Complex Systems Informatics and Modeling Quarterly (CSIMQ)
eISSN: 2255-9922
Published online by RTU Press, https://csimq-journals.rtu.lv
Article 189, Issue 34, March/April 2023, Pages 62–83
https://doi.org/10.7250/csimq.2023-34.03

Enterprise Architecture for Integration of Demand-Responsive Services in Public Transport

Mark-Oliver Würtz[1, 2 *] and Kurt Sandkuhl[1, 3]

[1] University of Rostock, Albert-Einstein-Str. 22, 18059 Rostock, Germany
[2] Jellyco GmbH, Am Fuchsberg 45, 28816 Stuhr, Germany
[3] Jönköping University, Box 1026, 55111 Jönköping, Sweden

mark-oliver.wuertz@uni-rostock.de, kurt.sandkuhl@uni-rostock.de

Abstract. The popularity of new mobility services (NMS), like car sharing, urban bikes or e-scooters, is increasing in many urban areas. In comparison to traditional supply-oriented public transport with defined timetables and transportation routes, NMS are demand-responsive services aiming to meet the ad-hoc needs of users. NMS have started to influence the way people move in urban areas, and they also have an impact on public transport operators which begin to offer their own NMS or integrate the services of established NMS operators. This article investigates the changes implied by NMS for the enterprise architecture (EA) of public transport operators. The paper presents and evaluates an EA approach for integrating demand-responsive services into traditional supply-oriented public transport. We propose a partial enterprise architecture as an extension of the established ITVU core model, which is an established reference model in the public transportation domain. Although EA management is recognised as relevant for public transport companies, there is a lack of such an extension addressing NMS integration. The contribution of this article are to (1) offer an overview of the state of research in enterprise architectures for public transport, (2) make a case study for illustrating the challenges and requirements of NMS integration, (3) provide a first version of the partial (core) reference EA for integration of NMS including an initial evaluation.
Keywords: Enterprise Architecture, New Mobility Services, Public Transport, Reference Enterprise Architecture, Demand-Responsive Service, Supply-Oriented Transport, Supply-Oriented Public Transport, Demand-Oriented Public Transport.

* Corresponding author

Reference: M.-O. Würtz and K. Sandkuhl, "Enterprise Architecture for Integration of Demand-Responsive Services in Public Transport," Complex Systems Informatics and Modeling Quarterly, CSIMQ, no. 34, pp. 62–83, 2023. Available: https://doi.org/10.7250/csimq.2023-34.03

Additional information. Author ORCID iD: M.-O. Würtz – https://orcid.org/0000-0003-3873-4619, K. Sandkuhl – https://orcid.org/0000-0002-7431-8412. PII S225599222300189X. Received: 20 February 2023. Revised: 20 April 2023. Accepted: 22 April 2023. Available online: 30 April 2023.

1 Introduction

The popularity of new or innovative mobility services (NMS) is increasing in many urban and metropolitan areas. NMS include, for instance, vehicle-sharing services such as car, bike or e-scooter sharing, or on-demand ridesharing services, such as shared taxi rides. Furthermore, mobility solutions are also offered in larger cities in pay-as-you-go or subscription models. This influences the way people move within short -last mile- and medium distances in urban areas [1]. NMS have been the subject of research, e.g. in terms of new architectures [2], business models [3], platforms [4] acceptance by end users [1] or required standards. However, the way new mobility solutions affect public transport companies and in particular the architecture of a company has hardly been researched so far.

In comparison to traditional supply-oriented public transport with defined timetables and transportation routes, NMS are demand-responsive services aiming to meet the ad-hoc needs of users. Public transport operators which begin to offer their own NMS or cooperate with established NMS operators faced the challenge of adapting their processes (e.g., for payment, service planning, logistics, or operational control), organizational structure, and information systems landscape (cf. Subsections 3.3 and 4). The aim of this article[†] is to investigate the integration of demand-responsive transport into classic public transport companies by elaborating required extensions of established architectural approaches in public transport. More preciseely, we base the extension on the ITVU core model, which is the recognised reference model in the German-speaking public transport sector. Our extension can be considered as partial enterprise architecture for NMS including the required connection to the established reference architecture. From a research perspective, this extension is a template solution for the public transport domain how to integrate NMS into enterprise architectures. It provides an additional "building block" for the established reference model (ITVU core), i.e., it also has to show the features of a reference model. The extension is the result of a design science research process (see Section 2) and manifested in ArchiMate models (see Sections 3 and 4).

In the course of this article, we focus on the presentation of our new enterprise architecture (EA) extension in the area of traffic planning. More precisely, we developed an EA model in ArchiMate that extends the ITVU core model with regard to:

a. connections between the strategic and motivational levels.
b. the business and application level.
c. the link between the strategic and motivational level (a.) and business/application level (b.).

The EA model is evaluated using general quality characteristics, expert interviews and general requirements of reference EA models.

The contributions of this article are (1) offering an overview of the state of research in enterprise architectures for public transport, (2) a case study for illustrating the challenges and requirements of NMS integration, (3) a first version of the reference EA for integration of NMS, and (4) an initial evaluation of this new EA.

The article is structured as follows: Section 2 introduces the research methodology used in the article. Section 3 discusses the relevant background and related works, including established architecture approaches in public transport. Section 4 presents a case study showing the requirements and challenges of NMS integration. Section 5 introduces our EA extension of the ITVU core model for integrating demand-responsive services. Section 6 presents an initial evaluation of the EA extension. Section 7 offers a summary as well as a look ahead at future work.

[†] This article is a revised and extended version of M.-O. Würtz and K. Sandkuhl "A Target Enterprise Architecture Approach for New Mobility Services in Demand-Responsive Public Transport," *Joint Proceedings of the BIR 2022 Workshops and Doctoral Consortium (BIR-WS 2022)*, Rostock, Germany, September 20-23, 2022. CEUR-WS proceedings, vol. 3223, 2022. Available: http://ceur-ws.org/Vol-3223/" (see the Section on research approach.). The extension primarily concerns the level of detail of the presented partial enterprise architecture, related work, the research and development process, and the relation to existing reference models.

2 Research Approach

The work presented in this article is part of a research programme that is aimed at developing methodical and technological support for the integration of demand-responsive services into supply-oriented public transport. The envisioned result is a partial reference enterprise architecture for NMS that can be used by traditional supply-oriented public transport companies as an instrument to facilitate the integration of demand-responsive services.

The overall research programme follows the paradigm of design science research (DSR) [5]. Within the DSR process, this study concerns the explication of the problem, the creation of the design artefact, and its initial evaluation. The main design artefact is an EA model of the extensions to traditional public transport EAs required for NMS on the motivational, business, and application architecture levels. The research presented in this article began with the following research question (RQ) based on the motivation presented in Section 1:

RQ: What requirements does a reference enterprise architecture for the integration of demand-responsive services into a traditional public transport company have to fulfil and how should the business and application architecture be designed?

The research method used to answer this research question is a combination of literature review, case study research and conceptual-deductive work. Starting with a literature review, relevant publications were identified (see Subsection 3.2), such as the (already outdated) ITVU core model [6], [7], which is a de facto industry standard for supply-oriented public transport, the VDV publication 7046 ("User requirements for an open mobility platform [8]"), and expert publications, e.g., [9], [10], and [11], which were analysed.

Furthermore, the NMS BerlKönig and its integration into the Berlin public transport was used as a case study to investigate requirements and challenges (see Subsection 3.3). More information about the case study including the case study methodology is available in [12]. Based on the requirements and literature review, the design of the NMS-ready EA model was begun, which forms the conceptual-deductive part of our work. The extended architecture was modelled on the basis of ArchiMate. The aim of this work is not to compare the established ITVU with our new architecture, but to model and present an extension of the established architecture. One challenge in the creation of this new EA was to consolidate the various approaches in different modelling forms and to model them anew and extended in ArchiMate. The practical modelling work focuses on the administration-oriented areas of the provision of services by public transport companies. The emphasis is on the interaction between the specialised departments and the use of IT. In Section 5, the most important components of an overall architecture are presented first. Based on this, we examine the area of transport planning.

Based on the results from the extended enterprise architecture, we argue that an integration of demand-driven transport (esp. NMS)—based on the strategic requirements—is efficiently possible on the basis of a reference EA.

Table 1 gives an overview of the information contained in the course of the research project. It is arranged according to the phases of the DSR process and contains the research activity, the results achieved, and references to the respective section in the article and to the respective previous work.

Table 1. Research activities performed in DSR phases and their results

DSR Phase	Research activity	Result	Section
Problem Investigation	Literature analysis to determine the state of research and existing reference architectures.	Determination of the state of research and identification of basic reference architectures.	3.2 [12], [13]
	Expert interview with the CIO of the largest public transport company in the German-speaking world.	Confirmation of the business need for a demand (NMS) responsive reference architecture for public transport.	3.1 [12]
Define Requirements	Argumentative-deductive work to derive requirements from results of problem investigation	Requirements based on a case study	4.2 + 4.3 [13], [14]
Design and develop Artifact	Conceptual-deductive work on the design of an extended reference architecture based on ArchiMate.	Reference architecture, illustrated in depth using the example of transport planning.	5ff [15]
Demonstrate	Application of the reference model	Community of users of the reference model	Not covered in this work/Future work.
Evalute Artifact	Survey among experts who want to use the reference model.	Relevance for practice confirmed; potential for improvement of the developed artefact (reference model).	Partially covered in Section 6

3 Background and Related Works

3.1 Previous Works

In previous works, we primarily focused on the business relevance of NMS integration into public transport, on identifying relevant literature, and on identifying challenges and requirements from local and global practice.

