Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2022) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Evaluation of the benefits of Functional Open Coupling of trains for railway undertakings and passengers

Filiz Kurt[a]*, Dr. Jürgen Ernst[b], Ruth Arregi[c]

[a]*Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Lilienthalplatz 7, 38108 Brunswick, Germany
[b]Deutsche Bahn AG, Richelstraße 3, 80634 Munich, Germany
[c]Construcciones y Auxiliar de Ferrocarriles S.A., José Miguel Iturrioz 26, 20200 Beasain, Spain

Abstract

Within the Shift2Rail (S2R) Joint Undertaking, technologies are developed to improve the future railway system. An important S2R innovation is "Functional Open Coupling" (FOC), an interoperable coupling of trains. Research on FOC is carried out in the S2R projects CONNECTA-1/2/3. With FOC it is possible to couple trains of different manufacturers, classes, and series as it is not possible today due to different control and electrical coupling parameters. To assess the overall impact of S2R innovations such as FOC on the railway system, an integrated methodology using key performance indicators (KPI) is developed in the cross-cutting activity Project IMPACT-2. The cooperation of the two S2R projects made it possible to conduct an in-depth analysis of the potential impact of FOC on three KPI (“life cycle costs”, “capacity” and “customer satisfaction”).

Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference
Keywords: Functional Open Coupling; Impact assessment; Standardisation; Shift2Rail; Key Performance Indicators; Ex ante evaluation

1. Introduction

The focus of the European Joint Undertaking of railway industry operators and research institutions Shift2Rail (S2R) is to transform and enhance the European railway system through innovative rail technologies [1]. Thereby, S2R has the objective to double the capacity of the European railway system, to increase its punctuality and service quality by 50% as well as to halve the life cycle costs (LCC) [2]. Targeting this objective, different technologies (hereafter called: S2R-innovations) are developed, demonstrated and evaluated in more than 40 projects in S2R. In

* Corresponding author. Tel.: +49-531-295-1092; fax: +49-531-295-3402.
E-mail address: filiz.kurt@dlr.de

Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference

order to assess the overall impact of all S2R-innovations on the railway system, an integrated methodology using key performance indicators (KPI) has been developed and implemented within the project IMPACT-2 [3].

IMPACT-2 aims to evaluate the achievement of the S2R objectives in terms of the KPI LCC, capacity, punctuality as well as customer satisfaction, once the S2R-innovations have been implemented [4]. One such technology that is assessed in IMPACT-2 is the so-called Functional Open Coupling (FOC). The research on FOC has started in the CONNECTA-1 project [5] and continued in CONNECTA-2 [6] and CONNECTA-3 [7] as an innovative railway solution of data interfaces between coupled trains. FOC provides the possibility to couple trains from different train manufacturers, classes, and series, as it is not possible today due to different control and electrical coupling parameters for each train manufacturer and vehicle type [8]. Through the collaboration of both S2R projects, an in-depth analysis of the expected benefits of FOC for railway operators and passengers is carried out. This paper will present the results of the analysis on the potential impact of FOC based on three KPI ("LCC", "capacity" and "customer satisfaction").

2. Effects of Functional Open Coupling on Life Cycle Cost

For passenger transport, most railway undertakings buy trains for a specific service or a specific line in order to cover a specific tender. Besides the trains needed for the regular service or line, additional so-called reserve trains need to be purchased, too. These reserve trains are for instance needed in case of a train breakdown or in cases when trains are in maintenance shop for longer than a nightshift. As trains from different manufacturers or classes are currently not compatible in terms of coupling due to different control and electrical coupling parameters, it is not possible to operate with reserve trains from other lines if these need to be coupled or shared. As FOC enables such interoperable coupling across different manufacturers, classes, and series, the number of reserve trains needed for two or more adjacent lines in the same service area can be reduced [9].

