Regional public transport

The balancing act of service planning

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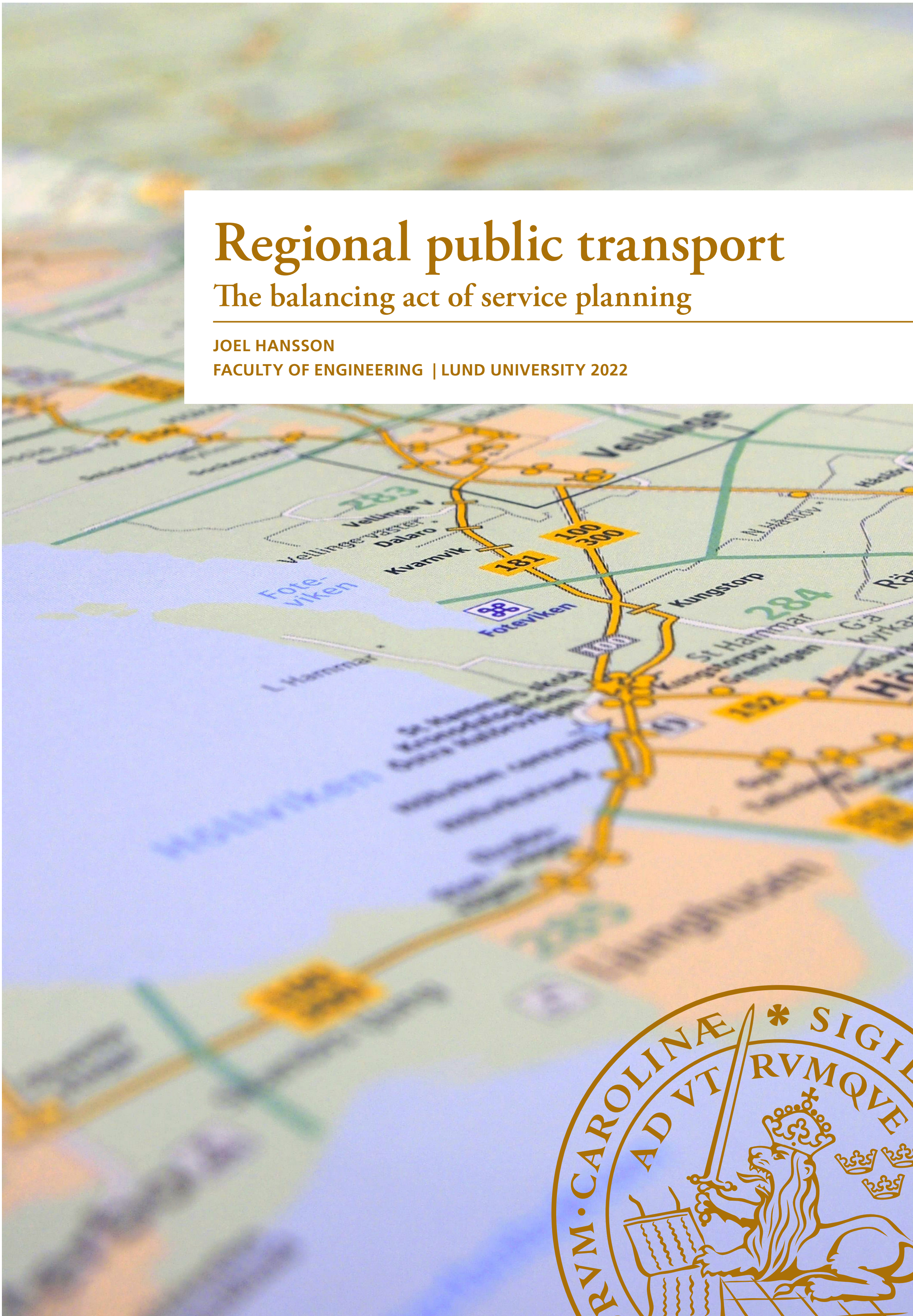
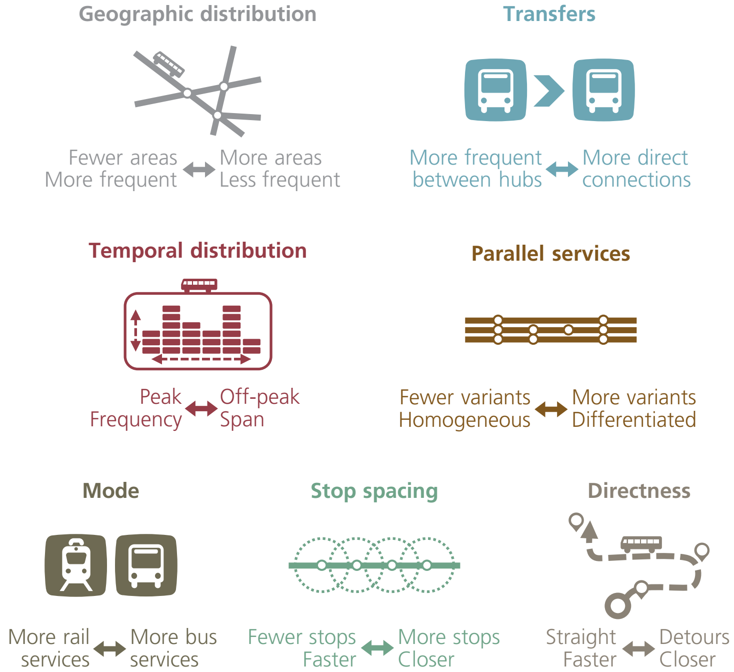
JOEL HANSSON

FACULTY OF ENGINEERING | LUND UNIVERSITY 2022





Public transport planning entails different types of trade-offs, within which different factors need to be balanced against each other, both for the network as a whole as well as for the individual services in the network. This thesis highlights the regional perspective in this balancing act and shows that the differences between local and regional public transport affect the connections from the service planning trade-offs to the overarching objectives of public transport provision.

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Regional public transport

The balancing act of service planning

Joel Hansson

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Regional public transport: The balancing act of service planning

Abstract

This thesis addresses the demand for more knowledge regarding regional public transport (between urban areas or to and from rural areas). More specifically, the aim is to develop a better understanding of the effects of different service planning decisions in terms of different trade-offs and their impacts on the overarching objectives of public transport provision. The studied trade-offs concern, for example, stop spacing in rural areas and the distribution of departures between peak hours and periods of lower travel demand.

The thesis includes four research papers with different orientations relative to the overarching aim. The first paper is a literature review that explores preferences in regional public transport and how different quality attributes influence modal choice, demand, and customer satisfaction. The other three papers contain in-depth studies of some regional rail, coach, and bus services in the southern Swedish region of Scania, employing different research setups and statistical analyses to enable detailed examination of some important aspects of the service planning trade-offs.

The results suggest that the trade-offs can be more complex than they may seem. For instance, stop spacing is commonly debated and assessed as a trade-off between travel time and spatial coverage. However, the results of this thesis demonstrate that stop spacing on regional bus services is not so much about travel time as it is about reliability. This is particularly evident for rural bus stops where buses rarely need to stop to pick up or drop off passengers. Also, the coverage aspect of the trade-off is complex, as higher service quality extends the catchment areas around the stops, not least by increasing the use of bicycles and cars as access modes.

Regarding the distribution of departures between peak and off-peak periods, the results of this thesis show that reasonable off-peak service levels are valuable not only for providing possibilities to access activities beyond school and work, but also for attracting new patronage. Despite low patronage levels on some off-peak departures, such departures may contribute substantially to the overall patronage.