In the first step, the topic and its terminology were explained via a literature review, the problem was outlined, and three hypotheses were used to confirm the need for integration of demand-responsive local public transport in the form of New Mobility Services (NMS) into the corporate architecture of classic transport companies as well as the scientific relevance of the topic. An extensive interview with the IT manager of Germany's largest public transport company, *Berliner Verkehrsbetriebe* (BVG) served as the main data source for the practical part [16], [12].

As a second step, the expected impact on the enterprise architecture was investigated, based on the selected example of the ticketing area. The aim of that paper was to further investigate the state of research as well as the relevance of the topic and the characteristics of the problem. The key question was how new mobility solutions affect the EA of public transport organisations. The main conclusion of the interview study was that public transport companies, from the perspective of the interviewees, can only survive in the long term if they themselves are able to integrate mobility platforms into the company and manage them. Hereby, it does not matter whether they operate the platform themselves or have it operated by third-party service providers. What is important is that the “ownership” is secured for the public transport companies. In order to achieve this goal, classic public transport companies should know what a possible target architecture for mobility platforms would ideally look like, which processes are associated with it, and how they can design the interfaces, products and services so openly that other mobility system providers can join in at any time. [13]

In the third step, the authors explored the need for recommending a standardised approach for the integration of NMS into the enterprise architecture of public transport companies. This should be done via a reference architecture, which offers such recommendations. The analysis of existing works showed that established reference architectures do not sufficiently consider NMS. Therefore, the focus of the third step was to investigate (a) the feasibility of an extension of the reference architectures for public transport and (b) the integration capability of NMS using an existing ride-pooling or on-demand ridesharing service, the BerlKönig service of the *Berliner Verkehrsbetriebe AöR* (BVG) [14]. The investigation of the integration of the sales/tariff management of the BerlKönig showed that this task is solvable. It turned out that the functional blocks examined were fulfilled comprehensively by *BVG* partner companies – here *ViaVan*. Hereby, it turned out that the partner company supported *BVG* in all points of the central value chain at a very low degree of IT integration.

During the previous work, the requirements were identified and considered in the artefact presented here.

The central functional and non-functional requirements for an NMS-considering core enterprise architecture are listed in the Table 2 and examined later in the context of the architecture. Only those requirements are listed that should also be reflected in the model.

Table 2. Functional requirements (A)

A. NMS	New Mobility Service requirements must be considered by the architecture. In the following sub-items (A) the main requirements are listed in order of the main core processes:
A.1 Planning	All planning (sub-) processes must be expanded to include demand-oriented components. Specifically, planning for demand-responsive transport and deployment planning for the NMS must be introduced and duty scheduling expanded accordingly.
A.2 Use of resources	The classic deployment of resources must be expanded to include the component of demand-oriented deployment of means of transport. In doing so, vehicle and personnel scheduling must be expanded to include the demand-oriented deployment of resources.
A.3 Tariff and Product Management	The area of fare and product management must be expanded to include “journey and rental design”, which shapes the demand-oriented transport charge design. In addition, the results from this new area must be incorporated into the product catalogue design and expanded with the offer-oriented fare data.
A.4 Operational steering	The traffic control section, which supports the control centres, must be expanded and developed so that it can optimally support demand-responsive local passenger transport (NMS).
A.5 Distribution	Distribution must be expanded to serve demand-responsive services (NMS) in addition to supply-oriented local passenger transport. The following processes and systems must therefore be functionally expanded: - Travel information/planning, - Booking, and - Settlement.
A.6 Digital platform	As an extension, a central and integrative platform must be provided in the sales area to handle the sales of the New Mobility Services, which optimally supports the requirements from A.5. This requirement must be optimally designed for the user – a perfect customer journey must be guaranteed.

In addition, the non-functional requirements for a reference enterprise architecture that takes into account demand-responsive local public transport (NMS) for a traditional public transport company are listed in Table 3. These criteria, based on [17], are also used in Section 6 for a first evaluation of the initially created enterprise architecture solution.

Other non-functional requirements for the enterprise architecture, such as reliability, reusability of components, monitoring, testing, and logging, as well as security, which are not the focus of the elaboration and were not explicitly considered in the development of the enterprise architecture, can be repected due to the intended open modularity of the enterprise architecture.

Table 3. Non-functional requirements for the enterprise architecture (B)

B.1 Platform independence	The EA must be designed as an extension of a reference architecture extensions hardware and software independent.
B.2 Scalability	The enterprise architecture must "fit" for different company sizes - therefore the architecture must have a high scalability.
B.3 Flexibility	The reference EA must be flexible and quickly adaptable for the rapidly changing market of demand-responsive local passenger transport (NMS).
B.4 Reusability of components	The enterprise architecture should support the reusability of architecture components along the process flow.
B.6 Interoperability	When developing the architecture, attention should be paid to interoperability encapsulated by interfaces and service.
B.7 Simplification	The enterprise architecture should be easy to understand and quickly comprehensible for public transport experts.

A classic public transport company can act on the market as a pure mobility service provider or, additionally, as an operator of NMS. It is be difficult to envision that the public providers, most of which are public transport companies in Germany, will only have the role of a classic mobility service provider in the future [16].

In our case, we consider a public transport company that represents or would like to represent the combination of a classic mobility service provider and (demand-oriented public transport) NMS operator. Here we primarily mean that the operation of NMS primarily refers to the support and the "technical operation" as core processes. The technical operation can be carried out internally with own resources or externally by a full-service provider. Even if the operation is carried out by an (external) full-service provider, the the public transport company must know what the (technical) architecture looks like in order to be able to successfully integrate it into an existing architecture landscape.

3.2 Related Research

The search for relevant literature on the topic was mainly done via Google Scholar. The topic includes books and articles from the field of regional public transport (RPT) and Enterprise Architecture Management, which were published internationally – mainly in English. In addition, there are recent publications from the area of "New Mobility Services" (NMS), "Mobility Platform" and "Mobility as a Service" (MaaS), which partly overlap with each other.

At the beginning of the research, the authors relied on the publication by Scholz "IT-Systems in for Public Transport Companies" [18], which contains the industry model (domain model) ITTC Core Model (ITVU) for public transport. This model describes business processes and fundamental data structures (classes), which are represented in packages (building blocks) and explained in their mode of operation.

In order to show for how long the discussion about "New Mobility Services" (NMS) has been going on, the authors have checked the sources for older publications on this topic and found the following: the debate on the substitution of inefficient passenger transport systems such as the car by other forms of transport, is as old as the car itself. It should be emphasized that the authors Heinze and Kill in their recommendation for action "Sustainable strategies for public transport in Berlin-Brandenburg" [19] in 1994 and the authors Beutler and Brackmann in their working paper "New mobility concepts in Germany: ecological, social and economic perspectives" [20] in 1999 already discussed all the same topics that are still being discussed today – more than 20 years later – in the same form, with the exception of a few technological components such as autonomous driving and air travel taxis. It should further be emphasized that in the publication by Beutler and Brackmann, the two areas of mobility management software (information) and mobility management hardware (transport systems) are already divided. A comparable discussion still exists today, whereby this discussion is divided into new transport systems and platform services (customer information).

In addition to the discussion of NMS, products based on new technologies have emerged that follow the “Mobility as a Service” (MaaS) approach. The focus for the customer is no longer on the means of transport and its provider, but on the service itself, in order to get from A to B quickly and cost-effectively. In some cities, this has now gone so far that customers can plan, book and pay for a trip from their front door to the front door of their destination. In 2016, this mobility integration was critically assessed in a review paper by the authors Kamargianni, Li, Matyas, and Schäfer entitled “A critical review of new mobility services for urban transport” [1]. This paper concluded that MaaS is a “...promising mobility solution and is expected to make a significant contribution to future urban reform” [3].

Finally, the sustainability of new mobility services should be mentioned in the technical analysis of the topic. Here, the authors Hildebrandt et al., 2015 have outlined a business model that is as sustainable as possible, using a car sharing service as an example [3]. The aim of the paper was to reconcile economic and ecological aspects in an alternative business model. Another publication that points in the same direction is the 2017 paper “Smart mobility and smart environment in the Spanish cities” [21] by the authors Aletà, Alonso, and Ruiz.

As a second step, after the classification of NMS, MaaS and Mobility Platform, the IT-relevant topics related to Enterprise Architecture Management were examined in the technical discussion, with the following publications being particularly notable in the context of the work. Pflüger et al. outlines in his 2016 concept paper “A concept for the architecture of an open platform for modular mobility services in the smart city” [2] the architecture of an open and modular service platform for mobile services in a future smart city. The paper concludes that the provision of data and services for the operation of mobility services will trigger even more innovation among mobility service providers. Another article from 2013 deals with a part of NMS, namely with the parking of cars in urban environments [22] and the possible control options in a modern mobility concept. This text is limited exclusively to parking in urban areas.

Yet another publication from 2015 deals with an intelligent mobility platform [23], which uses a map-based platform as its core component. In one project, an architecture was developed which is able to collect, update and process heterogeneous information and real-time data from different sources and actors in order to optimize the offers made to the users of public transport. The publication that comes closest to the topic is from 2017 by the authors Levina, Dubgorn, and Iliashenko with the title: “Internet of Things within the Service Architecture of Intelligent Transport Systems” [24]. The text discusses an enterprise architecture for the St. Petersburg situation center based on IoT technology. This paper is primarily concerned with monitoring traffic and road users and mostly refers to IT components rather than business processes that would have to be established.

