Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 72 (2023) 852–859

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Recommendations for a transition to 'Railway 4.0 for Europe'

Thomas H Zunder [a*], Christian Katschnig [b], Ming Chen [c], Angelo Martino [d]

[a] *Newcastle University, UK*
[b] *IITF, Austria*
[c] *TNO, Netherlands*
[d] *TRT, Italy*

Abstract

This research developed transitional scenarios for the European rail sector to transition to 'Railway 4.0' by the year 2050 based on interdisciplinary research informed by key choice variable modelling, co-created business model generation and semi structured interviews within the context of expert knowledge held by the authors and supported by desktop research. This work was developed in a mixed methods research framework. The number of interviewees is reported where appropriate to the methodologies concerned. We have detailed the impact assessment framework, CANVAS, and governance interviews developed and used. We have reported the individual key results from each approach and then an integration of same and finally policy recommendations.

Keywords: Railways, transport policy, key choice variable modelling, freight, forecasting, mixed-methods, CANVAS.

1. Introduction

We report the co-creation of recommendations for the European rail sector to transition to a user centric digital and service oriented 'Railway 4.0' by the year 2050; based on interdisciplinary research informed by key choice variable modelling, business model generation and semi structured interviews within the context of expert knowledge and supportive desktop research. The emergent definition of Railway 4.0 is based first on that set by Shift2Rail, but not exclusively:

Full system and life-cycle analysis on concepts as mobility as a service (MaaS), industry 4.0 (automated industry and industry as a service), railway clouds and decentralized ownership are among the ones this exploratory research should look at, providing a picture of the Railway 4.0. (Shift2Rail, 2019)

The research was funded by the Shift2Rail JU as the project Flex-Rail with the stated aim that:

* * Corresponding author. Tel.: +44-7967-323654.
E-mail address: tom.zunder@newcastle.ac.uk

10.1016/j.trpro.2023.11.477

... paradigm shifts on fundamental rail sector characteristics are required; both rail industry and organisation must target a lean, integrated, and flexible railway system, which will stimulate further innovation within the rail sector and will ensure that rail services can address the future user needs. This was a statement based upon EU rail research and innovation agendas, roadmaps, and visioning from the EU Transport White Paper of 2001(Zunder et al., 2012) through to Rail 2050 Vision research roadmap (Mazzino et al., 2017). The authors were tasked to research, envision, and critically address the Shift2Rail JU Multi Annual Action Plan (MAAP) which formed the backbone of (almost) all rail research and innovation (R&I) funding in the EU Horizon 2020 Framework Programme (H2020).

The MAAP was organised along 5 IP's which combined provide an operational solution for different system platform demonstrators (SPDs), each having different requirements. The interaction and interdependence of collective solutions was not obvious and was addressed by horizontal topics and defined Technology Demonstrators (TD's) in which different specific targeted technologies were merged to a collective innovation. As a result of these interdependencies, the specification of the work programme involved a multitude of cross-links (Haltuf, 2016; Shift2Rail, 2019). Our research output was focused at the system platform demonstrator scenario level (Shift2Rail, 2019, pp. 69–72) defined as main rail market segments. These SPDs were to simulate and test the interaction and impact of the various JU innovative systems in each of the relevant market segments: high-speed passenger rail, regional passenger rail, urban/suburban passenger rail and rail freight. Our work was to form reflection and critique on key transversal issues (megatrends) that were seen as critical for the sector: safety, security, energy, digitalisation, etc. In this regard this was parallel work to that of others who focused more closely on the sector roadmaps (Zunder et al., 2021)

2. Methodological Framework

This was mixed methods research; methodological pluralism - mixing quantitative and qualitative research methods in an integrated fashion. We hoped to find paradox and contradiction in initiating new perspectives from one method to the other, as questions or results were explored. Our three key methods were predictive modelling of possible futures based on the IMPACT-2 model, business models and transition pathways generation using the CANVAS approach (Osterwalder and Pigneur, 2010), World Café (Brown et al., 2005) style events and semi-structured interviews with key European rail stakeholders.

