TECHNOLOGISCHE WEITERENTWICKLUNG DES BAHNSYSTEMS

2016

Identifying the most effective technologies and innovations that will drive the future of railway systems in Switzerland.

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List of Abbreviation

AP	*Arbeitspaket*
ATO	*Automatic Train Operation*
CEO	*Chief Executive Officer*
CTO	*Chief Technical Officer*
COO	*Chief Operating Officer*
DLR	*Deutsches Zentrum für Luft- und Raumfahrt*
ERTMS	*European Rail Traffic Management System*
ETCS	*European Train Control System*
FABI	*Finanzierung und Ausbau der Bahn-Infrastruktur*
RSSB	*Rail Safety and Standards Board*
SBB	*Schweizerischen Bundesbahnen*
STEP (AS)	*Strategisches Entwicklungsprogramm Bahninfrastruktur (Ausbauschritt)*
TEN-T	*Trans-European Transport Networks*

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Preface

The rail system has been steadily, but quite slowly, developed in the last decades, in accordance with the other transport systems. However, recent perspectives in the field of autonomous cars and the increasing productivity pressure forces to speed up the innovation rate of the rail system. Human powered mobility is increasing its share in urban areas, the road public transport is widening its offer with more and more options (e.g. different sizes of bus, pods, new forms of taxi services, such as Uber), which allow for an increased flexibility both from the operator side and for the passenger side. Amongst all, most of the experts, agree that autonomous driving will lead the radical change that the transport system will have in the next years.

The present project aims at evaluating future trends in innovations and new technologies specifically dedicated to put forward the railway sector in the next decades. While the term "new technologies" is well defined and understood, the term innovation may be misinterpreted. What do we usually understand by innovation? Here we used the most general definition: Innovation is everything that changes, partly or completely, the current methods and methodologies, even (but not only) with the help of new technologies (software, materials, etc.). Innovations can be found in new types of operations, organizational schemes, integrated models, operating rules (e.g. circulating rules), etc.

Main purpose of the study is to collect, cluster and evaluate all promising innovations that will effectively help railway systems facing the challenges of the next decades and the competition with the other transport modes, in a "battlefield" completely redefined. At the same time, there are huge investments in the railway sector, meaning that the railway system is still considered an optimal solution and it will take part to the transport market of the future. But how? Clearly, its competitiveness must be enhanced, towards the level of the other transport modes, by reducing the weaknesses of the current system and reinforcing the strengths.

Moreover, keep following the SWOT analysis scheme, opportunities and threats have to be considered; for example, the possibility to use the acquired experiences from different sectors and their integration vs. the well-known "inertia" of the sector to modify the status quo. In the specific, maximizing the use of infrastructures, increasing schedule reliability, improving safety, and minimizing operative costs (e.g. increasing energy efficiency) are the current challenging topics under analysis, which allow optimizing an already optimal solution.

PREFACE

Considering the status and the challenging future scenarios, the rail system has to redefine and reinvent itself, with regard to the perspectives of the middle of this century. This will require a complete redefinition of standards and needs, which will reconfigure the entire transport system as known. In this perspective, railways should face these changes proactively by increasing the competitiveness. Applying carefully selected technical opportunities, already available and under development, in a consistent and consequent way the rail system has a serious chance to keep an important position in tomorrow's transportation landscape.

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November 22, 2016

Executive Summary (German)

Fortschritte im Strassenverkehr und neue durch die Kommunikation in Echtzeit ermöglichte Angebote (Bsp. Uber) führen zu mehr Flexibilität und setzen das System Eisenbahn zunehmend unter Druck. Damit der schienengebundene Verkehr auch in Zukunft, in dem sich durch das Autonome Fahren grundlegend veränderten Transportsektors, konkurrenzfähig bleibt, ist er auch auf technologischer Ebene grundlegend zu erneuern. Vorliegende Arbeit befasst sich mit den möglichen Innovations-Trends im Bereich der Eisenbahn. Ziel dieses Projekts ist es, diese Innovationen zu identifizieren und zu sammeln. Die gesammelten Innovationen werden auf ihr Potential hin untersucht und in sachlich zusammenhängende Innovationscluster unterteilt, auf deren Basis künftige Investitionsentscheide getroffen werden können. Oft bewirkt das gezielte Zusammenwirken von Innovationen mehr als die Summe der Einzelinnovationen, Der Begriff Innovation hat viele Bedeutungen, hier versteht sich jedoch der Begriff als eine Realisierung einer neuartigen, fortschrittlichen Lösung für ein bestimmtes Problem unter Einführung eines neuen Produkts oder die Anwendung eines neuen Verfahrens. Basierend auf den Innovationen in Forschungsschwerpunkten im In- und Ausland sowie aktuellen Publikationen konnten folgende Innovationsbereiche identifiziert werden:

- **Automatisierung im Betrieb:** Bezieht sich vor allem auf automatische Betriebsführung, autonome Fahrzeuge, führerloser Betrieb oder Führerunterstützung, automatisierte Sicherungseinrichtungen und Automatisierung im Passagier- und Frachtmanagement.
- **Nutzung bestehender Infrastruktur:** Neue Ansätze, die bestehende Infrastruktur auf innovativer Weise zu nutzen.
- **Neue Systemkonfigurationen:** Zielt darauf ab, neue Systemkonfigurationen zu nutzen und auf innovative Weise mit der vorhandenen Infrastruktur zu kombinieren.
- **Transfer von Entwicklungen aus dem Individualverkehr:** Intelligente Netze, die in Echtzeit kommunizieren, Car-Sharing sowie neue Konzepte für Betreiber und Kunden (Bsp. Uber).
- **Fortschritte im Schienenfahrzeugbau:** Verschiedene Trends, einerseits fahrzeugtechnisch durch neue Materialien etc. und andererseits durch modularen Aufbau von Fahrzeugkompositionen.
- **Angebotssysteme:** Übertragbarkeit von Angebotsansätzen des Metropolitanverkehrs auf die Vollbahn mit dem gemischten Verkehr.
- **Innovation in der Planung:** Neue Fahrplanplanung, Umgang mit Fahrzeitreserven, Haltezeiten. Diese können bezüglich Energieverbrauch und Nachfrage noch in Echtzeit optimiert werden.

Diese Innovationsbereiche wurden durch Interviews mit 14 verschiedenen Experten aus Wirtschaft und Forschung abgedeckt und verfolgen das Ziel, eine möglichst bereichsübergreifende Übersicht aller zukünftigen Innovationen zu liefern. Dafür wurden die Experten zu einem von uns in Zusammenarbeit mit dem BAV gewählten Innovationsbereich (A) sowie zu einem Innovationsbereich Ihrer Wahl (B) interviewt.

EXECUTIVE SUMMARY (GERMAN)

Die Selektionskriterien umfassten persönliche Expertise, objektive Betrachtungsfähigkeit, Abdeckung aller Bereiche und das Vertreten möglichst vieler Interessengruppen und haben zum Ziel die Plausibilisierung der Ergebnisse zu fördern. Die Experten konnten aus einer List von Innovationen, die basierend auf nationalen und internationalen Studien und wissenschaftlichen Publikationen zusammengestellt wurde, die Innovationen wählen, von denen sie einschätzen, dass sie tatsächliche Innovationen sind. Sie hatten darüber hinaus die Möglichkeit zusätzliche Innovationen einzubringen. Aus den Interviews gehen folgende Informationen hervor: Anzahl Expertenstimmen pro Innovation, Korrelationen zwischen Innovationen und Potential der einzelnen Innovationsbereiche (Aus Wahl B). Die Daten aus den Interviews wurden in Innovations-Gruppen zusammengefasst, welche das gleiche Konzept der die gleiche Technologie verwenden. Die Resultate der Experteninterviews für die einzelnen Innovationsgruppen sind in Abbildung zusammengefasst. Aus den Experten Interviews gehen die folgenden zwei wichtigsten Innovationsgruppen hervor:

- Volle Automatisierung des Eisenbahnbetriebs.
- Innovationen in der Erhaltung und im Unterhalt.

Zurückhaltend eingeschätzt werden, das Potential des Energiemanagements sowie Innovationen im Bereich der Bahntechnik.

Zusammenfassend sehen die meisten Expertem das grösste Potential im Bereich Automatisierung. Neuerungen in Richtung des vollautomatischen Betriebs sollen die Kosten senken, bei gleichzeitiger Kapazitätserhöhung, Angebotsverdichtung und Zuverlässigkeitssteigerung. Es herrscht Konsens darüber, dass die Automatisierung das System Eisenbahn grundlegend verändern wird. Vollautomatische Systeme sind bereits heute im Einsatz, wenn auch erst im speziellen Rahmen mit einem Fahrzeugtyp, einem Betreiber und sehr einfachem Netz (Bsp. Metro m2 Lausanne). Die grösste Herausforderung in diesem Bereich bleibt der Technologietransfer von den isolierten Systemen auf das gesamte Netz mit vielen verschiedenen Fahrzeugtypen und Betreibern.

Ein weiterer von vielen Experten gewählter Innovationszweig beinhaltet Neuerungen im Unterhalt. In diesem Bereich wird vor allem die Echtzeit-Zustandsbeurteilung des Netzes mit den daraus resultierenden Informationen für die Planung und Durchführung von Unterhalt als wichtigste Innovation gesehen. Hier liegen die Herausforderung vor allem im Umgang mit der enormen Menge an generierten Daten (Big Data Analysis). Die zeitlich und inhaltlich sehr hohe Informationsdichte zur Zustandsentwicklung erlaubt den Einsatz hochentwickelter mathematischer Verfahren, was neue Perspektiven hinsichtlich der Früherkennung und des präventiven Unterhalts eröffnet.

Weniger vielversprechend sind die Bereiche Infrastruktur und Versorgung, diese sind bereits heute zu einem hohen Masse optimiert.

EXECUTIVE SUMMARY (GERMAN)

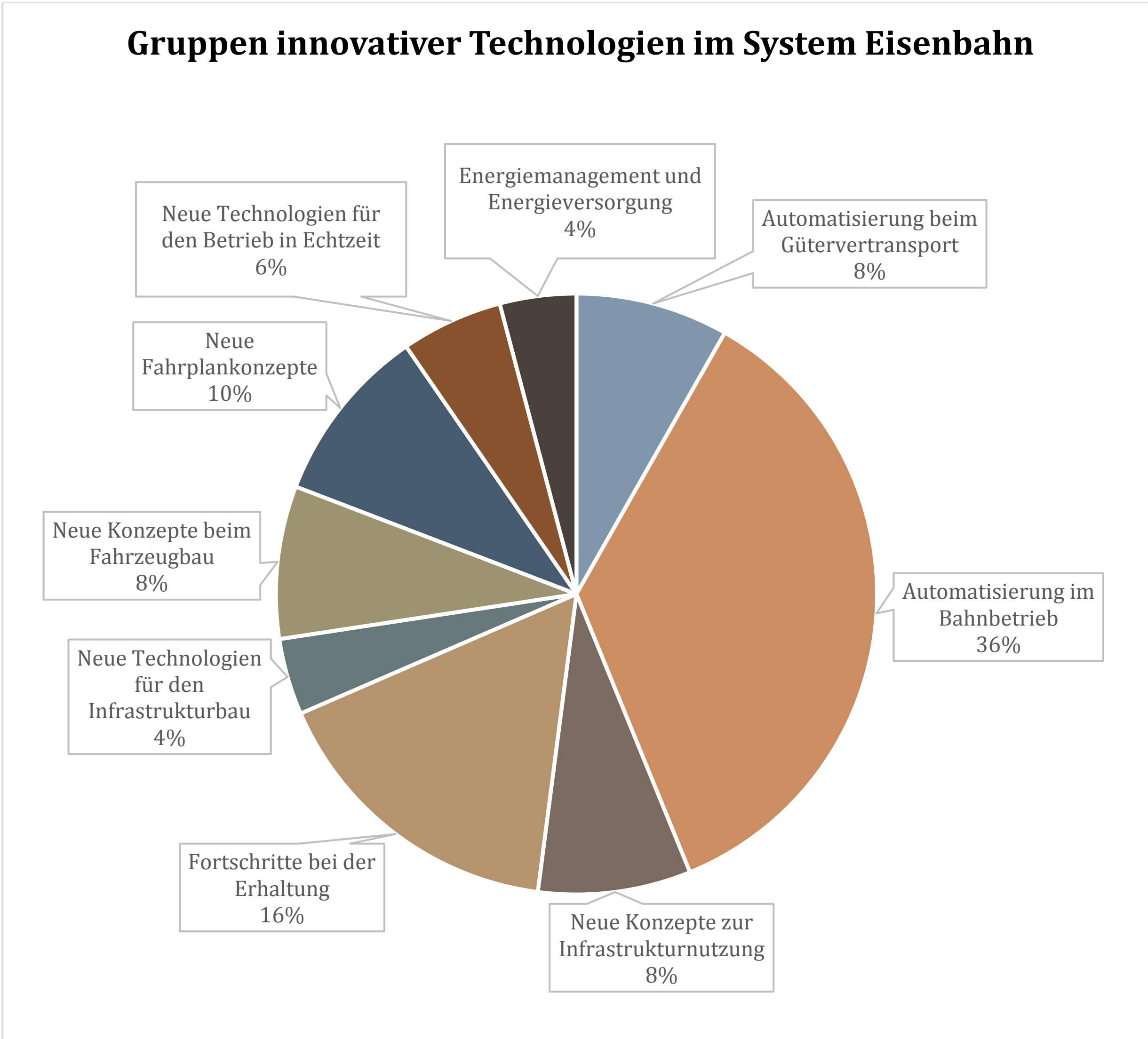

Abbildung 1. Resultate der Expertenwahl zusammengefasst in Innovationsgruppen.

