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Strategic Multimodal Assessment of Suburban Transport Infrastructure

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Abstract

Railway networks around medium-sized agglomerations in Europe face two major challenges: increasing capacity demands around the cities on the one hand and service cuts and infrastructure backlogs in more remote areas on the other hand. This paper presents an innovative three-stage multidisciplinary, iterative methodology for jointly handling demand, timetable, and infrastructure development. An intermodal transport model allows prediction of future intermodal transport demand taking demographic and structural changes into account. Sensitivity analyses are carried out to find the optimum of passenger frequency, infrastructure measures, and costs by varying travel time, stopping patterns and frequency, but also alternative bus services. This methodology has been applied to three railway networks, yielding infrastructure strategies ranging into the future as far ahead as 2045. Despite structural differences, the UITP goal of PTx2 could be achieved with sets of only moderate, yet targeted infrastructure measures for all three examples.

Keywords: Public Transport; Decarbonisation; Rural and Interurban; Transport Modelling and Management; Multimodal Transport Modelling; Sensitivity Timetable Decision Process; Suburban Railway Infrastructure

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1. Introduction

The focus on railway-based mass transport is a key factor in shifting transport towards more environmentally friendly modes. The ambitious vision of UITP (2011) launched at the Vienna World Congress in 2009 is to save 550m tonnes of CO2 by doubling the market share of public transport. Following this strategy, three use cases in Austria, aiming at doubling the modal split of public transport, are presented.

Railway networks around medium-sized agglomerations in Europe typically face two diametrically opposed challenges: increasing capacity demands right around the cities calls for large-scale infrastructure and service upgrades, while more remote network parts have seen service cuts and investment backlogs, calling for a detailed investigation of whether to continue rail service at all. In addition, these networks are to a great extent, reliant upon public service obligations and therefore need substantial amounts of public money for both operation and infrastructure development. Many commuter rails and regional lines are run based on a political commitment towards sustainable mobility. Their success might be jeopardized by changing financial circumstances or political opinions. The communities and railway infrastructure operators thus need a clear business case based on sound demand projection, smart service offer development, and a long-term infrastructure development strategy.

This paper discusses three regional railway upgrade programmes in Styria, Austria, forming a part of the regional commuter network. After defining boundary conditions and planning principles, we present demand projection, sensitivity analyses and the set of measures. Finally, the findings of the three case studies are presented.

2. Objectives

The objectives of the presented methodology and the discussed case studies can be summarized in six major topics. First, a timetable should be offered that reaches prior defined performance indicators such as modal share, patronage, and revenue. Second, there is the need to first design the operational concept based on fictional infrastructure and subsequently to derive upgrade measures by iteration of both operational concepts and infrastructure constraints. This allows for a minimum of upgrade measures needed to run the best performing target timetable.

Third, a robust strategy is to be provided without overoptimistic predictions. Conservative official estimates about demographic changes and spatial shifts are used, and policy issues, such as oil price or traffic restrictions, remain unchanged within this study. Change in demand will be identified by “Ceteris paribus” modeling based on the impact of infrastructure upgrade itself without any external influences.

Fourth, a clear and transparent decision structure is to be guaranteed by installing milestones after each step of iterative design within the methodology. This will provide the opportunity for discussing the current findings and achieving a consensus on the approach to be taken. As a result there will be no renewed discussion of previous findings following approval by all stakeholders.

Fifth, due to the large investments needs and unstable financial perspectives of railways, smaller sets of measures are linked together to form operative bundles, thus allowing for a step-by-step implementation.

Finally, rail infrastructure often has a service live in excess of several decades. Long planning horizons thus need to be taken into account to provide stakeholders with a clear concept for infrastructure development. To avoid stranded costs, all railway subsystems, covering traffic demand, railway operation, and railway infrastructure, must be integrated in the process from the very beginning.

3. Basic planning principles

Since this work tackles a wide range of disciplines, including Timetable Design, Railway Infrastructure Design, Demand Projection and Decision-Making, the crucial findings in these disciplines needed to be incorporated in the design process.

Decision-making processes such as Cost-Benefit-Analyses pose a wide variety of dangers concerning data quality, political wishes, and case modelling, as described by Mackie and Preston (1998). Furthermore, Mackett and Edwards (1998) as also De Bruijn and Veeneman (2009) and Beukers et al (2012) stress the importance of clear assumptions, avoiding overoptimistic predictions and changing circumstances in terms of both demand and the legal framework. Therefore, the design process presented here needs to be as conservative as possible concerning chances and as cautious as possible concerning risks of decision making.