The main contribution of the thesis is twofold. First, it sheds light on the balancing act that public transport service planning entails. Second, it highlights the regional perspective and shows that the differences between local and regional public transport affect the trade-offs that exist at the core of service planning.

Keywords
Public transport; Network planning; Regional bus; Regional rail; Rural accessibility; Service planning; Trade-offs

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Populärvetenskaplig sammanfattning

Kollektivtrafikplanering är en balansakt. Å ena sidan är det viktigt att satsa där det finns potential för många resor. Då krävs en koncentration av resurserna till stråk och noder med stort befolkningsunderlag. Å andra sidan är det också angeläget att skapa en rättvis fördelning av den offentliga service som utgörs av kollektivtrafiksystemet, så att även människor i mer glesbefolkade områden ges möjlighet att resa.

På ett mer individuellt plan sker en liknande balansakt mellan olika preferenser och behov. I vissa situationer eller för vissa individer kan det vara viktigt att ha nära till hållplatsen och mindre viktigt hur snabbt resan går. I andra situationer eller för andra individer kan det vara värt att ta sig till en hållplats lite längre bort om resan därifrån går snabbare eller om det är tätare mellan avgångarna där. De olika preferenserna och behoven ställer motstridiga krav på kollektivtrafiken och därför måste de vägas mot varandra när systemet utformas.

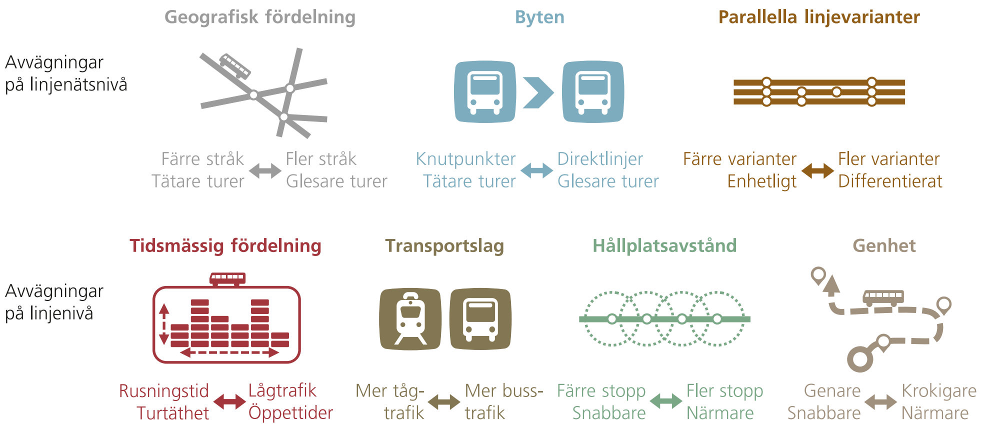
I denna avhandling har dessa balansakter studerats i form av olika typer av planeringsavvägningar i regional kollektivtrafik (mellan tätorter och på landsbygd). De avvägningar som studerats är till exempel hur tätt det ska vara mellan hållplatser eller hur avgångarna ska fördelas mellan rusningstid och perioder med färre resenärer. En översikt med fler typer av avvägningar visas i Figur a.

Avhandlingens resultat visar att planeringsavvägningarna kan innehålla en väsentligt högre grad av komplexitet än vad som vanligtvis framgår i debatter och utvärderingar. Detta kan leda till att viktiga effekter förbises och att beskrivningen av avvägningarna därmed blir vilseledande.

Till exempel beskrivs hållplatsers vara eller icke vara ofta som en avvägning mellan snabbhet och närhet eller geografisk täckning. Ju fler hållplatsstopp desto långsammare blir resan, men samtidigt får fler invånare nära till en hållplats.

En av avhandlingens delstudier visar dock att landsbygdshållplatser som används sällan har ytterst marginell påverkan på den genomsnittliga körtiden. Däremot finns risk för att körtiden på varje enskild tur blir svårare att förutspå, vilket innebär försämrad punktlighet. Effekterna av fler eller färre hållplatser på regionala busslinjer handlar följaktligen inte så mycket om snabbhet som om pålitlighet.

Även vad gäller geografisk täckning är avvägningen mer komplex än den först kan verka. Trots att landsbygdshållplatser tas bort kan kollektivtrafikresandet i motsvarande



Figur a Planeringsavvägningar
Olika typer av avvägningar som behöver balanseras i kollektivtrafikplanering, dels för linjenätet som helhet och dels för enskilda linjer. Figuren framställer en förenklad bild av avvägningarnas mekanismer, men speglar ändå huvuddragen i hur de vanligtvis debatteras och utvärderas. Avhandlingen visar att det kan vara av avgörande betydelse, i synnerhet i regional kollektivtrafik, att beakta effekter bortom de mest uppenbara sambanden som ofta hamnar i fokus.

område öka om mer högkvalitativ kollektivtrafik samtidigt tillkommer vid andra, närliggande hållplatser eller stationer som är tillgängliga med cykel eller bil från omgivande landsbygd. Detta studerades genom ett antal fall där tågtrafik införts i mindre orter och då ersatt busstrafik med betydligt fler hållplatser.

Den tidsmässiga täckningen, det vill säga huruvida det är möjligt att resa vid olika tider på dygnet, är också avgörande för att kollektivtrafiken ska vara attraktiv. Avhandlingen visar att avgångar utanför rusningstid kan ha stor betydelse för det totala resandet, även om antalet resor på de specifika avgångarna i fråga är få. På de tåg- och busslinjer som ingick i den delstudien ökade resandet kraftigt efter att några luckor i tidtabellen täppts till mitt på dagen och på kvällen, så att konsekvent timmestrafik kunde erbjudas från morgon till kväll.

Slutligen kan man fråga sig vad som är det nya med dessa resultat? Det finns två övergripande svar på denna fråga. För det första har den balansakt som kollektivtrafikplanerare utför blivit synliggjord. För det andra har det tidigt under arbetets gång kunnat fastslås att det funnits en kunskapslucka: Tidigare kollektivtrafikforskning har i stor utsträckning fokuserat på stadstrafik. Denna avhandling har i stället lyft fram det regionala perspektivet och visat att skillnaderna i förutsättningar påverkar de avvägningar som finns i kollektivtrafikplaneringens kärna. Resultaten kan förhoppningsvis komma till nytta i planering av regionala linjenät och tjäna som utgångspunkt för många fler studier om regional kollektivtrafik framöver.

Preface (with acknowledgements)

Before you lies the doctoral thesis "Regional public transport: The balancing act of service planning", a compilation thesis consisting of a framework story (*kappa*) and four scientific papers. The thesis explores various types of trade-offs that essentially are present in all planning of public transport services.

To start from the beginning, being a middle child, I began practicing the art of compromise and trade-offs already in my early childhood. Some argue that such a background may be a perfect foundation for a career in diplomacy, but I chose a different path. However, during the progress of this thesis I have realised that this path, after all, is not as different as I previously thought.

Nevertheless, it would not be fair to claim that the origin of this thesis can be traced to my childhood. In reality, the project upon which this thesis is built started with an application for research funding in the summer of 2015. Before continuing, I would like to take the opportunity to acknowledge the effort put into this (eventually) successful application by Fredrik Pettersson-Löfstedt and Anders Wretstrand at Lund University and K2 – the Swedish knowledge centre for public transport – with support from Stephan Bösch and Lena Smidfelt Rosqvist at Trivector.

