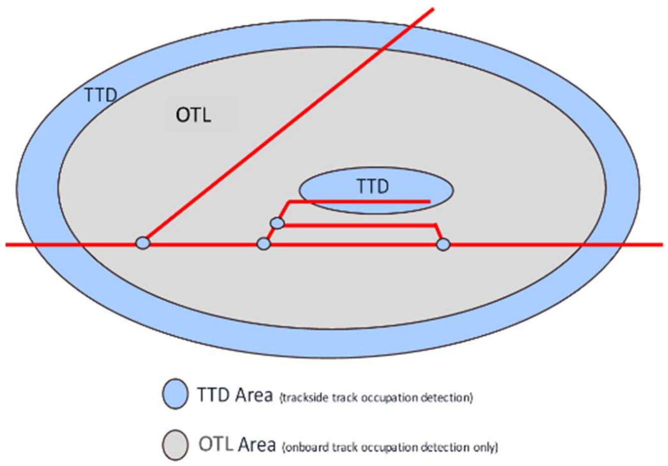


Figure 7 Typical application train positioning

In Figure 7, the outer blue circle forms the protection against unequipped trains. In this figure, critical infrastructure like points are provided with TTD for performance and safety reasons. Within the grey area, accurate onboard localisation saves trackside assets for detection of equipped trains. Without TTD, the presence of a unequipped wagon or train is not detected, which could cause hazardous situations.

5. Migration of CCS Track Side

5.1. Conditions for migration

As described earlier, IMs must complete certain activities which are not brought by standardisation, e.g., defining one's own system architecture (start, target, steps between them), coordination with railway undertakings, the design of the (power and information) network, defining performance (RAMS, degraded modes, etc.), etc., supported by the national business case. This leads to individual IMs needing to have their own migration scenarios to move towards implementation of the RCA architecture.

Also from the suppliers view it may be preferable to limit the diversity in standards, baselines and versions. In some cases it is possible to have one technical system meeting different baselines or versions at the same time (under certain conditions).

5.2. Equipment for migration

"One system fits all": if this were really to be the case with the trackside CCS system, migration to a new configuration would be "replace the CCS system as a whole". However, several (sub-) systems can be distinguished in the CCS domain and all these systems can be subjected to migration. In the migration process of the entire system architecture, we take these subsystems into account, which we also call modules. The migration principle is to make every module (or set of modules) exchangeable; independent of the supplier. Every time we consider two subsystems in the system architecture, the interface between these subsystems also belongs to the system architecture. Both the interface and the systems on both sides of the cutting edge must be defined to execute the migration process.

Figure 8 shows the exchangeability from system 1 to system A and/or from system 2 to system B on each side of a defined interface. The change from the existing to the new configuration can be implemented in various steps (scenarios).

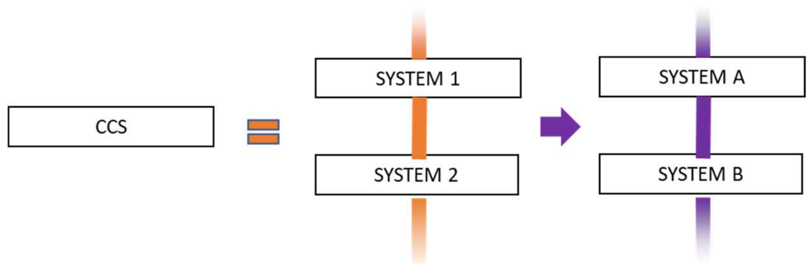


Figure 8 Basic approach principle of migration

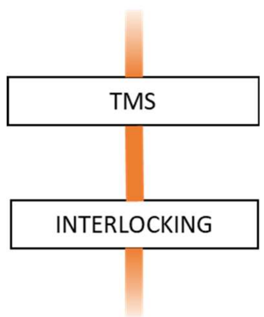


Figure 9 Possible starting situation

Each of the IMs involved distinguishes a more or less different starting situation. This starting situation in which IMs find themselves with the legacy system architecture is close to the basic approach. By keeping this approach as simply as possible, a minimum of different layers can be defined: TMS and interlocking (Figure 9).

It is clear that the most optimal target situation is not feasible in one go, but the need of one or more developments must become clear. Therefore, the following four step approach can be followed by each IM:

1. Define the target ambition / plateau / option;
2. Define the system architecture;
3. Define the needed equipment;
4. Develop the missing systems.

5.3. Typical implementation examples

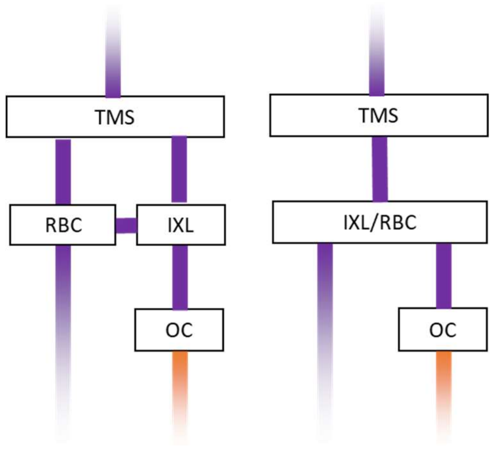


Figure 10 Two examples of different ERTMS implementations

5.3.1. ERTMS

Many migration scenarios from the legacy situation, which is unique per IM, to the target situation are possible. This means that the number of choices in migration has the potential to explode, other choices are distinguished by simplicity. Figure 10 shows an example of the current situation with ERTMS: some IMs set requirements for a combined RBC/Interlocking system (on the right, possibly physically separated because products with this architecture don't exist), other IMs specify their system architecture in a way that the RBC and the interlocking are separate systems with a (standard) interface (on the left). And each of the choices have different consequences in system management, market approach, costs, etc. The most optimal choice for the migration process must be demonstrated by an analysis.

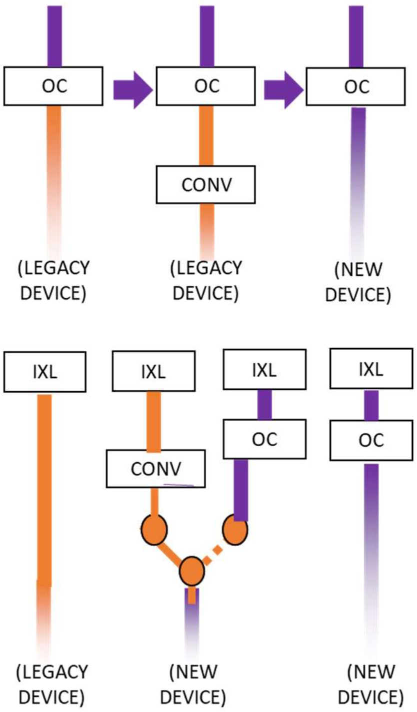


Figure 11 Two different implementations of temporary power converters

5.3.2. Power supply differences

National legacy signalling equipment often suffer from solutions that have been developed in the past and are based on outdated technology. By applying backwards compatibility, existing investments can be protected with the introduction of new future-proof equipment. In Figure 11, two solutions of two IMs are presented. In the first example, the new developed object controller is used in combination with a legacy device, using a cheap (power) converter. As soon as a newly developed device with a new object controller is applied, the converter can be removed. In the second example, a converter is added as soon as the legacy device is replaced by a newly developed version. A switch facilitates the test period with the new interlocking and object controller, which is removed in the final situation.