Since railway infrastructure and operation are subject to several authorities and train operating companies, we face two different requirements in the context of process design: On the one hand, there is a need on the engineering level for as little sequence and as much iteration as possible. At the political level, sequential design should prevail and iteration should be avoided completely as stated by Walter (2016). Based on the classical iterative engineering design process for regional railways designed by Sonntag (1977) an innovative mixed sequential iterative design was developed by Walter and Fellendorf (2015) and further adopted by Walter (2016) as shown in Fig.1. A demand model, including demographic and spatial predictions at community level are needed as also the current status of railway infrastructure conditions. Furthermore, detailed knowledge in several sub-disciplines such as infrastructure-, operation-, and vehicle engineering is needed to define sustainable railway upgrading measures. Interdisciplinary feedback loops facilitate an iterative optimisation, comprising demand modelling, timetable construction, and upgrade measure design.

A target definition as mentioned in Fig.1 needs to be based upon national and regional transport strategies that define timetable hubs, target mobility patterns and service standards. The requirements of all affected subnetworks need to be interconnected in the main hubs according to the principles of the Integrated Timetable. In addition, timetable changes due to upgrading of connecting lines need to be considered since these can have a significant impact on the prevailing conditions of the respective line. Finally, suburban railway lines are often questioned due to low passenger frequency. Alternative bus services thus also need to be investigated by analysing expected demand, infrastructure measures and costs.

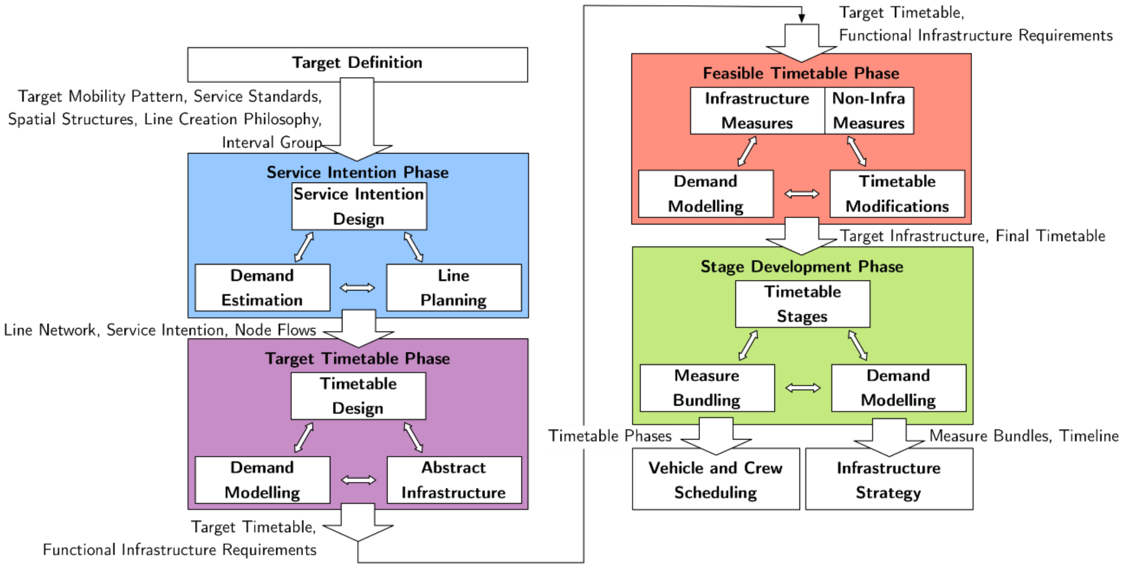

Fig. 1 Mixed Sequential Iterative Design Model (Walter 2016)

The presented methodology has feedback loops at several stages integrating demand modelling as described in chapter 5. Consequently, different model timetables are selected by sensitivity analyses (see Chapter 6). Finally, a target timetable and a bundle of measures in an infrastructure upgrade model are defined. This iterative sequential methodology makes the model a highly iterative and yet robust strategy.

4. Transport model of greater Graz

Macroscopic transport models can be used to investigate the impact of different measures in the process of transport planning. Based on an appropriate validation and calibration, an analysis of the current situation as well as different predicted scenarios is possible. The evaluation of deficits and improvements of planning measures is feasible with various parameters.