The research application was based on the so-called Regional Superbus Concept, which was to be implemented during the following years. At this stage, the project aimed at evaluating some of the measures to be put into practice. To me, this was an exceptionally intriguing setup because I, as a consultant, had been involved in the development of the Regional Superbus Concept since its inception almost ten years earlier. In this regard, a posthumous acknowledgement should be given to Patrik Lindblom, then at the regional development body Region Skåne, as the person chiefly responsible for the progress of this development.

As it turned out, the implementation of the Regional Superbus Concept was postponed several times. At the time of the initial research application, the inauguration of the first service was planned for 2016, but at the time of this writing, this is still in the future (planned for December 2022). I will not delve into the reasons for these postponements here – this is a potential research topic in itself.

Consequently, the intended empirical material has been absent throughout the course of the research project. Admittedly, this has led to some gnashing of teeth over

the years. In hindsight, however, it was perhaps the best thing that could have happened for me as a doctoral student. Not only did the involuntary change of research approach force me and my supervisors to deconstruct the Regional Superbus Concept and find ways to study its components in other settings, but it also opened the door for a broader and even more intriguing research topic, in my opinion.

Here, it is high time to acknowledge the invaluable contributions of my supervisors: Anders Wretstrand, Helena Svensson, and Fredrik Pettersson-Löfstedt. Ever since the first supervision meeting in *Snickarboa* at the former K2 office, our discussions have always boosted my energy. I wish we could continue with these meetings regularly for the rest of my career! By the way, I may have expressed a few times during the process that "I could stick to being a doctoral student forever" and similar statements. I sensed that this was met with a certain amount of unease in the eyes of my supervisors (my apologies). However, I hope that the statements evoke other emotions in retrospect, as they should be interpreted as the highest possible grade for the supervision.

On that note, I have really enjoyed being a student again. It has been a privilege to have been given the opportunity to read, think through, and discuss various interesting topics (with a varying degree of relevance for my own research) – a privilege made possible by the research funders. Thus, I owe a great debt of gratitude to the Swedish Transport Administration, the main sponsor of the thesis project.

The research grant provided by K2 is also greatly appreciated. Even more so, K2 has provided an inspiring work environment with fantastic colleagues from many different research backgrounds but still working together on the common theme of public transport. I would especially like to acknowledge the extraordinary doctoral student community – former and present doctoral students at K2 together with the captain of this community, Helena Svensson.

Despite my mostly sporadic appearances at my other office, the Division of Transport and Roads at the Department of Technology and Society of Lund University, the people there have always made me feel welcome. Thanks to that, I have had a perfect base for my teaching activities in the undergraduate course in public transport – for which the teaching expertise of Andreas Persson should be particularly acknowledged – as well as for my learning activities at the postgraduate courses given by the Faculty of Engineering. These courses have been both enjoyable and valuable to my academic development.

My more practical, subject-oriented development, though, gained momentum some years earlier, when I had the privilege of working with some of the most skilled public transport planners imaginable. In particular, I would like to express my gratitude to PG Andersson and Mats Améen at Trivector for showing me the delights of neat *principle timetables* and other exciting and crucial elements of public transport planning. This experience has been fundamental to the making of the thesis.

There are also a number of reviewers to acknowledge for their ingenious comments and thereby important contributions to the thesis. Starting from the end of the process this time, Karin Brundell-Freij and Tom Rye deserve praise for their excellent advice at my so-called final seminar. In fact, Tom Rye deserves double praise because he also made a brilliant contribution to the halfway review. Furthermore, I am grateful for the contributions of the anonymous reviewers of the included research papers. In this case, my gratitude has undergone a transition from a rather insincere "thank you" to a genuine *thank you* – in parallel with the sometimes painful process of digesting constructive feedback.

These processes have been made much more comfortable thanks to my family and friends, who have given me pleasant reasons to temporarily (?) forget some of the more indigestible issues. In particular, my dear Liv, Ines, and Gry deserve my deepest gratitude for having pulled me out of my work bubble on a daily basis and thereby kept me reasonably sane even during periods of academic confusion.

Finally, to link back to the beginning of this preface, I am glad I chose a career in public transport planning (not that diplomacy was ever a real option, but anyway). For "outsiders", though, I have never really managed to pinpoint exactly what makes it so interesting. I believe that the balancing act described in this thesis may be a clue.

Joel Hansson
Lund, July 2022

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Introduction

Prologue

In early 2019, the Suffolk County Council in the east of England faced significant budget cuts. The passenger transport budget was not exempt from these cuts, and after a few months of investigations it was announced which bus services were under the axe. Overall, 23 rural bus services were suggested to be cancelled before the end of the year. The proposal was supported by figures that revealed low patronage levels and high costs; the 23 bus services accounted for only 0.7 percent of the total number of bus trips in the county, and the subsidy on some services amounted to more than £25 for each return journey (Geater, 2019).

One of the services subject to the bus cuts was the 375, connecting a number of villages to the town of Bury St Edmunds. Despite very limited frequency, with only three departures a week, the impending closure did not go unnoticed. A few weeks before the planned cuts were to take effect, residents along the route gathered in a protest (Berriman, 2019). The protestors in one of the villages are pictured in Figure 1. As can be seen in the picture, the villagers carried some strong arguments for saving the 375, such as "Go green", "Don't cut off our rural community", and "Don't exclude our non drivers". It is hard to imagine that the county council would oppose any of these arguments, which could conceivably correspond to relevant goals for the regional public transport network, but obviously a trade-off has had to be made and the 375 drew the short straw.

Similar protests surfaced in the early months of 2020 on the Falsterbo Peninsula in the south-westernmost part of Sweden. However, the backdrop of these protests differed considerably from the protests in Suffolk. In the Falsterbo case, the protests were not about suggested bus cuts but were the result of a proposal for a public transport investment named *Regional Superbus*. With the intention of developing a higher level of service on the peninsula, the public transport authority had suggested a more direct route with fewer but more well-equipped bus stops and coaches with a higher level of comfort than the buses they were to replace. Some of the areas that would end up far from the more direct route were to be provided with feeding services (Landelius, 2020).

Figure 1 "Save our 375"
Protests against rural bus cuts in Suffolk in the east of England. From "Hawstead, Lawshall, Nowton and Shimpling villagers concern as axe hangs over thrice-weekly bus service", by C. Berriman, 2019, October 20, *Bury Free Press*. Picture by M. Westley. Copyright 2019 by Iliffe Media. Reprinted with permission.

The protestors argued that the longer access distances could have effects in direct opposition to the intention of the project and that the loss of direct connections in some areas would have particularly negative consequences for the older population. They also expressed concerns about increased traffic in connection with the proposed park-and-ride facilities (Landelius, 2020).

One year later, the public transport authority released a revised plan with a less direct route in favour of maintaining proximity to the service in certain areas, but at the expense of travel times (Landelius, 2021). Hence, the revised plan entailed a slightly adjusted position in the trade-off between proximity and speed. The strategic planning manager at the public transport authority summed up the events by stating, *if you zoom in properly, there are always conflicts of interest that need to be navigated* (J. Gomér, as cited in Landelius, 2021).

The two stories from Suffolk and the Falsterbo Peninsula illustrate some of the tensions that must be addressed in the planning of regional public transport services. The tensions exist regardless of national context and permeate the service planning trade-offs that need to be balanced irrespective of whether the background is a matter of cuts or investments.

Concrete things such as travel time savings and proximity to stops are often at the centre of the debates. However, the tensions in the debates are essentially signs of conflicts between different overarching objectives. These conflicts come to the surface in the service planning, but the connections between the service planning trade-offs and the overarching objectives are unclear in many cases.