Introduction and preliminary considerations

According to the development framework STEP AS 2030, the future railway services will be planned and the dedicated infrastructures measures will be determined for the time starting with the year 2030. The plans are based on the assumptions that traffic behavior does not change significantly and technological developments have no relevant influence on the Swiss railway system.

For a long-term perspective, these assumptions may be most probably too conservative, and considering the current technological research and development, there are opportunities to increase performance of the rail system further more. Its innovation potential is widely considered as weak, due to inherent obstacles to innovation, but also to the low level of competition. But in fact there are many and promising innovative ideas, showing the potential to put forward the rail system significantly.

Many of these innovations have a noticeable local impact. Rather rarely, the innovations have a network-wide scope of utilization and could, if used to the full, significantly change the whole railway system. In the railway system, the length of the innovation period differs from other sectors considerably. This period is almost exclusively much longer than in other sectors. At the same time, the period needed till the innovation becomes the norm rather than the exception is also significantly longer.

Widening our view to the other transport modes, in the next decades the whole transport system is going to change radically, and the competitiveness of the single systems will be deeply redefined. To give an example, autonomous vehicles will completely redefine the meaning of safety, since human errors will no more be considered as a fundamental cause of accidents. Consequently, researchers and practitioners are focusing all their attentions and efforts on the development of effective innovations that will lead the future transportation market. One of the key areas of innovation in transport is the optimal operation and management of existing systems in their complexity and interactions, considering both private and public operators. Big Data environments allow for new possibilities for short-term control, as well as medium term adjustments in their operations and schedules. In the very recent past, data availability and computational power lead simply to a new world of methods for capacity allocation and on-line dispatching of complex transport systems. More and more of these methods are generic, able to be used in all kinds of transport and logistic systems. These innovations in methods and systems will clearly lead to fully autonomous transport means, completely reshaping the transport system as such.

It is therefore important to investigate which technical developments in the railway sector appear to be promising in the long term and can be supported by the Confederation. They should contribute to quickly extend capacity and quality, by reducing system costs at the same time. The overarching goal is to improve the performance of the Swiss rail system in the next decades at least in accordance with the other transport systems or even more. Suitable support mechanisms must thus be identified, to avoid a lack of investment in railway infrastructure and to avoid from focusing on processes for technological development.

INTRODUCTION AND PRELIMINARY CONSIDERATIONS

OBJECTIVE AND EXPECTED RESULTS

Main aim of the project “Technologische Weiterentwicklung des Bahnsystems” is to identify opportunities for improving the competitiveness of rail transport. In addition, these developments must be considered or even promoted within the framework of STEP. The target sizes or prioritization criteria are therefore in particular:

- Additional functionalities that reduce the comparative advantages/disadvantages with the other transport modes.
- Efficiency increase of the entire railway system.
- Increased performance and quality.

Both optimizations of today's railway system as well as new approaches with regard to operating characteristics and technologies must be identified for freight and passenger traffic. The potential impacts (efforts produced vs. potential efficiency increase) should be roughly quantified. Based on the results, promising set of innovations will be identified in coordination with the STEP AS 2030 or with regard to further STEP development stages.

The topics for innovations are:

- Automation (coupling, manual operation or guide support, automatic operation, freight terminals, etc.)
- Concepts for the use of infrastructure (separation of traffic modes, shuttle service between nodes to simplify operation and infrastructure, etc.)
- New system configuration for singular new projects, separated from existing railway system
- Assessment of the transferability of developments in the private transport system to the public transport system
- Perspectives and limits of rail vehicle construction, including alternative train formation concepts for Passenger and Freight
- Supply systems (transferability of metropolitan transport supply systems to the mixed-traffic railway lines
- Impact of this innovation on planning (timetable planning, using of travel time reserves, dwell times)
- Power supply with regard to innovation potential, but not with regard to supply security

Also to be identified are interrelations and interactions between different innovations and the resulting additional benefits. For all innovations the following chronological values will be estimated:

- Current maturity
- Possible prototype application
- Possible first series application
- Possible integration of innovations to nowadays' systems and possible system migration
- Possible completion of the network-wide migration

- Innovation and implementation barriers to each innovation in technical, financial and regulatory terms
- Social and political acceptance

Concerning contents and temporal conditions, coherent innovation packages must be defined and technological objectives of the Swiss railway system must be highlighted.

BOUNDARY CONDITIONS AND TIME HORIZON

The STEP AS 2030 is currently under development. The results of the project "Technologische Weiterentwicklung des Bahnsystems" must be incorporated into the STEP AS 2030, either as input for research topics funding or as a pilot project. Correspondingly, the results have to be delivered by the end of 2016 in order to include selected topics in the Explanatory Statement for the STEP.

The time horizon of the innovation is 2030-2040. The study is focused on the railway system only. In principle, however, it is not possible to exclude any developments and innovations of the upstream and downstream systems (e.g. energy distribution, local distribution/ last mile, intermodal customer information, etc.).

The Integrated Periodic Timetable can be also challenged, for example, from the aspect of full automation. The planning processes themselves are not the subject of the investigation.

The target state definition must be based on the prioritized innovation potentials. The inverse approach with the development of a railway vision as the first step and the derivation of the innovation requirement as a second step would be beyond the scope of the contract. Moreover, it would not be appropriate for the highly evolving technological renewal process of the railway system with its long-term innovation cycles.

In terms of content, it is not the aim of this project to propose concrete technical feasibility or the development of new technologies and concepts, but to document the spectrum of their opportunities and threats, in case of implementation. At the same time, an expert assessment to the feasibility should be carried out.

The direct impact of the spread of shared economy, new service providers in the mobility sector, the development of multimodal mobility platforms or electric vehicles for the public transport system are not considered in this project.

Methodology

DEVELOPMENT OF THE RELATED ACTIVITIES

The procedure of this study was based on the collection, evaluation and prioritization of innovative solutions in the form of experts' discussions. This approach was considered as the most appropriate to ensure the most complete answers and opinions. This will later improve the acceptance of the results too. The experts' knowledge had to cover the following areas: (rolling stock) industry, universities / research institutions, regulatory authorities and governance, social partners, technical experts (safety and signal technology, rolling stock, information technology, etc.), logistics and freight transport, other industries with similar challenges. The experts discussed all the topics to which they could contribute. The experts have been selected together with the BAV (Bundesamt für Verkehr). Criteria were in particular:

- Personal expertise
- Impartiality or at least the ability to answer the questions in a neutral way
- Cover all topics
- Mutual supplementation of the subject areas and the different point of view by different players

The work sequence was divided as follows:

- **AP1**: Preparation of the query of expertise, discussion procedure in accompanying group, formulation of hypotheses to be examined in the discussions
- **AP2**: Consultation of expert knowledge (via workshops and / or interviews)
- **AP3**: Preparation and deepening of expert knowledge on the formulation of driving directions, design of prioritization criteria
- **AP4**: Assessments and definition of prioritization criteria
- **AP5**: Formulation of a road map for the innovation of the Swiss rail system

THE EXPERTS TEAM

Experts from various professional fields contributed their opinions. In total, 14 experts from railway operation companies, industry companies as well as universities have been interviewed. Table 1 is representative of the areas of expertise, defined in the contract, where the experts have been selected.

Specifically, Peter Grossenbacher, COO of SBB Infrastructure, has been recognized as the expert in the field of supply systems for passenger transport services. Stephan Moll (Director of Production Planning in BLS Cargo) and Dirk Bruckmann (Professor of Rhine University) are professional in logistics and freight transport. For rolling stock technology, we interviewed Prof. Oldrich Polach, who is rolling stocks expert from Bombardier Transportation AG and Stefan Bühler who is CEO of PROSE AG. Gabrio Caimi, who is Head of Project Solution Center Infrastructure by SBB-IT, is a representative for operation management. Melchior Kehrli (Project manager ETCS Level 2 at SBB Infrastructure) and Markus Montigel (CTO of Systransis) are in the field of information and security technology. Markus Meyer, from Emkamatik GmbH, is an expert in the field of power supply. For infrastructure planning, we interviewed Rolf Steinegger from ZHAW Winterthur

(Project manager and consultant) and Patrick Frank from Bundesamt für Verkehr (BAV). In the field of infrastructure conservation, methods and procedures, Thomas Vogel (Head Interval Planning SBB Infrastructure), Ingolf Nerlich (System engineer for cross-questions about the vehicle / track interaction of SBB Infrastructure) and Matthias Manhart (Head of Technology in Rhomberg Sersa AG) are the representative experts.

Table 1. Area of expertise and selected expert.

Areas of expertise	Experts													
	Stephan Moll	Dirk Bruckmann	Melchior Kehrli	Markus Montigel	Thomas Vogel	Ingolf Nerlich	Matthias Manhart	Rolf Steinegger	Patrick Frank	Oldrich Polach	Stefan Bühler	Peter Grossenbacher	Gabrio Caimi	Markus Meyer
Logistic and freight transport	×	×												
Technologies for safety and information			×	×										
Infrastructure management, methods, procedures					×	×	×							
Infrastructure planning								×	×					
Rolling stock technology										×	×			
Supply system planning for passenger transport												×		
Operation management													×	
Power supply and energy management														×

Activities description and results

AP1. PREPARATION

The main aim of this activity was to fix the procedure and the contents of the discussion with the experts, in order to obtain the needed information for the final output of the work. This phase was critical since possible misunderstandings during interviews may generate wrong evaluations. To prevent this threat, the interview procedure has been based on a supervised discussion approach. Briefly, it consisted of face to face interview, and experts had the opportunity to explain in detail their opinion regarding future scenarios, the fields of innovation and specific technologies. Before starting, an introduction to the interview gave a brief explanation of its purposes and formulation.

A questionnaire has been prepared as supporting tool for the interview. It is composed by lists of innovations, which have been defined considering national reports and studies (e.g. IVT - ETHZ thesis and dissertation, IVT - ETHZ projects, etc.), reports from other countries (e.g. Arup Railway vision 2050, etc.) and scientific articles (Digital libraries: Scopus, IEEE Xplore. Keywords: Integrated rescheduling models, energy efficient speed profiles generation), references and more details can be found at page 24. Following the topics scheme proposed in the contract, the lists of innovations in the questionnaire are organized as follow:

- The topic of Automation includes a wide variety of technologies, and related applications in different fields. Therefore, for a matter of clarity, several subtopics have been identified. In particular, all the automation technologies related to both train operation (e.g. autonomous driving) and traffic control (e.g. automation of rescheduling processes) are included. Regarding operation of rail freight, also automation for train composition and decomposition has taken part to our considerations. No other aspects (e.g. automatic heating regulation) have been considered.

- Referring to the topic of existing infrastructures, innovations can be mainly grouped in some subtopics: new types of rail traffic management (the use of infrastructures with different traffic types), adoption of new signaling systems (ETCS Level 2 or 3), the use of feeder systems (e.g. Pods) and innovation in maintenance (e.g. remote control management). All these innovations will mainly contribute to the better use of the existing infrastructures and therefore allowing reduction of specific operating costs.

- Considering the topic of new system configurations with new infrastructures, the work has been focused on the identification of possible innovation in case of both isolated systems and systems partially connected with the existent infrastructures.

- Vehicle construction field is an important topic of railway innovation and subjected to continuous innovations. Main trends include vehicle building (towards lighter vehicles), modular design of rolling stocks (for both freight and passenger trains), passenger entertainment and services (cinema, meeting areas, executive class).

- The topic related to innovations in supply systems includes both technologies that can be totally/partially/conceptually transferred from private transport systems (i.e. connected vehicles for real time information on traffic) and technologies related to Metro systems (homogeneous traffic). The firsts have been initially considered as a separate topic ("Assessment of the transferability of developments in the private transport system to the public transport system") and then include in this wider supply system topic. Those latter refer to metro systems, which have, due to their characteristics, optimal values of performance parameters, e.g. capacity utilization, headways, energy recovery. Possible solutions are also linked with the technology transfer from passenger trains to freight trains, since these latter usually are those with the oldest technology installed.
- The topic related to planning, such as timetabling (energy efficient timetabling, introducing resilience into timetabling, etc.) and special operation are considered. Enhancing planning during operation is one of the most effective actions to take since it is economically sustainable and it produces significant reduction of operative costs (e.g. in case of energy efficient timetable, energy reduction is estimated to be around 10% on average with respect to normal operating conditions).
- The topic of energy management and power sources, mainly refer to, respectively, operative costs reduction and investment cost reduction. Regarding energy management, main innovations are related to the capability of the system to recover and reuse energy, while innovations on power sources mainly concern different type of propulsion (e.g. fuel cells).

Figure 10 reproduces the main scheme of the questionnaire.

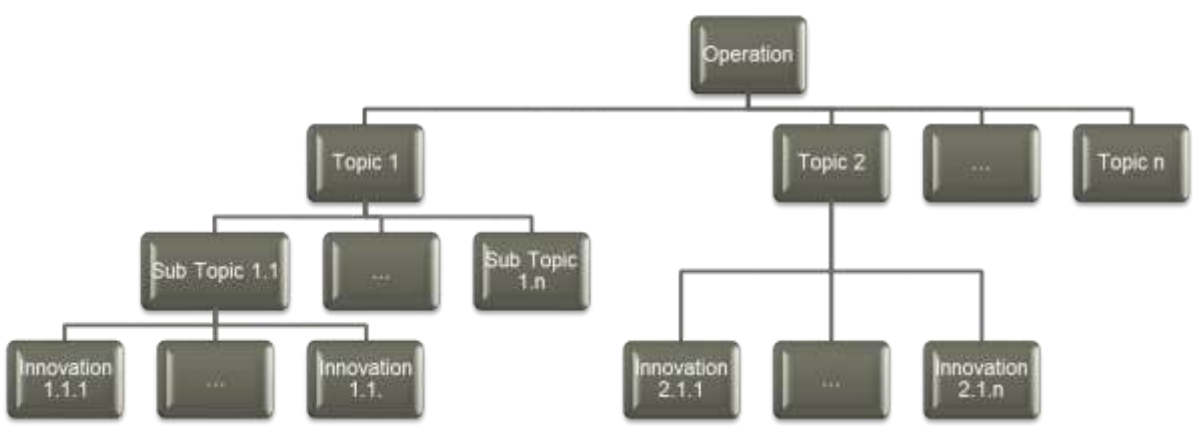

Figure 1. Scheme of questionnaire.