5.3.3. Preparation for migration

In anticipation of migration steps, the following steps can already be taken into account in projects. This is called "prepared building" or "RCA prepared". Specific requirements can be set for this. The purpose is to save (conversion) time and costs in the migration process.

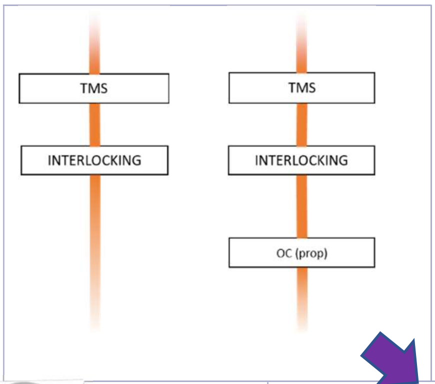
Examples are: replacing or renewing cables with facilities that are suitable for a next migration step (preventing double digging, extra (fibre) cables, laying empty pipes), being prepared for larger cabinets / housing for future equipment (land acquisition), early installation of Object Controllers, etc.

6. Inventory of architecture migration of some IMs

6.1. Introduction

An overview has been drawn up of some IM migration initiatives in order to assess whether or not they are in line with RCA. An indicative representation of the source information is shown for reasons of recognisability [4]. The symbols used are explained in Chapters 2 and 3.

6.2. Banedanmark



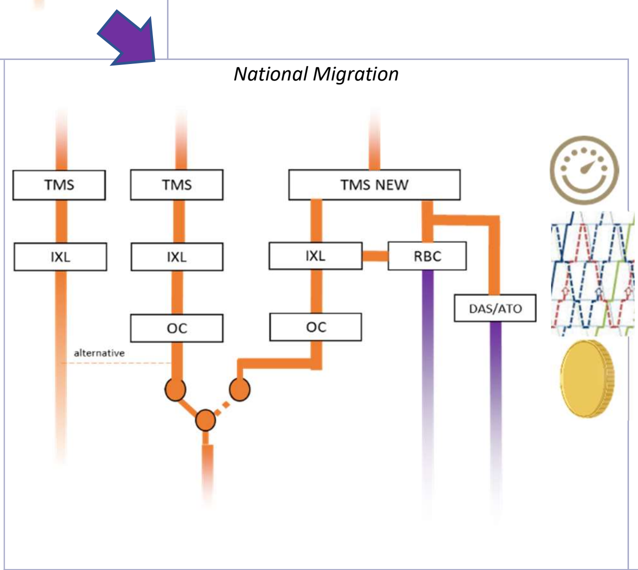
Legacy

Segmentation:
TMS on core routes (most of main lines), major stations with local control.
Secondary lines on old CTC systems or local control.

Scope / architecture:
Relay interlocking. Or electronic interlocking with proprietary object controllers. Without ERTMS

↑ Source (indicative)

National Migration



Segmentation:
National program for the entire network, but split in two parts

Scope / architecture:
ERTMS, Track side (incl. TMS), Onboard

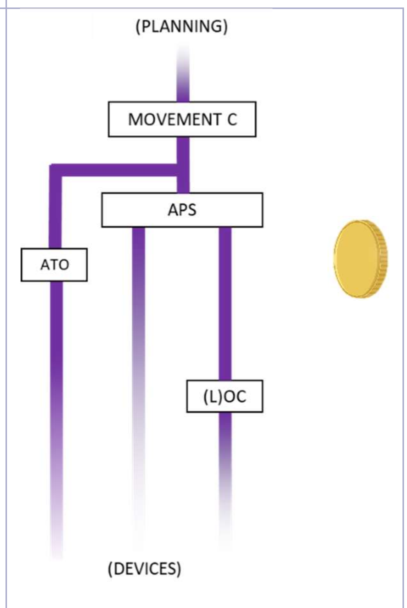
Period:
- 2030

Competition model:
Suppliers per segment.

The scope of the current program of Banedanmark corresponds to Plateau 1 (Figure 4).

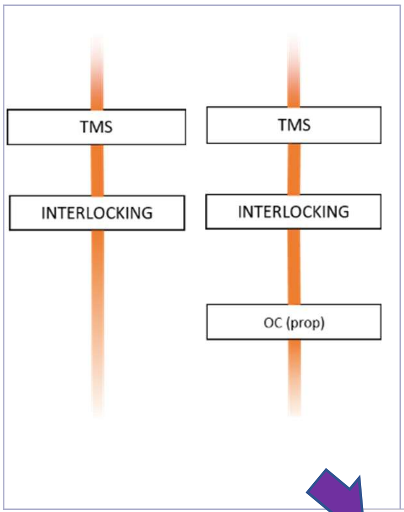
National migration comes in line with RCA with the following change in architecture:

- TMS → Movement C + Planning
- IXL / RBC → APS
- DAS → ATO
- OC (prop) → (L)OC.



Reference European target

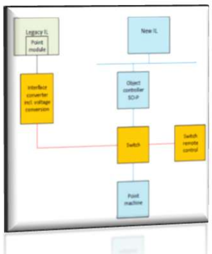
6.3. BaneNOR



Legacy

Segmentation:
Much of the signalling systems in Norway has reached or is approaching its technical service life.