The regional, multimodal transport model of greater Graz (GUARD), is based on an analysis of working day traffic. In addition, to the city of Graz, the planning area also covers the eastern, southern and western parts of the province of Styria, together comprising a population of approximately 870,000 people. The total planning area consists of 983 traffic zones, 290 of them are in the urban area of Graz. The spatial resolution of the traffic zones is very high in the agglomeration of Graz. The resolution of traffic zones is reduced, however, with increasing distance from Graz.

4.1. Methodology

The population in the planning area is split into homogenous behaviour groups. These groups are person-categories that differ significantly by their specific travel behaviour, whereas members of the same group should show quite identical travel behaviour (Fellendorf et al, 2000). The factors age, level of employment and car ownership were used in this research project to define 13 groups with homogeneous behaviour. Consequently, the planning principles for demand projection are aligned to RVS 02.01.11 and RVS 02.01.22, which define the process of transport planning in Austria.

In the GUARD methodology (see Fig. 2), the creation of traffic supply and calculation of traffic demand is based on the constituted input data (grey boxes). The transport model uses the tour-based VISEM model for calculating the traffic demand: a disaggregated, behaviour-oriented demand model as shown in PTV Vision (2015). This calculates the demand in three steps: trip generation, trip distribution and mode choice. In contrast to the standard 4-step-model, these three logical units are not processed separately in succession. Instead, trip distribution and mode choice are carried out simultaneously as described in PTV Vision (2015). A logit impedance function is used to calculate the trip distribution and mode choice. Furthermore, trip distribution considers the willingness to accept distances in dependence on person group and activity. The calculation of mode choice differs for every person group by different values that influence the impedance function.

The traffic demand is calculated for every hour of a working day. In the next step, the 24 matrices of PrT and PuT are assigned to the traffic supply. A volume-dependent equilibrium assignment is used for PrT and a timetable-based assignment for PuT. Pedestrians and cyclists are taken into account in the computation of demand. However; these matrices are not assigned. The results of the assignments are traffic volumes and journey distance distributions as well as passenger kilometers. In the step of calibration, the calculated results are compared with empirical data. The impedance parameters of destination choice and mode choice are variated until the gap between the calculated results and empirical statistic data is minimised.

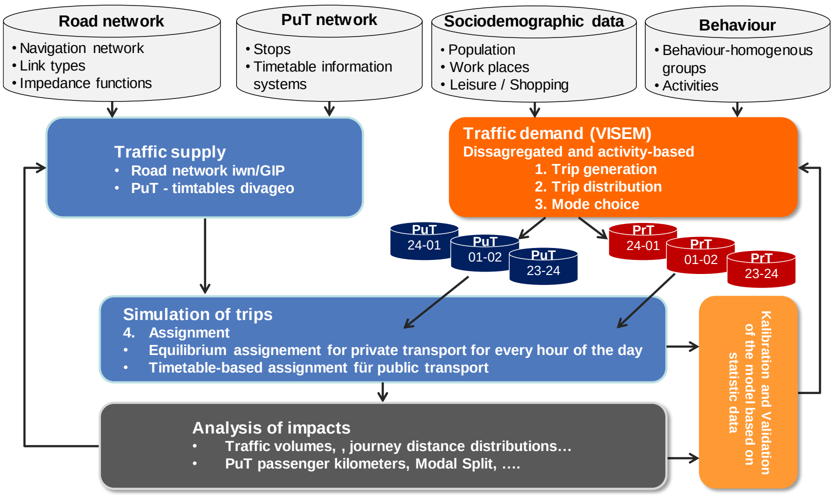

Fig. 2 Methodology of GUARD

A precise analysis of demand effects, based on changes in service frequency or line management of PuT-lines, is possible due to the hourly calculation and accurate classification of zones in the model. These changes influence the number of passengers as also the modal split. In addition, the hourly calculation of demand allows for deeper capacity investigations for peak hours.

4.2. Population exploration until the year 2030

To ensure long-term planning, the different scenarios had their planning horizon in the year 2030. Latest structural data were incorporated and demographic changes were considered, based on data of the forecast of the “Austrian conference on spatial planning” (ÖROK) (Statistics Austria, 2010). As shown in Fig. 3, population is decreasing in rural areas and further away from railway infrastructure. The population in Graz and the suburban area of Graz is increasing. The demographic shift can be observed also in the behaviour-homogeneous groups. Especially in areas with decreasing population, the number of older people with car ownership is growing. The number of people in the planning area is projected to increase to 916,000 inhabitants.