In addition, the authors were able to research some articles in Chinese publications, but only the title and the abstract were accessible. Among them are the following articles listed by their titles:

- Research on the Architecture and Implementary Scheme of Intelligent Public Transportation System in China [25].
- Build Up and Development of Intelligent Dispatching Management System of Beijing Public Transport [26].
- Systematic Design of Qingdao Intelligent Public Transportation Control [27].

All articles and papers presented herein contain important partial solutions for managing an integrative mobility concept for public transport companies. A comprehensive platform that covers all important functions from the customer's point of view, such as offer presentation, search for offers, offer selection/optimization, operational planning/implementation, fare calculation, conclusion of the contract of carriage, connection information, and safety assurance across all modes of transport was not found in the course of the research—even the abstracts of the Chinese texts did not indicate this.

As presented above, the literature we researched on the structure and architecture of NMS or mobility platforms was mainly about the platforms itself. However, we found no information regarding by whom and how these central services are developed and operated and who is responsible for them or how a public transport company could integrate them into its existing business architecture.

3.3 Enterprise and IT-Architecture Models for Public Transportation

In the public transportation sector, two architecture models have been identified that structure the IT support required for the management of public transportation companies into functional blocks and corresponding IT systems or applications (also called "systems"). Both models do not cover new mobility services or demand-oriented public transport, but they address the conventional functions of public transport. Thus, these architectures form an excellent starting point for the integration of NMS-specific functional blocks and systems, and for identifying the functions in conventional public transport companies to be adapted. The architecture models are the ITVU sector model (Sub-subsection 3.3.1) and the VDV reference architecture (Sub-subsection 3.3.2), which have been identified in the search for related works.

3.3.1 ITVU Sector Model

The ITVU sector model was developed and maintained by Gero Scholz, an employee of *IVU Traffic Technologies AG*, as a kind of simplified industry model of traditional public transport until 2016 [7]. The latest version of this model can be found in the publication "IT systems in public transport" [18], in which the domain model describes generic business processes (see Figure 4 in [18]) on the one hand, and fundamental data structures (classes) of public transport on the other.

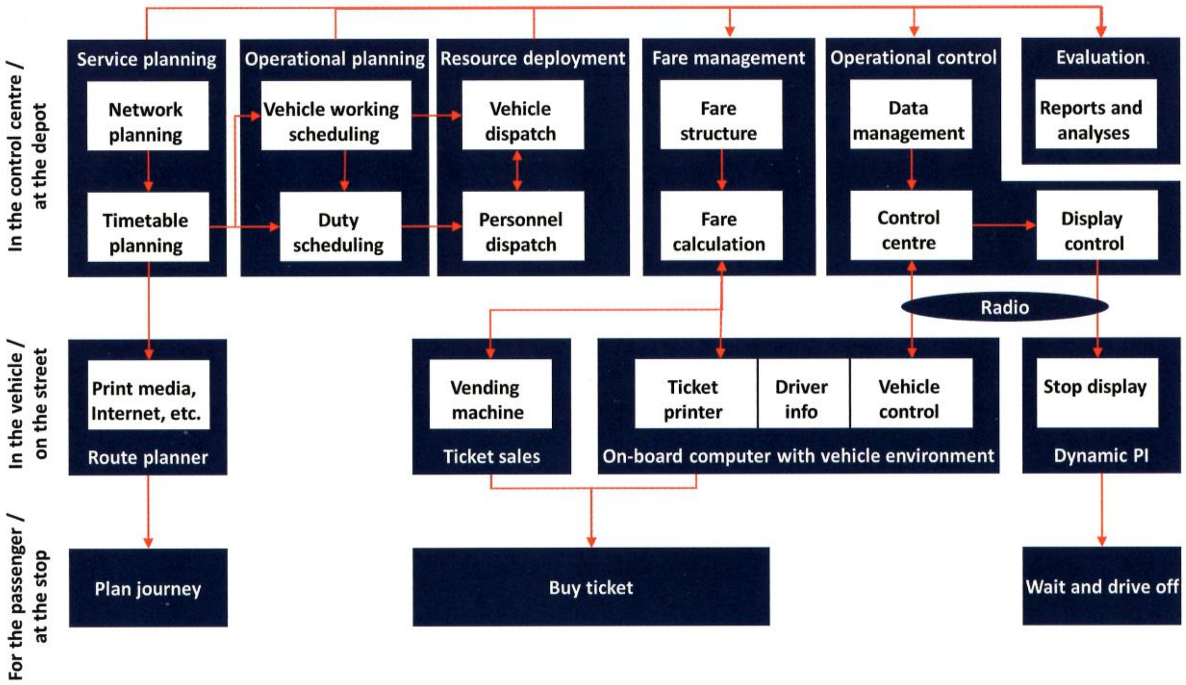

Figure 1. Systems of the ITVU sector model [18]

In the ITVU model, 42 IT systems/applications are described in short profiles. These fact sheets contain:

- Names in the form,
- Designation,
- Brief summary of the function,
- Data flows to and from the individual applications in an overview,
- Users/actors in the form of roles.

Figure 2 shows the corresponding part of the class model on which the ITVU model [18] is based – the attributes (see above) were shown as an example for the application “timetable planning”.

Name	plan.timetable
Designation	**Timetable planning**
Type	Central
User	Timetable planner
Functions	■ Describing travel paths ■ Planning track occupancies and station run orders ■ Defining routes ■ Registering runtime profiles per link and time of day ■ Setting trips, assigning vehicle types ■ Using variable validity patterns (timetable period, day type, individual calendar day) ■ Assigning aspects (regular transport, roadworks, school transport, works service) to trips ■ Defining connections
Data flows	→ **plan.block** ■ Set of trips → **pool.data** ■ Set of trips for coordination with association partners and for creating print products → **contract.management** ■ Timetable data ■ Binding connections

Figure 2. Application profile of the ITVU sector model [18]

In the ITVU sector model, users and actors (roles) are further stored in 16 roles, which are described in detail with activity profiles.

As an example, the description of the role “journey planner” in a profile text is reproduced here: “The journey planner implements the traffic demand on the previously created network. Often the roles of network planner and timetable planner are not separated, as both activities are closely related. The timetable planner defines the journeys for each line (frequency and exact times) and takes connection relationships into account. He determines the type of vehicle to be used and takes restrictions that may result from the routing into account. In addition, any special equipment required, such as disabled access, is specified. Network and timetable planning can be the responsibility of the transport company or can be specified in the transport contract, depending on with how much differentiation the public transport authority specifies the transport services to be provided” [7].

Based on the applications shown in Figure 1 (ITVU industry model), the underlying data and process structures are assigned to the systems in a class model [18].

A general evaluation of business processes, such as accounting, human resources management or marketing, etc., is not comprehensively considered by the model – however, it offers a good introduction to special areas of the enterprise architecture of a public transport company.

3.3.2 VDV Reference Architectures

The Association of German Transport Companies (VDV), in which all German public transport companies are organized, continuously publishes papers and communications on topics in its individual areas of specialisation in its series of publications. In this context, the area of specialisation of operation “Digitization: Central Systems” represents the area that was examined by the authors.

In this paper, the authors list the series of publications that received special consideration for the enterprise architecture developed by the authors in more detail. The communication VDV-7046 [8] from 03/2018, which describes the definition and documentation of user requirements for an Open Mobility Platform, and the three publications VDV-436-1 [28], VDV-436-2-1 [29] and 2-2 [30] from 08/2019, which describes an Open Mobility Platform, were considered.

The publications considered here include the area of the mobility platform, which was only used for the enterprise architecture created for alignment with the requirements for a mobility platform. Therefore, a longer presentation, as in 3.3.1, is omitted here.

The intensive study of the VDV publications led to the central idea of using an enterprise service bus (see Figure 1), which centrally standardizes and regulates the exchange of data between applications. In this way, companies are able to create new services more easily at any time using a kind of intermediate architecture. This solution offers many advantages, such as centralized tariff conversion, which enables all connected sub-systems, such as ticket vending machines, bus cash registers, etc., to be converted according to tariff via an application.

The use and deployment of an enterprise service bus as a communication interface was confirmed as a good idea by many experts in our evaluations. However, it was pointed out that the existing systems prevent this idea from being implemented in the short term because it is not possible to convert an evolved system landscape.

4 Case Study for Elicitation of NMS Integration Requirements

In connection with an investigation of the NMS BerlKönig of the *Berliner Verkehrsbetriebe*, the central points of an enterprise architecture could be determined in comparison with existing architectures. The basis of this investigation is an interview with *BVG* expert Michael Bartnik [31].

4.1 Introduction to Case Study Berlin BerlKönig

Berlin-based BerlKönig was a ride-pooling service developed as a new mobility service until July 2022, including digital infrastructure [32]. The service was operated by *BVG* in two variants:

BerlKönig A: Call pooling cab with free destination selection in the eastern inner-city area of Berlin: tariff zone A (inner Berlin S-Bahn ring). BerlKönig A was operated in cooperation between the companies *BVG* and *ViaVan*, a subsidiary of the *Daimler Group*. *ViaVan* operates the service on behalf of *BVG* and supports management decisions by providing information.