Scope / architecture:
Legacy without ERTMS



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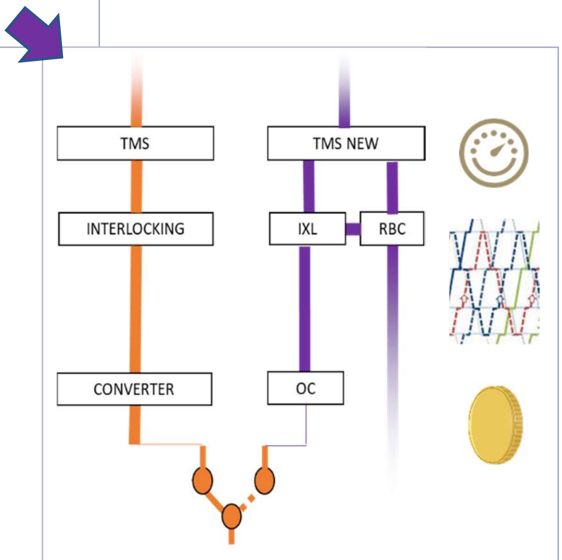


National migration

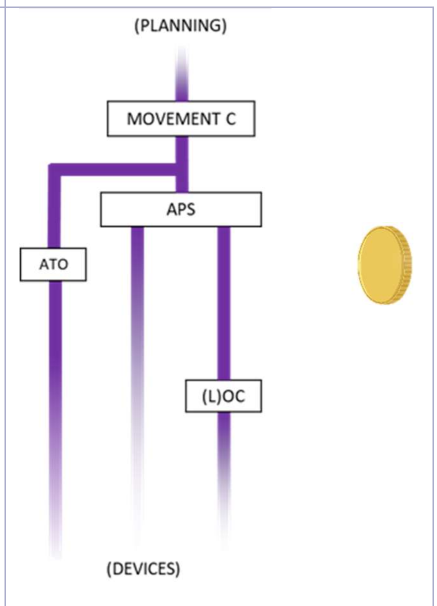
Segmentation:
National program National ERTMS Implementation program for the entire network

Scope / architecture:

- A new Traffic Management System (TMS) for the complete network;
- Fitting 4200 km of railway with new signalling systems including interface standardisation by EULYNX and ERTMS L2;
- Fitting app. 600 trains with ERTMS L2.

Period: 2012 - 2034

Competition model: Three suppliers for TMS, signalling trackside and onboard.



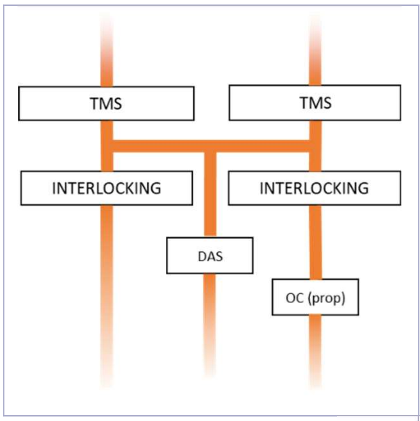
Reference European target

The scope of the current program of BaneNor corresponds to Plateau 1 (Figure 4).

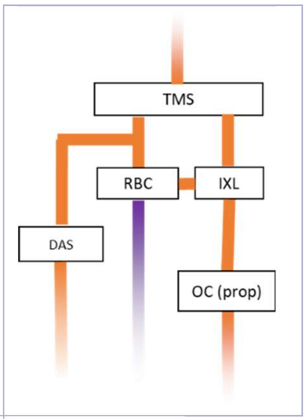
National migration comes in line with RCA with the following change in architecture:

- TMS → Movement C + Planning;
- IXL / RBC → APS;
- OC → (L)OC.

6.4. DB



Legacy

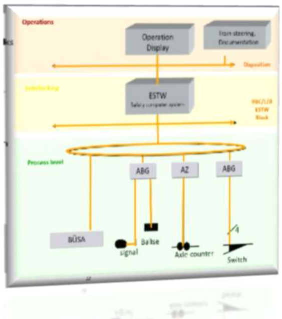


Legacy

Segmentation:
Turnkey projects.

Scope / architecture:
Left: TMS and different generations of interlockings in various technology. Entirely proprietary system chain.

Right: ETCS Level 2 without signals at Halle/Leipzig – Erfurt



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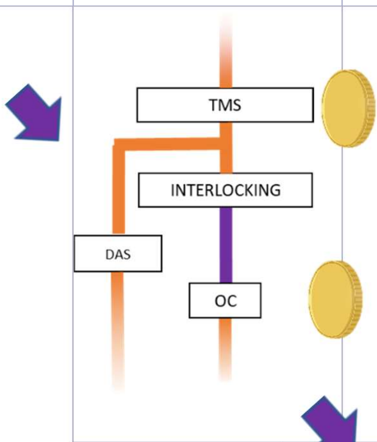


Migration

Step 1

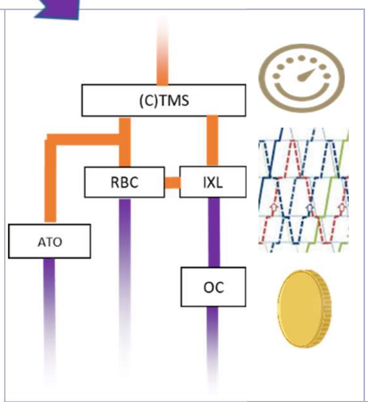
NeuPro pre-series

Segmentation:
NeuPro pre-series projects on small line sections;

Scope / architecture:
Standard interfaces with multiple suppliers (NeuPro, Rel. 1);
Reduction of dispatchers;
Reduction of cable cost.

Period: In realisation

Competition model:
Interlocking and OC from same supplier.



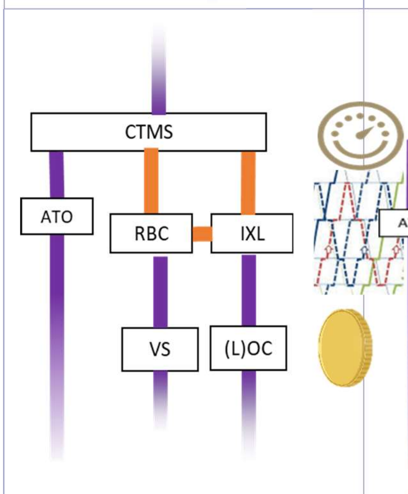
Step 2

Starter packet

Segmentation: Larger sections.

Scope / architecture: ERTMS L3 with virtual blocks; reduction of TTD and signals. Gain capacity by flexible block section lengths; EULYNX Baseline 3/4;

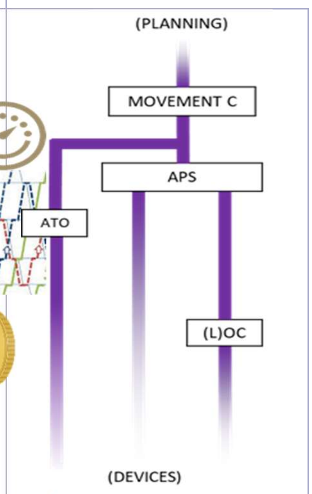
Competition model: Reduce OC LCC by diagnostics and exchangeability of suppliers