4.3. Modelling of Park and Ride

In the rural areas of the investigated railways Park and Ride traffic is of great importance. Heavy urban sprawl in these areas leads to long distances between residential areas of municipalities and the railway stations. An appropriate approach for this type of traffic was essential for an adequate modelling, furthermore the affinity of commuters to Graz should be modelled. The approach assumes that both cars and carpools are used as access transport to the Railway station. Furthermore, it is assumed that passengers walk short distances (< 500 m), use bikes for middle distances (up to 2 km) and use cars for longer distances. As a result, different connector speeds are used for different distances.

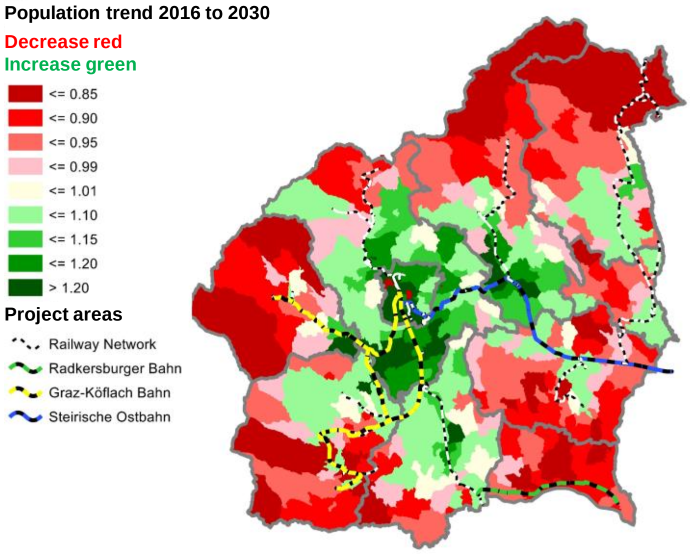

Fig. 3 Population trend 2016 to 2030 and project areas

4.4. Rail bonus

An important aspect for mode choice in public transport is the distinction between rail-based and bus-based PuT. Monheim (1997) found that light rail and streetcars have a significantly higher market acceptance than busses due to their better recognition factor and greater comfort. Further literature about the rail bonus based on models, were found in Axhausen (2001) and Ben-Akiva (2002). Bunschoten (2013), Schulz (2003) and Scherer (2011) explain the rail bonus based on the subjective attitude of passengers in case studies. Heimerl et al. (1988) also include a rail bonus in their work concerning the standardised assessment of public transport infrastructure investments.
Although the short project duration did not allow a comprehensive SP survey and in consequence an integration into mode choice (nested logit), this observed "rail-bonus" is considered with a simplified approach in the transport model. Based on Heimerl et al. (1988), a rail bonus depending on travel time was implemented into the mode choice. There is a bonus for the assessment of travel time for rail/streetcar. For short travel times no bonus exists. However, for longer travel times the bonus leads to a higher usage of rail/streetcar compared to busses.

4.5. Cross-border demand potential

In the course of the investigations, the transport model has been extended to model cross-border links to Hungary and Slovenia. Traffic countings and a detailed survey in cross-border areas delivered data concerning the origin and destination as well as the frequency and purpose of trips. Based upon this data it was possible to determine an expected shift of demand from PrT to PuT depending on travel time savings and demographic changes. Through this approach the supplementary demand potential could be integrated into the demand calculation.

5. Strategic timetable development

5.1. Sensitivity analyses

Since transport policy needs to be broken down to form clear objectives in terms of railway infrastructure design, several sets of sensitivity analyses need to be carried out. This is to reduce the amount of design cases and ensure a fast decision procedure.

The sensitivity analyses carried out tackle only one timetable property at once, and vary the most extremal characteristic thereof. For example, and most important for railways, there is a trade-off between travel time and the stopping pattern, where a case with the least stops and the fastest travel time is compared its opposite. For every sensitivity analysis, both extremal cases are analysed in depth concerning their impact on travel behaviour.

Sticking with the example of travel time and stopping pattern: if there is a need to reduce stops by a given number, an in-depth investigation is needed for each station whether the benefit of decreased riding time outweighs the cost of not serving a station. Consequently, critical stations with a low passenger demand can be identified and excluded from further investigations.