ACTIVITIES DESCRIPTION AND RESULTS

AP2: INTERVIEWS

The set of interviews has been organized considering the availability of the single experts and their needs on meeting location. Meeting points have been organized in places where the expert feels comfortable, which means not only working places but also in public spaces like university facilities. Finally, the interviewer conducted the set of interviews within the Cantons of Zurich, Bern and Luzern. The period dedicated to interviews' making was approximately 2 months (August-September 2016). The questionnaires supporting the interview process is reported in Appendix A.

The interviews have been conducted also considering the possibility to answer either in German or in English. Given the wide variety of potential candidates, the questionnaire has been formulated in English since the comprehension of concepts and clearness of keywords is generally ensured.

Before starting with the interviews to experts, the questionnaire has been tested with BAV executives, in order to fix possible errors related to the procedures.

Experts had the possibility to answer on two different topics. Definitely we had:

- ***Choice A***. Choice given in the field where the expert has been selected for the questionnaire by the project team.
- ***Choice B***. The expert could make a second choice in another field chosen by himself/herself, in addition to Choice A. Depending on his/her knowledge, he/she could indicate an effective innovation in railway systems out of its recognized field of expertise. (this choice is optional)

Choices B represented a degree of freedom in the expert discussion, which allowed increasing the confidence and the availability to answer (expert feel free to talk about their opinion, not necessarily related to the topic we selected for them). The choices made on a different topic may still be considered as given by an expert of the field, since it is assumed that an expert has usually interactions with other working groups, previous experiences, consolidated overview of the current railway issues, etc.

After choosing the topics and before discussing the lists of innovations, the interviewers asked the expert to think briefly about the main innovation for the chosen topic and to keep in mind; his idea either matched one of the options in the list or not. In this latter case it was possible to describe his/her ideas in a specific section and therefore, the expert was not primarily influences by the list of innovations. The expert had also the possibility to choose up to 3 options, in case of systems integration (system components). In case of possible misinterpretations, experts had also the opportunity to ask for explanation on the single innovations to the interviewers.

Definitely, experts were free to explain their positions, their vision, additional innovation not included and possible correlation between innovations. Together with these innovations, specific question were formulated. In particular, we wanted to obtain information on:

- Classification (Current maturity / possible first application / possible serial application / possible completion of the network-wide migration)

- Influence scope (Single technical improvement / technical breakthrough to whole network)
- Specific differences / improvements compared to current situation.

Regarding Choice A, the following table shows the match proposed to the expert. Table 3 summarizes the total amount of experts' choices per topic (number of choices A + B).

Table 2. Choice A – Selected topic per expert.

Topics	**Experts**													
	Stephan Moll	**Dirk Bruckmann**	**Melchior Kehrli**	**Markus Montigel**	**Thomas Vogel**	**Ingolf Nerlich**	**Matthias Manhart**	**Rolf Steinegger**	**Patrick Frank**	**Oldrich Polach**	**Stefan Bühler**	**Peter Grossenbacher**	**Gabrio Caimi**	**Markus Meyer**
Automation	×	×	×	×										
The use of current infrastructures					×	×	×							
New system configuration for singular new projects								×	×					
Perspectives of rail vehicle construction										×	×			
Supply system of passenger transport												×		
Innovation in planning													×	
Power supply and energy management														×

Table 3. The total number of experts' responses (choice A +B).

Topics	The total number of experts' responses (choice A + B)
Automation	29
The use of current infrastructures	26
New system configuration for singular new projects	6
Perspectives of rail vehicle construction	10
Supply system of passenger transport	4
Innovation in planning	8
Power supply and energy management	3

AP3: EVALUATION OF THE INTERVIEWS

From the interviews, we retrieved the following very first raw information:

1) number of times an innovation has been chosen (total answers choices A and B)
2) correlation between innovations
3) preferences on topics (choices B)

Number of times an innovation has been chosen (total answers choices A and B)

Results are here proposed with histograms, where the magnitude of the column represents the number of times an innovation has been chosen by the experts (results of choices per topic) separately for each Topic. This provides a first idea about the importance given by the experts to the different innovations, but shouldn't be already considered as prioritization. The description of single innovations is reported in Appendix B.

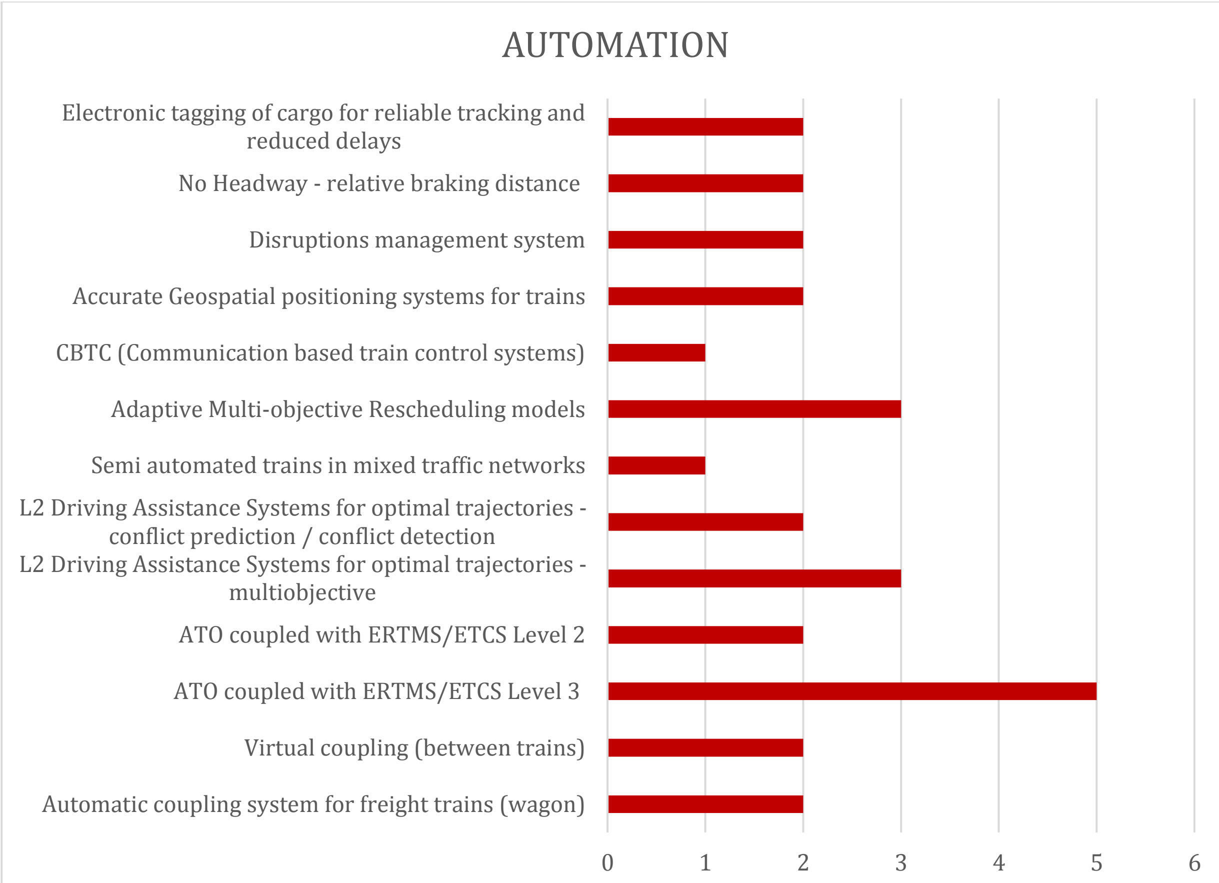

Figure 2. Innovation chosen for the topic of automation.

For the topic of automation, there are mainly 13 innovations chosen by the experts as shown in Figure 2. The most choice is "ATO coupled with ERTMS/ETCS Level 3", which is of the greatest importance in the automation topic. The innovation "Adaptive Multi-objective Rescheduling models" and "L2 Driving Assistance Systems for optimal trajectories – multi-objective" are the second most chosen topic. In contrast, only one time has been chosen for the innovations "Semi automated trains in mixed traffic networks" and "CBTC (Communication based train control systems)". Every other single innovation gets two choices.

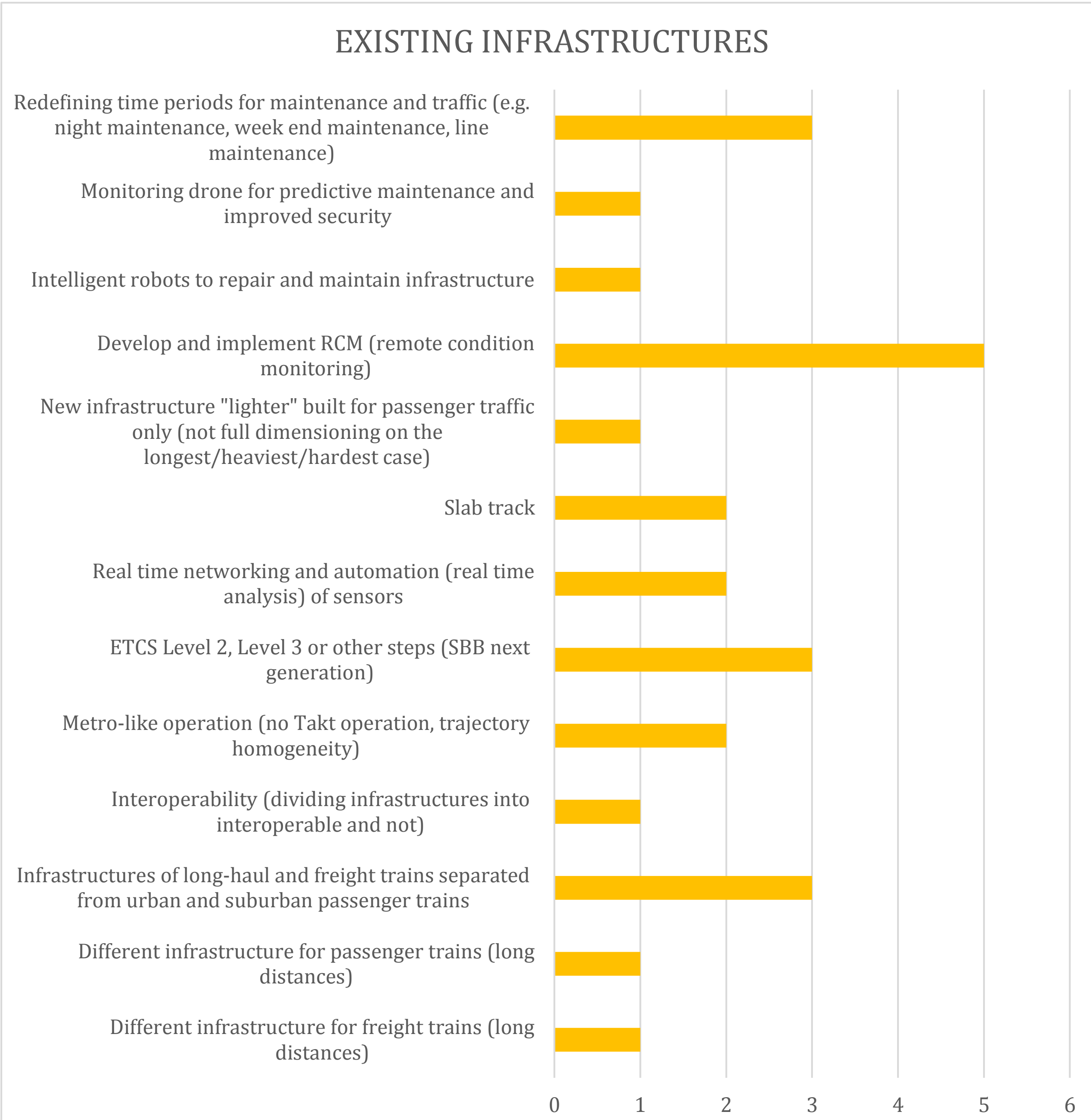

Figure 3. Innovation chosen for the topic of existing infrastructures.

For the topic of existing infrastructures shown in Figure 3, the innovation “Develop and implement RCM (remote condition monitoring)”appear particularly important from the experts’ viewpoint. Three other innovations are also important: “Infrastructures of long-haul and freight trains separated from urban and suburban passenger trains”, “ETCS Level 2, Level 3 or other steps (SBB next generation)” and “Redefining time periods for maintenance and traffic (e.g. night maintenance, week end maintenance, line maintenance)". Next, "Metro-like operation (no Takt operation, trajectory homogeneity)", "Slab track" and "Real time networking and automation (real time analysis) of sensors" are also important in the topic of existing infrastructures. Last but not least, other single innovations (e.g. "Different infrastructure for freight trains (long distances)", "Monitoring drone for predictive maintenance and improved security") are also selected by some experts.