In November 2017, the partners applied for approval for the BerlKönig concept, and the service began operations in September 2018. [32]

BerlKönig BC: call-sharing cabs with a fixed destination (nearest *BVG* subway station) and semi-variable route: tariff area BC (outer Berlin S-Bahn ring and the villages east of Berlin). BerlKönig BC was the result of an initiative of the Berlin Taxi Guild in cooperation with *BVG*, *ViaVan* and Taxi Berlin. The federally funded service began operations in summer 2019. This variant was discontinued by *BVG* in May 2021 due to the cancellation of federal funding. Therefore, this variant was no longer considered/examined at the time of the investigation. [33]

4.2 Organisational and IT Integration of Berlin BerlKönig

The current situation of the BerlKönig was determined via an expert interview with Michael Bartnik of the *BVG* [31]. The result of this interview, i.e., the organizational-procedural and IT integration on the basis of the ITVU technical architecture, is presented in Figure 3.

In the context of the study, the following two questions were asked about integration:

1. Is a sub-service provider involved in the provision of the BerlKönig service and if so, in what form and to what extent does the provider support *BVG*?
2. To what extent is the IT of the BerlKönig integrated into the structures of the *BVG*?

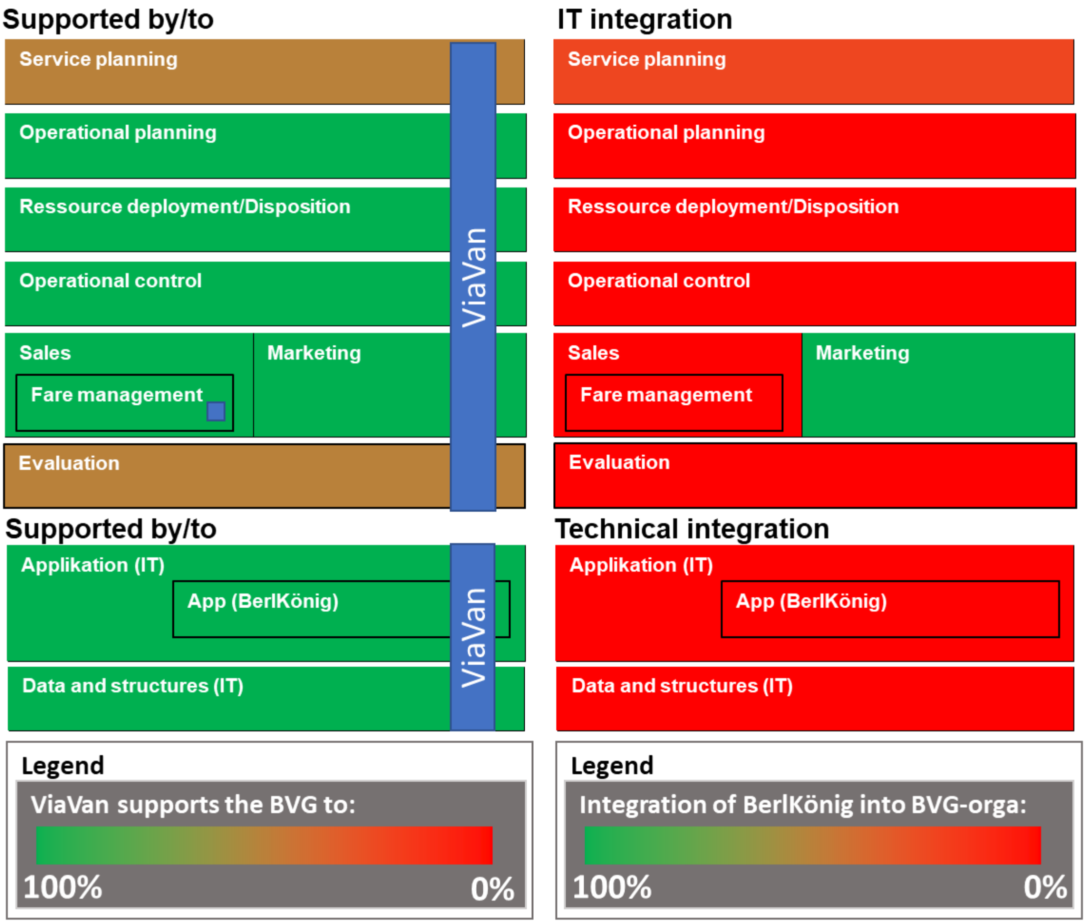

Figure 3. BerlKönig: Professional integration and use of sub-service providers

As can be seen from the left side of the diagram (see Figure 3), the company *ViaVan* supports BVG in the provision of the BerlKönig service to a considerable extent. This support amounts to 100% in almost every area. With the exception of offer planning and evaluation, the partner operates this service almost entirely on behalf of *BVG*. Offer planning is supported by *ViaVan* with information and experience derived from operations – this also applies to the evaluations necessary for operations (as well as for sales and marketing campaigns).

As the right-hand side of the diagram (see Figure 3) shows, IT integration of the individual service modules is virtually non-existent compared to operational integration. One exception is a low level of integration in the areas of service planning and marketing, which can be attributed to the common use of standard software (e.g., Microsoft Office).

In summary, the questions posed at the beginning of the section can be answered as follows: The BerlKönig service is operated to an extremely high degree by *ViaVan*. The technical and organizational support provided by *ViaVan* to *BVG* is very high; the IT systems used are not integrated into the IT architecture of *BVG*.

4.3 Integration of NMS into a Supply-Oriented Public Transport Company Using BerlKönig as an Example

In this section, the authors will present the required functions with regard to an integration of an NMS service (BerlKönig) into a supply-oriented public transport company. For this purpose, they will outline the simple integration of the sales area/fare management of the BerlKönig service as an example of an NMS service into the *BVG* structure. The envisioned solution is based on the *BVG*'s current orientation, which follows the organizational and business model of a traditional company. This is a first step towards the development of a more comprehensive enterprise architecture that integrates the supply-platform-oriented public transport operations on the one hand and the demand- and platform-oriented modern NMS on the other hand. This level of consideration was tested in this section – it was found to be too deep and a choice was made between the ITVU sector model and this modelling level, which corresponds to that of the 2 process level.

In Figure 4 the individual function blocks of an overall solution are considered. Hereby we look at the sales area and in particular the fare management, which is triggered by the upstream ticketing processes. The BerlKönig service is only offered via the app distribution channel. There is no other way to order and use this service. Therefore, the design of the app in terms of usability and availability is of great importance.

The above-mentioned functional blocks are divided into seven systems; together they form the structure of the *Sales system*.

In each individual system, there are application functions that are relevant for the fulfilment of the system requirements. As an example, the area of the *Settlement system* is highlighted below.

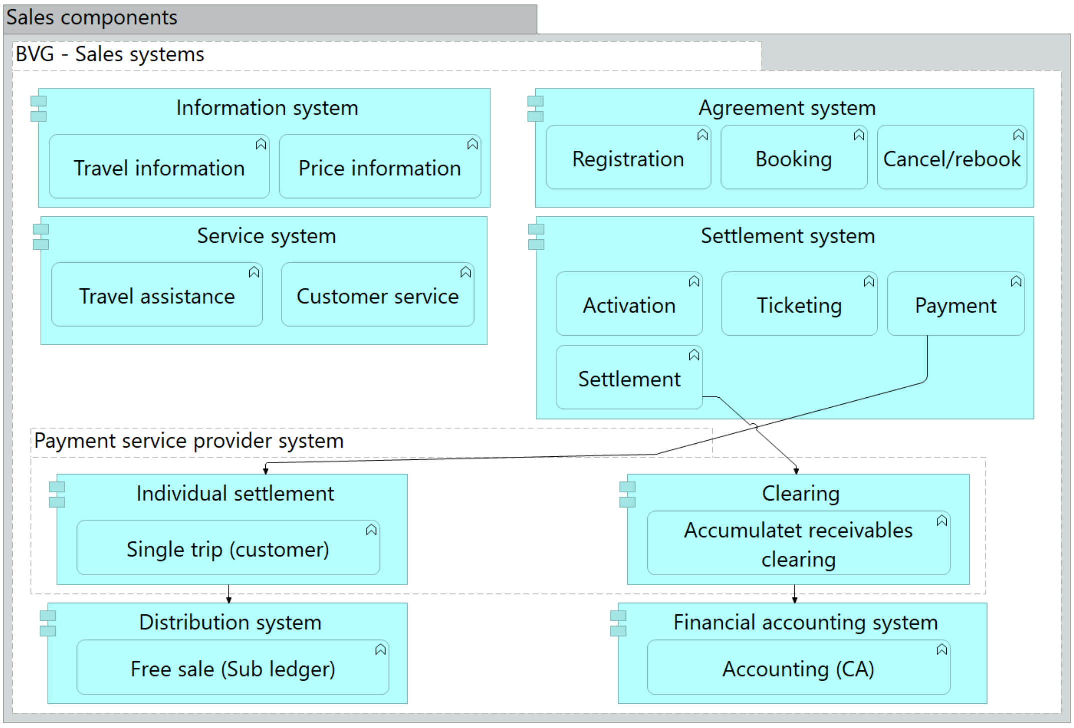

Figure 4. Functional blocks of an NMS integration using BerlKönig as an example

The following application functions are important for handling the business process in the *Settlement system*:

- *Activation*: After registration (agreement system), the customer still has to be activated so that they can conclude transactions on the platform.
- *Ticketing*: The travel authorization booked is expressed in a product, the ticket.