Step 3

Rollout phase 1

National migration

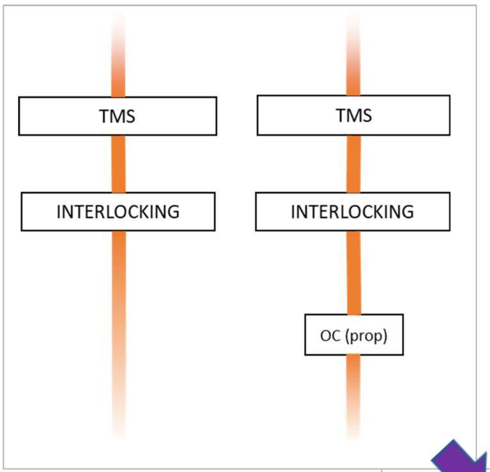


Reference European target

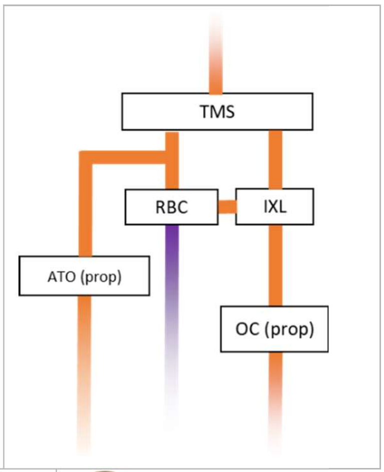
National migration comes in line with RCA, when:

- CTMS → Movement C + Planning;
- IXL / RBC → APS;
- OC → (L)OC.

6.5. Network Rail



Legacy



Legacy

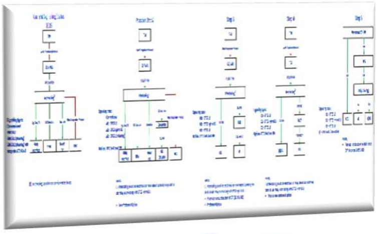
Left:

Mechanical, Relay and Electronic interlockings connected to bespoke TMS systems.

Electronic interlockings use proprietary OC's.

Right:

Cambrian ETCS L2; Heathrow L2 overlay; Thameslink L2 overlay with ATO GoA2.



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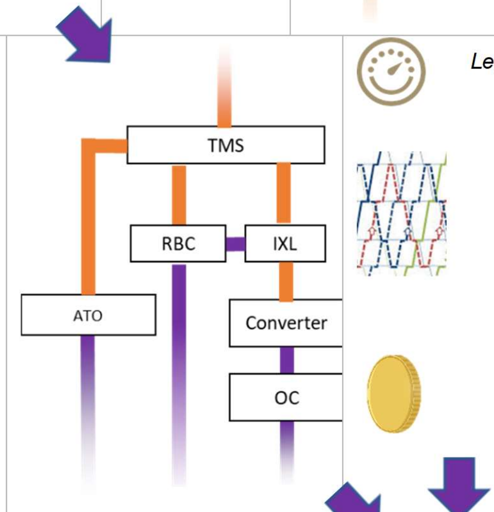


National migration

<u>Segmentation:</u>

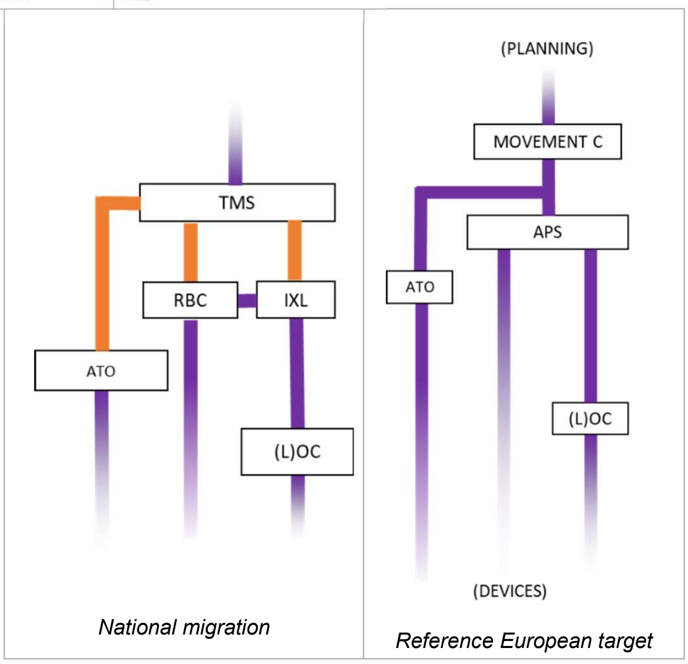
Digital Railway Program

<u>Scope / architecture:</u>

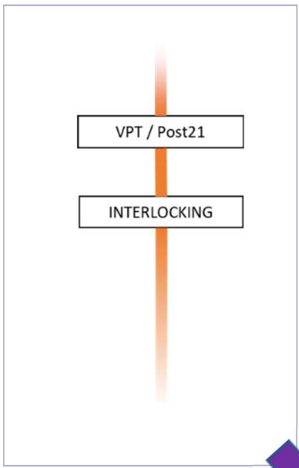
Future Applications to be ETCS L2, ETCS Hybrid L3 and ETCS L3 with ATO GoA2 as an option. The intent is to reduce the number of migration steps from those shown as the plans are further developed.

National migration comes in line with RCA, when:

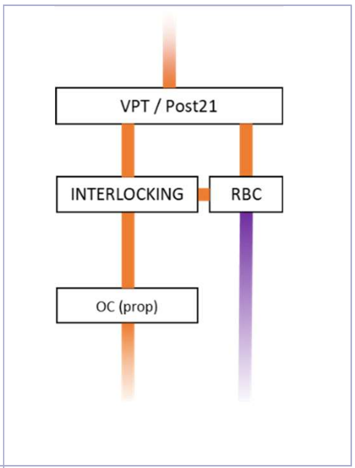
- TMS → Movement C + Planning;
- IXL / RBC → APS.



6.6. ProRail



Legacy

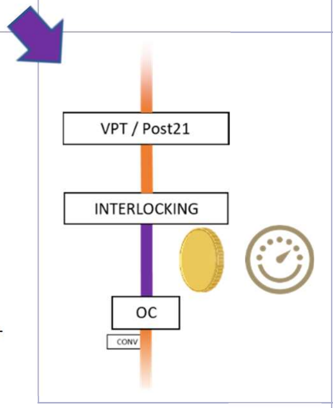


<u>Segmentation, Scope / architecture</u>

Centralised Traffic Control

Left: 90% of the network, relays (60%) or electronic interlockings (30%).
Right, with ERTMS, incl. trains: 10% (High Speed, Betuwe Freight).

Mixed ERTMS / legacy signalling: Amsterdam – Utrecht, Hanzelijn.



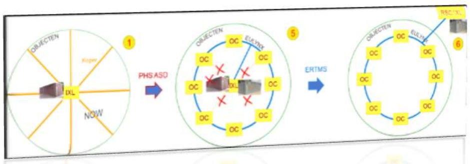
No change at non-large segments.