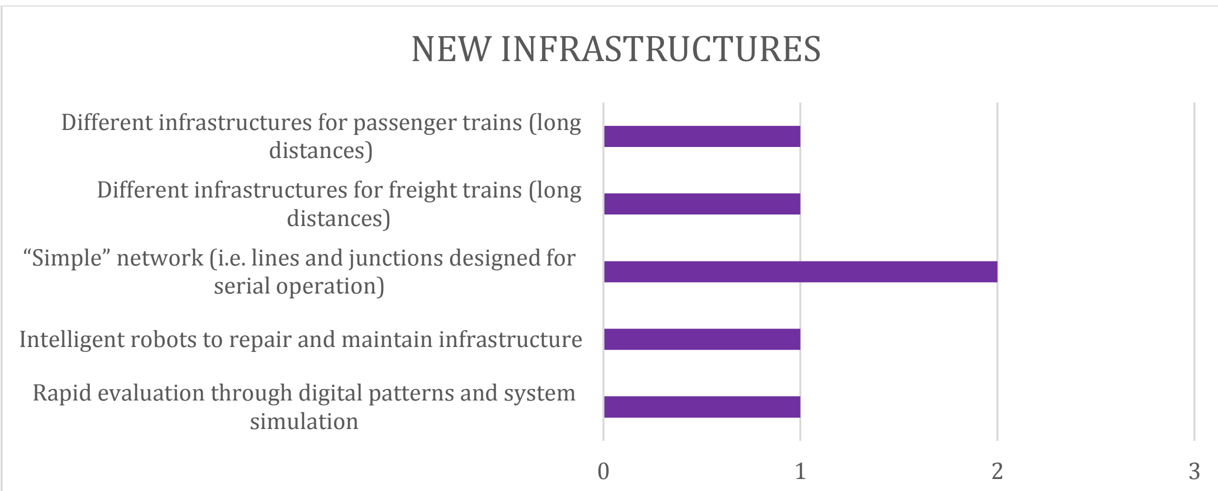

Figure 4. Innovation chosen for the topic of new infrastructures.

For the topic of new infrastructures shown in Figure 4, "'Simple' network (i.e. lines and junctions designed for serial operation)" is considered as the most interesting innovation. In addition, the other four innovations "Different infrastructures for freight trains (long distances)", "Different infrastructures for passenger trains (long distances)", "Intelligent robots to repair and maintain infrastructure" and "Rapid evaluation through digital patterns and system simulation" are also interested by some experts.

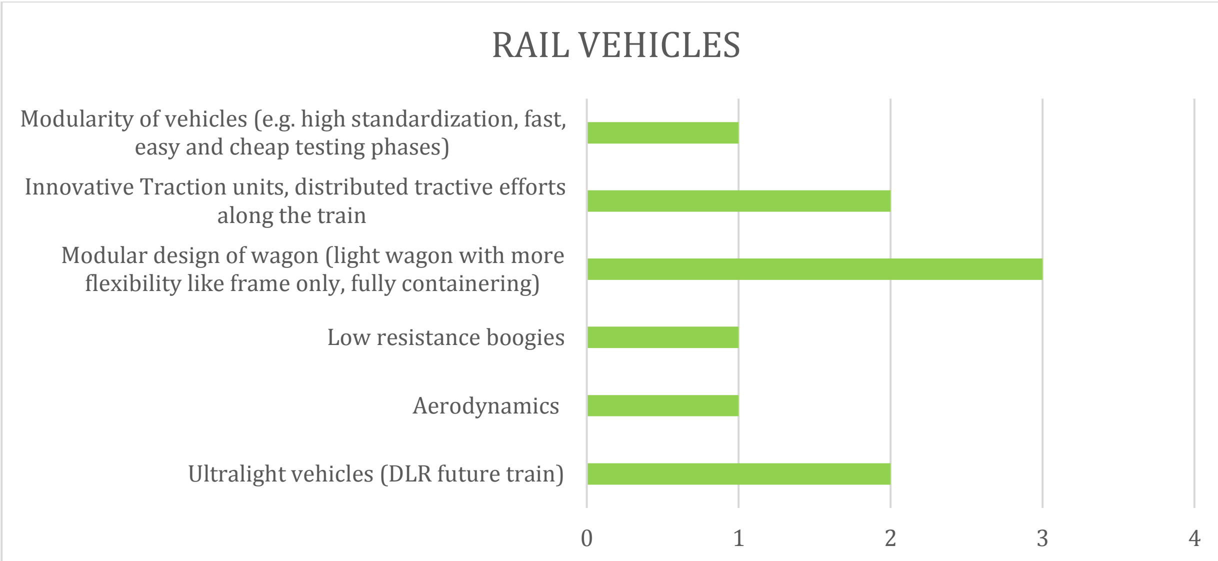

Figure 5. Innovation chosen for the topic of rail vehicles.

As is shown in Figure 5, the innovation "Modular design of wagon (light wagon with more flexibility like frame only, fully containering)" attracts most interest for the topic of rail vehicles. Secondly, "Innovative Traction units, distributed tractive efforts along the train" and "Ultralight vehicles (DLR future train)" are also two interesting innovations. Last, "Modularity of vehicles (e.g. high standardization, fast, easy and cheap testing phases)", "Low resistance boogies" and "Aerodynamics" are mentioned by some experts.

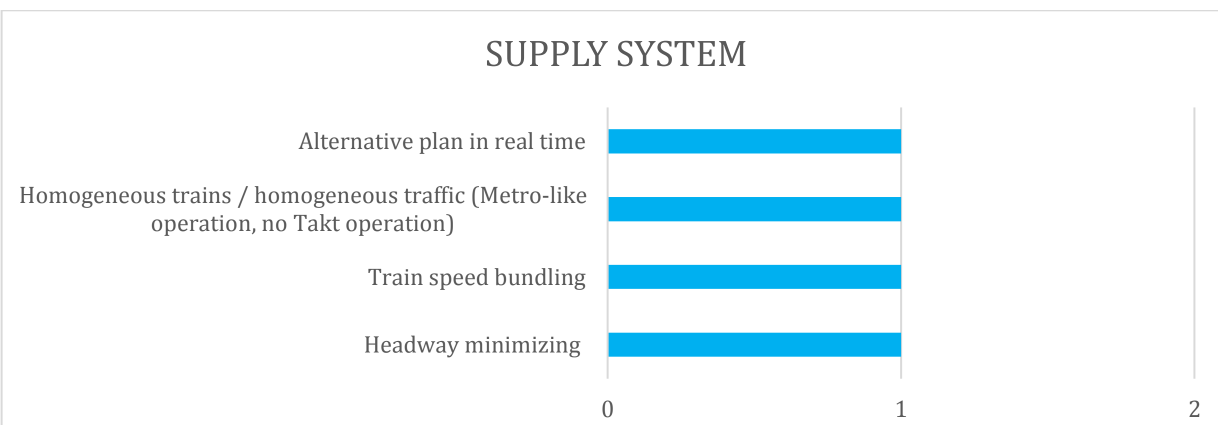

Figure 6. Innovation chosen for the topic of supply system.

For the topic of supply system demonstrated in Figure 6, interest of experts is mainly shown in four innovations: "Alternative plan in real time", "Homogeneous trains / homogeneous traffic (Metro-like operation, no Takt operation)", "Train speed bundling" and "Headway minimizing".

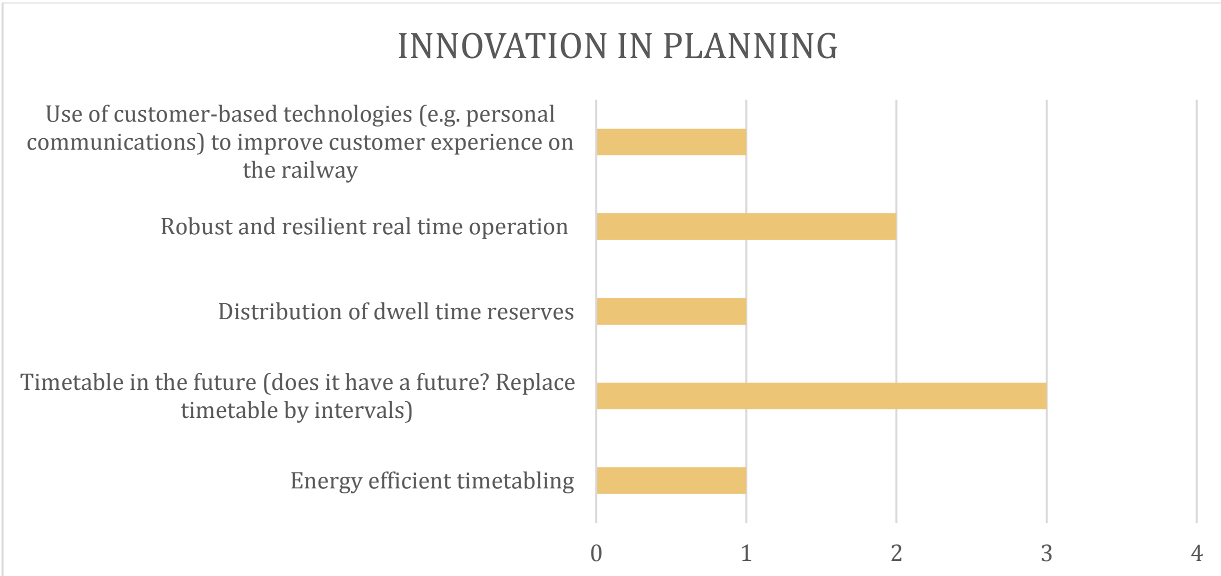

Figure 7. Innovation chosen for the topic of innovation in planning.

As demonstrated in Figure 7, experts show the most concern on the innovation "Timetable in the future (Does it have a future? Replace timetable by intervals)". Also, "Robust and resilient real time operation" is also of great importance for the topic of innovation in planning. Moreover, "Use of customer-based technologies (e.g. personal communications) to improve customer experience on the railway", "Distribution of dwell time reserves" and "Energy efficient timetabling" are also interesting innovations for this topic.

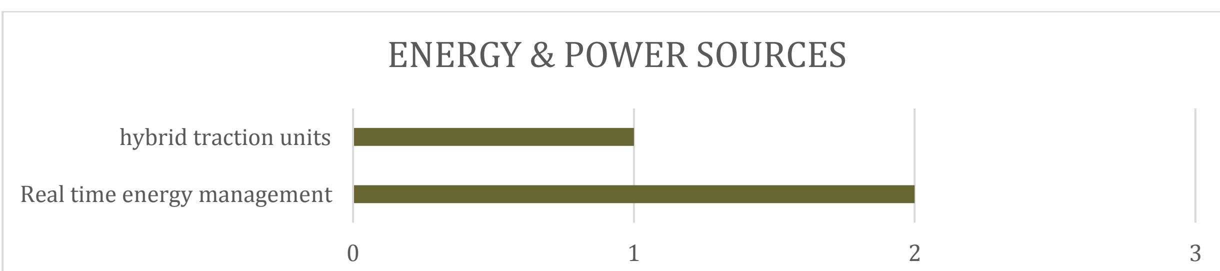

Figure 8. Innovation chosen for the topic of energy management and power sources.

As is shown in Figure 8, "Real time energy management" is the most concerned innovation for the topic of energy management and power sources. In addition, "Hybrid traction units" is also an interesting innovation for this topic.

Correlation between innovations

In general, the importance given to the different innovations strongly reflect the huge opportunities of information systems, sensor techniques and computational power. All revealed correlations between innovations, highlighted by the experts, concerns either Automation or Existing infrastructures. In particular, the following innovations correlations in the field of automation during operation have been highlighted:

- ETCS Level 2 and ETCS Level 3 are strongly related one to each other. In particular, experts highlighted the importance of Level 2 investments as fundamental for future consideration on Level 3 implementation. Level 3 is expected to be fully operational only after the time horizon of this project.
- ETCS Level 2 and 3 are strongly related with innovative traffic management systems, able to automatically generate rescheduling solutions, including serious disruptions cases.
- Next generation traffic management systems are strongly centered on automation. Thus, fundamental features must include accurate geospatial positioning systems for trains and CBTC (Communication Based Train Control) operating frameworks, which means continuous communication.

Moreover, the following innovation correlations in the field of existing infrastructures have been highlighted:

- New concepts for maintenance of the existing infrastructures strongly relates to the development and implementation of Remote Condition monitoring approaches (networks dense of sensors, probe vehicles, etc.) with new approaches to time period definition for maintenance (since extraordinary maintenance will be drastically reduced) and introduction of automation in maintenance (intelligent robots to repair and maintain infrastructures).
- The use of infrastructure would tend to differentiation of traffic types (different infrastructures for passenger and freights). This would lead also to optimize the dimensioning of infrastructures parts during both construction and replacement.

Preferences on topics (choices B)

Results are shown in Figure 9. From this result, it is possible to highlight the most interesting topics according to the experts' view, without considering the assigned field of expertise. Even in this case, automation in operation and existing infrastructures are the most analyzed topics.