2.1. Methodology for Estimating the Fleet Size Reduction through Functional Open Coupling

In order to determine the potential impact of FOC on fleet size reduction, the number of trains required for one turnaround in a regular operation of a service for different adjacent lines with different tenders is determined as a first step, see Figure 1. Today for every line trains of different manufacturers or train classes are purchased („Original service of Railway Undertakings “). In the second step, the fleet size is determined in which trains of different manufacturers or train classes cannot be coupled with each other ("fleet size without FOC"). Besides the trains required for regular operation, reserve trains are determined, planned by railway undertakings on the one hand as operational reserve in case of train failures or when trains become unavailable and on the other hand as maintenance reserve. In general, 15% or at least two reserve trains are taken as a basis, depending on the number of trains of each manufacturer. Finally, the fleet size resulting through the use of FOC is determined ("fleet size with FOC"). The number of reserve

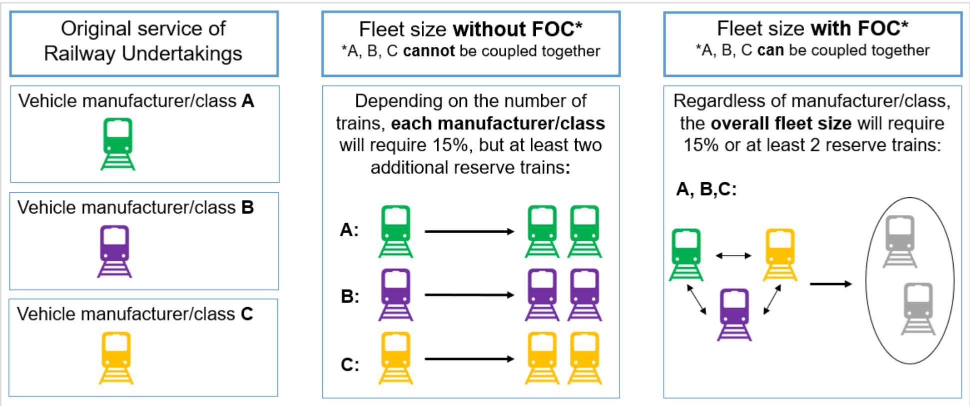

Figure 1: Methodology for estimating fleet size reduction through Functional Open Coupling in Shift2Rail

trains is calculated based on the number of trains required for regular operation with 15% or at least two additional reserve trains, but not for each manufacturer or each vehicle type, but for the entire fleet of the railway undertaking. As a result, the LCC of the railway undertaking will decrease as the number of reserve trains can be lower.

2.2. Reserve Train Reduction through Functional Open Coupling

As shown in Figure 2 for the S2R **High Speed scenario**, it is assumed that eight trains of three different manufacturers are the bases or a part of the original service, i.e. a total of 24 trains for regular operation. Without FOC, reserve trains of 15% are additionally considered for each manufacturer, but at least 2 reserve trains, resulting in a total of 6 required reserve trains, 2 per manufacturer. With FOC, 15% reserve trains are to be considered regardless of the manufacturer. Accordingly, with FOC only 4 instead of 6 reserve trains are required for the regular operation of 24 trains. That represents a fleet size reduction of 2 trains or -7% i.e. a reduction in the number of required reserve trains of -33%.

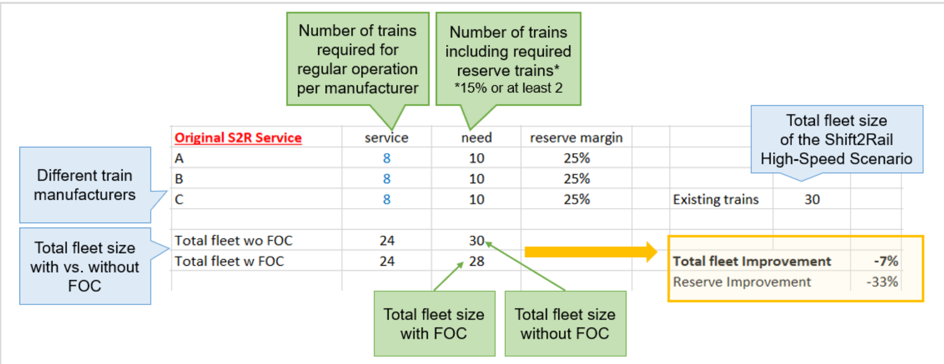

Figure 2: Estimation of reserve train reduction through Functional Open Coupling for the Shift2Rail High-Speed Scenario

For S2R Regional scenario, a total fleet of 24 trains is assumed, divided among three different train manufacturers. Each manufacturer is assumed to have 6 trains for regular operation plus 2 additional reserve trains. Hence, with no FOC, a total of 18 trains are required for regular operation plus 6 reserve trains. Comparatively, with FOC, only 3 reserve trains are required. Thus, a reduction of the fleet size of -13% (21 instead of 24 trains) or a reduction of -50% in the number of reserve trains (3 instead of 6 reserve trains) is achieved.