2.1. Specification of the model runs for the assessment of rail innovations

New models were developed in Flex-Rail to consistently address a user-oriented approach and the key choice variables (KCVs) identified. A framework was developed about the interrelationships among critical influential factors, from the user side perspective, and user decision variables, with a focus on passengers. The newly developed semi-quantitative modal innovation assessment model allows for a user-oriented approach and a refined assessment of the potential for improvement of different innovations for rail and road.

The runs with the described models, were done with the following inputs:

- Initial corridor assumptions described the situation in the base year which is set at 2020.
- The Reference Scenario described the socio-economic and other relevant changes for the mobility context in line with the EU-Reference Scenario.
- The Baseline Scenario was a combination of the Reference and the road innovation scenario.
- The Rail Innovation Scenarios included
    - The individual packages of rail innovations in combination with the Baseline Scenario.
    - Rail Innovation Scenarios consisting of a combination of rail innovation packages or sub-sets thereof in combination with the Baseline Scenario.

With the results of these model runs the following assessments of impacts were done:

- By comparing the initial corridor assumptions with the Reference Scenario, the expected changes/trends for mobility demand, modal-split and socio-economic impacts were determined.

- By comparing the Baseline Scenario with the Reference Scenario, the impacts of the road innovation scenario were determined.
- By comparing the Baseline with the rail scenarios, the impacts of the rail scenarios were determined.

2.2. Business Model and Transition Pathway Generation Methodology

For the business modelling and transition pathway generation we deployed the Business Model Canvas (BMC). We adopted the definition from Osterwalder & Pigneur which stated: "a business model describes the rationale of how an organisation creates, delivers, and captures value". Since the original face-to-face (Brown, Isaacs, and World Café Community of Practice, 2005) workshops were not possible in the pandemic, these were approximated using online meetings, breakout rooms, *MIRO* boards and so on. The scenario packages were assessed using 3 main areas of interest. The 'impact optimization' implementation was addressed, the MAAP and the Rail 2050 Vision documents were both clearly aimed at a collaborative mobility sector by 2050. These clustering of scenario packages were informed by the modelling results showing which had the most impact on the future of European railways.

- Railway 4.0 – service platform - impact optimization of rail in a collaborative mobility sector comprising of final scenario packages:
    - D-User oriented Door-to-door services and
    - F-User oriented physical adaptions of rail services
- Railways 4.0 system platform - impact optimization of rail in a collaborative mobility sector comprising of final scenario packages:
    - A-Real time network management
    - B-CCAR - Cooperative Connected and Automated Railways (CCAM/ATO)
    - C-Reshaping rolling stock
- Railways 4.0 freight - impact optimization of the rail freight sector comprising of final scenario packages:
    - A-E and H, in that freight is an SPD and must select from all.

Once the main BMC was populated, a vote was taken to rank the importance of the key partners, activities, and resources on the supply side. These were then clustered where individual components were duplicates or logically nested within a broader heading.

3. Modelling Findings

In the modelling work two implementation scenarios: 'cost effective innovation of railway' and 'impact optimization – rail in a collaborative mobility sector' were developed as potential pathways to the future. Within both implementation scenarios the same scenario packages of solutions had been modelled as shown in Table 1.

Table 1: Specific solutions per innovation package

Innovation package	Specific solution	Solution name
A – Real time network management	A1	Flexible routing and scheduling of the rail system
	A2	Demand prediction for stations - duration stops, crowd management
	A3	Avoid unnecessary stops at stations/terminals (off-peak and rural)
	A4	Terminals as part of the Rail system
	A5	Flexible routing and scheduling in multi-modal environment - rail separate infra
B – CCAR (CCAM/ATO)	B1	ATO (human independent) - including remote control
	B1.1	Reduce need for waysides assets/on-board technology
	B2	Align tram with CCAM in urban areas
C – Reshaping rolling stock	C1	Smaller trains with higher frequency and direct connections - old train technology but more smaller trains