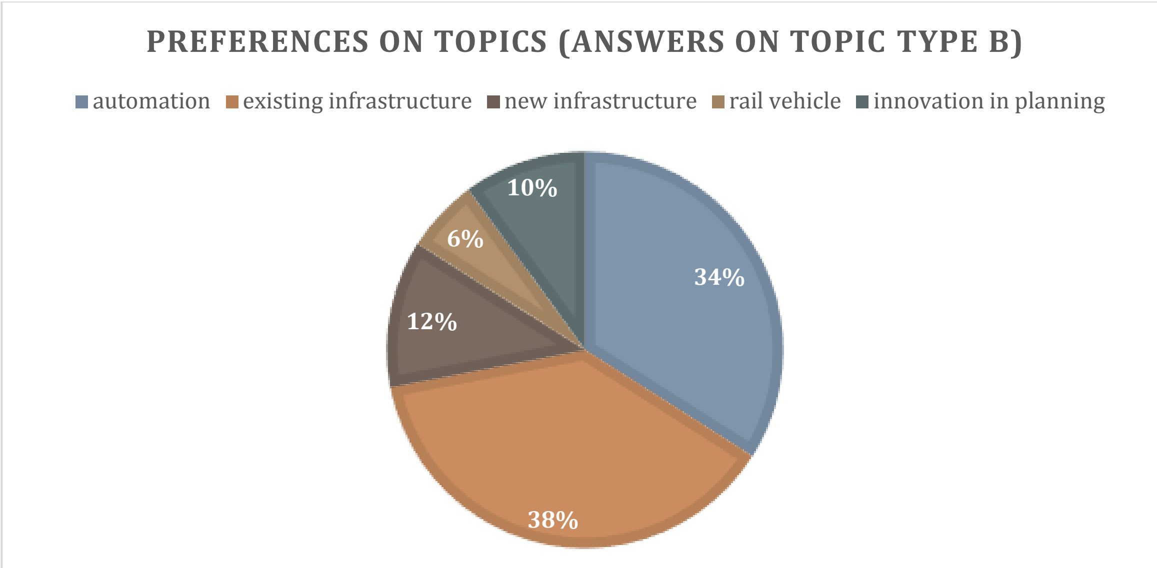

Figure 9. Shares of answers on topics – choices B.

AP4: PRIORITY FIELDS OF ACTION

In this section, the most promising trends of innovation will be defined. From the data analysis of the previous activity, it is possible to highlight that a single innovation may be an element of one or more topics. For example:

- ETCS technologies are meant to both support automated operation and enhance the safety system itself in a rail infrastructure;
- Different uses of infrastructures may refer to existing ones or to new ones.

Moreover, according to the choices made by the experts and the consequent common discussions, many technologies are part of an integrated view.

In order to include also these aspects in the present analysis, the dataset of choices has been divided into **clusters**, which identify the most promising direction for innovations and technologies developments. Clusters have been defined as sets of innovations and technologies independent from topic area, which mainly share the same innovation concept or the same technology. The following clusters have been identified:

a) Automation for Rail Freight

b) Automation in Railway Operation

c) New approaches to infrastructures use

d) Advances in Maintenance

e) New technologies for infrastructures construction

f) New design concepts for vehicles

g) Multi-objective methodologies for timetabling

h) New technologies for real time operation

i) Energy management and power sources

Clusters a) and b) respectively represent automation solutions expressly dedicated to rail freight and automation solution for general railway operation. The first considers also operation in shunting yards and it includes innovations for wagons coupling, electronic tagging of containers, etc. The latter focused on railway operation, and it includes automatic train operation, automatic traffic management, etc. together with all the related technologies such as global positioning systems, ETCS Level 2 or Level 3, etc.

Clusters c), d) and e) are representative of the infrastructure side of innovations. Cluster c) represent of the innovative solutions for an optimized use of infrastructures, such as differentiation based on traffic types, separate infrastructures for urban mobility of goods, dividing infrastructures into interoperable and not, etc. thus optimizing also economic resources for maintenance and rebuilding. Cluster d) refers to maintenance aspects of infrastructures and it includes monitoring solutions, innovative planning for maintenance, robots for repair phases, etc. Cluster e) represents all the innovations dedicated to construction elements, such as slab tracks, lighter materials, etc.

Cluster f) refers to the advances in rail vehicles in the field of design optimization for costs reductions. Typical examples are: wagon modularity, ultralight vehicles, high standardization, etc.

Cluster g) and h) are clusters of solutions related to traffic control. The first refer to specification of timetables following new design concepts, such as increase of capacity use, resilience, energy efficiency, etc. The latter is merely focused on the real time operation and it includes aspects like robust and resilient procedures for dispatching, use of customer-based technologies (e.g. personal communications) to improve customer experience on the railway, etc.

Cluster i) includes both solution for energy management systems (new technologies for energy storage system on board, smart energy management onboard) and for the introductions of alternative sources of power (fuel cells, distribution through smart grids). Figure 10 shows the clustering results.

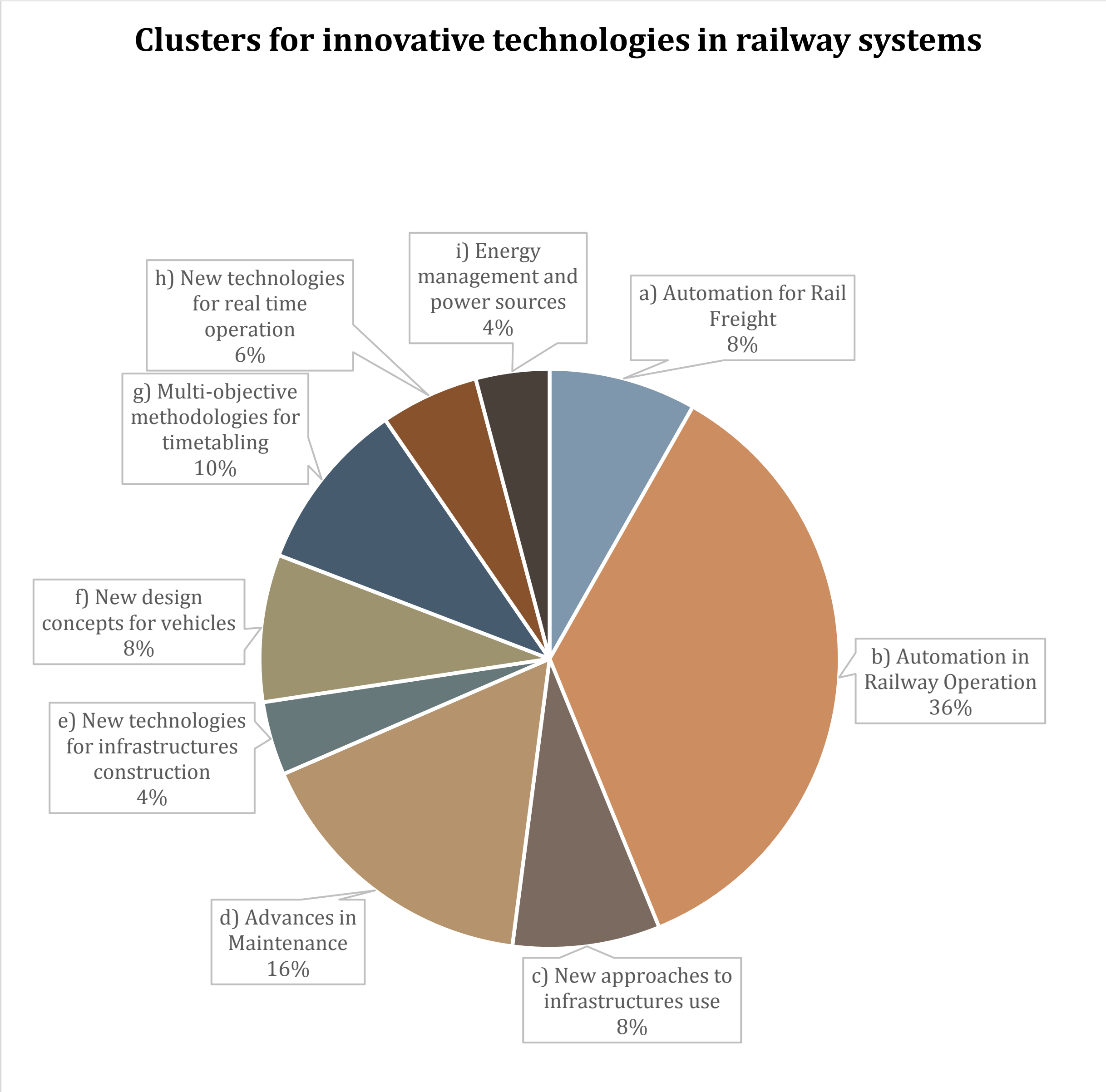

Figure 10. Expert choices grouped into clusters.

These considerations of the experts as well as our own evaluation lead us to give priority to two main promising innovation clusters: Automation in Railway Operation and Advances in Maintenance. These two clusters together collected more than 50% of the answers (and therefore the attention) from the selected experts, and from authors opinion these are the two most promising directions for innovations development. They profit consequently from the adaptation of new technologies in information and sensor techniques. Automation strengthen the comparative advantages of the rail system, Advances in Maintenance will substantially reduce costs by improving availability and quality.

AP5: ROADMAP

Automation in Railway Operation is the cluster where most of the experts and practitioners expect breakthrough innovations that will lead to less variability to planned conditions, decrease of operative costs, increase of the overall system safety and optimal use of system capacity. Automation in transport systems operation is constantly increasing its presence and it is commonly recognized as the trend that will completely change the knowledge of transportation as such. Autonomous driving is not only a challenge in the road sector. Railway systems have already examples of successful applications of autonomous driving, although in very particular conditions such as in metro lines, where one type of traffic, one type of vehicle, one operator and very simple infrastructure networks are mostly present (e.g. Metro m2 Lausanne). The challenge is therefore to introduce automation in mixed traffic networks. For this purpose ATO, ETCS Level 2 and then Level 3 are fundamental characteristics of the future systems.

The second most rated cluster is the cluster **Advances in Maintenance**. Experts and practitioners think that the match for competitiveness of the railway system vs the other transport modes will be played in this field. Preventive maintenance, sensors network coupled with standard vehicles equipped with measuring instrument ('probe vehicles'), and alternative monitoring systems will allow maintenance cost reduction and minimization of infrastructure unavailability. The innovations in this field will introduce also new important challenges of our days such as Big Data Analysis; how to manage all the dense information that will come from different sources.

The consequent Road map for possible investments on technologies and innovative solutions can be defined by analyzing the specific characteristics, the interrelations between the single innovations and the technology readiness.

Specific characteristics of Automation in Railway Operation

For the cluster Automation in Operation, the following innovations/technologies have been selected:

1. ATO coupled with ERTMS/ETCS Level 3 (long term perspective)
2. ATO coupled with ERTMS/ETCS Level 2 (medium term perspective)
3. ETCS Level 2, Level 3 or next SBB signaling systems
4. L2 Driving Assistance Systems for optimal trajectories - multiobjective
5. L2 Driving Assistance Systems for optimal trajectories - conflict prediction / conflict detection
6. Semi-automated trains in mixed traffic networks
7. Adaptive Multi-objective traffic management
8. Disruptions management system
9. CBTC (Communication based train control systems)
10. Accurate Geospatial positioning systems for trains
11. Relative braking distance

ATO (Automatic Train Operation) systems allow automatic driving regimes when coupled with signaling systems such ETCS Level 2 and Level 3. The safety issues will be enhanced and, at the same time, the capacity use will be increased (points 1, 2, 3).

Driving Assistance Systems or semi-automated trains are systems that increase the adherence to schedules when manual driving is still present during operation. Currently these systems can work either as isolated systems, e.g. definition of optimal trajectories for energy consumption minimization, or in communication with traffic control centers, e.g. in case of train control for conflict detection and resolution. (points 4, 5, 6).

The development of new traffic management system is largely focused on the automatic generation of optimized solutions, thus exploring a wider variety of options than the currently adopted ones. Main idea is to consider multiple objectives and different operating scenarios (i.e. adaptive rescheduling), including also the management of disruption cases (points 7, 8). CBTC (Communication based train control) systems are systems that allow for instant monitoring, real time elaborations and possible modifications. More than an innovation itself, a CBCT system is an innovative concept for a new generation of traffic management systems. The main technological challenge is the continuous and guaranteed communication between trains and control centers. Main data exchange must refer to train position and its integrity, thus accurate measures of train position must be ensured (point 9, 10, 11).

Specific characteristics of Advances in Maintenance

For the cluster Advances in Maintenance, the following innovations/technologies have been selected:

1. Real time networking and automation (real time analysis) of data from sensors
2. Develop and implement RCM (remote condition monitoring)
3. Intelligent robots to repair and maintain infrastructure
4. Monitoring drone for predictive maintenance and improved security
5. Redefining time periods for maintenance and traffic (e.g. preventive maintenance, night maintenance, week end maintenance, line maintenance)

Real time analysis of infrastructures data from sensors and RCM systems are two interesting topics that grew up in the recent years. The implementation of a network dense of sensors (fixed position information) and the use of probe vehicles (moving position information) will entail, from one hand, the precision of the monitored conditions of the infrastructures, from the other hand, the challenge of Big Data management in terms of analysis and decision making, even in real time. Advantages are relevant, since the possibility of emergency maintenance will be drastically reduced with positive implications on rail traffic and maintenance costs (points 1, 2)

Intelligent robots to repair and maintain infrastructure and monitoring drone for predictive maintenance allows to reduce risks for human beings and to speed up the related working phase. This would also lead to a redefinition of the job positions in the field since human supervision will be always necessary, even though behind a screen (Points 3, 4).

Alternative plans for maintenance, in terms of periods, will allow reducing tracks unavailability in time and number of tracks, thus reducing possible reduced operation, delays, etc. This is an important aspect of the overall operation economies: new solutions for maintenance plans can be introduced for every type of technology installed (point 5).