<u>Segmentation:</u> Per large segment; high capacity yard;

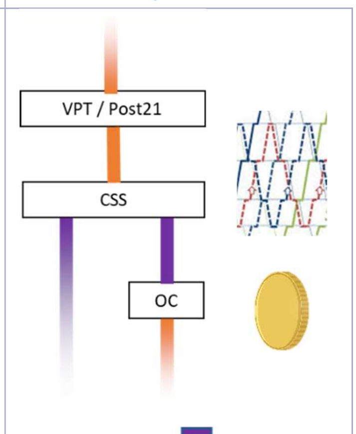
<u>Scope / architecture:</u>
ERTMS Prepared; i.e., EULYNX interfaces; Fibre instead of copper; Bigger steering distance; Less interlockings;

<u>Period:</u> 2020 -2025

<u>Competition model</u>: Open interlocking; Open interface OC



↑ Source (indicative)



<u>Segmentation:</u>
ERTMS National Program

<u>Scope / architecture:</u>
L2, HL3, no signals, including trains, high capacity corridors

<u>Period</u>: -2032

<u>Competition model:</u>
Open CSS, Open interface OC

National migration comes in line with RCA, when:

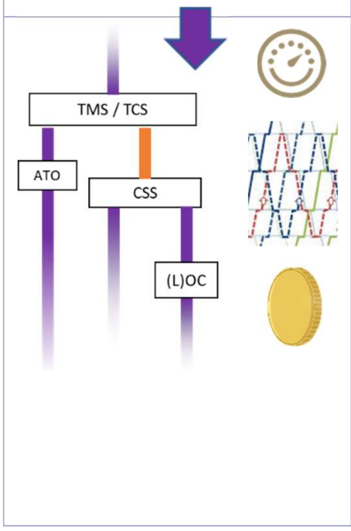
- TMS/TCS → Movement C + Planning
- CSS → APS
- OC → (L)OC

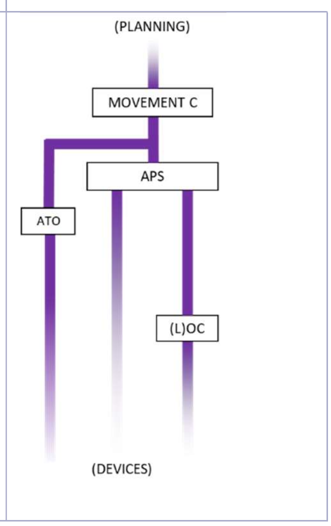
<u>Segmentation:</u>
ERTMS National Program

<u>Scope / architecture:</u>
L2, HL3, no signals, ATO including trains, High capacity network, Less devices (train detection)

<u>Period</u>: -2032

<u>Competition model:</u>
Open CSS, Open interface CSS, Open interface OC



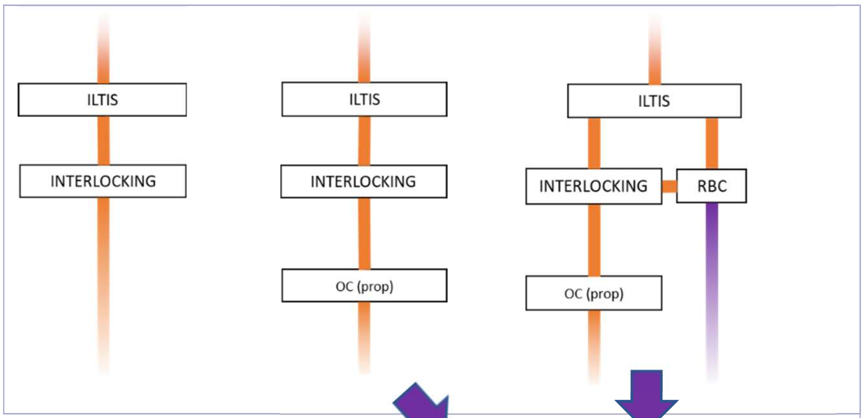


P.S. CSS = Central Safety System ProRail

National migration

European target

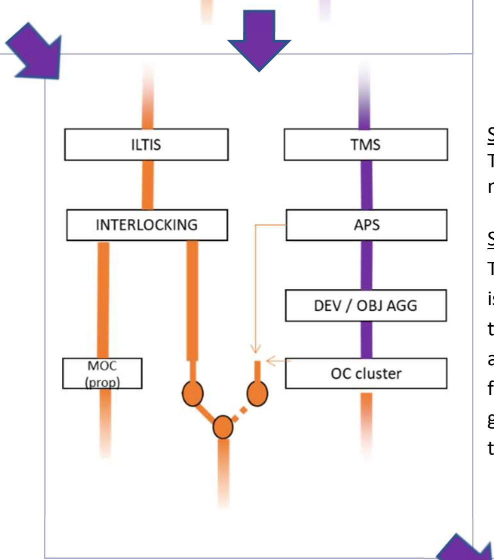
6.7. SBB / BLS / SOB (Switzerland)



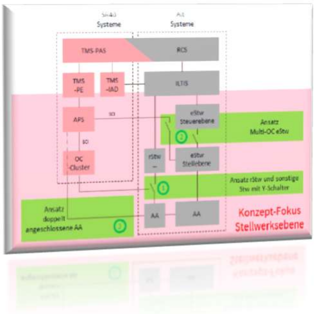
Legacy

Segmentation:
Migration to ERTMS almost completed:
- the Class B Systems have been migrated to ETCS L1 LS (Baseline 3)
- Eight important Lines are equipped with ETCS L2 (Baseline 2)
- 1’300 Vehicles are equipped with ETCS-Onboard (mostly Baseline 2, few Baseline 3)

Scope / architecture:
Relays or electronic interlocking.



National migration

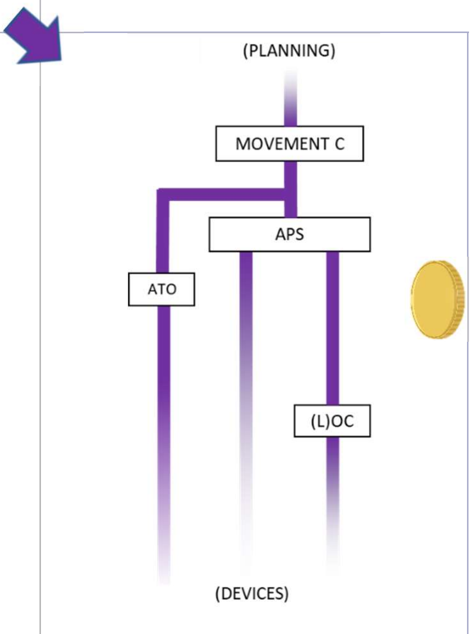


↑ Source (indicative)

Segmentation:
The migration takes place via three implementation steps

Scope / architecture:
The aim of the Smartrail 4.0 Program (SR40) is to equip as much of today's railway facilities with new technology and interface standardisation by ERTMS and EULYNX; the central functions and area processes are first migrated before the actual rollout takes place in the network.