Innovation package	Specific solution	Solution name
	C1.1	Small pods/services (personal pod during off peak hours)-new small train units
	C1.2	Self-propulsion wagons (battery)
	C2	Increase safety: Avoidance of collisions by higher rolling resistance (breaking)
D – User oriented Door-to-door service	D1.2	Personalized seat reservation
	D1.3	Personal preferences during trip
	D1.7	Tracing back and informing people that have been close to or in the same space with an infected person
	D2	On-demand personal mobility service (multi-modal) - uni-modal performance trip
	D3.1	Automated registration of service providers and individuals involved in the rail service
	D3.2.2	Automatic payment upon actual use of services
	D4.1	Ensure cyber security
	D4.2	Ensure no alternative use of personal data (GDPR)
E - Smart sensing solutions	E1	Remote maintenance sensing
	E2	Automated ‘inspection’ drones
	E3	Monitor risk factors along track; automatic identification
	E4	Crowd management and surveillance (at stations and in trains)
	E5	Nano particle weapon detection (at stations)
	E6	Automated cargo surveillance (weight sensors, cameras, movement sensors)
F – User oriented physical adaptations of rail service	F1	User oriented interior design - non-adaptable
	F2	Provide non-mobility service/ facilities at waiting area
	F3	Provide non-mobility service/facilities on board (shopping, package delivery, fitness facility etc.)
	F4	(Self-)adaptable train interior based on personal preferences
G – Production alternatives	G1	Increase energy efficiency - all except G1.1 solutions
	G1.1	Composite and lightweight materials (less weight less energy use)
	G2	Full electrification by battery/hydrogen locos on non-electrified tracks
	G3	Optimization of railway components to cause less infrastructure wear and tear
	G4	Modular design
	G5	Circular production processes and corresponding material use

The highest potential to improve competitiveness of rail for one or more SPD’s was obtained equally from.

- A - Real time network management (SPD 1, 2 and 4)
- C - Reshaping rolling stock (SPD 2 and 4)
- D - User oriented Door-to-door services (SPD 1, 2 & 4)
- E - Smart sensing solutions (SPD 1)

It should be noted that for package C the development and uptake of multi-modal pods led to the most impact but is also the most complicated to achieve. The remaining parts of package C led to a significantly lower contribution to the competitiveness of rail.

A moderate contribution to improvement of competitiveness of rail was obtained equally from packages:

- B - CCAR: Cooperative Connected and Automated Railways (CCAM/ATO) (SPD 1, 2 and 3)

A relatively low contribution to the improvement of competitiveness of rail in the different SPDs was eventually obtained from packages:

- F - User oriented physical adaptions of rail services
- G - Production alternatives

4. CANVAS Findings

Six CANVAS workshops were held online and the attendance varied from 5-10 over time.

4.1. CANVAS Findings on Railway 4.0 – service platform

Analysis of the CANVAS and the relationships between activities, partners, and resources, we saw that the activities with most weight and needing most attention are the provision of user-oriented services, smart ticketing, and payment, organising the multi-modal trip, tailoring offer to user and provision of secure consented data using common ontologies, they have the highest weighting. Their relationships to the actors: service (ICT) platform, public transport operators and railway operators, are weighted strongly but there was a gap with how this relates to society. The resources most relied on by these key activities are a MAAS platform, multi-modal real-time planning and scheduling of transport, and data exchange infrastructures and protocols. In that all these key activities are in the two key roadmaps for innovation in the sector it appears that to achieve a viable Railway 4.0 the transition pathways are in place.

4.2. CANVAS Findings on Railway 4.0 – system platform

From analysis of the CANVAS and the relationships between activities, partners, and resources that the most heavily weighted activities for focus in any business model and hence transition were the development of governance and regulations; adaptation of legislation, establishment of data management, prediction, and management of schedule and stops dynamically, the research and create of new transport concepts, development, and installation of IOT infrastructure, apps, and systems. These are all extant the in the MAAP and the Rail 2050 Vision, and the only noticeable activity that lacked a link to either partners or resources was the establishment of a master platform for vehicles. The key partners for the achievement of Railway 4.0 were seen to be ICT partner(s), infrastructure managers, public transport operators and railway operators. Government was seen to be a key partner for the development of governance and regulations with associated adaption of legislation.