Interaction between innovations

Concerning the cluster Automation in Railway Operation, the enhancement of signaling systems towards ETCS Level 2 and Level 3 standards is the basis for the development of all the considered innovations. Most of the innovations linked with the automation field aim at optimizing the current rail operation performances, i.e. increase the capacity use of infrastructures, reduce energy consumption, etc. by modifying operation times, i.e. running times, dwell times, buffers, headways. The main prerequisite for these modifications is the respect of safety conditions, thus new generation signaling systems are a fundamental requirement for future enhancement of the railway operation.

Concerning the cluster Advances in Maintenance, it is worth to highlight that the integration of point 5 with the technologies and the innovations of points 1 and 2 can bring very interesting results in terms of economies and system efficiency. Points 3 and 4 will further boost the rail system performances both at the maintenance level and at the operation level.

Technology readiness

Regarding the cluster Automation in Operation, the technology for ATO systems, driving assistance systems, Semi-automated trains, already exists and has interesting applications. Experiences with ATO systems in particular are consistent in metro systems, while technologies where human supervision and actions are required, i.e. Driving Assistance Systems and semi-automated trains, are even more enhanced in mixed traffic networks. ETCS Level 2 is at an implementation level. In Europe it is widely recognized as the new standard to adopt for the next decades, and national infrastructure managers are now upgrading their network, starting from main national corridors and TEN-T directions.

At the same level, although with less applications, new traffic management systems for automated generation of solutions CBTC systems and enhancement on train positioning are object of a constant research development, both in the academia and in the industry sector.

ETCS Level 3 is now at a very prototyping stage. Some significant, although limited applications returned promising results. More relevant tests will follow the development of technologies related to communication systems, in order to ensure data transfer in every operating condition. Main reason relies in the operating characteristics of ETCS Level 3, and in particular on the monitoring of system integrity through radio communication. In any case, important considerations are worth to highlight:

- First application of Level 3 signaling systems are out of time horizon of this project
- Costs for system conversion from the current one to Level 3 are presumably sensibly higher than from Level 2 to Level 3.
- The real state of development of Level 3 has to be considered as very limited, comparable with the one of Level 2 at the beginning of the 1990ies; there are no broad development activities on the supplier side.
- Interlocking equipment have to be completely replaced for Level 3.

Thus, the complete installation of ETCS Level 2 signaling systems must be considered both fundamental for the development of the other related technologies and propaedeutic for possible conversion to ETCS Level 3. But the broad application of Level 3 on the entire network can't be expected before the middle of this century.

Regarding the cluster Advances in Maintenance, sensors and probe vehicles are already available technologies, which can be enhanced by experiences from other sectors (e.g. road traffic). The main challenge is on Big Data management in the field, which is currently object of research projects from academia and industry. Nevertheless, some preliminary experiences show that data management for specific applications can be already implemented and provide very promising results. Especially expert systems forecasting failures and degradation of components, based upon neural networks or similar self-learning methods, are close to broad application and will be able to provide their advantages in a near future. Intelligent robots to repair and maintain infrastructure are already used in some countries, while the use of drones is still object of studies with few specific ongoing application. Definitively, these innovations, starting from the introduction of RCM systems, can be considered as ready for application.

Figure 11 and Figure 12 give a qualitative indication about the expected timing for technology introduction and possible lifetime, respectively regarding Automation in operation and Advances in Maintenance. The colors represent the technologies of a specific sub system (orange is signaling system, yellow is train operation, green is traffic control).

Figure 13 and Figure 14 describe the technological dependencies within the single clusters. In particular, concerning the Advances in Railway Operation cluster, the ETCS evolution from Level 2 to Level 3 is conceived as a technological path to follow, which is the main concept of ETCS systems since their introduction; clearly there is an overlap representing the switching period for technology substitution. L2 driving assistance systems can be considered as an alternative to semi-automatic trains, i.e. trains with predefined acceleration profiles and automatic speed setting activated by the train driver; alternatives choice clearly depends on multiple aspects, including of course financial evaluations of train operators. ATO will be the final evolution of driving systems, and the future "train driver" will be able to drive more than one train per time with remote driving control. Technology linked with the traffic control, mainly depend on ETCS Level 2 implementation and on the development of accurate systems for train positioning; the development of these technologies will be the basis for CBTC systems, possible relative braking distance systems and, consequently, advanced traffic control systems (disruption management, multi-objective adaptive rescheduling) and ETCS Level 3.

Regarding the cluster Advances in Maintenance, the Remote Condition Monitoring (RCM) concept (and related sensor technologies) should allow for a complete automation of repair and maintenance processes with robots and remote control. This will also allow for a redefinition of the maintenance concept, with real time analyses and decisions, and a redefinition of maintenance timing so generating a loop where each further innovation leads to further optimization on the entire system. It is worth to highlight that the redefinition of maintenance periods can be introduced according with the current technologies involved, therefore it is not dependent from any technological development.

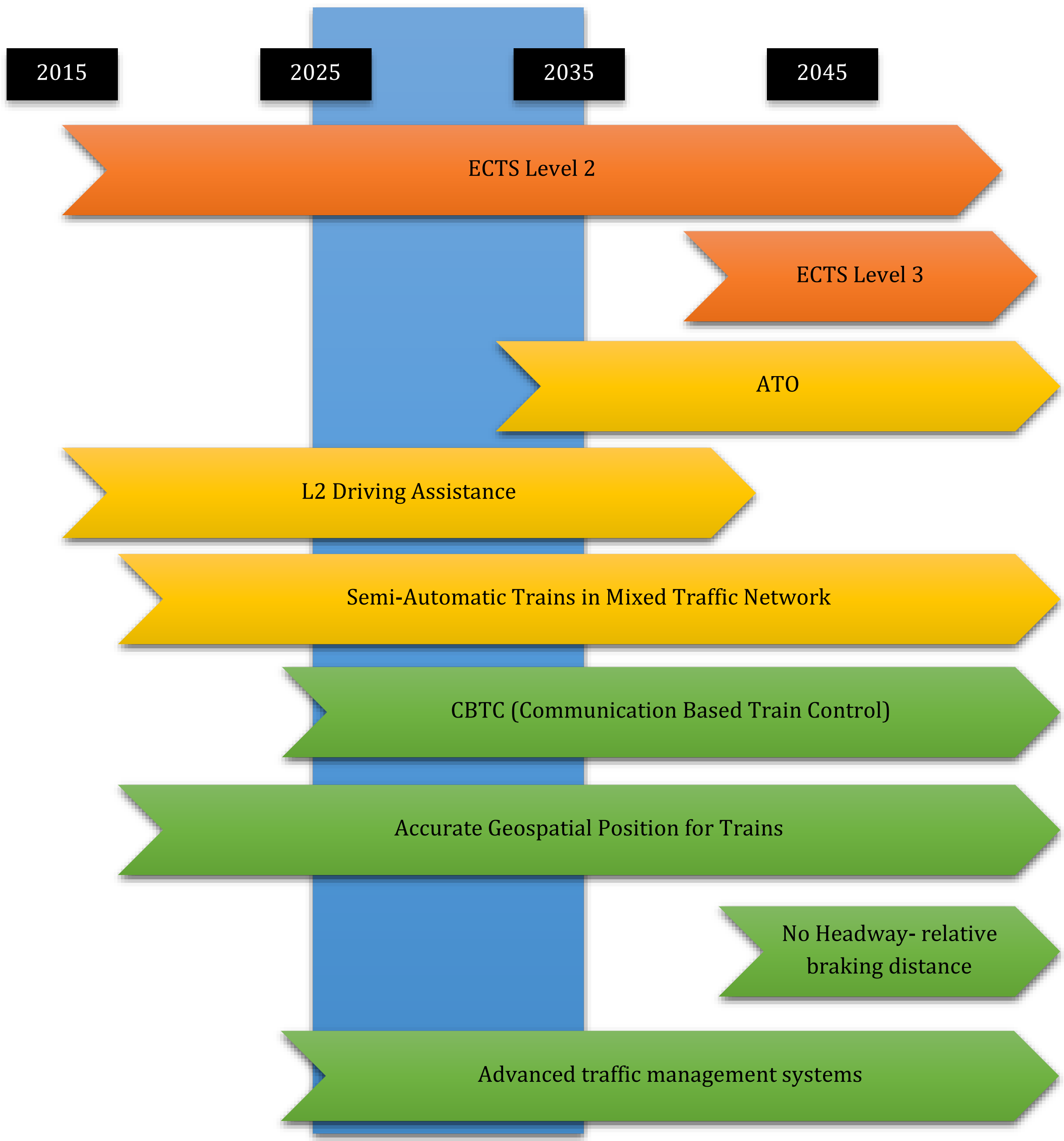

Figure 11. Roadmap for Advances in Railway Operation.

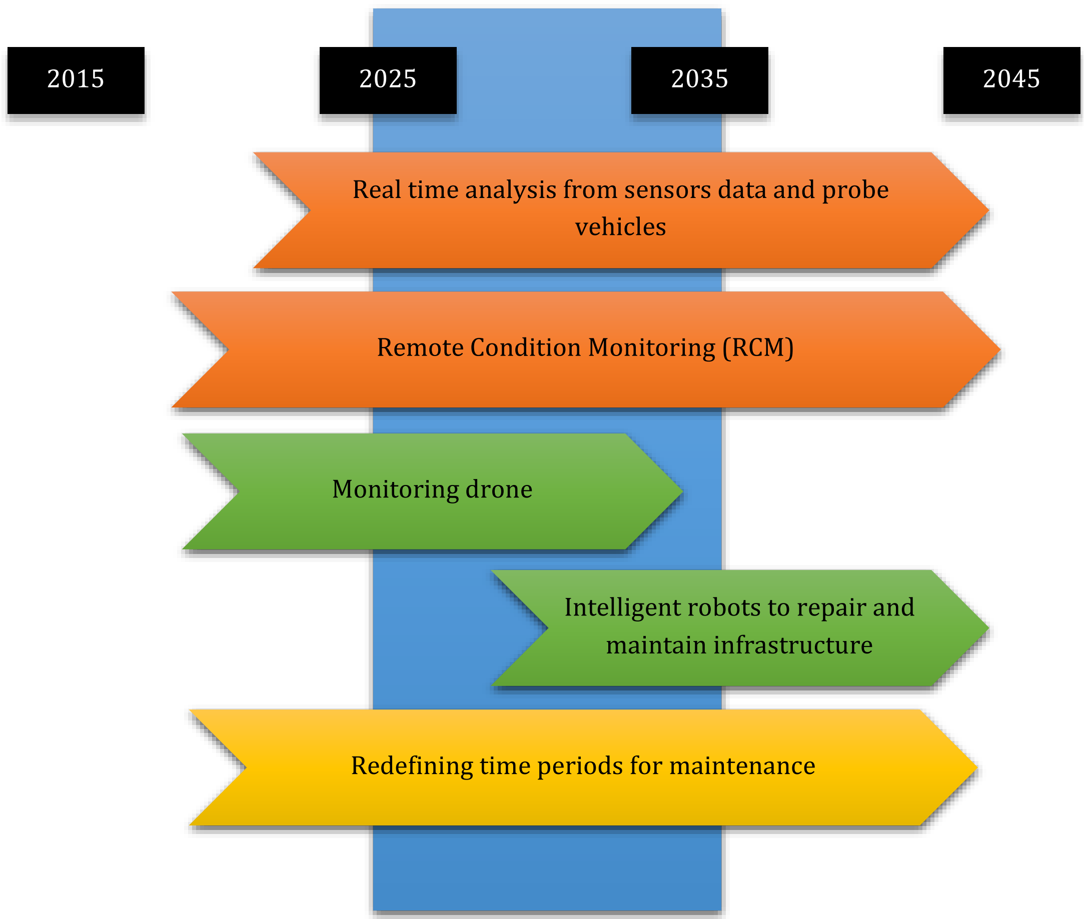

Figure 12. Roadmap for Advances in Maintenance.

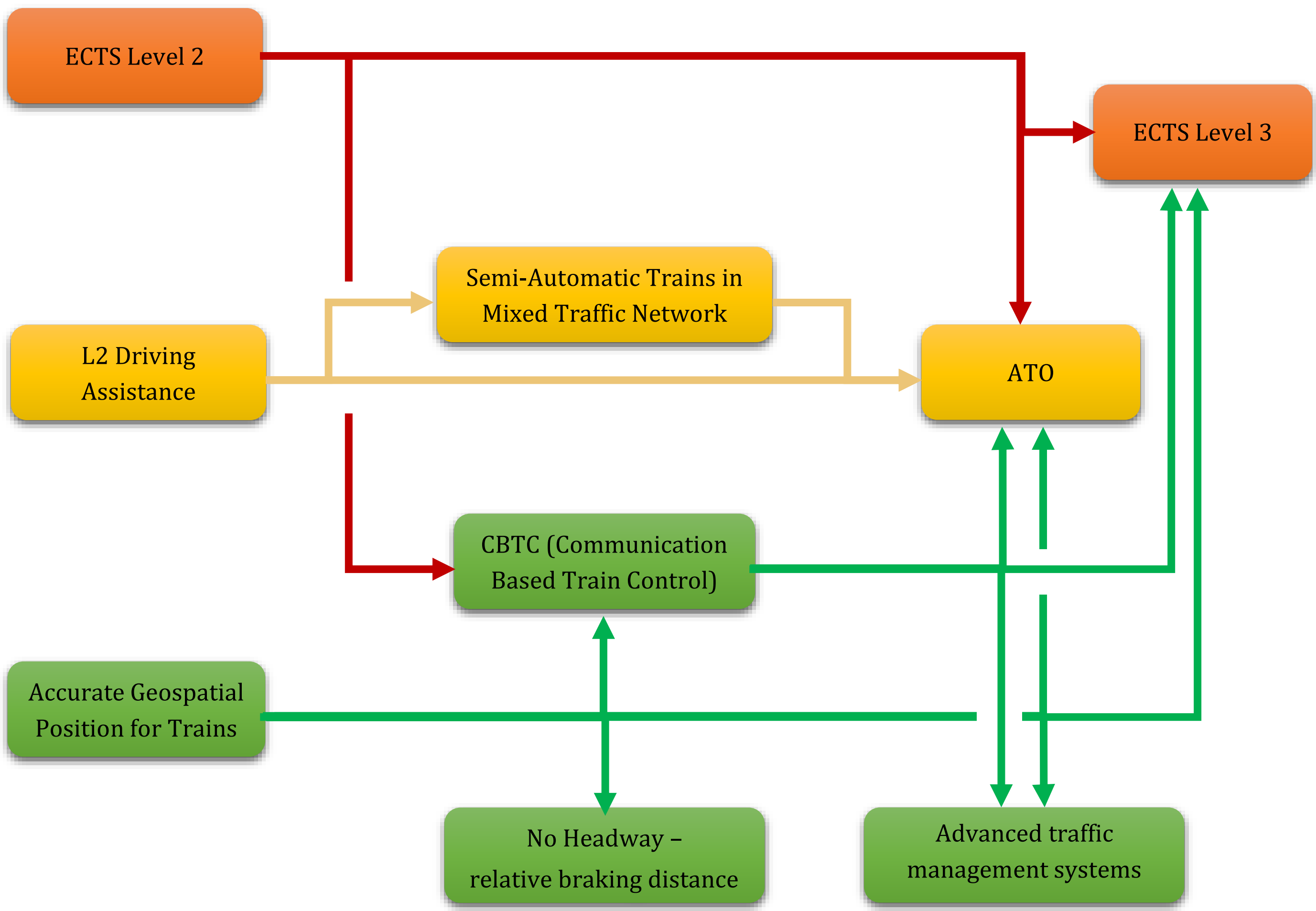

Figure 13. Technological dependencies within the cluster Automation in Railway Operation.