- *Payment*: The payment process runs via a payment service provider (external) who collects the amount from the customer (passenger).
- *Settlement*: Settlement takes place between the payment service provider and the *BVG* on an agreed day each month. Money and information (individual and total transaction/s) are exchanged here.

Figure 5 depicts an architectural solution developed by the authors for integrating the sales and fare management areas of the BerlKönig service. In later discussions with experts, it turned out that this level of detail is too deep for an end-to-end consideration of the entire core model and that the depth of the ITU sector model is just right [31]. The experience gained from this first architectural approach was taken into account in the context of further consideration.

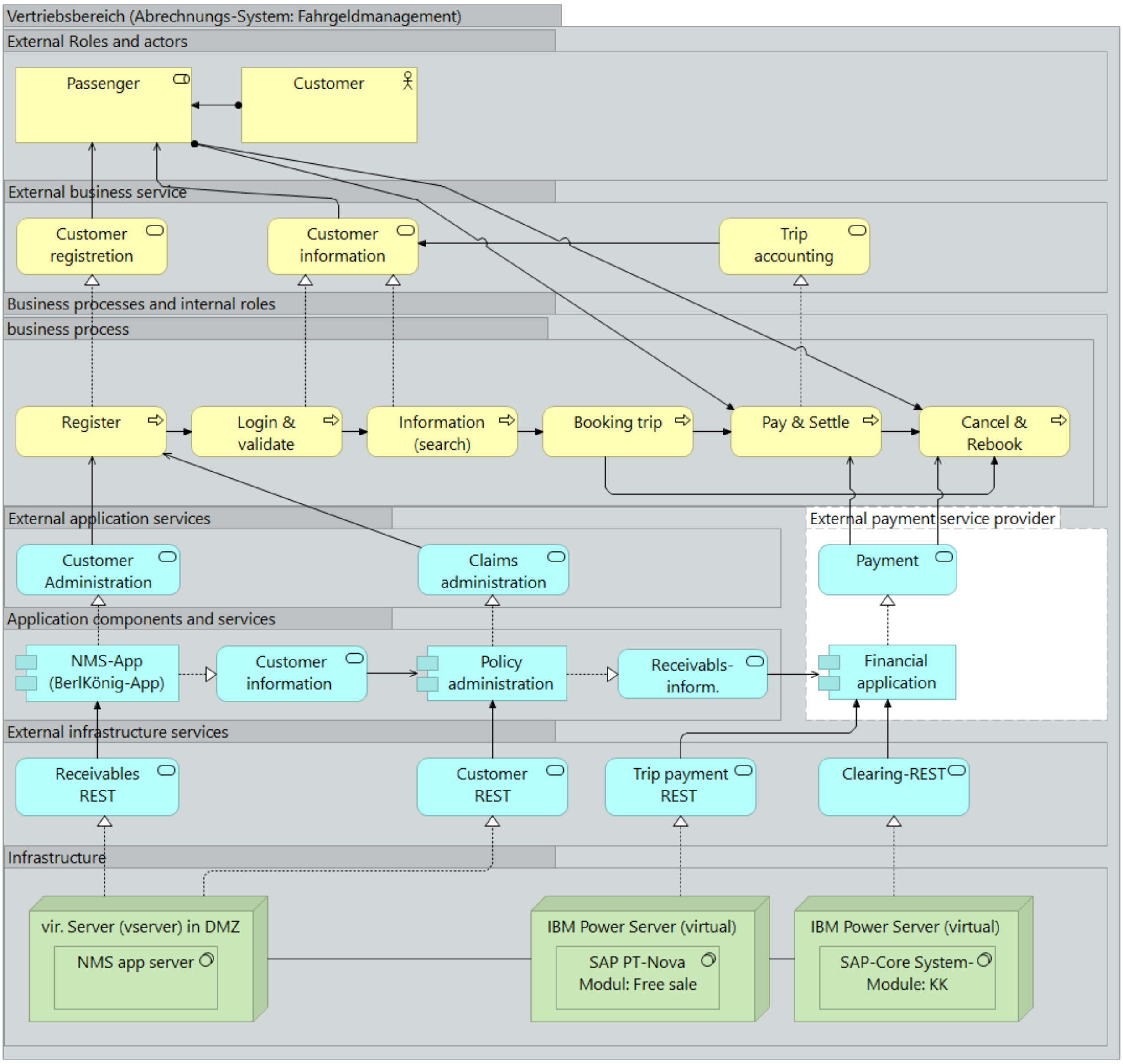

Figure 5. Target architecture for the integration of the sales area/fare management of the BerlKönig service

Hereby, the focus is on receivables management. The infrastructure used is – apart from the background software of the app – identical to the one used by the *BVG*. This means that three software systems are used on the hardware mentioned:

- PT-Nova (Hansecom) on SAP as a sub-ledger for the distribution channel,
- NMS app Server (background software) as the central application for the app,
- *BVG*'s SAP core system for billing the payment service provider (clearing).

Based on these central systems, the authors then modelled a modern architecture that encapsulates the individual levels through standardized services.

5 Integration of NMS into the Enterprise Architecture of Public Transport Company

Based on the results from [14], an initial consideration of the demand-responsive NMS BerlKönig (Berlin's taxi-based service) and the resulting requirements for a demand-responsive local transport system was prepared. Based on that consideration, this section (especially Subsections 5.1 and 5.2) concentrates on the presentation of the components of a reference/target architecture that integrates a demand-responsive local passenger transport (or NMS) into a classically oriented public transport company. In Subsection 5.3, the modelled reference/target architecture (EA) is presented as an example based on a selected process (transport planning).

In the last Subseection 5.4, the sub-architectures (strategic/operational) created in 1 and 2 are linked to check whether the capabilities are supported by the operational sub-architecture.

5.1 Strategic Consideration of Demand-Responsive Transport in the Context of Classic Public Transport Companies

In this subsection, the strategic connections, such as the capabilities and control of resources, which a classic public transport company must fulfil, if it wants to integrate demand-oriented transport into its organisation, are presented. The strategic view is flanked by the motivation level, which connects and maps requirements, results, end states and changes of the organisation and their impact on the responsible stakeholders of the organisation (Figure 6).

With this view of the goal architecture, a better understanding of the connection between the strategic level and the motivational level is created.

In Figure 6, the lowest level shows the business capabilities that a modern public transport company must have in order to be able to offer demand-responsive transport. In addition to the business capability that a classic public transport company needs as well, such as customer service and IT development, there are new capabilities such as digital platforms and the management of demand-oriented local passenger transport. In addition, there is (nowadays) the ability to conduct driving-related environmental protection management. In Germany, environmental protection is embedded in the statutes of all public transport companies and must be taken into account.

Figure 6 further illustrates how capabilities affect the requirements that a corresponding enterprise must realise through the control of resources. The implementation of the requirements leads to a result, which brings about the fulfilment of an end state. This end state changes the organisation, which in turn is desired or respectively must be accepted by stakeholders.

In this context, it should be emphasised that the ability to manage demand-responsive public transport opens up the possibility of serving customers on the last mile. This increases the number of customers and ensures shorter waiting times through better connection options. The improved utilisation of means of transport and the increase in the number of customers leads in total to a reduction of exhaust gases within the area where the public transport company operates. Customer satisfaction increases due to improved connections and the environmentally friendly transport service. In addition, turnover increases due to increased demand. These drivers pay into the goals of the respective stakeholders CIO and CFO.