The key resources given most weight were real time network information, incl. station/train utilisation using real-time data and predictive models, a uniform EU rail system of standards, regulation and governance, sensors (V2X, V2V, X2X), indicative scheduling/modelling of trains and passengers using innovative algorithms, moving block trains with virtual coupling and novel braking and personalised information. This final point about personalised information links to concerns expressed about future data economies expressed in TER4RAIL (Zunder *et al.*, 2021).

4.3. CANVAS Findings on Railway 4.0 – Freight

From analysis of the CANVAS and the relationships between activities, partners, and resources the key activities identified were flexible capacity management of infra/ rollingstock/ paths/ terminals, real-time traffic management, shorter trains/modules with higher frequency and direct connections and data sharing and communication between IM-RU- terminals -client. Key partners were seen to be ICT and service platform providers, road, postal, IWW, maritime, logistics providers, terminals and ports, infrastructure managers, and the rail supply industry. Note that government was weighted very low and does not relate to any of the key activities, confirming the tendency for logistics to act away from government intervention in the early 21st century. Note also that the workshops did not identify railway operators as distinct to all forms of logistics operators, again suggesting that rail freight companies are seen as and need to be fully multi-modal providers.

The key resources seen as having most weight in supporting new business models and transition were autonomous [small] rail vehicles (with automated driving), asset management systems, freight exchange platforms, appropriate

data interoperability standards, Internet of Things OT (network, train, sensors.), mathematical model for routing and satellite systems (GNSS). The activities of demand prediction and automated registration of service providers were not linked to identified key resources and this suggests gaps for further research.

There are three key activities which we feel may not be adequately reflected in the MAAP and Rail 2050 Vision and these are flexible capacity management of infra/ rollingstock/ paths/ terminals, on-demand capacity allocation, demand prediction (volume, date, specifications), and automated registration of service providers. The most stated comment in the post workshop discussion was that a single point of contact for customers and single responsible agent is (still) rare and the transport corridors are not functional, which coincides with the recent Evaluation of Regulation (EU) No 913/2010 which stated that "the overall objective of giving sufficient priority to rail freight does not seem to have been achieved so far." (Enrico Pastori et al., 2020)

4.4. Governance Findings

Having the results and conclusions of the modelling and CANVAS a focussed written interview process was initiated. The following stakeholders were contacted and asked in mid-April 2021 to answer 8 questions based on key issues that had been uncovered and which had relationships with governance, and that these stakeholders had an expertise and a vested interest in. Not all stakeholders responded but by 1st June 2021 we had responses from most, or from people of expertise able to comment as individuals. One respondent wished to remain anonymous, another that their views were personal to them and not their organisation in that there was no current institutional viewpoint.

The stakeholders were sent a five-page summary of the project, our results so far and asked to answer 8 questions:

1. How might the governance of multiple urban modes be developed to enable such a multi-modal, demand differentiated, and multiple actor approaches to be considered and/or actioned?
2. How can governance be developed to accommodate divergent business model and technological transition pathways for European rail freight?
3. How can governance manage the choices between cost and impact of innovations moving forward from now to 2050 at a long-distance and regional level within Europe?
4. How can the governance of the sector support the provision of such capacity, which may be quite different in each of the SPDs?
5. Does always perceiving of the rail sector at a pan-European level also limit innovation at the regional level or in freight. Would 4-6 regulated regional monopolies suit European rail better? Is a single European rail system really an agenda of political cohesion rather than operations?
6. If the future is user centric, data rich, and part of Mobility as a Service / Physical Internet, then what role should rail have in future? Should rail just be a component within the mobility sector or should rail try to be the host of the complete mobility system given its extensive data ownership, and service platforms? What governance would be required for such a future and given that the scope of that service for SPD2 and SPD3 lies as much outside of the sector than inside, would this be rail governance anymore?
7. It has been stated that despite the introduction of corridors for rail freight a single point of contact for customers and single responsible agent is (still) rare & that the transport corridors are not functional. How well do the governance structures for rail freight address this?
8. How will governance of control and self-control of autonomous be governed as our cities and suburbs become self-organised?