National migration in line with RCA.



Reference European target

6.8. Evaluation

Based on the translation from the RCA to the national architecture migration steps using the unified symbols, a comparison is possible. This proves:

1. Architecture migrations of IMs described in this document are all in line with the target RCA;
2. In detail each of the IMs follow a different migration strategy, determined by national characteristics; more coordinated migration and developments accelerate the availability of innovated COTS products (e.g., Object Controllers), from which more IMs can benefit (implementation together with point 6 below);
3. Based on this, migration to game changers is a driver for faster European standardisation following RCA;
4. Migration programs are often carried out in large steps, which is a consequence of the chosen concept, procurement requirements, the scale of development and implementation which come together in the business case; migration while changing track layouts makes it complex, but the advantage is that a more optimal situation can be built; as soon as the system is made modular (by interface standardisation) smaller migration steps are possible, else small steps lead to high adjustment costs (if technological diversity does not decrease, there are less benefits in maintenance);
5. It appears that segmentation (in migration, in tendering) can take place in different ways (always related to the migration of rolling stock), illustrated in Figure 5;
6. The devil is in the detail: governance and management (of IMs *and* suppliers, in the form of guidance of specialists according to the RCA principles, training, etc.) must ensure that no new national implementations of standard functionalities arise and that existing ones are harmonised as much as possible. One functional requirement may not have (too) many different implementation variants at one supplier, based on national characteristics. This can go hand in hand with some harmonisation of operational processes. There are opportunities for harmonisation when requirements documents are shared between IMs and efforts are combined to develop (COTS) subsystems within the configuration, i.e., further standardisation within the CCS architecture.

7. Conclusion and outlook

Many issues play a role in improving the cost position and performance of the CCS systems. Therefore, the target situation is developed (RCA); the process of changing from the existing to the target situation, the so-called migration, is described in this document. Later “game changers” are taken into account. Migration based on the common agreed target system architecture combined with interface standardisation brings advantages for all parties involved.

Before the RCA existed, several IMs already applied the RCA principles. Migration scenarios are created on the basis of all this information:

- Migration starts with the target modular system architecture RCA that delivers the desired ambition level with different possible migration plateaus and provides the steps forward, from the current legacy architecture to the defined target;
- The minimum requirement is the use of radio-based ETCS and a step-by-step migration towards it (for reasons of costs and network availability);
- The strategy of each IM is determined by the national characteristics of the assets (technical lifespan, required network capacity, geographical extent) and the available budget;
- Architectural analysis determines which system developments or modifications are necessary (as limited as possible), including needed inexpensive solutions for interfacing to existing systems;
- The scenarios also describe which combinations of geography and operational use are distinguished for the roll out;
- There is a relationship between the required developments, the roll out and the role of market parties: even if an IM wants to reach the target for the entire country with a single tender, the IM must (together with the supplier(s)) prepare a step-by-step migration. If a decision is made for a number of smaller (geographic) lots for tendering, the management of migration steps is the responsibility of the IM itself.

A complete solution however includes the vehicles, this determines the business model of the Railway Undertaking (RU). For each configuration / scenario the RU can map the (business) economic benefits of migration on the vehicle side for a given functionality of the infrastructure.

Despite the many migration parameters mentioned in this document, it can be stated on the basis of the inventory that the intended RCA system architecture for each of the IMs is technically feasible, with national strategies based on national characteristics determining the migration in detail.

The typical result for migration in Europe is represented in Figure 12.

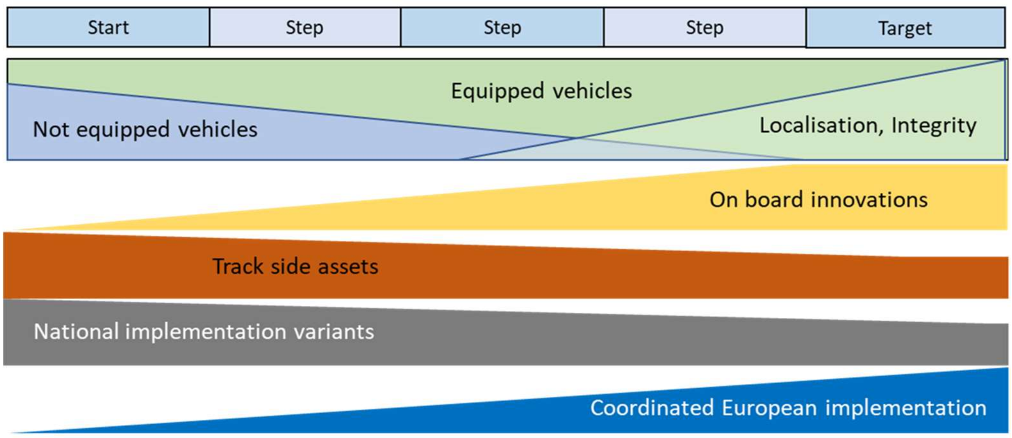


Figure 12 Migration program

With no doubt it can be said that this document does not provide an answer to all questions. Both on the part of IMs and on the part of RU’s and supplying parties, when applying architectural migrations, new questions will emerge that can be processed in a subsequent version.