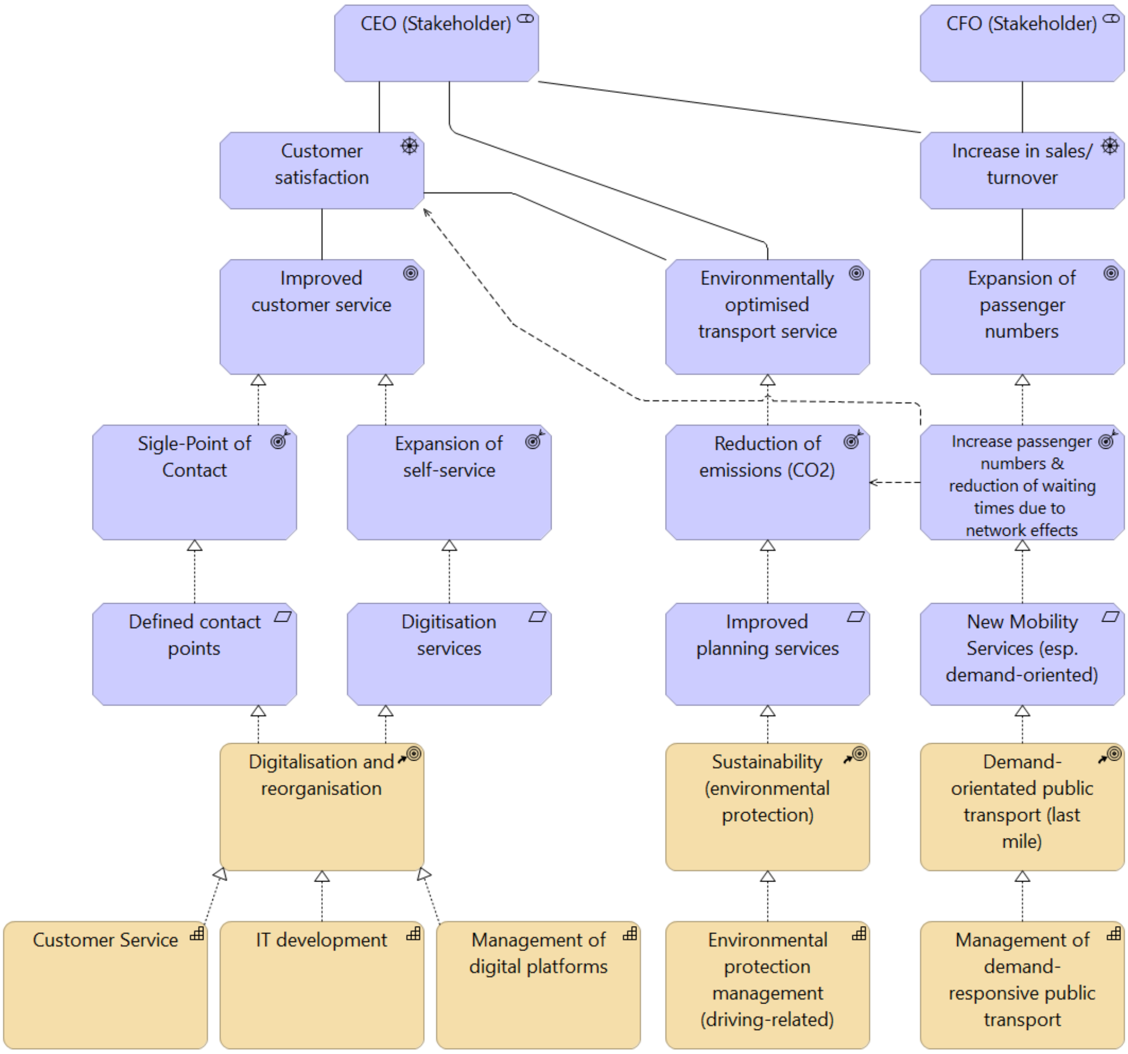

Figure 6. Strategic consideration of demand-oriented local passenger transport – especially NMS – in classic public transport companies

5.2 Business and Application Level

In this subsection, we will consider the relationship between the processes and the respective roles/actors that a public transport company must have in place for the provision of driving services, as well as at the application level.

The arrangement of the process elements within this architecture artefact follows the usual representation of (value-added) processes, according to which the processes are arranged by input to output from left to right (see Figure 7).

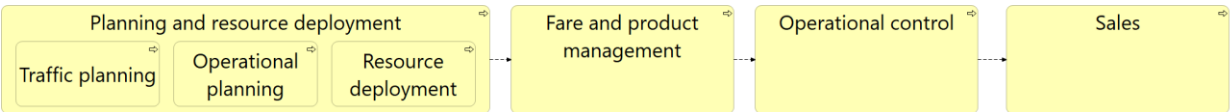

Figure 7. Process structure of the reference/target architecture

All further element types of the proposed architectural representation are oriented towards this process structure. In order to develop a modern architecture that can be adapted to the new challenges, the following two approaches were considered:

1. Service-oriented architecture approach at the business and application level to increase the flexibility of the organisation.

2. Central communication between the components with the help of an enterprise service bus on the application side, which standardises and technically channels the communication.

Figure 8 shows the overall architecture with the business and application levels. In this context, the required data objects were assigned to the applications and explained in more detail.

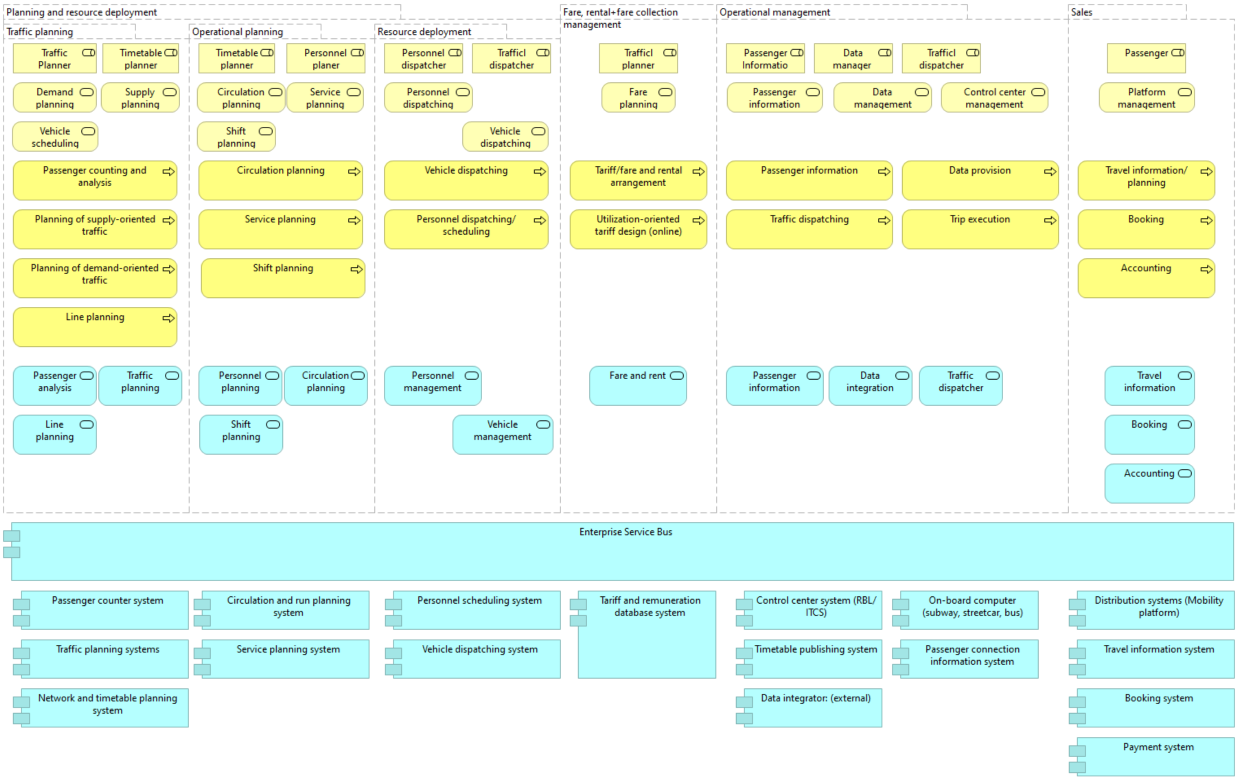

Figure 8. Components of a reference/target architecture of a public transport company with demand-oriented NMS

The architecture presented here is structurally divided into the executive business roles, services and processes as well as the application services and applications. As presented at the beginning of Section 5, the EA is divided into the analysed process structure of public transport companies and thus into the following main areas:

- *Planning and use of resources*
  This area contains the planning components for service provision. Here, traffic is combined with operational planning and resource deployment. The goal is to create an integrated, interdependent traffic and operational planning for efficient service delivery.
- *Fare-/rental-fare collection management*
  Here, on the one hand, the supply-oriented planning results are transferred into products and tariffs and, on the other hand, the demand-oriented services are provided with rental prices; or rental prices by external service providers are consolidated and made available for billing.
- *Operational management*
  In operational management, the services are provided; or their provision is supported by business services such as traffic dispatching, trip execution or passenger information.
- *Sales*
  This area includes the complete travel planning, booking and billing of the fare or rental. The central point of this customer-oriented area is a mobility platform that connects all forms of mobility – whether supply or demand-oriented – offered by a public transport company with each other.

After the presentation of the architectural components of an architecture that fulfils these requirements, the next subsection of this article will exemplify the architecture in the area of "traffic planning" and discuss the identified requirements that must be taken into account in the integration of demand-responsive traffic.

5.3 Enterprise Architecture Using Traffic Planning as an Example

In this subsection, we present *Traffic planning* in the context of an EA. The architectural parts shown are oriented towards the process sequence. In Figure 9, these parts are shown as a part of the overall architecture.

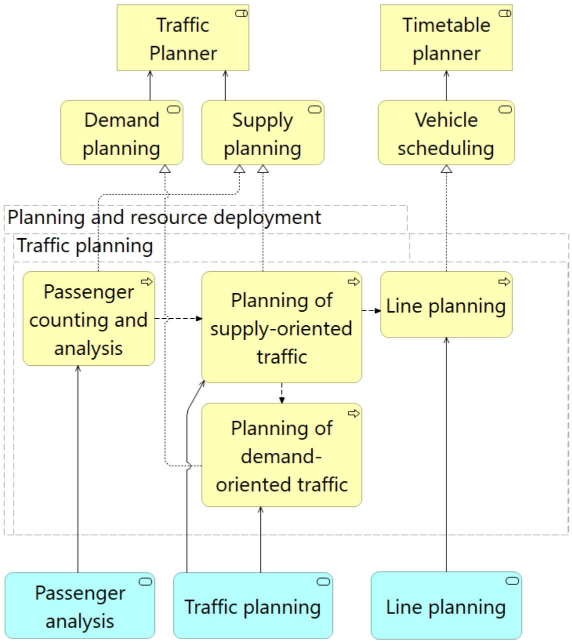

Figure 9. Traffic planning—a part of the overall architecture

The roles *Traffic Planner* and *Timetable Planner are* involved in *Traffic planning.* They carry out the following process steps via the defined business services *Demand planning*, *Supply planning* and *Vehicle scheduling:*

a. *Passenger counting and analysis*

In this process step, the *passenger counting* and *passenger survey* activities are combined. The output (data on passenger numbers and flows) of this process is passed on to the following process step (b.).

b. *Planning of supply-oriented traffic*

This process step can be found in every classic public transport company. At this point, the traffic is planned on the basis of passenger count data, traffic data (usually from the traffic office etc.) and, e.g., holiday data.
The output of this step is processed traffic data that structures the demand for supply-oriented traffic (lines). In classical companies, this is followed by the process step *Line-planning* (d.). In public transport companies that have integrated demand-oriented traffic, the process *Planning of demand-oriented traffic* (c.) follows in parallel.

c. *Planning of demand-oriented traffic*

This step in the process implements the key requirements that a public transport company must fulfil in the planning area if it wants to integrate demand-responsive transport and manage it within its sphere of influence.