The present thesis explores some of these connections with regard to the effects of different service planning decisions in regional public transport. The effects are discussed in terms of different types of trade-offs that are present in the planning process. The emphasis on regional public transport is important because previous research on public transport service planning has largely focused on local services (within urban areas).

Definition of regional public transport

When studying public transport, it is relevant to acknowledge the differences between different geographic scales, i.e. local, regional, and interregional. This is because the general characteristics of local travel are different from regional travel, and similarly there are important differences between the regional and interregional levels.

Features distinguishing regional public transport from local are, typically, longer distances, lower passenger volumes, and higher travel speeds (Luke et al., 2018). There is also an important difference regarding alternative transport modes available. Walking and cycling are viable options for local travel, but for regional travel public transport is generally the only alternative to the car.

Concerning the regional and interregional levels, trip distance is again an important difference together with typical trip purposes and trip frequencies. Many regional trips are made on a regular basis, whereas interregional travel is dominated by trips that are made less frequently.

These differences in travel characteristics have an impact on the preferences of potential and existing passengers as well as on the prerequisites for planning public transport services (Román et al., 2014).

In this thesis, the following working definition of regional public transport is adopted, distinguishing between local and regional public transport based on urban and rural areas and between regional and interregional based on typical trip frequency:

- *Regional public transport targets passengers travelling between separate urban areas (interurban) or to and from rural areas (rural or rural-urban), and a majority of the trips are made on a regular basis (daily to weekly in general).*

Importantly, the working definition focuses on public transport *services* rather than individual *trips* or *passengers*. This means, for example, that some passengers on a regional service may travel less frequently than once a week, but the majority of the passengers on the service travels more frequently. Analogously, some passengers may use a regional service for local trips within an urban area, but the main purpose of a regional service is to connect different urban (or rural) areas.

In terms of comparisons between the different geographic scales, the present thesis focuses on differences between the local and regional levels, separated by the first part of the definition. Furthermore, it focuses on conventional public transport services along fixed routes and with fixed schedules, which on the regional scale means rural and interurban bus, coach,[1] and rail services.

It should be noted that *rural* may have different meanings in this thesis depending on the context. On an overall regional level, rural areas denote all areas outside cities and larger towns, which means that smaller settlements are included in the rural areas. On a sub-regional, more zoomed-in level, the term is rather used as a contrast to urban areas of all sizes, even villages and smaller towns. Despite this ambiguity, it should be clear from the context (or explicitly stated) which meaning is intended. To avoid misunderstandings regarding the definition of regional public transport, rural areas in this case denote all areas outside urban areas regardless of size.

Objectives of regional public transport provision

Regardless of geographical scale, public transport is essentially about making society accessible by enabling people to travel to and from work, education, leisure activities, and services. There are a variety of objectives around this basic idea, and this is quite similar for local and regional public transport. However, the differences in passenger volumes, trip distances, and available transport mode options affect the respective significance of local and regional public transport for the various objectives.

Reducing the negative effects of private car use

Both local and regional public transport are important for reducing car traffic in cities – for the objectives of alleviating congestion, reducing the need for parking and road

[1] In this thesis, coach services denote a type of regional bus service operated with vehicles with a higher level of comfort and typically on longer routes than most other regional bus services. Coach services generally operate along major roads with relatively few stops.

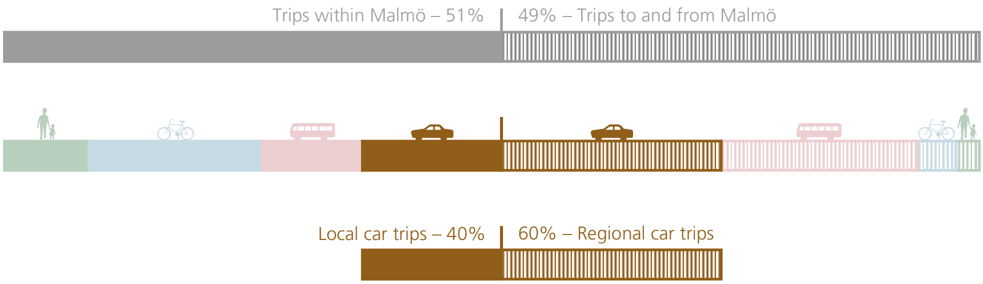

Figure 2 Distribution of local and regional trips in Malmö
Distribution of trips, modal splits, and distribution of car trips according to a recent travel survey (Region Skåne, 2019).

space, and improving air quality and noise (UITP, 2013) – but the relative significance of local and regional public transport for these objectives depends on the context.

As an example, the situation in the southern Swedish city of Malmö (pop. 350,000) is illustrated in Figure 2. As can be seen in the figure, roughly half of all trips made in Malmö are regional trips (Region Skåne, 2019).[2] However, as walking and cycling constitute a substantial share of the local trips, the share of car trips is smaller for the local trips than for the regional trips. Thus, a majority of the car trips in Malmö are, in fact, regional. This means that addressing regional travel is essential when dealing with issues such as congestion, road space, and environmental problems in the city. Regional public transport then plays an important role as the only viable alternative to the car in most cases.

Outside cities, issues related to congestion, urban space, air quality, and noise are less prominent. Nevertheless, reducing car traffic is still a valid objective – in corridors with sufficient demand regional public transport can contribute to improving energy efficiency as well as reducing greenhouse gas emissions. Local trips are much more frequent, but the total distance travelled globally is comparable in size for regional trips because of the longer trip distances: 21 and 15 trillion passenger-kilometres per year, respectively, for local and regional travel (ITF, 2021). These numbers correspond to 51% and 36%, respectively, of all surface travel. Despite continuing urbanisation, the proportions are predicted to remain stable in the coming decades. In absolute numbers, though, global demand for both local and regional travel is expected to more than double by 2050 (ITF, 2021). Together with a shortage of concrete decarbonisation policies for non-urban transport, this means that the share of greenhouse gas emissions

[2] Most of the issues concerning car traffic are related to the total distance travelled (vehicle-kilometres) rather than the number of trips. In cities, however, there is less variation in trip distances than in larger geographic entities. In the case of Malmö, the number of trips is assumed to be a valid indicator for the objectives related to reducing car traffic in the city.

coming from regional travel is likely to increase: "Non-urban transport is an overlooked step-child of climate policy" (ITF, 2021, p. 158).

Replacing car travel with public transport may also bring health benefits through increased physical activity (Kwan & Hashim, 2016; Rissel et al., 2012). In other words, regional public transport with walking and cycling as first-mile and last-mile solutions can help to counteract sedentary lifestyles.

The aforementioned objectives are basically related to the negative effects of extensive car traffic. These objectives are thus served by an increased market share of public transport in relation to the private car, which usually is strongly related to public transport patronage growth (Walker, 2008).

Economies of scale

Increased patronage may be valuable also in a more direct manner in terms of accessibility. Higher demand means a greater basis for better supply, which in turn means an improvement in the level of accessibility that the public transport system can provide. For example, an increase in service frequency can be justified on welfare grounds because it leads to shorter waiting times for both new and existing passengers (Mohring, 1972). These economies of scale also apply to other elements of the public transport system, such as network structure and its influence on travel times (Fielbaum et al., 2020).

Social inclusion

In addition to the objectives related to increased market share or patronage, there are also objectives of regional public transport that are instead related to social inclusion and to the structuring effects of public transport services (Johansson, 2020).