Furthermore, the target interval is assessed. Even though a higher frequency generally leads to higher demand, this does not necessarily increase the number of passengers. Higher frequency fo train also requires addional tracks, and train crossings might in turn slow down train rides. The demand for dense intervals needs to be evaluated in the context of demand, requirements for infrastructure and costs. If sensitivity analyses result in an adoption of the frequency, the construction of a new working timetable is necessary. Apart from these two operational boundary conditions, the given railway infrastructure should be used efficiently and the need for new infrastructure minimised.

If railway lines in rural areas struggle with low passenger numbers they need to be compared with alternative bus services. It is to be examined whether existing infrastructure like Park and Ride lots can be integrated and whether bus stops should be situated at railway stations or if it is for them to be accessible at central locations in rural settlements. Furthermore, to allow for the highest demand in the public transport system, the connection of alternative bus services does not necessarily have to be at the same hub than the respective railway line. However, railway lines and alternative bus lines need to be compared at equal boundary conditions to guarantee an objective result.

This process finally provides the decision criteria for mode choice and transport assignments.

5.2. Set of measures

Once the target timetable is defined, the railway infrastructure is altered with several sets of measures, sketching different alternatives of how to allow the target timetable to be run. There is basically a subdivision into infrastructure measures and non-infrastructure measures. The latter comprise vehicle acceleration or increased lateral acceleration. Infrastructure measures range from minor track geometry actions via interlocking modifications to alignment measures and electrification. These measures can be divided in groups for safety tasks, travel time reduction and capacity improvement and indicate different benefits and costs. A detailed set of measures including travel time relevance and cost values is given in Veit et al 2014. In addition, maintenance actions increasing speed limits and extensions of park and ride lots need to be considered.

Removal or equipment of level crossings with signal pre-emption places a major issue in the upgrade of suburban railway lines and is required in Austria by 2025 due to legal changes. Apart from that, it can significantly cut travel times, since unsecured level crossing pose a speed limit of 60 km/h.

In Austria the maximum speed of branch lines is widely limerited by 80 km/h. Raising the maximum speed often requires a cost-intensive adaption of the signalling system. Increased lateral acceleration and cant modification are cost-effective and easy to implement. Realignment of specific track sections, however, seldom allows for significant travel time improvements.

With the current rolling stock used in Austria, diesel lines are restricted to 120 km/h. Electrified commuter railcars reach up to 160 km/h and higher acceleration and deceleration parameters. However, electrification is costly.

Operationally indicated measures are crossing points and double track sections. Station layout has a huge impact on capacity of networks as well as it affects travel time. Double and more track sections offer overtakings and crossings as well as parallel exits in case switches offer a respective maximum design speed.

5.3. Infrastructure upgrade model

Finally, the necessary infrastructure measures are clustered in order to establish a long-term step by step upgrade model. Intermediate timetables allow the sequence of upgrading measures to be defined, since modifications in the railway system usually take several years to implement. Upwards compatibility of all measures is to be maintained to prevent stranded investments. Additionally, the upgrading plans of companies in the surrounding areas need to be considered to be able to prioritise key projects.

6. Case studies

This methodology has been applied to three suburban railway sub-networks in the proximity of Graz, Austria. Fig. 4 shows the three sub-networks in the network context within the province of Styria.

Fig. 4 The three sub-networks this methodology has been applied to within the network context of the province of Styria

6.1. Graz-Köflacher Railway

The Graz-Köflacher Railway (GKB) operates three lines in the south-west of Graz, covering both suburban and regional transport. The three branches run from Graz via Lieboch to Köflach (line S7), from Graz via Lieboch to Deutschlandsberg (line S61) and from Graz via Deutschlandsberg to Wies-Eibiswald (line S6). Together they form a 90km railway network in possession of GKB, while line S6 runs on parts of the infrastructure of the Austrian Federal Railways (ÖBB) between Graz and Wettmannstätten.

The project goal was to develop a comprehensive infrastructure strategy ranging from 2015 to 2045. The existing responsibilities and competences connected with the development of both infrastructure and timetable, however, rendered a systematic approach for a joint development of timetable and infrastructure impossible. This called for a reorganisation of the entire decision process towards a guided process incorporating both iterative and sequential elements (see chapter 4). With this model, all relevant stakeholders could be incorporated in the decision process, while retaining a high grade of iteration between demand, timetable, and infrastructure design as shown in Veit et al 2014 as well as Walter and Fellendorf (2015).