The output of this step is traffic data, such as the establishment of mobility hubs like stations (e.g., Jelbi stations in Berlin or hvv switch in Hamburg) where demand-oriented transport systems are made available for rent. In addition, neuralgic points that are important for strengthening last mile transport are identified and noted for the provision of sharing services. This also includes the mobility hub mentioned above.
The subsequent process step *Shift planning* belongs to operational planning rather than transport planning.

d. Line-planning

Line *planning* shapes the supply-oriented traffic in the form of lines on the basis of the output of (b.). The output—planned lines—of this process is made available to the two processes of *vehicle scheduling* and *duty scheduling* in the operational planning area.

The processes relevant here are served by application services that are realised directly with the applications or via a construct such as, for example, an integration layer. In the second case, the corresponding applications that organise the functionality and data storage would be accessible via the integration layer. This fulfils the requirement for a flexible, decoupled modern enterprise architecture that offers the advantages described in 3.2.

5.4 Supporting the Strategy (Capabilities) through the Operational Architecture

This section examines to what extent the strategy is supported by the business and application level. This examination focuses on the demand-oriented transport context—but not on environmental protection, which was taken into account in the motivation strategy.

The model shown in Figure 6 is used as the basis for this review. The diagram in Figure 10 shows which elements of the business support/fulfil the achievement of the overarching strategic capabilities:

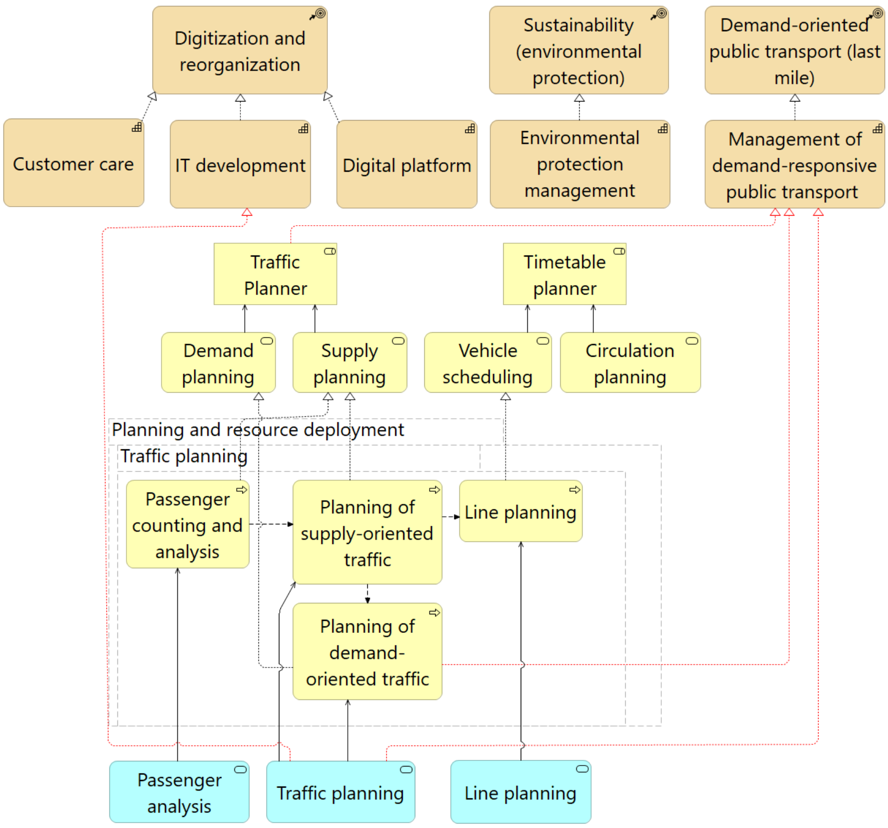

Figure 10. Traffic planning in the context of strategic requirements

Figure 10 identifies the operational components that act on the capabilities as strategic behaviour. The business service *Demand planning*, the business process *Planning of demand-orientated traffic* and the application service *Traffic planning* contribute to the implementation of the capability *Management of demand responsive public transport*. Furthermore, the application service *Traffic planning* also contributes to the implementation of the capability *IT-Development*.

Traffic planning will have several effects on the most important capability *Management of demand responsive public transport* of a demand integrated public transport company.

6 Architecture Evaluation

In the following subsections, the architecture is evaluated against general quality attributes (Subsection 6.1) the requirements visible in the case study (Subsection 4.2).

6.1 Initial Criteria of an Architecture Evaluation

For an initial evaluation of the proposed EA approach, we use established quality attributes for enterprise architectures, as defined, for instance, in [17]. The intention of the architecture draft is to support the integration of NMS in the areas of claims and fare management. The architecture is supposed to take into account the existing software application of the *BVG*, which has to be central to the evaluation. Table 4 shows the quality criteria and our impression regarding to what extent they were covered.

Table 4. Initial evaluation of the architecture

Quality Attribute	Evaluation
Platform independence	Assessment: partly met Coverage of the most important applications and functions by services.
Scalability	Assessment: fully met Due to the structured distributed structure, it is possible to achieve a high scalability.
Flexibility	Assessment: partly met Flexibility is provided by orchestrating appropriate services.
Reliability	Assessment: shortcoming
Component reusability	Assessment: fully met High reusability through the use of services.
Interoperability	Assessment: fully met The different applications are served by the standard interfaces of the services.
Simplicity	Assessment: partly met Simplification is only possible to a limited extent in the architecture.
Monitoring, auditing, logging	Assessment: fully met Can be fully implemented in architecture.
Security	Assessment: fully met Security can be specifically considered in this distributed architecture.

The individual quality criteria presented in Table 4 provide information about the integration capability of the architecture. The service orientation aimed for in the design enables the architecture to adopt a flexible structure, whereby its functions can be provided by various applications.

In conclusion, it can be said that this first draft of an appropriate architecture can be integrated well into existing infrastructures—or, in particular, into those of the *BVG*—due to its service orientation. However, this initial architecture version needs further development and evaluation outside the context of *BVG*.

6.2 Evaluation against Requirements

In this subsection, the authors summarize the requirements, established in Sub-subsection 3.3.2 of this article, regarding the integration of New Mobility Services into a classic public transport company and present them in comparison to the established architecture. This article only examines the requirements that were presented in the context of the part of the architecture examined as an example in Subsection 5.3 of the article, i.e., traffic planning.

The requirements of integrating service planning are addressed in the traffic planning process Subsection 5.4. In order to support New Mobility Services (NMS) in the context of traffic planning, demand-oriented planning was considered in the classical planning process as follows: The planning subprocess *Planning of demand-orientated traffic* is established in parallel with *Line planning* (supply-orientated line planning) and receives its information from the network planning of the process *Planning of supply-orientated traffic*.

This process extension is supported by the newly created business service *Demand planning*. This service is filled by the role *Traffic planner* and contains all the technical activities that occur in the context of the above-mentioned process. One example is the identification of gaps in the supply-oriented system that can be covered by demand-oriented traffic.

The technical service *Traffic planning* must be extended by a demand-oriented part. That is, in addition to supply-oriented network planning, the service must also take into account an analysis of the use of demand-oriented traffic, such as serving the last mile. For this, the underlying application must also be adapted.

In conclusion, it can be stated that the requirements for the integration of the planning of demand-responsive traffic services (NMS) are addressed by the presented architecture. It does not matter whether the service is provided internally or externally by a service provider – in either case, the public transportation company must understand that this is a field of activity that must be filled in order to achieve the integration of NMS.

7 Summary and Future Work

In order for public transport operators to continue to fulfil their leading role in local public transport in the long term, they must be able to understand and manage the core services of demand-responsive transport in the context of their traditional work. This does not necessarily mean providing the services themselves, but rather establishing administrative and control processes as well as the systems that enable central planning and control. The autonomy of demand-responsive local transport should not be questioned in this context.

In this work, an initial target or reference architecture was developed on the basis of the strategic requirements and the most important enterprise components identified. Subsequently, these were operationally concretised in the sub-area of transport planning.

The excerpt of the developed reference/target architecture shows that changes in the area of planning of public transport companies arise in the context of the integration of demand-oriented transport. Not only do new business services and processes have to be developed, but additional application services and applications also have to be expanded or adapted.

The architecture is encapsulated by services at the business and application levels. This enables the organisation to integrate new NMSs quickly and easily or to outsource individual functions. In addition, an enterprise service bus makes it possible to combine a wide variety of applications and data sources into new services or use the data for inter-application communication. Flexibility of the architecture is thus ensured.

In future work, the following topics will have to be investigated:

- Elaborate the entire reference enterprise architecture building block for NMS integration.
- Provide evidence of the operational architecture's support for strategic requirements.

- Continue the evaluation of the developed architecture according to quality attributes for enterprise architectures, based on [17].
- Evaluate the architecture in additional episodes (e.g., additional expert interviews), following on the design science approach, and present the resulting changes or architecture versions.