No-one directly referenced the existing governance structures, although they implicitly supported them or challenged them. ERFARAIL, for example, adopted a position supporting the vertical and horizontal separation and liberalisation inherent in the EU Transport Policy since 2011(Zunder et al., 2012). CER, tended to emphasize the traditional strengths of the traditional integrated incumbent railways, a position adopted strongly by Deutsche Bahn in their relatively successful push back against much of the original Fourth Railway package (Maczkovics, 2017) UITP/Haon talked more of the role of overall urban governance, which is their stated area of concern and has already some of the institutions in place, but rarely integrated between all modes, MaaS/data providers and/or freight. The independent observer was strongest in addressing the need to critique current and speculate about future governance.

Multiple responses spoke of innovation, or the allocation of contested resources being based on viable business models, and yet at the same time the role of society as a customer that sometimes supersedes the individual user. There was an acceptance of liberalisation and market mechanisms in the rail sector to deliver services and innovation, but within regulation. There was a pushback on this from CER who seemed warm to the idea that a smaller number of supra-national regional monopolies may make sense. CER also spoke strongly of land use planning as a way of shaping freight demand. CER spoke primarily as a representative of the freight rail sector, which may have understated their very significant membership amongst the European rail passenger sector. They tended to adopt a 'rail-oriented' approach and not a 'user-oriented' one.

The opportunities for data, integration and sharing were stated multiple times, both as an enabler of further efficiency and delivery of MaaS/LaaS, but also as an enabler/driver of innovation and new businesses in the future. Rail sector actors were noted as being well placed to take a strong role. There was a view that pre-definition of roles was to be avoided and that governance needed to be at the level of data access, data sharing, integration, and exploitation *conceptually separate to modal operations.*

The emergence of autonomous cross modal issues was viewed sceptically by some respondents, with some caution by others, and not recognised as a pressing and emergent issue by any, which was notably different to the BMC/transition workshops. The issue regarding focus and skills saw the sector strongly defended and strongly criticised, but perhaps the respondents failed to flag up the noted problems the rail and separately the logistics sectors have with skills and competencies. It may be that the proven technical skills of the rail sector outshine the other competencies needed to deliver user centric approaches. No clear suggestion for governance was suggested here beyond the new proposed JU. The current top-level corridor and train capacity scheduling governance at an international level were strongly criticized or weakly nuanced. The current TTR initiatives and the CEF programme appear to need to deliver improvements in governance.

5. Integration

To achieve the impact optimisation scenarios identified, especially in the areas of service platform, system platform and freight, key activities were identified. There were some commonalities in all three. The need for platforms that are data driven, real-time, and dynamic was given the highest weight. An integrated and multi-modal data system was called for as the key enabler to deliver viable business models, transition, and impact. This raises a variety of questions and issues. The data economy that is called for may or may not lie in the hands or, or even the governance of the rail or transport sector. Whilst it is clearly in the sector plans, this question of who identifies, who owns, who delivers and who benefits from such a new data economy is unlikely to lie clearly within one domain. Note that such a data economy will not just consider passenger details, it will hold and transfer data on trains, rolling stock, locomotives, infrastructure, capacity, terminals, paths, cargos, shippers, receivers, operators of all kinds. It will contain mixtures of personal, commercial, safety critical and security sensitive data. It is unlikely to be stored or messaged in single data ontologies, for all that some called for that in workshops, some infrastructure data may be detailed in one of competing Building Information Management standards (ISO 19650:2019), rail freight operations may be managed using the Telematics Application for Freight TSI (TAF-TSI), but just as easily may be shared between legacy systems using Universal Business Language 2.x (ISO/IEC 19845:2015). The Smart-Rail ontology could be considered as a common unifying language and as input for standard development. This facilitates information systems within the rail sector ensuring connectivity of information systems relevant for rail users. It is as likely that in a liberal economy, that multiple standards will compete and that parsable messages between systems using semantic languages will be key .

Government was mentioned as a key partner in all workshops and given a relatively high weight for service and system, but low for freight. Except for the development for the system platform, it was not linked strongly to strongly weighted activities or resources. Perhaps the term was too broad, covering EU, national, regional, and local administrations; but it raises the question as to whether the transition can proceed with a light touch, save in ensuring that governance is sound.