2.3. Service Extension through Functional Open Coupling

Generally, railway undertakings acquire a certain number of trains for a line, based on the expected number of passengers travelling on that line. After some years, the number of passengers often increases so that new trains have to be acquired. In such cases, railway undertakings need to ensure that the new trains can be coupled with the old trains if coupling and sharing is required for operation. For railway undertakings not using FOCs, the consequence is that either only same vehicle types can be ordered which leads to a high price due to a limited number of trains and competition being excluded. Or additional trains can be ordered which are not able to be coupled with the old ones. However, in both cases more trains have to be ordered, which would mean a worse turnaround and more reserve trains. By using FOC, railway undertakings have the possibility to acquire additional trains competitively and to combine the trains for other services. Thereby, the train prices are reduced and less reserve trains, if any, are needed. Using the S2R Regional scenario the regular operation is extended by the acquisition of 21 additional trains of a further manufacturer, see Figure 3. According to the 15% or minimum 2 reserve trains requirement, without FOC an additional 4 reserve trains are needed to cover the 21 trains. In total, 25 trains need to be acquired in order to extend the service, resulting in a total fleet size of 49 trains. With FOC, no additional reserve trains are required for acquiring 21 trains from its manufacturer. Thus, for service extension FOC leads to a reduction of the fleet size from 49 trains (without FOC) to 45 trains (with FOC), which represents a fleet size reduction of -8%.

Considering the acquisition of 21 additional trains for service extension in the S2R High-Speed scenario, FOC results in a fleet size reduction from 55 trains per fleet (without FOC) to 52 trains per fleet (with FOC), representing a fleet size reduction of -5%. satisfaction".

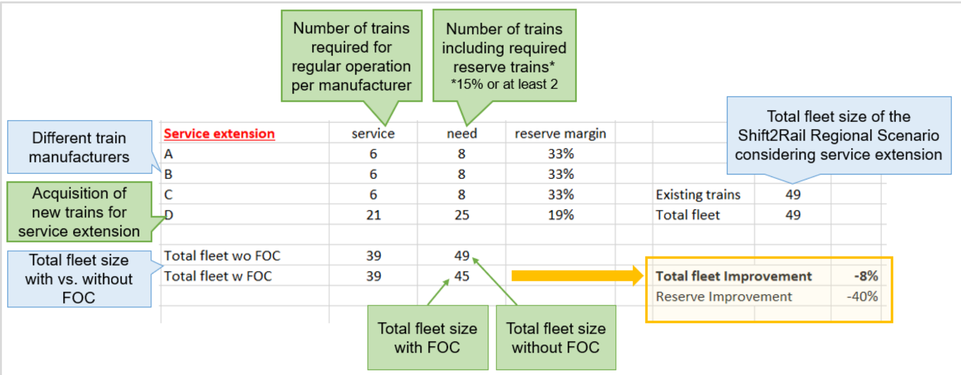

Figure 3: Estimation of the effects of Functional Open Coupling for a service extension in the Shift2Rail Regional Scenario

2.4. Use of Retrofitted Trains with Functional Open Coupling

Tenders for regional transport usually have an operating period of 10 years. By not winning the subsequent tender, railway undertaking may no longer run the trains, even if they technically could run for another 10 years or more. Often it is not possible to use these trains for a different service as a higher number of trains would be needed. As a result, trains have to be written off, leading to capital losses for railway undertakings. As these trains have FOC capability, it would be possible to use the refurbished trains for another service or line by combining them with new trains and/or refurbished trains from another line. As these trains could technically run for up to 20 years, only the interior equipment would need to be renewed. By using refurbished trains, the costs for new tenders can be significantly reduced. However, this possibility of reducing the fleet size through FOC is not considered in the framework of S2R.