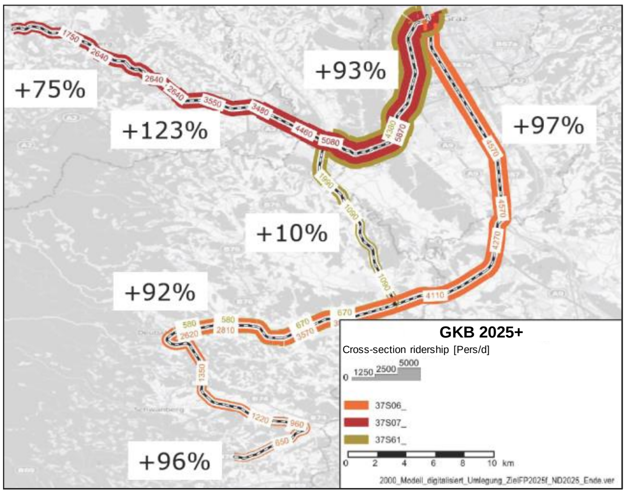

Fig. 5 Patronage increases (person kilometres) and cross-section ridership (persons) on the Graz-Köflacher Railway Network, target timetable

First, the demand projection for the year 2015, overlain with the timetable offer of 2011, showed a significant patronage decrease (–2% in total and up to –6% on line S7) i.e. the do-nothing option could be dropped immediately. Against this background, a set of model timetables covering extreme cases of service offer, were developed. The first decision was made to compare a peak hour 15-minute headway in peak hours with a 30-minute headway. This showed that the denser interval was necessary only in the proximity of Graz, while it did not result in a significant patronage increase further afield. The second decision was to compare a timetable model with the current stopping pattern with one of significantly reduced amount of stops and riding time. Here it was shown that an over-proportional patronage increase could only be achieved with significantly decreased riding time. The decision was thus made to (i) pursue a strategy with denser intervals between Graz and Lieboch and (ii) to significantly reduce the number of stops further outside this area. For every single stop in question, a comparison was made as to whether the number of passengers lost by skipping the stop outweighed the number of passengers won by reducing the travel time. Finally, an (operationally feasible) target timetable was constructed just as described in the methodology.

This resulted in a comprehensive set of measures of all types, where each individual measure could be traced back to its demand effects and judged against its alternatives. Finally, a joint timetable and infrastructure strategy could be developed with a patronage increase of up to 100 % (see Fig. 5) and a modal split for PuT of 18 to 33 %.

One significant result of the study was the decision on whether or not to electrify the network. It had been clearly demonstrated that electrically powered vehicles outperformed diesel vehicles by so much in terms of acceleration that compensating infrastructure measures were required to achieve the same timetable in electric and diesel traction. These compensating measures added up to infrastructure upgrade costs comparable to an electrification of the network, with the result that the infrastructure strategy is to (i) electrify the network, (ii) close three minor stations, (iii) selectively increase riding speeds, (iv) double-track two sections, and (v) technically secure all level crossings.

6.2. Spielfeld-Bad Radkersburg

The second sub-network to which this methodology has been applied was significantly more complex in terms of design cases, while the line itself is considerably simpler. While integrated into the suburban railway (S-Bahn) network of Graz as line S51, the Spielfeld–Bad Radkersburg line primarily serves local and regional transport. Due to its nature as a minor branch line, the closure of the line and replacement by bus also needed to be considered as a design case. In extension of the comparison of extreme cases as shown for the Graz-Köflacher Railway network, a five-step decision process (see Fig. 6) was developed as shown in Veit et al (2017a).

Since the closure of the line was one option, the running costs of keeping the railway service were also considered. In the initial analysis, a similar result as for Graz-Köflacher Railway was obtained: the do-nothing option, i.e. keeping up the current service, would result in a 12 % decrease in patronage, while still requiring a double-digit million euro sum in infrastructure costs. The modal Split of PuT would drop to 7 %. The remaining decisions to be made differed considerably, however, largely due to the different nature of this railway.