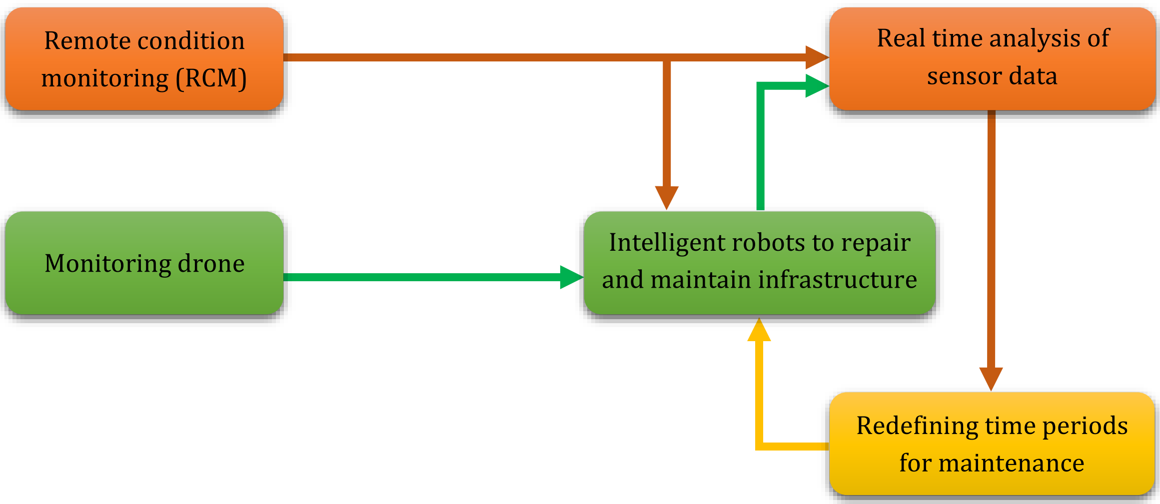

Figure 14. Technological dependencies within the cluster Advances in Maintenance.

Conclusions and recommendations

INNOVATIONS AND CLUSTERS

There is a wide range of innovations and ongoing studies aiming at optimizing the whole railway system, from new technologies to system integration, new materials, new operating models, etc.

Within the wide variety of proposals, the identification of clusters, representatives of the trends in research, development and application, can be the most useful representation for the output of this project. In this project, the innovations clusters have been considered according with the main characteristics of the rail system in Switzerland. Considering the results from interviews, the following clusters have been specified

a) Automation for Rail Freight

b) Automation in Railway Operation

c) New approaches to infrastructures use

d) Advances in Maintenance

e) New technologies for infrastructures construction

f) New design concepts for vehicles

g) Multi-objective methodologies for timetabling

h) New technologies for real time operation

i) Energy management and power sources

The total of all the innovations included in the clusters is a subset of all the innovations considered for the present project. The reason is that some innovations have been almost neglected or not even considered as such during the survey; therefore, they are not included in clusters. Definitely, considering the choice preferences and the clusters so defined, the following sections will describe in order: the innovations not considered relevant, the clusters considered relevant for specific sectors, the cluster unanimously considered relevant.

INNOVATION AND TECHNOLOGIES NOT RELEVANT

Within our lists of innovation, some of them have not been considered as such. It is the case of all the technologies linked with **leisure and entertainment** on board. Main reason is that a wide range of solutions is already available in the market and many examples across Europe are already available (Cinema Coaches, meeting rooms, etc.), so this is not seen as real innovation in the field. Moreover, this topic would not lead to substantial benefits for the railway system in the future. With the same reasons, **automation in ticketing and ticket validation** is not a relevant field of innovation for the future.

Another set of innovations not considered relevant in the sector is linked with the concept of **shuttles** and **pods**. Pods are intended as small (4-6 passengers) shuttles, completely automated, modular and able to couple/decouple automatically one each other. Pods are hardly studied in the road sector as an innovative solution in the field of autonomous vehicles in public transport. In the rail sector, the innovative characteristics of pods cannot be deeply deployed. In addition, there are already some application of this concept in isolated systems (e.g. people movers at the Heathrow airport, London), but is not seen as real innovation at all. Finally, **safety in terminal areas** for exposed crowds (e.g. prevention from terrorist attacks) has not been recognized fundamental for the next generation railway, since this issue will be mainly co-managed with local authorities and new technologies can be easily adopted without early planning.

TECHNOLOGIES AND INNOVATIONS RELEVANT FOR SPECIFIC SECTORS

These technologies resulted not relevant from some experts and relevant from some others. This output represents all those technologies and innovations that could have great potential for improving management aspects, such as operative costs savings, but are not deeply investigated and there are not enough resources and projects dedicated on them (or in alternative, there are huge investments on other solutions and technologies, which catch all the attentions and the efforts).

This is the case for example of all the technologies involved in the following clusters:

- **multiobjective methodologies for timetabling** (energy efficiency, resilience, etc.),
- **new technologies for real time dispatching** (e.g. robust and resilient procedures real time operation, use of customer-based to improve customer experience on the railway, etc.),
- **energy management and power sources** (real time energy management, hybrid traction units, etc.),
- **new design concepts for vehicles** (ultralight vehicles, modular design of wagon),
- **new technologies for infrastructure building** (new design elements, slab track, etc.),
- **new approaches to infrastructure use** (differentiation of infrastructure use by traffic type).

TECHNOLOGIES GENERALLY CONSIDERED RELEVANT

The innovations within the **Automation in operation** cluster received most of the attentions from our pool of experts. In particular, the use of integrated choices such as coupling advanced traffic management systems and automation in driving has been identified as the most effective innovations.

In particular, it has been highlighted that the combination of **ETCS Level 2 and ATO systems** must be a primary interest for Switzerland, since the ETCS Level 3 is seen as a technology that will be available not before the current technology will be completely paid back. Moreover the ETCS Level 2 already provides an increase of railway performances that will be completely deployed not before the time horizon of STEP 2030 and other ongoing national programs (FABI, Vision 2050, etc.).

CONCLUSIONS AND RECOMMENDATIONS

Other important innovations are within the cluster of **Advances in maintenance.** Experts agree that this topic will be more and more important and decisive in the future, with important benefits for railway operation, such as reduction of cost, increase of infrastructure use and assets monitoring.

FUTURE VISIONS

The pool of experts also had the possibility to introduce their future visions about what the railway will be and what will be the main challenges to address.

Internet of goods. This vision is mainly linked with the use of Internet and its characteristics. Main application would be on freight transport. The dominant concept is that we have to find the best (fastest, cheapest, etc.) way to deliver a package from an origin to a destination, without regarding the route.

Big Data Management. Big Data will be one of the biggest challenges in our future life. Huge networks of sensors, multiple sources of information, real time management and elaborations will pervade every part of transport systems. Maintenance will have great benefits from all these information, providing the railway systems with prompt, short and economically sustainable services.

Decongesting station from connecting transfers. Through automatic coupling and decoupling of coaches, train composition may be modified also during running phase; in this way, coaches may be dedicated to specific destinations, and decoupling on the run can reduce the time spent for this type of operation at station as well as saving time for the passenger travelling only through.

BACKGROUND, REFERENCES AND ADDITIONAL SOURCES

Background, references and Additional sources

Over the last few years, the IVT has already written several papers on the innovation of the rail system, or has been involved in studies. In particular, they are:

- Initialprojekt Forschungspaket Güterverkehr des VSS
- LEILA – Leichtes und lärmarmes Güterwagen-Drehgestell – Markteinführungsstudie Schweiz
- Sustainable Freight Transport on the Local Level
- Produktion Personen-Fernverkehr Schweiz 2020
- Advanced Impacts Evaluation Methodology for Innovative Freight Transport Solutions AIMS
- Verifikation Stromeinsparung durch effizientes Zugsmanagement
- Informationstechnologie in der zukünftigen Gütertransportwirtschaft
- Einsatzoptionen für eine Intra-Zugkommunikation im Wagenladungsverkehr
- Study on Single Wagonload Traffic in Europe – Challenges, prospects and policy option ViWaS
- Migration Informationstechnologien der zukünftigen Gütertransportwirtschaft
- Prozesse systemorientierter bahntechnischer Innovationen
- Integration des Bahnsystems
- Innovationen im intermodalen Verkehr
- Second Opinion Verkehrsführungssysteme Betrieb SBB
- Automation der Betriebsführung der SBB
- Vision Mobilität 2050
- Innovationen im alpenquerenden Güterverkehr

In addition to our current knowledge and on our ongoing technological studies, we considered scientific papers and recent reports of the last years, such as Arup 2050 report, RSSB report, our Railway's Future, Wascosa info letter and Smart Rail World website.

APPENDIX A – QUESTIONNAIRE FOR THE INTERVIEWS

Appendix A – Questionnaire for the interviews

APPENDIX A – QUESTIONNAIRE FOR THE INTERVIEWS

INTERVIEW DATA

Name	
Surname	
Job Position	

COMPANY

☐ Corporate career

☐ Freelance, Consultancy

☐ Academia

☐ Local authorities

Other:

FIELDS OF INNOVATION – 1

	A) **Check the field where you have been selected as expert for the questionnaire.** B) **Based on your knowledge, please indicate, in addition to A, in which of the following field you believe there will be or there can be an effective innovation in railway systems. If there is no match with your ideas, please go to the end of the document, section "Additional notes".**	**A**	**B**
1.	Automation (coupling vehicles, driverless operation, driving assistance systems, automatic operation, Intelligent rail traffic management systems, Freight Terminals, etc.)	☐	☐
2.	The use of infrastructure (separation of traffic types, shuttles services to simplify railway operation, etc.)	☐	☐
3.	System configurations with new infrastructures (isolated systems)	☐	☐
4.	Perspectives in rail vehicle construction (passenger, freight)	☐	☐
5.	Supply systems (technology and solution transfer from other services, information to customers)	☐	☐
6.	Innovations in planning (timetabling, use of travel time reserve, dwell times)	☐	☐
7.	Potential innovations in energy management and power sources (energy efficient rail operation, smart grid, alternative power sources)	☐	☐

APPENDIX A – QUESTIONNAIRE FOR THE INTERVIEWS

INSTRUCTIONS (READ IT TO THE INTERVIEWEE)

The following sections present the lists of innovations. You answer only to those selected in column A and B of the previous page; e.g. if your selection is field 2, we will go to section "Innovations - 1.2" of the following document.

Before reading the list and referring on your experience, think about the most effective innovation in the railway sector and keep in mind. Then check in the list if one of the options matches your idea. Our team will give you the support for all the explanations you may need.

You can decide either that one of the options on the list is better than your idea or keep your position.

In any case, your idea is very important for us and it would be very helpful if you can describe it in the "Additional Notes" section, at the end of this document.