3. Effects of Functional Open Coupling on Capacity

To fulfil the target of the European Green Deal there is the objective in many European countries to double the modal share of rail transport. However, this is only possible if the capacity of lines and nodes is increased. Here FOC can contribute a lot. Capacity bottleneck for passenger traffic are mainly located in densely populated areas and high utilised stations and lines. These are also the areas with increasing traffic volume in the future. Measures for increasing capacity should increase the capacity of these stations and lines. The maximum capacity in railway nodes and main stations is limited by the number and length of the platforms in the main station, the train length, and the number of trains per hour on the lines serving the main station. In general, capacity improvements cannot be implemented by increasing the number of platforms in main stations due to adjacent buildings and infrastructure. However, in order to achieve capacity improvements, it is possible to increase the utilization of the platform length.

Most large main stations generally provide a standardised TSI platform length of a maximum of 400 m, which is well utilized for high-speed trains. But as regional trains usually have a length of 50 to 200 m, limited by the platform length in the region, optimisation potential for platform use becomes apparent in regional traffic, as the platform utilisation for regional trains of main station is less than 50 %. But it can be increased by coupled trains at the main station and splitting the trains in the suburbs leading to different destinations, see Figure 4. Although this is already common practice in many areas, up to now the coupling of trains is limited to trains of the same manufacturer, classes, series, and operator. This can be widened to different trains if the coupling interfaces and related functions are standardised by means of FOC. FOC even enables the introduction of additional regional connections through the coupling of electric trains with future battery or hydrogen trains on non-electrified lines.

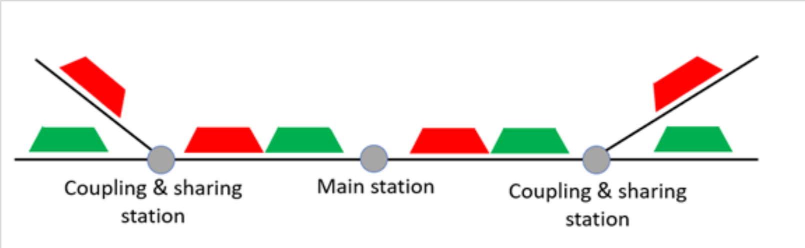

Figure 4: Coupling and sharing of trains

In order to estimate the possible capacity increase through FOC due to coupling and sharing of trains some exemplary large nodes in Germany with capacity bottleneck are analysed [9]. Figure 5 represents the example of Frankfurt which has enough (long) platforms, but capacity constraints on train paths. Instead of using many short trains entering and leaving Frankfurt, many trains can be coupled to increase the capacity, e.g. running two coupled trains between Frankfurt and Mainz and split them in Mainz for their destinations Saarbrucken and Koblenz. In this case electrical train (black) has to be coupled with a battery or hydrogen train (green) since the line to Saarbrucken is not electrified.

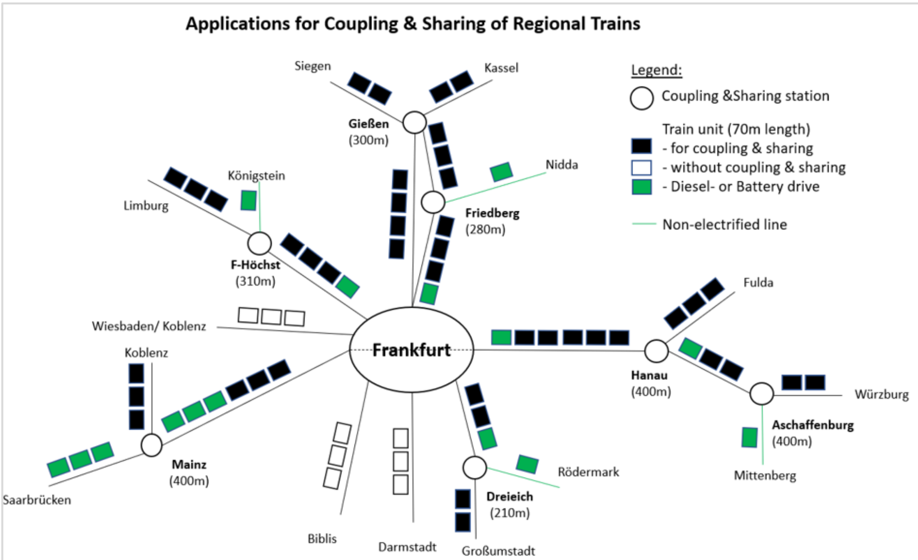

Figure 5: Application for coupling and sharing of regional train through Functional Open Coupling