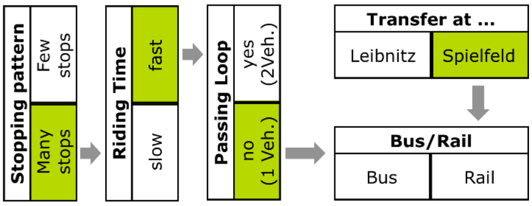

Fig. 6 Decision Process for the Spielfeld–Bad Radkersburg Line

First, the stopping pattern was evaluated as described above. This showed, however, that many stops are required to increase patronage, while reduced riding time did not result in comparable increases. Second, the riding time (current riding time of 41 min compared to 30 min) showed a clear preference for the latter. Third, an evaluation was made on whether to decrease riding time as far as possible, while still being able to run with one vehicle only (26 min) or alternatively to use two vehicles with a slightly longer riding time (30 min) combined with a passing loop. While comparable in patronage, the extra infrastructure measures needed for an even shorter riding time proved less expensive than the additional passing loop. A completely separate decision was to be made on whether to retain the current transfer point at Spielfeld or to continue the service to the next largest urban centre, Leibnitz, instead of the main S-Bahn line S5. While the latter option performed better when only taking the Spielfeld–Bad Radkersburg line into account, the bigger picture showed far more patronage decreases on the Leibnitz–Spielfeld line, resulting from the significantly higher patronage and the associated negative effects of additional transfers there.

The final and most difficult decision had to be made between rail and bus services. The bus service performed in a manner similar to the do-nothing case (–16 % patronage and 6 % modal split for PuT), while requiring only 25 % of the investment costs and 44 % of the running costs (infrastructure maintenance and service offer) when compared to the do-nothing case. The best-performing design case for railway service, however, showed a 67 % patronage increase and 10 % modal split for PuT. This solution, however, also requires 30% more investment costs and 21 % more running costs for the maintenance and service provision. With roughly 1,200 passengers a day, this design case is the only one to achieve the so-called system adequacy, a term coined by ÖBB infrastructure to justify railway infrastructure.

In total, the results of the study call for a political, rather than a technical, decision: While it is clear that the do-nothing option is the most expensive and least effective one, the decision here depends on whether the financial aspect of the significantly lower costs of a bus service, or the transport policy aspect of the significantly better performance of a rail service prevail. No decision on these two options has been made on the political level so far.

6.3. Graz-Szentgotthard

The Graz–Szentgotthárd line is the latest infrastructure project to be assessed with the current methodology. This line shares most properties with Graz–Köflacher Railway, and additionally serves as major freight traffic line. Furthermore, this line is a strategic link with Hungary. Therefore, one additional design case to be considered in this project is a planned high-performance rail link between Graz and Gleisdorf.

A precise modelling of bus corridors in far greater detail than on the other network was necessary here. Fig. 7 shows the strong interdependencies between rail and bus, with bus serving attractive downtown locations in Graz and express buses directly connecting Graz with the important towns of Hartberg and Fürstenfeld.

Compared with the Graz-Köflacher Railway, the upgrade possibilities between Graz and Gleisdorf, where most suburban demand could be allocated, were minor. Furthermore, the dense timetable models allowed for no riding-time decreases, and the initial target service offer even increased riding times for longer-distance passengers.

A much more detailed investigation of timetable models thus had to be carried out, with the need to compare operationally feasible timetables, rather than model timetables. Additionally, the target service offer of four trains per hour between Graz and Gleisdorf was even decreased to three trains per hour in order to provide faster paths for limited service trains. Even further, the integrated timetable service originating at Graz station needed to be redesigned completely in order to allow for an adequate performance, especially east of Gleisdorf. Only then could a performance be achieved that allowed to increase patronage east of Gleisdorf.

The frequent changes in the service intention itself called for 9 different design cases in total, branching out from three base scenarios. Remarkably, the design case of only three trains per hour also performed better on the suburban part of the line, since the riding time advantages of the faster trains could also be used for the bigger stations west of Gleisdorf. This shows that a total of 48% patronage increase (person kilometres), or a 27 % modal split for public transport, was possible as presented by Veit et al (2017b).

Fig. 7 Bus and Rail dependencies for Graz–Szentgotthárd

Surprisingly, the electrification of the line did not allow for significant changes in patronage when compared to the diesel service; this is mainly due to the aforementioned capacity constraints between Graz and Gleisdorf. East of Gleisdorf, the higher possible top speeds of electrically powered vehicles could be made utilised.

The question of the high-performance rail link, however, had to be postponed to a more sound investigation of international travel demand, both in freight and passenger service. Since the electrification directly interferes with this link in terms of service lives, the decision to electrify was also postponed to be jointly decided upon.

7. Conclusion and outlook

This paper discusses not only a planning process for a long-term upgrade strategy of regional railway lines but also strategies for questioned lines that face the challenge of replacement by bus services.