Objectives related to social inclusion are oriented towards providing a decent base-level travel option for all (Loader & Stanley, 2009). Poor public transport availability implies an absence of transport options, particularly affecting the level of accessibility for residents with limited or no access to a car. These objectives are especially important when the trip distances are beyond the walking and cycling range (Scheurer, 2020), which is common in rural areas. Rural residents with limited access to a car and poor public transport availability are at risk of being excluded from participation in normal relationships and activities. Children and adolescents are particularly exposed to such risks (Berg & Ihlström, 2019) together with older people who eventually become unable to drive a car (Camporeale et al., 2019).

Social exclusion can exist for several transport-related reasons (Church et al., 2000), with two categories of particular interest for public transport service planning, namely geographical exclusion and time-based exclusion. Geographical exclusion is linked to the geographic extent of the public transport network – spatial coverage – and time-based exclusion is linked to travel times and the span and frequencies of the timetables – temporal coverage.

Option values

Public transport availability in rural areas is also valued among the parts of the population that are not dependent on public transport for their everyday mobility (Jokinen et al., 2021). Even those who normally do not use the services at all may still value this availability based on rare events when their own car is not available, uncertainties about changes in the life situation in the future, or simply a preference towards more alternatives. These so-called option values depend on the number of available transport options, which means that they are more apparent in locations where public transport is the only viable alternative to the car (Bondemark et al., 2021).

Structuring effects and regional equality

Option values have been shown to be associated with property values (Bondemark et al., 2021), and can thus be linked to objectives concerning the structuring effects of public transport. For these objectives, the idea is that public transport connections can spur development along the routes (Adolphson & Fröidh, 2019; Bohman & Nilsson, 2021; Johansson, 2020).

Furthermore, it can be argued that the public transport network should support balanced economic growth and welfare distribution across the region by providing regional access to jobs, higher education, hospitals, culture, and commercial services (Portinson Hylander, 2021). In rural contexts, access to regional public transport services of sufficient quality is suggested to stimulate rural development and opportunities for living in rural areas (Pettersson, 2018; Šťastná & Vaishar, 2017).

Conflicting objectives

Most of the objectives cluster around two conflicting poles with different requirements for the public transport network, namely objectives served by patronage and objectives served by coverage (Walker, 2008). Objectives served by patronage are those that are related to the extent that people use the service, either directly or as an indicator for the market share of public transport in relation to private cars, and include environmental and health objectives as well as objectives regarding congestion, urban space, and economies of scale. Objectives served by coverage are those that are related to the availability of the services regardless of their patronage, including social inclusion objectives and option values together with objectives concerning regional equality.

Service planning challenges

Tensions between the objectives propagate through the strategic–tactical–operational chain (van de Velde, 1999). In particular, the tensions come to the surface on the tactical level where service planning decisions are made. Service planning involves balancing different types of trade-offs on the tactical level that essentially can be linked to the tensions between the patronage and coverage objectives on the strategic level. A central trade-off is between coverage and frequency:

> Network planning is all about understanding the frequency versus coverage trade off. If budgets are fixed, then more frequency means less coverage and vice versa. This links of course to the objectives for public transport. (Mulley & Nelson, 2021, p. 389)

Service frequency is one of the most important quality attributes for getting people to choose public transport over their cars (Khan et al., 2021; Redman et al., 2013), which means that this trade-off rather straightforwardly can be translated into patronage versus coverage objectives.

Reducing coverage in favour of increasing service frequencies on high-demand routes – or, in more general terms, concentrating resources to trunk services – has proven to be an effective strategy to increase patronage overall (Khan et al., 2021; Walker, 2008). These trunk services can consist of rail modes as well as bus and coach services. In recent decades, trunk bus services in urban networks have increasingly been developed as Bus Rapid Transit (BRT)[3] services (Hidalgo & Muñoz, 2015). High service frequency is a key element in most BRT applications, but it must be seen as part of a broader concept, typically also including bus lanes and other bus priority measures as well as upgrades regarding stations, vehicles, transport system technology, ticket validation, and branding.

In contrast, similar high-quality bus or coach concepts on the regional scale have not yet been widely implemented. One of the rare initiatives that involves rural areas has

[3] Here, the notion of BRT includes Buses with a High Level of Service (BHLS), which can be described as a European counterpart of BRT (Hidalgo & Muñoz, 2015). It can be argued that BHLS differs from BRT in some respects, but in the context of this thesis it is not considered necessary to distinguish between the concepts. Correspondingly, there is also significant variation within the term BRT and how it is used in different settings (Deng & Nelson, 2011).

been discussed in the southern Swedish region of Scania for the last 10–15 years, called the Regional Superbus Concept (*Regionalt Superbusskoncept*) (e.g. Region Skåne, 2016; Trivector, 2010). During the development of this concept, conflicts appeared between the different actors involved (Pettersson, 2018), revealing tensions even slightly beyond the frequency versus coverage trade-off. The most debated trade-off in this case concerned stop spacing, which essentially is about travel time and reliability versus coverage. Fewer bus stops are generally assumed to speed up the service and make travel times more predictable, at the expense of longer access distances and less coverage. Conversely, more stops mean shorter access distances and increased coverage but can also be assumed to make the service slower and travel times less predictable.

Another key aspect concerns a variation of the frequency versus coverage trade-off, focusing on temporal coverage instead of spatial coverage. High service frequencies as well as generous operating hours are described as important features of the Regional Superbus Concept (Trivector, 2014), which in fact need to be balanced against each other. Within a fixed budget, a more frequent service can be provided for a shorter time and vice versa. In other words, there is a trade-off between the maximum frequency and the span of the timetable.

The service planning trade-offs described above impact the overarching objectives of public transport provision in different ways. Some of these impacts are intuitive, but often there are also more complex mechanisms in the links between the trade-offs and the objectives. These relationships between the service planning and the overarching objectives are important to understand to be able to make planning decisions in accordance with the intentions, and there is a demand for more knowledge in this regard (Johansson et al., 2017).

This knowledge demand can be expected to be particularly critical for regional services because most of the available literature on network and service planning either focuses explicitly on urban services (e.g. Grisé et al., 2021; McLeod et al., 2017; Nielsen et al., 2005) or has a more general approach without much detail on the specifics of regional services (e.g. Mulley & Nelson, 2021; Nielsen, 2021; Scheurer, 2020). The lack of studies with a pronounced regional perspective can also be discerned in public transport research in general. A bibliometric analysis conducted a few years ago revealed that terms such as *regional*, *interurban*, and *rural* are absent among the most-used keywords, unlike *urban* that appears in several of the most common keyword compositions (see Heilig & Voß, 2015).

Aim and scope of the thesis

This thesis addresses the demand for more knowledge into regional public transport service planning. More specifically, the aim is to develop the understanding of the effects of different service planning decisions in terms of different trade-offs and their impacts on the overarching objectives.

The aim originates in experiences from the development of the Regional Superbus Concept and other similar schemes, where it became clear that much of the existing knowledge into service planning is primarily based on local public transport. As a reaction to this, this thesis project was launched with a focus on studying the effects of various measures related to the Regional Superbus Concept (or Regional BRT in more general terms, or high-quality regional public transport in even more general terms). During the course of the thesis project, this initial focus was processed with respect to a couple of key aspects. This processing resulted in three research questions that together led to the overall aim of the thesis.

First, it was recognised that the measures in question are best understood as trade-offs, i.e. they are not a simple matter of quality improvements in exchange for monetary costs, but are rather a balance between different interests. These trade-offs are typically handled by public transport planners who are thus given the role of *street-level bureaucrats* (Lipsky, 2010). As such, they work at the end of the policy chain and make decisions based on official policy but still with a high degree of autonomy (Sevä, 2015).