The possible increase in train length / number of coupled train units mainly depends on the length of the suburban coupling and sharing station as well as stations between the main station and the coupling and sharing station. For calculation of the possible capacity increase of nodes the following methodology is used, see Table 1:

1. Determining the number of trains per hour departing at a node today (sum of all destinations) based on today's timetable
2. Identification of destinations/ lines where coupling& sharing can be applied (e.g. Frankfurt – Mainz – Koblenz/Saarbrucken)
3. Determining the train length today as the number of train units with a length of 70m

4. Determining the train length in the future by applying coupling and sharing while keeping the number of trains per hour constant
5. Calculation of the number of train units per hour today and in the future
6. The quotient is the improvement in capacity

Table 1: Exemplary analysis of the capacity increase for one destination/ line

Coupling & sharing station	Traffic segment	Destination	No of trains per h		No of train units per train			No of train units per h		Capacity increase [%]			Train units with shorter intervals
			Today	Tomorrow	Today	Tomorrow		Today	Tomorrow	Total	Regional	High speed	
Mainz	R	Koblenz	1	2	3	3	6	3	12	100	100		3
		Saarbrucken	1		3	3		3					3

The results for the possible increase in capacity for the three nodes are shown in Table 2. The average possible increase for regional traffic is 46 % which is quite high. If high speed lines are also considered the overall capacity increase is about 20 %. However, as the analysis of capacity increase through FOC has been carried out using exemplary major nodes in Germany, an estimation of nodes in other European countries should be carried out to validate the results for the European application.

Table 2: Estimation of the potential capacity increase in large German main stations

Main Station	Possible Capacity increase [%]	
	Regional	Total
Hamburg	64	33
Frankfurt	91	35
Hannover	28	13
Cologne	0	0
Average	**46**	**20**

4. Effects of increased Capacity through FOC on Customer Satisfaction

For reaching the target of doubling the modal share of rail it is important to achieve benefits for customers. Here FOC can contribute on the one hand to more direct connections due to coupling of electrical and diesel trains and on the other hand to shorter train intervals for regional destinations. These effects were analysed for the exemplary nodes above [9]. The following methodology was used, where step 1 and 2 are identical for the capacity calculation before:

1. Determining the number of trains per hour departing at a node today for every destination based on today's timetable
2. Identification of destinations/ lines where coupling& sharing can be applied
3. For these destinations/ lines the train interval can be halved
4. Adding the number of lines and train units with halved intervals (last column in Table 1)
5. Calculation of the improvement with respect to shorter train intervals as the quotient of the sum of the destinations with reduced intervals by the total number of destinations

The results are shown in Table 3.

Table 3: Estimation of the potential benefits for customers through Functional Open Coupling in large German main stations

Main Station	Regional trains with shorter intervals [%]	Additional direct regional connections [%]
Hamburg	55	18
Frankfurt	91	3
Hannover	28	0
Cologne	0	0
Average	**43**	**5**

The number of trains with shorter intervals (mainly 2 trains/h instead of 1 train/h) can be increased by 43% (in average) and the number of additional direct connections (without interchanging) can be increased by 5% (in average). As a result of the increase in the number of trains per hour, operators can provide more frequent connections, thus providing an improved service and more passenger seats on that destination. These mentioned points will have a positive impact on the customer satisfaction, which will lead to an increase in the number of passengers travelling by train and subsequently to an increase in the modal split. Further analyses carried out within the S2R project PINTA3 verified the described results on capacity increase through FOC by means of additional direct connections in Germany due to the coupling of electrical and battery trains [10]. Further studies are being carried out in the project "Coupling ability of regional trains" from the German Centre for Rail Traffic Research (DZSF) [11].