The examples shown in this paper show the benefit of joining demand modelling, timetable construction, and infrastructure design in a single interdisciplinary, iterative design process. The target timetable and the infrastructure measures needed to implement it are treated simultaneously, with the result that every measure can be traced back to its benefit. Within the process, we were able to precisely derive individual measure bundles for three different network setups. While verification of the findings in this project can only be verified in the future, the results have been approved by all stakeholders. All milestones were finalised and approved by milestone decisions. The decision framework follows state-of-the-art practice in each field; but, the combination of demand modelling, timetable construction and infrastructure design, however, has not been seen in the past for regional transit concepts. The methodology and planning framework is universal and can be adapted to other regional rail infrastructure upgrades applications.

The experiences gained are currently used to allow for one further step: the development of a full-scale long-term multimodal public transport strategy for the entire greater Graz region.

8. References

Axhausen, K. W., 2001. Searching for the Rail Bonus. European Journal of Transport and Infrastructure Research, 353-369.

Ben-Akiva, M., 2002. Comparing ridership attraction of rail and bus. Transport Policy 9, 107-116.

Beukers, E., L. Bertolini, and M. Te Brömmelstroet, 2012. Why Cost Benefit Analysis is perceived as a problematic tool for assessment of transport plans: A process perspective. Transportation Research Part A: Policy and Practice, Vol. 46, No. 1, pp. 68–78.

Bunschoten, T., 2013. Tram or bus; does the tram bonus exist? Paper presented at the European Transport Conference 2013.

De Bruijn, H. and W. Veeneman, 2009. Decision-making for light rail. Transportation Research Part A:, Vol. 43, No. 4, pp. 349–359.

Fellendorf, M., Haupt, T., Heindl, U., Scherr, W., 2000. VISEM – An activity chain based traffic demand model, PTV AG, Karlsruhe.

Heimerl, G., W. Meier, H. Dobeschinsky, H.-U. Mann and B. Götz (1988) Standardisierte Bewertung von Verkehrswegeinvestitionen des öffentlichen Personennahverkehrs, report to the Bundesministerium für Verkehr, Verkehrswissenschaftliches Institut, Universität Stuttgart and Intraplan Consult, Stuttgart and München

Mackie, P. and J. Preston, 1998. Twenty-one sources of error and bias in transport project appraisal. Transport Policy, Vol. 5, No. 1, pp. 1–7.

Monheim, H., 1997. Grundsätze für die Aufstellung von Nahverkehrsplänen und die Förderung eines attraktiven ÖPNV, Handbuch der Kommunalen Verkehrsplanung Chapter 3.3.3.7, Economica Verlag, Bonn.

PTV Vision, 2015. PTV Visum 15 Manual, PTV AG, Karlsruhe.

Scherer, M. 2011. The image of bus and tram: first results. Paper presented at the 11th Swiss Transport Research Conference.

Schulz, M. 2003. Quantifizierung des Schienenbonus. Der nahverkehr 6/2003, 26-29.

Sonntag, H., 1977. Linienplanung im öffentlichen Personennahverkehr. Dissertation, TU Berlin, Berlin.

Statistics Austria, 2010. Kleinräumige Bevölkerungsprognose für Österreich 2009 – 2050 (ÖROK – Prognose): Endbericht zur Bevölkerungsprognose, Vienna, Austria.

UITP 2011. Towards low/zero-carbon urban mobility in Europe. Online; last accessed: October 02, 2017. URL: http://www.uitp.org/sites/default/files/cck-focus-papers-files/FPNov2011.pdf.

Veit, Peter, Stefan Walter, and Martin Fellendorf, 2014. GKB Weissbuch 2025+. Strategic Plan for GKB regional railway in Styria. Final Report (in German). Tech. rep. Graz University of Technology.

Veit, Peter, Martin Fellendorf, Martin Smoliner, Karl Hofer, and Stefan Walter, 2017a. Verkehrskonzept Radkersburger Bahn. Final Report (in German). Tech. rep. Graz University of Technology.

Veit, Peter, Martin Fellendorf, Martin Smoliner and Karl Hofer, 2017b. Verkehrskonzept Steirische Ostbahn. 3. Lenkungskreissitzung (in German). Presentation. Graz University of Technology.

Walter, S., Fellendorf, M., 2015. Long-Term Upgrade Strategy for Light Rail and Regional Rail. In: Transportation Research Record: Journal of the Transportation Research Board 2534.

Walter, S. 2016. Long-Term Railway Infrastructure Development. Expansion of the Integrated Timetable on Mixed-Traffic Passenger Railway Networks, Dissertation, TU Graz.