Second, the studied effects need to be discussed in a relevant context so that the service planning decisions can be appropriately linked to the strategic policy level. To this end, the framework of patronage objectives versus coverage objectives is adopted as a point of departure. The idea is to explore how the tensions in the service planning trade-offs can be linked to tensions between different overarching objectives.

Finally, there is a loop back to the origin of the thesis regarding implications for the development of high-quality regional public transport services.

Hence, the following three research questions were addressed in order to guide the thesis towards the aim:

1. In what ways are the service planning trade-offs different in regional public transport compared to local (urban) public transport?
2. What are the effects of the trade-offs in terms of the balance between patronage objectives and coverage objectives?
3. What are the implications for the development of high-quality public transport concepts on the regional scale, such as Regional BRT?

The aim of the thesis is aligned with a view of public transport as a public service, where coordinated network planning is a recipe for success in terms of the ability to reach the overarching objectives (Buehler et al., 2019). In contrast, public transport that is oriented towards market competition entails a risk of fragmentation and thus leaves less room for network planning (Mulley & Nelson, 2021). Institutional frameworks are typically located somewhere in-between the extremes of coordinated planning and market competition. This thesis covers service planning trade-offs and their links to the overarching objectives, and views the trade-offs as policy issues rather than profit-maximisation tools. This means that the thesis leans towards the coordinated planning approach (the public service approach) that to a greater extent allows long-term planning and cross-subsidy between services (Mulley & Nelson, 2021).

Even with a view of service planning as fundamental to success, it must be acknowledged that there are many more pieces to the puzzle. The ability to reach the overarching objectives is affected by factors outside the control of public transport management and governance (external factors) – for instance, factors related to land use, population density, and car accessibility – as well as internal factors beyond the scope of service planning (Taylor et al., 2009). These factors include fares, vehicles, information to the public, and infrastructure management, factors that to a large extent interact with service planning.

Furthermore, the focus of the thesis is on conventional public transport services along fixed routes and with fixed schedules. In other words, it focuses on the bus, coach, and rail services that are used by the vast majority of the regional public transport passengers (White, 2016). However, this should not be seen as an argument against the importance of Demand Responsive Transport (DRT)[4] in the service portfolio of regional public transport. DRT is an instrument with an ability to cover areas of low demand that lie beyond the reach of networks of fixed route services (Mulley & Nelson, 2021; Sörensen et al., 2021; Ušpalytė-Vitkūnienė & Ranceva, 2022).

[4] DRT refers to a service where the route is fixed shortly before departure based on trip requests. It is sometimes called Flexible Transport Services (FTS) and is usually operated with smaller vehicles than conventional bus services (Mulley & Nelson, 2009). It can be argued that conventional public transport services are demand responsive as well, in the sense that the travel demand is an important basis for the planning of all types of services. The distinction between fixed and flexible is a matter of time perspective (Brake et al., 2004).

Structure of the thesis

The following *Background* chapter provides deeper background to three central concepts in the thesis that are connected to each of the three research questions and thereby develops the theoretical framework of the thesis. First, a taxonomy of service planning trade-offs is presented along with brief descriptions of the dynamics in these trade-offs. This part of the background has a general approach in terms of geographic scale, without much detail on the specifics of local or regional public transport. Second, the tensions between patronage and coverage objectives are elaborated on and are described as the patronage–coverage dichotomy. Finally, a brief review of high-quality bus services on the regional scale is presented.

The four research papers included in the thesis are introduced in the *Research design* chapter. The chapter begins with a presentation of the orientations of the four papers and continues with a description of the methods and the empirical material on which the studies were based.

Summaries of the results and conclusions in the four papers of the thesis are laid out in the *Findings* chapter.

The synthesis of the findings is presented in the *Discussion* chapter, addressing the aim of the thesis. The discussion is structured according to the three research questions (which means that it also mirrors the *Background* chapter) and is concluded with some thoughts on the methods used and suggestions for future research.

Finally, the main implications of the thesis are condensed in the *Conclusions* chapter.

Background

Service planning trade-offs

If the infrastructure and vehicles are the *hardware* of public transport systems, service planning is akin to the *software* that specifies the spatial and temporal connectivity of the services (Dodson et al., 2011). Service planning determines the when and where of public transport, i.e. the core of the offer to the public, which is made concrete through network diagrams and timetables. This view of planning was adopted, for example, in the development of the renowned Swiss public transport system (Petersen, 2016; Stähli, 1990). One of the fundamental principles in this development was that *the timetable is the core of the offer of public transport* (Stähli, 1990, p. 1464). Putting service planning at the centre of attention was in stark contrast to the usual focus on infrastructure, vehicles, and other technical aspects of the operations (Stähli, 1990). Indeed, there is an interaction between service planning, infrastructure, vehicles, and operational planning, but the logic behind focusing on service planning before the more technical aspects is that the network structure is the primary interest of the passengers. The passengers do not really need information about the technical features of the public transport system to get to their destinations (Dodson et al., 2011).

General mechanism of the trade-offs

Within a fixed budget, service planning involves trade-offs of various kinds, i.e. public transport planners are faced with a number of choices about how the available resources should be used. These choices lead to varying outcomes in terms of the objectives of the public transport provision.

A model of the relationship between the service planning trade-offs and the objectives is illustrated in Figure 3. In the model, the trade-offs are depicted as controls that can be adjusted to achieve certain objectives. The trade-offs are constrained by financial limits and, at least in short-term planning, by the available infrastructure.

The relationship between the trade-offs and the objectives goes through a conflation of different service quality attributes and their spatial and temporal distribution. As an example, one of the service planning trade-offs concerns route directness, with primary

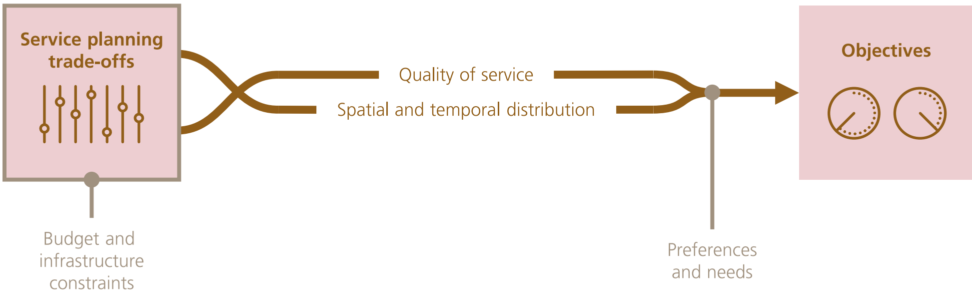

Figure 3 Relationship between service planning trade-offs and objectives
The service planning trade-offs can be viewed as controls through which different quality attributes are either improved or impaired. The trade-offs also control the spatial and temporal distribution of these qualities. Moderated by the citizens' preferences and needs, the composition of the quality of service and its spatial and temporal distribution affects the outcomes in terms of the various objectives of public transport provision.

effects on the quality attributes of access distance and travel time. These effects vary between different areas along the route: A less direct route (a detour) may infer shorter access distances in some areas, but on the other hand it will cause longer travel times in other areas that are affected by the longer travel distance through the detour.

On a more individual level, there are similar trade-offs between different preferences and needs. In certain situations or for certain individuals, having a bus stop nearby is more important than a short travel time. In other situations or for other individuals, it may be worthwhile to get to a stop or station a little farther away if the journey from there is faster or if the departures there are more frequent.