References

[1] M. Kamarianni, W. Li, M. Matyas, and A. Schäfer, “A critical review of new mobility services for urban transport,” *Transportation Research Procedia*, vol. 14, pp. 3294–3303, 2016. Available: https://doi.org/10.1016/j.trpro.2016.05.277

[2] C. Pflügler, M. Schreieck, G. Hernandez, M. Wiesche, and H. Krcmar, “A Concept for the Architecture of an Open Platform for Modular Mobility Services in the Smart City,” *Transportation Research Procedia*, vol. 19, pp. 199–206, 2016. Available: https://doi.org/10.1016/j.trpro.2016.12.080

[3] B. Hildebrandt, A. Hanelt, E. Piccinini, L. Kolbe, and T. Nierobisch, “The value of IS in business model innovation for sustainable mobility services-the case of carsharing,” *Wirtschaftsinformatik Proceedings 2015*, pp. 1008–1022, 2015.

[4] P. Marchetta, E. Natale, A. Pescapé, A. Salvi, and S. Santini, “A map-based platform for smart mobility services,” 2015 *IEEE Symposium on Computers and Communication (ISCC)*, pp. 19–24, 2015. Available: https://doi.org/10.1109/ISCC.2015.7405448

[5] P. Johannesson and E. Perjons, *An introduction to design science*. Springer, 2014. Available: https://doi.org/10.1007/978-3-319-10632-8

[6] C. Dohmen und G. Scholz, *IT-Systeme für Verkehrsunternehmen: Das Branchenmodell ITVU*, MKWI, 2012 (in German).

[7] C. Dohmen und G. Scholz, “IT-Systeme für Verkehrsunternehmen: Das Branchenmodell ITVU,” *IT-Systeme für Verkehrsunternehmen: Das Branchenmodell ITVU*, 2012 (in German).

[8] T. Steinert, R. Koreng, C. Mayas, and C. Dohmen et al., “Definition und Dokumentation der Nutzeranforderungen an eine offene Mobilitätsplattform: VDV-Mitteilung,” *Verband Deutscher Verkehrsunternehmen e.V. (VDV)*, Köln, VDV 7046, 2018 (in German).

[9] C. Dohmen, “Qualitätssicherung im Lebenszyklus des itcs – Anspruch und Wirklichkeit,” 2012 (in German). Available: https://docplayer.org/14193363-Qualitaetssicherung-im-lebenszyclus-des-itcs-anspruch-und-wirklichkeit-dr-claus-dohmen-25-10-2012-frankfurt-main.html

[10] C. Dohmen, “itcs – integriertes System aus modularen Bausteinen,” 2013 (in German). Available: https://docplayer.org/894190-Itcs-integriertes-system-aus-modularen-bausteinen-dr-claus-dohmen-13-03-2013-hamburg.html

[11] C. Dohmen, “Integration von Bedarfsverkehr in klasssiche Systeme von Verkehrsunternehmen,” 2019 (in German). Available: http://docplayer.org/142791891-Integration-von-bedarfsverkehren-in-klassische-systeme-von-verkehrsunternehmen-2-forum-neue-mobilitaetsformen-th-wildau-dr.html

[12] M.-O. Würtz and K. Sandkuhl, “Impact of New Mobility Services on Enterprise Architectures: Case Study and Problem Definition,” *Business Information Systems Workshops. BIS 2020. Lecture Notes in Business Information Processing*. Springer, vol.394, pp. 45–56, 2020. Available: https://doi.org/10.1007/978-3-030-61146-0_4

[13] M.-O. Würtz and K. Sandkuhl, “Neue Mobilitätsdienste und ihre Auswirkungen auf Unternehmensarchitekturen,” *INFORMATIK 2020, Gesellschaft für Informatik*, pp. 149–163, 2021 (in German). Available: https://doi.org/10.18420/inf2020_15

[14] M.-O. Würtz and K. Sandkuhl, “Towards a Reference Architecture for Demand-Oriented Public Transportation Services,” *2021 IEEE 25th International Enterprise Distributed Object Computing Workshop (EDOCW)*, pp. 122–129, 2021. Available: https://doi.org/10.1109/EDOCW52865.2021.00041

[15] M.-O. Würtz and K. Sandkuhl, “A Target Enterprise Architecture Approach for New Mobility Services in Demand-Responsive Public Transport,” *Joint Proceedings of the BIR 2022 Workshops and Doctoral Consortium co-located with 21st International Conference on Perspectives in Business Informatics Research (BIR 2022)*, CEUR Workshop Proceedings (CEUR-WS.org), vol. 3223, pp. 35–43, 2020.

[16] F.-W. Menge, *Digitale Transformation in einem ÖPNV*. Verband Deutscher Verkehrsunternehmen e.V. (VDV), 2020 (in German).

[17] M. Razavi, F. S. Aliee, and K. Badie, “An AHP-based approach toward enterprise architecture analysis based on enterprise architecture quality attributes,” *Knowledge and Information Systems*, vol. 28, pp. 449–472, 2011. Available: https://doi.org/10.1007/s10115-010-0312-1

[18] G. Scholz, *IT systems in public transport: Information technology for transport operators and authorities*. Heidelberg: dpunkt.Verlag, 2016.

[19] G. W. Heinze and H. H. Kill, “Zukunftsfähige Strategien für den ÖPNV in Berlin-Brandenburg: Handlungsempfehlungen und Visionen für einen finanzierbaren öffentlichen Verkehr,” *Der Nahverkehr: öffentlicher Personenverkehr in Stadt und Region*, vol. 10, pp. 8–16, 1994 (in German). Available: https://doi.org/10.14279/depositonce-7221

[20] F. Beutler and J. Brackmann, “Neue Mobilitätskonzepte in Deutschland: Ökologische, soziale und wirtschaftliche Perspektiven,” *WZB Berlin Social Science Center*, 1999 (in German).

[21] N. B. Aletà, C. M. Alonso, and R. M. A. Ruiz, “Smart mobility and smart environment in the Spanish cities,” *Transportation Research Procedia*, vol. 24, pp. 163–170, 2017. Available: https://doi.org/10.1016/j.trpro.2017.05.084

[22] R. E. Barone, T. Giuffrè, S. M. Siniscalchi, M. A. Morgano, and G. Tesoriere, “Architecture for parking management in smart cities,” *IET Intelligent Transport Systems*, vol. 8, no. 5, pp. 445–452, 2013. Available: https://doi.org/10.1049/iet-its.2013.0045

[23] P. Marchetta, E. Natale, A. Pescapé, A. Salvi, and S. Santini, “A map-based platform for smart mobility services,” *2015 IEEE Symposium on Computers and Communication (ISCC)*, pp. 19–24, 2015. Available: https://doi.org/10.1109/ISCC.2015.7405448

[24] A. I. Levina, A. S. Dubgorn, and O. Y. Iliashenko, “Internet of Things within the Service Architecture of Intelligent Transport Systems,” *2017 European Conference on Electrical Engineering and Computer Science (EECS)*, pp. 351–355, 2017. Available: https://doi.org/10.1109/EECS.2017.72

[25] Y. Zhaosheng and H. Jianming, “Research on the Architecture and Implementary Scheme of Intelligent Public Transportation System in China,” *Communication and Transportation Systems Engineering and Information*, vol. 1, 2001.

[26] Z. Guowu, “Build Up and Development of Intelligent Dispatching Management System of Beijing Public Transport,” *Journal of Northern Jiaotong University*, vol. 23, no. 5, pp. 1–6, 1999.

[27] J.-H. Geng, N.-P. Hu, and G. Tong, “Systematic Design of Qingdao lntelligent Public Transportation Control System,” *Journal of Qingdao University of Science and Technology*, vol. 6, 2003.

[28] T. Steinert, R. Koreng, C. Mayas, and C. Dohmen et al., “Offene Mobilitätsplattform (OMP) – Teil 1: Rollenmodell & typische Kooperationsszenarien,” *Verband Deutscher Verkehrsunternehmen e.V. (VDV)*, 2019 (in German).

[29] T. Steinert, R. Koreng, C. Mayas, and C. Dohmen et al., “Offene Mobilitätsplattform (OMP) – Teil 2-1: Referenzarchitektur,” *Verband Deutscher Verkehrsunternehmen e.V. (VDV)*, 2019 (in German).

[30] T. Steinert, R. Koreng, C. Mayas, and C. Dohmen et al., “Offene Mobilitätsplattform (OMP) – Teil 2-2: Interaktionen zwischen den Systemkomponenten,” *Verband Deutscher Verkehrsunternehmen e.V. (VDV)*, 2019 (in German).

[31] M. Bartnik, Integration von NMS und MaaS in Unternehmen der ÖPNV-Branche. Remote (Microsoft Teams).

[32] I. Rentz, “Der ‘BerlKönig’ kommt – und mit ihm die Ochsenknechts,” 2018 (in German). Available: https://www.horizont.net/marketing/nachrichten/bvg-macht-ridesharing-der-berlkoenig-kommt---und-mit-ihm-die-ochsenknechts-170128. Accessed on Aug. 12, 2021.

[33] A. Rühle, “Keine Bundesmittel Mehr: Berlkönig BC Dankt AB,” 2021 (in German). https://www.taxi-times.com/keine-bundesmittel-mehr-berlkoenig-bc-dankt-ab/. Accessed on Aug. 2, 2021.