8. Glossary

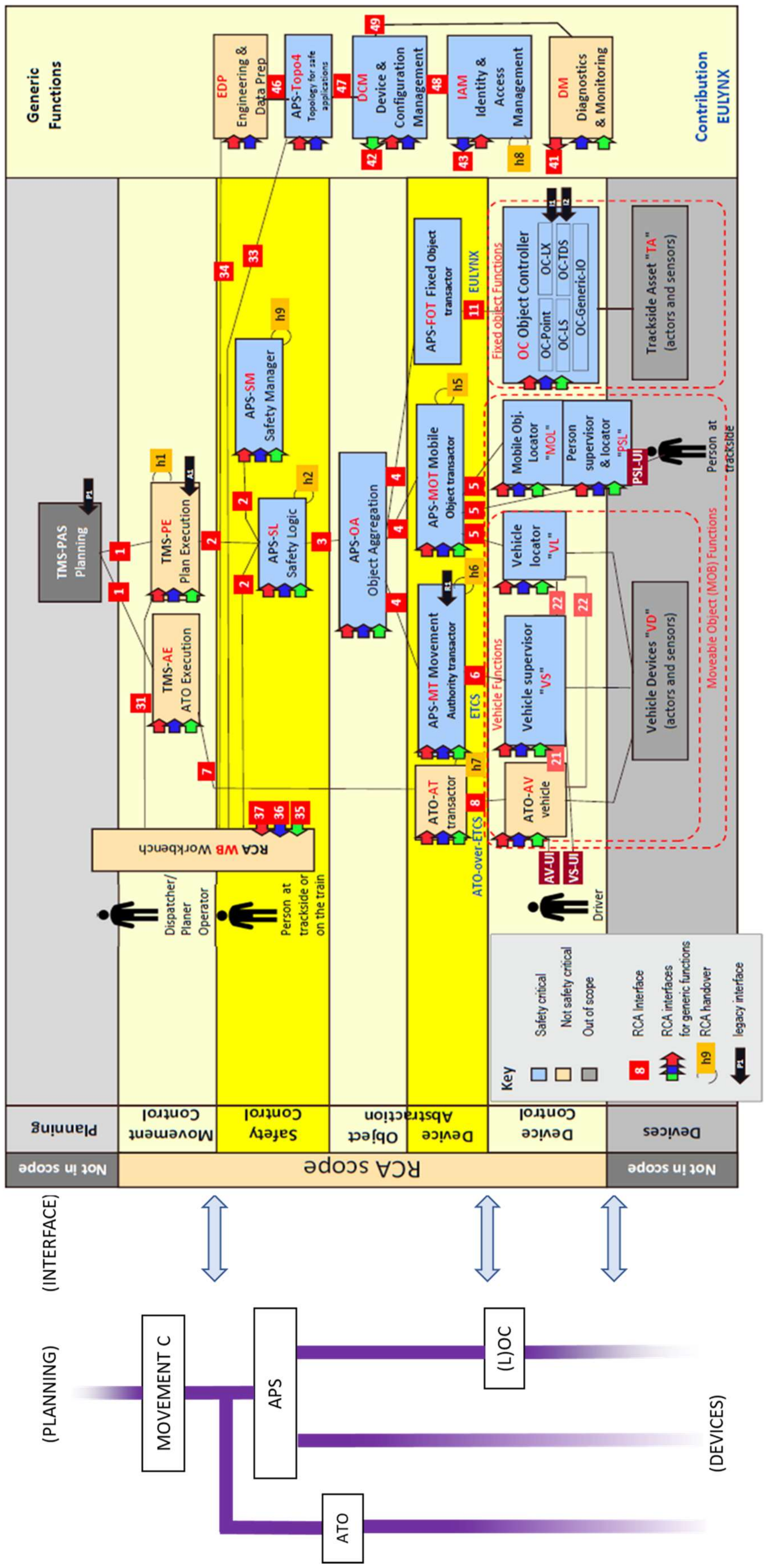
Short	Meaning
APS	Advanced Protection System (RCA)
ATP	Automatic Train Protection
ATO	Automatic Train Operation
CONV	Converter
CCS	Control Command and Signalling
COTS	Commercial Off-The-Shelf
CSS	Central Safety System (ProRail)
CTC	Centralised traffic control
DAS	Driver Assistance System
DB	Deutsche Bahn
DEV	Device
ERTMS	European Railway Traffic Management System
EULYNX	Initiative of IM's to standardise interlocking interfaces
EVC	European Vital Computer (ERTMS Onboard)
FRMCS	Future Railway Mobile Communication System
GSM-R	Global System for Mobile Communications – Railway
HL3	Hybrid Level 3
ILTIS	Part of TMS system of SBB
IM	Infrastructure Manager
IXL	Interlocking
L1LS	Level 1 Limited Supervision (ERTMS)
LSL	Enhanced Level 3 Supervision, trackside / onboard Localisation
(L)OC	Locator or OC
MOC	Multi OC
MOVEMENT C	Movement Control (RCA)
OC	Object Controller
OCORA	Open CCS On-board Reference Architecture
OTL	Onboard Train Localisation
Prop	Proprietary
RAMS	Reliability, Availability, Maintainability, Safety
RBC	Radio Block Centre (ERTMS)
RCA	Reference CCS Architecture
RU	Railway Undertaking
SBB/BLS/SOB	Partners in migration of Swiss Infrastructure
SIL	Safety Integrity Level
TEN-T	Trans-European Transport Network
TIM	Train Integrity Monitoring
TTD	Trackside Train Detection
TMS	Traffic Management System
VPT	Part of TMS system of ProRail

Table 2: Glossary

9. References

[1] RCA White Paper, RCA.Doc.1;
[2] RCA Architecture Overview, RCA.Doc.2;
[3] OCORA; https://github.com/OCORA-Public/Publication (01012020)
[4] Several IM source documents, implementation or program documents.

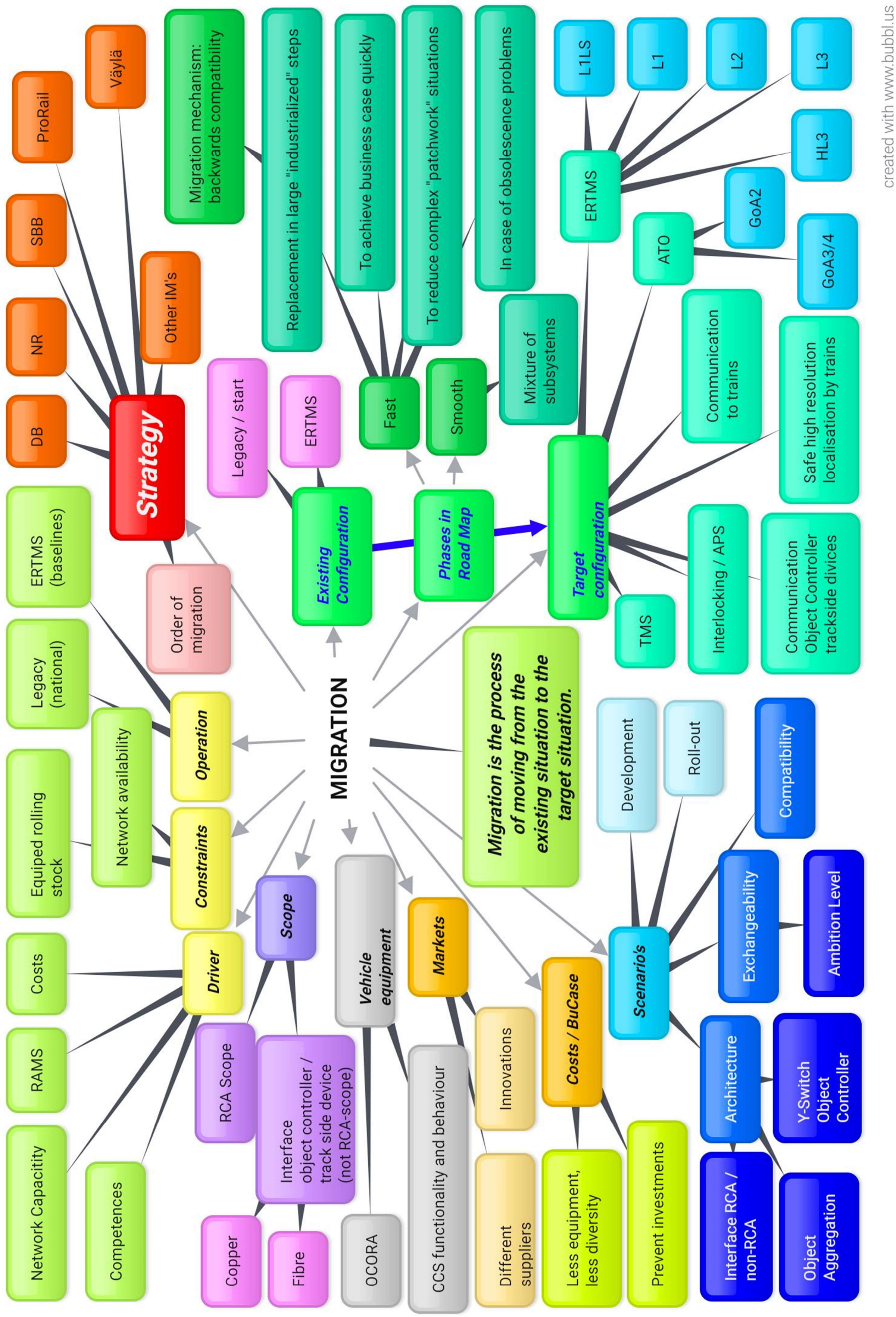
Annex 1: Derivation of Figure 4 from RCA