At the intersection between the quality of service offered and the citizens' preferences and needs, the outcome is generated in terms of the objectives of the public transport provision. In the example of a detour, the shorter access distances in some areas are likely to result in increased patronage there and may also, for example, contribute to reducing risks of social exclusion. The extent to which these objectives are met is determined by the citizen's preferences and needs, particularly regarding access distances in this case. Similarly, the longer travel times in other areas are likely to result in less patronage there, but the extent of the decline is determined by preferences and needs regarding travel time.

In other words, the service planning trade-offs are visible also at this end of the relationship through their effects on the different overarching objectives. One of the more clear-cut examples of this relationship concerns the geographic distribution of public transport services. On the one hand, it may be important to meet people's preferences where there is potential for high patronage. This requires a concentration of resources to more densely populated areas. On the other hand, it may also be important to create a fair distribution of the resources to be able to meet the needs of people also in more sparsely populated areas.

A taxonomy of trade-offs

Service planning concerns many different aspects of the public transport network and thus involves different types of trade-offs. As an attempt to get an overview of these different types, a taxonomy is illustrated in Figure 4. The taxonomy involves service planning trade-offs at two levels, the *network level* and the *route level*. The network planning trade-offs concern the network structure and the interplay between different services, while the route level trade-offs relate to the design of individual services in the network.

The taxonomy contains seven categories of trade-offs, three of which are on the network level. The primary trade-off on this level relates to geographic distribution, i.e. the extent and density of the network, which needs to be balanced against the service frequency. Network planning also involves considerations of the extent to which travel patterns should be met with direct connections or a transfer-based network structure, i.e. more direct services with lower frequencies but fewer transfers or vice versa. Furthermore, there is a trade-off concerning the level of differentiation of services within a corridor, from a single service in each corridor to parallel services with different stopping patterns or slightly different routes in the vicinity of each other. More parallel services mean more degrees of freedom to adjust to different needs, but lower frequency on each service and a less clear network structure.

The remaining four types of trade-offs in the taxonomy are on the route level (or individual service level). First, the trade-off regarding temporal distribution concerns the distribution of departures, which either can be concentrated to peak hours or evenly spread over the day and over all days of the week. Second, service planning on the route level includes consideration of different public transport modes, where more rail

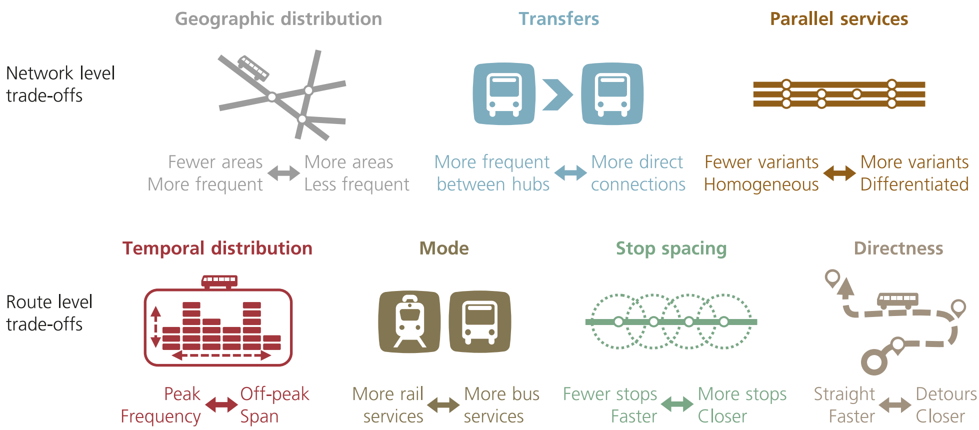

Figure 4 Taxonomy of service planning trade-offs
Different types of trade-offs in public transport service planning on the network level and on the route level. Figure redrawn based on the work of Wittmann (2019).

services can be provided at the expense of bus services or vice versa. This is a trade-off with a particularly tight connection to infrastructure planning. Third, stop spacing is a trade-off between, on the one hand, more stops and shorter access distances and, on the other hand, fewer stops in favour of higher service speed and better reliability. Finally, the directness of the route implies a similar trade-off between short access distances on the one hand and a straighter and faster route on the other.

Each of the trade-offs is described in a little more depth in the following subsections.

Geographic distribution

Network structures focusing on spatial coverage in principle aim for equal access to public transport. This means that service levels are spread across the service area, resulting in low frequencies and generally low patronage levels (Mulley et al., 2017; Walker, 2008). Despite the low frequencies, the availability of the services may be essential for the so-called captive users with few or no alternatives to travelling via public transport.

Conversely, the most productive network structure in terms of patronage in previous studies into network planning is suggested to focus on corridors with high demand (e.g. Mulley & Nelson, 2021; Nielsen et al., 2005; Walker, 2008). In effect, this implies a concentration of resources to a network of trunk services, enabling economies-of-scale improvements with higher frequencies as well as investments to enhance the speed and reliability of the services (Mohring, 1972; Nielsen, 2021; Scheurer, 2020). However, the concentration of resources leads to a more coarse-meshed network structure with the risk of leaving considerable parts of the service area without public transport access.

In reality, most public transport networks are planned with the aim of striking the right balance between the two principles. There is an interesting dynamic in this balance, as many passengers are willing to walk further to access a public transport service of better quality (El-Geneidy et al., 2014; Mamun & Lownes, 2014; Mulley et al., 2018; van Soest et al., 2020). This means that the catchment areas around the stops increase, which might justify differentiated spatial coverage indicators depending on the quality of the service (see Grisé et al., 2021). However, it is important to acknowledge that actual access distances depend on individual characteristics and perceptions of personal capabilities. This translates to a diversity that is difficult to catch with conventional accessibility measurements (Ryan & Pereira, 2021), let alone with fixed threshold distances around bus stops and train stations.

Transfers

Transfers are generally disliked by public transport users (van Lierop et al., 2018). In fact, many passengers are willing to accept significantly longer trip times to avoid transfers, especially if multiple transfers are needed (Berggren et al., 2021). Also, transfers can be particularly stressful if the connections are perceived to be unreliable (Iseki & Taylor, 2009). By extension, placing emphasis on this reluctance for transfers leads to a direct-service network structure, sometimes referred to as a door-to-door model (Grisé et al., 2021).

Yet, networks that adopt transfers as key components are suggested to generally outperform direct-service networks, both in terms of patronage and for facilitating synergy between patronage and coverage services (Grisé et al., 2021; Mulley & Nelson, 2021; Scheurer, 2020; Walker, 2008). Transfers enable a more balanced service supply, as strategically located nodes can be utilised to reduce duplication of services (Chowdhury & Ceder, 2016). Networks with fewer high-frequency services instead of many direct services are also less vulnerable to operational disturbances and less prone to irregular headways (Nielsen et al., 2005).

The optimal structure is somewhere in-between the extremes of a direct-service network with exclusive links for every potential trip relation – the demand ideal – and a transfer-based network with single services between hubs – the supply ideal (Bertolini, 2017). The idea of seamless transfers throughout the network is appealing because a much wider array of destinations can be served compared to what can be done with single-seat journeys in a direct-service network. However, the multi-destination effect – the network effect – requires quick and reliable transfers, which is best facilitated by high service frequencies across the network. With longer headways than approximately 10 minutes, rigorous coordination of the services is needed in order to enable timed transfers (Dodson et al., 2011; McLeod et al., 2017; Nielsen et al., 2005).