Autonomy for trains or wagons was not given a high weighting in the service or system platform workshops but was considered key in the freight workshop. Virtual coupling, or the moving block train, was considered highly in both the system and freight platforms. Given that in mainline rail operations there is little need for interaction between rail and other modes, this suggests that the development of autonomy, be it automated train operation (ATO) or self-

organising trains of freight / passenger coaches / wagons, could be a rail mode development developed from ECTS/ERTMS and the Grade of Automation (GAO) classifications defined in IEC 62290-1. Autonomy is developing fast in urban road vehicles, cars, and delivery robots. Urban rail systems have the highest level of GAO automation so far. With congested space in cities, it is likely that soon there will be a need for an autonomous road vehicle to negotiate autonomously with an autonomous rail vehicle. This is a gap that has not been addressed yet by the rail sector and/or the road sector, which has different protocols and standards.

6. Conclusions

Based on this research work, we recommend to the Shift2Rail JU, it's successor, ERRAC, all stakeholders and the European Union that the rail sector should address these recommendations, in addition to the core plans already in the MAAP to achieve the Rail 2050 Vision and more.

- Focus on the solutions that deliver change, either as 'cost effective' and 'impact optimisation'
    - A - Real time network management (SPD 1, 2 and 4)
    - C - Reshaping rolling stock (SPD 2 and 4)
    - D - User oriented Door-to-door services (SPD 1, 2 & 4)
    - E - Smart sensing solutions (SPD 1)
- Deliver the activities that support viable business models for Railway 4.0
- Address the need for a new governance and fix the broken
    - Fix the Governance of Capacity
    - Plan the Governance and Transition for Urban Mobility in Smart Cities
    - Plan the Governance and Transition to an Integrated Data Economy for Mobility
    - Plan the Governance and Transition on Autonomy

Moving to user-oriented will inevitably mean becomes less rail-oriented, but this will apply to all actors and domains.

Acknowledgements

We acknowledge our colleagues on the Flex-Rail project who contributed: Marco Brambilla, Mark Robinson, Manfred Ninaus, Eleni Charonti, Jaco van Meijeren, Marco Gatto. Flex-Rail received funding from the European Union's Horizon 2020 programme under grant agreement No. 826189. The information and views set out in this article are those of the author(s) and do not necessarily reflect the official opinion of Shift2Rail Joint Undertaking (JU). The JU does not guarantee the accuracy of the data included in this article. Neither the JU nor any person acting on the JU's behalf may be held responsible for the use which may be made of the information contained therein. All public project deliverables and data are available at https://flex-rail.org/deliverables/.

References

Brown, J., Isaacs, D., World Café Community of Practice, 2005. The World Cafe Book: Shaping Our Futures Through Conversations that Matter. Berrett-Koehler Publisher.

Enrico Pastori, Marco Brambilla, Marco Laoreti, Werner Rothengatter, Simon Mader, Markus Himmelsbach, Sabine Langer, Ian Skinner, 2020. Support study: Evaluation of Regulation (EU) No 913/2010 of the European Parliament and of the Council of 22 September 2010 concerning a European rail network for competitive freight.

Haltuf, M., 2016. Transportation Research Procedia 14, 1819–1828.

Maczkovics, C., 2017. European Competition and Regulatory Law Review 1, 115–126.

Mazzino, N., Perez, X., Meuser, U., Santoro, R., Brennan, M., Schlaht, J., Chéron, C., Samson, H., Dauby, L., Furio, N., Hernandez, C., 2017. Rail 2050 Vision - Rail - the Backbone of Europe's Mobility. Brussels.

Osterwalder, A., Pigneur, Y., 2010. Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. John Wiley & Sons.

Shift2Rail, 2019. Multi-Annual Action Plan Part A and Part B. Brussels.

Zunder, T.H., Aditjandra, P.T., Islam, D.M.Z., 2012. Europe's freight transport policy White Paper 2001 to White Paper 2011, Proceedings of the 91st Annual Meeting of the Transportation Research Board. Transportation Research Board, Washington, DC.

Zunder, T.H., Carrillo, A., Robinson, M., Tardivo, A., Hassoun, C., Herranz, A., 2021. Consensus and Dissent for Rail Visions of 2050: Delphi Study and Paper: Ter4Rail D2.1 Final. Brussels.