5. Conclusion and Future work

The cooperation of both S2R projects made it possible to analyse the benefits of FOC both from the operator's and the passenger's point of view. As a result of the analysis, it was found that FOC will lead to a reduction of LCC based on reduced fleet size due to the reduction of reserve trains. Moreover, it became clear that FOC will contribute to an optimised platform utilisation, especially for regional trains, resulting in an increased capacity, particularly in large nodes of densely urban areas. Due to the capacity increase, positive effects on passenger experience of railway use were also found, leading to an increase in the number of passengers travelling by train and thus to an increase in the modal split. Hence, FOC plays a major role in the coupling of trains across different manufacturers, classes and series. However, this requires standardised coupling interfaces. The topic of standardisation has already started within the framework of the Europe-wide Shift2Rail initiative in the CONNECTA-1/2/3 projects for several vehicle modules, such as Heating, Ventilation and Air Conditioning (HVAC), brakes and traction. However, the research has to be continued for further vehicle modules in the follow-up projects of the European Rail Joint Undertaking. Accordingly, it is essential to share the research on FOC with other decision makers in the railway sector worldwide and to invite railway companies and industry as well as governmental institutions for regional tenders to participate in the development of FOC.

Acknowledgements

The projects IMPACT-2 has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No 777513. Also, the project CONNECTA-2 has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No 826098. The JU receives support from the European Union's Horizon 2020 research and innovation program and the Shift2Rail JU members other than the Union.

References

[1] Shift2Rail Joint Undertaking, "About Shift2Rail," 2022. [Online]. Available: https://shift2rail.org/about-shift2rail/. [Accessed 01 April 2022].

[2] Shift2Rail Joint Undertaking, "Shift2Rail Strategic Masterplan," 24 September 2014. [Online]. Available: https://shift2rail.org/wpcontent/uploads/2021/06/Shift2Rail-Master-Plan_approved-by-S2R-GB.pdf. [Accessed 01 April 2022].

[3] Shift2Rail Joint Undertaking, “IMPACT-2,” 2017-2022. [Online]. Available: https://projects.shift2rail.org/s2r_ipcc_n.aspx?p=IMPACT-2. [Accessed 05 April 2022].

[4] Shift2Rail Joint Undertaking , “Multi Annual Action Plan,” 14 November 2019. [Online]. Available: https://shift2rail.org/wpcontent/uploads/2020/09/MAAP-Part-A-and-B.pdf. [Accessed 01 April 2022].

[5] Shift2Rail Joint Undertaking, “CONNECTA-1,” 2016-2018. [Online]. Available: https://projects.shift2rail.org/s2r_ip1_n.aspx?p=CONNECTA. [Accessed 05 April 2022].

[6] Shift2Rail Joint Undertaking, “CONNECTA-2,” 2018-2021. [Online]. Available: https://projects.shift2rail.org/s2r_ip1_n.aspx?p=CONNECTA-2. [Accessed 05 April 2022].

[7] Shift2Rail Joint Undertaking, “CONNECTA-3,” 2020-2023. [Online]. Available: https://projects.shift2rail.org/s2r_ip1_n.aspx?p=CONNECTA-3. [Accessed 05 April 2021].

[8] CONNECTA-2, “Joint Final Conference CONNECTA & Safe4RAIL,” 26 September 2018. [Online]. Available: file:///C:/Users/kurt_fi/Downloads/CTA-WEB-B-CAF-012-01_-_Final_Conference_Presentation.pdf. [Accessed 05 April 2022].

[9] CONNECTA-2, “Deliverable 8.3 "KPI Assessment",2021.

[10] Shift2Rail Joint Undertaking, “PINTA3,” 2020-2023. [Online]. Available: https://projects.shift2rail.org/s2r_ip1_n.aspx?p=PINTA3. [Accessed 05 April 2022].

[11] Deutsches Zentrum für Schienenverkehrsforschung (DZSF), “Kuppelbarkeit von Fahrzeugen des SPNV,” 24 März 2022. [Online]. Available: https://www.dzsf.bund.de/SharedDocs/Standardartikel/DZSF/Projekte/Projekt_99_Kuppelbarkeit.html. [Accessed 05 April 2022].