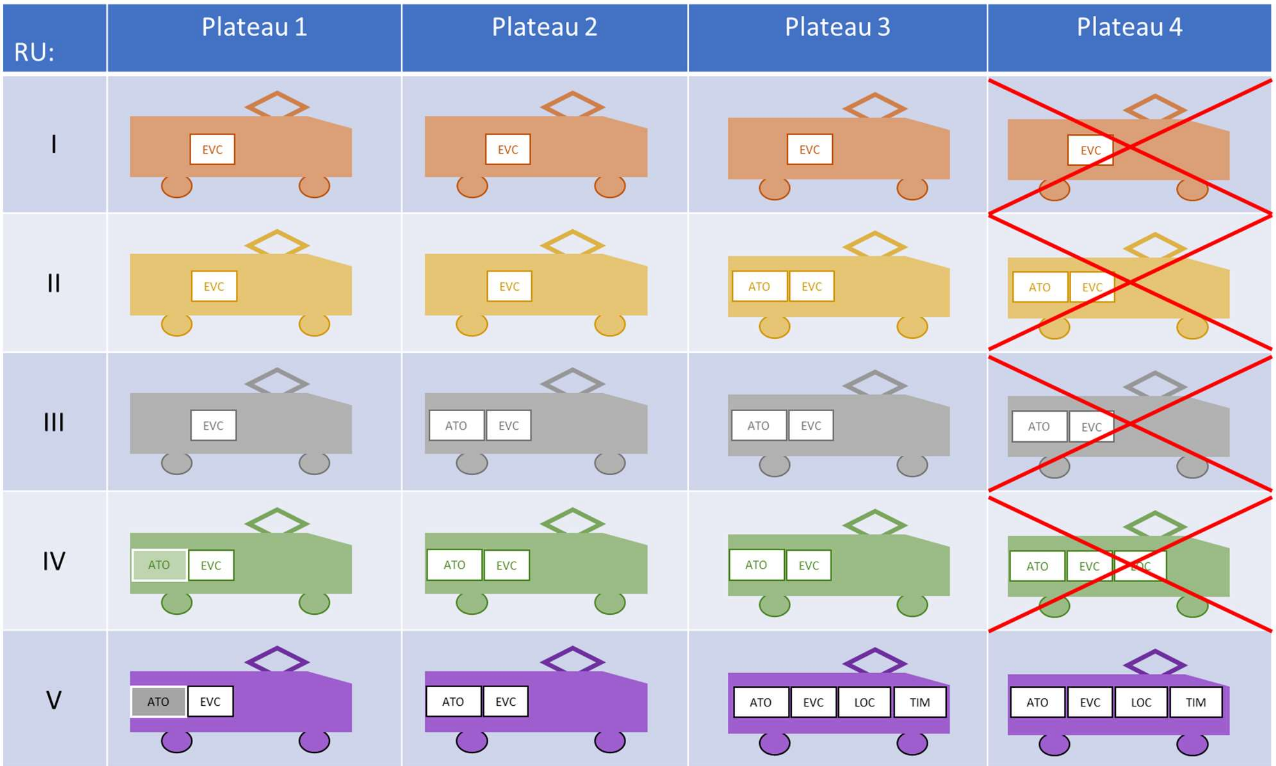
Annex 2: Migration Mind map (Table)

Strategy	Per IM		
Steps	Existing Configuration	Legacy / Start	
		ERTMS	
	Phases in Road Map	Fast	Replacement in large industrialised steps
			To achieve business case quickly
			To reduce complex patchwork situations
			In case of obsolescence problems
		Smooth	Mixture of subsystems
	Target Configuration	TMS	
		Interlocking / APS	
		Communication Object Controller Trackside devices	
		Communication to trains	
		Safe high resolution onboard localisation by trains	
		ATO	GoA2
			GoA3/4
		ERTMS	L1LS
			L1
			L2
			HL3
			L3
Scenario's	Architecture	Interface RCA/Non-RCA	
		Object Aggregation	
		Y-Switch Object Controller	
	Exchangeability	Ambition Level	
	Compatibility		
	Development		
	Roll out		
Variables	Drivers	RAMS	
		Costs	
		Competences	
		Network capacity	
	Constraints	Rolling Stock	
	Operation	Legacy	
		ERTMS	
Commercial	Markets	Different suppliers	
	Business case	Less equipment	
		Prevent investments	
Vehicles	CCS functionality and behaviour		
	OCORA		
Scope	RCA Scope		
	Non-RCA Scope: interface OC/ Track side device		Copper
			Fibre

Annex 3: Migration Mind Map (Graphic)



Annex 4: Example of different onboard configurations of railway undertakings (RU) to determine a business model



<u>Combination of trackside migration (Figure 4) and different onboard configurations.</u>

Some reading examples:

- A Railway Undertaking (I, II, III, IV, V) may be the owner of different configurations of trains (ATO, EVC, LOC, TIM);
- At least the EVC must be onboard;
- Railway Undertakings IV and V have trains with ATO onboard, but onboard ATO has no added value combined with Plateau 1.
- The trains of Railway Undertaking V with onboard localisation and monitoring of train integrity (LOC, TIM) may be combined with Plateau 4; the positioning of other trains is not possible without TTD.