The "Additional info" field is present in every section and it is discretionary. Together with your personal opinion, we also appreciate if you can give us some comments regarding your choice on the following aspects:

1. **Classification (Current maturity/ possible first application/ possible serial application/ possible completion of the network-wide migration)**
2. **Influence scope (Single technical improvement/ technical breakthrough to whole network**
3. **Specific differences/ improvements compared to current situation**

APPENDIX A – QUESTIONNAIRE FOR THE INTERVIEWS

INNOVATIONS – 1.1

	Please indicate which of the following innovations in the field of AUTOMATION are the most effective	
	Coupling	
1.	Automatic coupling system for freight trains (wagon)	☐
	Automatic coupling system for passenger trains (wagon)	☐
	Electronic coupling between wagons (information, heating, etc.)	☐
	Virtual coupling (between trains)	☐
	Driverless operation	
	ATO coupled with ERTMS/ETCS Level 3	☐
	ATO coupled with ERTMS/ETCS Level 2	☐
	Driving support system	
	L2 Driving Assistance Systems for optimal trajectories - multiobjective	☐
	L2 Driving Assistance Systems for optimal trajectories - conflict detection	☐
	Automatic operation	
	Automatic gauge change for cross border travel	☐
	Semi automated trains in mixed traffic networks	☐
	Intelligent rail traffic management systems	
	Adaptive Multi-objective Rescheduling models	☐
	CBTC (Communication based train control systems)	☐
	Accurate Geospatial positioning systems for trains	☐
	Disruptions management system	☐
	No Headway - relative braking distance	☐
	Freight terminals	
	Electronic tagging of cargo for reliable tracking and reduced delays	☐
	Intelligent robots unload and sort cargo	☐

INNOVATION 1.1 – ADDITIONAL INFO

APPENDIX A – QUESTIONNAIRE FOR THE INTERVIEWS

INNOVATION – 1.2

	Please indicate which of the following innovations in the field of THE USE OF INFRASTRUCTURE are the most effective.	
	Split of traffic types	
1.	Underground freight pipelines for moving goods in cities	☐
2.	Different infrastructure for freight trains (long distances)	☐
3.	Different infrastructure for passenger trains (long distances)	☐
4.	Infrastructures of long-haul and freight trains separated from urban and suburban passenger trains	☐
5.	Interoperability (dividing infrastructures into interoperable and not)	☐
6.	Metro-like operation (no Takt operation, trajectory homogeneity)	☐
	Safety systems during operation	
7.	ETCS Level 2, Level 3 or other steps (SBB next generation)	☐
8.	Real time networking and automation (real time analysis) of sensors	☐
	Security systems	
9.	Anti-fraud and information protection technology	☐
10.	Surveillance and security technology for exposed crowd	☐
	Shuttle services	
11.	Personal Rapid Transit Pods	☐
12.	Pods for freights	☐
13.	Optimal dimensioning of shuttles	☐
	Innovative construction elements and design	
14.	Slab track	☐
15.	Silent block and sleepers for reduction of noise and vibrations	☐
16.	New infrastructure "lighter" built for passenger traffic only (not full dimensioning on the longest/heaviest/hardest case)	☐
	Advances in maintenance	
17.	Develop and implement RCM (remote condition monitoring)	☐
18.	Intelligent robots to repair and maintain infrastructure	☐

	Please indicate which of the following innovations in the field of THE USE OF INFRASTRUCTURE are the most effective.	
19.	Monitoring drone for predictive maintenance and improved security	☐
20.	Redefining time periods for maintenance and traffic (e.g. night maintenance, week end maintenance, line maintenance)	☐

INNOVATION 1.2 – ADDITIONAL INFO

APPENDIX A – QUESTIONNAIRE FOR THE INTERVIEWS

INNOVATION – 1.3

	Please indicate which of the following innovations in the field of SYSTEM CONFIGURATIONS WITH NEW INFRASTRUCTURES are the most effective.	
	Innovative construction elements and design	
1.	Rapid evaluation through digital patterns and system simulation	☐
2.	Intelligent robots to repair and maintain infrastructure	☐
3.	Monitoring drone for predictive maintenance and improved security	☐
4.	Slab track	☐
5.	Silent block and sleepers for reduction of noise and vibrations	☐
6.	“Simple” network (i.e. lines and junctions designed for serial operation)	☐
7.	***Split of traffic types***	
8.	Different infrastructures for freight trains (long distances)	☐
9.	Different infrastructures for passenger trains (long distances)	☐
10.	Rapid evaluation through digital patterns and system simulation	

INNOVATION 1.3 – ADDITIONAL INFO

INNOVATION – 1.4

	Please indicate which of the following innovations in the field of PERSPECTIVES IN RAIL VEHICLE CONSTRUCTION are the most effective.	
	Passengers' comfort	
1.	Long distance train amenities & business services (cinema, meeting rooms, etc.)	☐
2.	Window sensors for heat control	☐
3.	Connectivity and leisure technology in rolling stock	☐
	Vehicle design and innovative components	
4.	Disc brakes for freight wagons	☐
5.	Braking efficiency (e.g. adhesion independent systems)	☐
6.	Aerodynamics	☐
7.	Ultralight vehicles (DLR future train)	☐
8.	Low resistance boogies	☐
9.	Modular design of wagon (light wagon with more flexibility like frame only, fully containering)	☐
10.	Modularity of vehicles (e.g. high standardization, fast, easy and cheap testing phases)	☐
11.	Innovative Traction units, distributed tractive efforts along the train	☐
12.	Innovative & alternative fuels for non-electric vehicles (e.g. hybrid, hydrogen, bio fuels)	☐

INNOVATION 1.4 – ADDITIONAL INFO

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INNOVATION – 1.5

	Please indicate which of the following innovations in the field of SUPPLY SYSTEMS are the most effective.	
1.	Headway minimizing	☐
2.	Train speed bundling	☐
3.	Homogeneous trains / homogeneous traffic (Metro-like operation, no Takt operation)	☐
4.	“Simple” network (i.e. lines and junctions designed for serial operation)	☐
5.	Real time information on traffic congestion on board	☐
6.	Alternative plan in real time	☐
	Ticketing	
7.	Deploy contactless technology (pay with contactless credit cards)	☐
8.	Ticketless policies	☐
9.	Virtual Ticketing Agents	☐

INNOVATION 1.5 – ADDITIONAL INFO

INNOVATION – 1.6

	Please indicate which of the following innovations in the field of INNOVATIONS IN PLANNING are the most effective.	
1.	Energy efficient timetabling	☐
2.	Resilience into planning	☐
3.	Robust and resilient dispatching	☐
4.	Timetable in the future (does it have a future? Replace timetable by intervals)	☐
5.	Simulation based time reserve definition (statistic methods)	☐
6.	Distribution of dwell time reserves	☐
7.	Intelligent Traffic management systems feed real time Customer	☐
8.	Use of customer-based technologies (e.g. personal communications) to improve customer experience on the railway	☐

INNOVATION 1.6 – ADDITIONAL INFO

APPENDIX A – QUESTIONNAIRE FOR THE INTERVIEWS

INNOVATION – 1.7

	Please indicate which of the following innovations in the field of POTENTIAL INNOVATIONS IN ENERGY MANAGEMENT & POWER SOURCES are the most effective.	
1.	Real time energy management	☐
2.	Energy Recuperation System	☐
3.	Smart Grids	☐
4.	Alternative power sources from hydrogen, nuclear, air propulsion or magnetic levitation	☐
5.	Multi, dual & hybrid traction drives	☐

INNOVATION 1.7 – ADDITIONAL INFO

ADDITIONAL NOTES

Are there additional information? Are there other innovations not mentioned in this questionnaire? If yes, how do you position this/these innovation(s) in this scheme? In addition, how would you evaluate its/their importance in comparison with choices A and B?

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

Appendix B – Description of the innovations included in the survey

Theme	Sub-Theme	Innovation	Description
Automation	Coupling	Automatic coupling system for freight trains (wagon)	
		Automatic coupling system for passenger trains (wagon)	
		Electronic coupling between wagons (information, heating, etc.)	
		Virtual coupling (between trains)	
	Driverless operation	ATO coupled with ERTMS/ETCS Level 3	Automatic train operation under the signalling system of ETCS Level 3
		ATO coupled with ERTMS/ETCS Level 2	Automatic train operation under the signalling system of ETCS Level 2
	Driving support systems	L2 Driving Assistance Systems for optimal trajectories – multiobjective	Multiobjective: energy saving, delay recovery (single train operation)
		L2 Driving Assistance Systems for optimal trajectories – conflict prediction / conflict	Multi train operation

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

		detection	
	Automatic operation	Automatic gauge change for cross border travel	
		Semi automated trains in mixed traffic networks	Automation supports driver in normal operation; deviation from normal operation are solved by the driver
	Intelligent Railway Traffic Management System	Adaptive Multi-objective Rescheduling models	Adaptive: it adapts the solution considering type of traffic, time period, area of rescheduling (weights of the multi-objective function)
		CBTC (Communication based train control systems)	Railway signalling systems that use the telecommunications between the train and track equipment for the traffic management and infrastructure control
		Accurate Geospatial positioning systems	
		Disruptions management system	The systems dynamically recover a predetermined operational plan when various disruptions prevent the original plan from being executed smoothly

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

		No Headway - relative braking distance	Virtual coupling of trains, leader-follower(s) system
	Freight Terminals	Electronic tagging of cargo for reliable tracking and reduced delays	
		Intelligent robots unload and sort cargo	
The use of existing infrastructures	Split of traffic types	Underground freight pipelines for moving goods in cities	
		Different infrastructure for freight trains (long distances)	
		Different infrastructure for passenger trains (long distances)	
		Infrastructures of long-haul and freight trains separated from urban and suburban passenger trains	
		From parallel to sequential trajectories for traffic optimization (no Takt operation; towards metro-like operation)	
		Interoperability (dividing infrastructures into interoperable and not)	The ability of a rail system to allow the safe and uninterrupted movement of trains which accomplish the required levels of performance for these lines

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

	Safety system during operation	ETCS Level 2, Level 3 or other steps (SBB next generation)	European Train Control System Level 2, Level 3 or SBB next generation
		Real time networking and automation (real time analysis) of sensors	Continuous monitoring and real-time analysis
	Security systems	Anti-fraud and information protection technology	
		Surveillance and security technology for exposed crowd	Monitoring of the behaviour, activities, or other changing information
	Shuttle services	Personal Rapid Transit Pods	Pods are small autonomous vehicles for 2-6 people
		Pods for freights	
		Optimal dimensioning of shuttles	
	Innovative construction elements and design	Slab track	Consists of a continuous slab of concrete with the rails supported directly on its upper surface (using a resilient pad)
		Silent block and sleepers for reduction of noise and vibrations	
		New "lighter" infrastructure built for passenger traffic only (not full dimensioning on the longest/heaviest/hardest case)	

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

	Advances in maintenance	Develop and implement RCM (remote condition monitoring)	Use infrastructure fixed points to monitor rolling stock and use rolling stock to monitor fixed infrastructure. Reduce costs for maintenance checks
		Intelligent robots to repair and maintain infrastructure	
		Monitoring drone for predictive maintenance and improved security	
		Redefining time periods for maintenance and traffic (e.g. night maintenance, week end maintenance, line maintenance)	Optimal maintenance scheduling which consider parameters such as type of maintenance, travel demand variances, infrastructures availabilities and rail traffic to reduce service interruption
System configuration with new infrastructures	Innovative construction elements and design	Rapid evaluation through digital patterns and system simulation	
		Intelligent robots to repair and maintain infrastructure	
		Monitoring drone for predictive maintenance and improved security	
		Slab track	Consists of a continuous slab of concrete with the rails supported directly on its upper surface (using a resilient pad)
		Silent block and sleepers for	

		reduction of noise and vibrations	
		“Simple” network (i.e. lines and junctions designed for serial operation)	
	Split of traffic types	Different infrastructures for freight trains (long distances)	
		Different infrastructures for passenger trains (long distances)	
		Rapid evaluation through digital patterns and system simulation	
Perspectives in rail vehicle construction	Passengers’ comfort	Long distance train amenities & business services (cinema, meeting rooms, etc.)	
		Window sensors for heat control	
		Connectivity and leisure technology in rolling stock	
	Vehicle design and innovative components	Disc brakes for freight wagons	
		Braking efficiency (e.g. adhesion independent systems)	E.g. eddy current brakes, in which the drag force is an electromagnetic force between a magnet and a nearby conductive object in relative motion

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

		Aerodynamics	aerodynamics to reduce the motion resistances, especially in freight trains
		Ultralight vehicles (DLR future train)	
		Low resistance boogies	
		Modular design of wagon (light wagon with more flexibility like frame only, fully containering)	
		Modularity of vehicles (e.g. high standardization, fast, easy and cheap testing phases)	
		Innovative Traction units, distributed tractive efforts along the train	
		Innovative & alternative fuels for non-electric vehicles (e.g. hybrid, hydrogen, bio fuels)	
Supply system	Technology transfer from Metro lines to mixed lines	Headway minimizing	Minimizing possible distance or time between vehicles in a transit system, without a reduction in the speed of vehicles

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

		Train speed bundling	Bundling helps to reduce the headway between trains, hence make it possible to increase network capacity. More generally, train bundling involves arranging trains into types.
		Homogeneous trains / Homogeneous traffic (Metro-like operation, no Takt operation)	
		"Simple" network (i.e. lines and junctions designed for serial operation)	
		Real time information on traffic congestion on board	
		Alternative plan in real time	
	Ticketing	Deploy contactless technology across the network	
		Ticketless	
		Virtual Ticketing Agents	Automatic Ticket validation when inside the vehicle
Innovation in planning		Energy efficient timetabling	Link the railway timetable and the consumption of energy
		Resilience into planning	
		Robust and resilient dispatching	
		Timetable in the future (does it have a future?	

APPENDIX B – DESCRIPTION OF THE INNOVATIONS INCLUDED IN THE SURVEY

		Replace timetable by intervals)	
		Simulation based time reserve definition (statistic methods)	
		Distribution of dwell time reserves	
		Intelligent Traffic management systems connected in real time to Customer	Communication of service modifications in real time with e.g. mobile technology
		Use of customer-based technologies (e.g. personal communications) to improve customer experience on the railway	
Potential innovations in energy management & power sources		Real time energy management	
		Energy Recovery System	Minimize the request of energy from public grid thanks to energy recovery from electric braking and by reusing or storing for successive requests
		Smart Grids	Includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources
		Alternative power sources (Fuel cells)	Any energy source that is an alternative to fossil fuel
		Hybrid traction drives (diesel + electric)	

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