Parallel services

Limited-stop services can offer significant travel time savings for many passengers (Ibarra-Rojas et al., 2015; Leiva et al., 2010). The effect is amplified by the fact that passengers tend to overestimate these time savings (El-Geneidy & Surprenant-Legault, 2010). Spatial duplication, i.e. full-stop services parallel to limited-stop services or bus services parallel to rail services, means that it is possible to maintain complementary layers of public transport accessibility along the corridor (Scheurer, 2020).

However, without this duplication of services, the available resources can instead be concentrated to a single service, enabling higher frequency or longer operating hours on that service. The principle of a single service in each corridor corresponds to a *ready-*

made approach to network planning, resulting in a simple and stable network throughout the day, all days of the week. The opposing approach is the *tailor-made approach*, which is tailored to fit the needs of different users and the varying needs at different times of the day. These tailor-made networks tend to be more difficult to supply efficiently and to be more complicated for the users. (Mulley & Nelson, 2021; Nielsen et al., 2005)

Temporal distribution

The temporal distribution trade-off is about operating hours and frequency, where a less frequent service can be provided for a longer time and vice versa. There is also a similar trade-off regarding days of service, where weekend services can be extended at the expense of weekday services and vice versa. Because the travel demand during peak hours typically is much higher than off-peak, the customary demand-oriented planning has led to networks predominantly designed for commuters (Grisé & El-Geneidy, 2018; Tzieropoulos et al., 2010). For other trip purposes, as well as for commuters with non-standard working hours, there is thus a general need for improved off-peak services (Alsger et al., 2018; Vitrano & Mellquist, in press).

However, there is an obvious risk that service improvements during periods of low demand will entail high costs in relation to the number of trips. Even though the effect of frequency on patronage (the elasticity) has been found to be higher during evenings and weekends than during peak hours, the effect is still typically inelastic, i.e. the relative patronage increase is lower than the relative frequency increase (Totten & Levinson, 2016; Wallis, 2013). With the comparatively low level of demand, considerable financial support is needed to provide what can be seen as excess capacity during these periods.

On the other hand, off-peak improvements should not be assessed in isolation. Some studies suggest that extended operating hours affect patronage not only during the corresponding times of the day, but also to some extent during periods when services are unaltered (Currie & Loader, 2009; Simmons & Haas, 2016). However, these cross-effects between different periods have been suggested to be relatively limited, at least in the short term (Totten & Levinson, 2016). Still, the more long-term effects (after some years) may be more tangible (Loader & Stanley, 2009), but there is a need for more knowledge in this regard (Simmons & Haas, 2016).

Also, as in all of the service planning trade-offs, there is more to it than just costs in relation to the number of trips. Extending the operating hours may be important for reducing social exclusion by providing possibilities to access activities beyond school and work (Markovich & Lucas, 2011). Importantly, the benefits of the extended operating hours will only be realised if an adequate service frequency is offered throughout the period (Loader & Stanley, 2009).

Mode

The roles of different public transport modes need consideration. In general, rail services (regional rail, commuter rail, light rail, metro) are associated with a higher level of service quality than most bus services, which means that rail services may attract more passengers (Scherer, 2010; Werner et al., 2016). Some studies suggest that this preference for rail goes beyond differences in basic quality attributes such as travel time and frequency (Scherer & Dziekan, 2012; Utsunomiya & Shibayama, 2021; Varela et al., 2018). This so-called rail factor or rail bonus can at least partly be explained by more intangible quality attributes such as perceived reliability, information availability, comfort, and safety (Ben-Akiva & Morikawa, 2002), but social and emotional aspects may also contribute (Scherer & Dziekan, 2012).

These benefits must be balanced with the considerably higher costs that are associated with rail investments and operations. The trade-off often also includes longer access distances because rail services are less flexible than bus services in terms of stop spacing and routes. Rail services are generally associated with wider stop spacing than the corresponding bus services and they are technically restricted regarding detours. However, that inflexibility can also be an asset, as the inherent permanence may infer a structuring effect towards land-use planning with high levels of public transport accessibility – i.e. transit-oriented development (Currie, 2006; Pettersson & Frisk, 2016).

Stop spacing

Determining stop locations is often described as a trade-off between access time and in-vehicle travel time, for which many studies have proposed advanced optimisation techniques (e.g. Murray & Wu, 2003; Tirachini, 2014). In addition to travel time and its impact on operating costs and in turn on service frequency, these optimisations may include aspects such as overall connectivity (Mamun & Lownes, 2014), emissions (Shrestha & Zolnik, 2013), and differing land use types (Chen et al., 2016). However, despite the complexity of these optimisation models, they have been found to generally lack some important features of the trade-off, particularly those related to social inclusion and equality (Stewart & El-Geneidy, 2016). Furthermore, the impacts on travel time variability and in turn on service reliability are rarely featured in research into bus stop planning (El-Geneidy et al., 2006).

Taking service reliability into account is particularly important for services with on-call stopping regimes, where vehicles can bypass stops if there is no boarding or alighting demand. This results in varying stopping patterns, causing travel time variation. Fixed stopping regimes where vehicles always stop at all stops or stations cause less travel time variation, but are only suitable on services with large passenger volumes (Kikuchi & Vuchic, 1982).

Directness

Similar to stop spacing, route directness entails a trade-off that primarily involves access distances, in-vehicle travel time, and service reliability. Straight routes are suggested for urban trunk services in favour of faster and more reliable services for most passengers, but at the expense of longer access distances for some (Nielsen, 2021). The effects of a potential detour depend to a large extent on the available infrastructure. Application of public transport priority measures can mitigate the negative effects on travel time and service reliability (Currie, 2016; Sørensen et al., 2021).

The effects on travel time and service reliability in turn affect operating cost and fleet size. Alternatively, within a fixed budget, more efficient operations can be converted to a higher service frequency (Stewart & El-Geneidy, 2016). Ideally, passengers facing longer access distances are compensated with a higher service frequency along with a faster and more reliable service. A higher service quality means that many passengers are willing to walk longer distances to access the stops (El-Geneidy et al., 2014; Mamun & Lownes, 2014; Mulley et al., 2018; van Soest et al., 2020).

The patronage–coverage dichotomy

The inescapable tensions between *patronage objectives* and *coverage objectives* permeate the service planning trade-offs. Patronage objectives relate to economies of scale and mode shift from cars to public transport, while coverage objectives instead emphasise social inclusion and geographic equality. These two groups of objectives place conflicting demands on the design of the public transport network (Walker, 2008). The patronage–coverage dichotomy reoccurs in much of the literature on public transport service planning, with slight variations in the terminology, for example, efficiency versus equity (Mulley et al., 2017, p. 2), pragmatic versus idealistic transport policy goals (Jacques et al., 2013, p. 643), productivity versus coverage (Walker, 2008, p. 437), efficient transport versus social policy (Mulley & Nelson, 2021, p. 388), and mass transit versus social transit (Loader & Stanley, 2009, p. 106).

Applications

The patronage–coverage dichotomy was originally described in conjunction with the trade-off concerning geographic distribution (Walker, 2008), but it has proven useful for understanding other types of service planning trade-offs as well. For example, it has been suggested that services supporting patronage growth should generally emphasise directness and relatively wide stop spacing at the expense of spatial coverage (e.g. Mulley et al., 2017; Nielsen, 2021). Consequently, the tensions between patronage and coverage objectives can be discussed both on the route level, e.g. in terms of route directness and stop spacing, and on the network level, e.g. in terms of concentrating resources to the more densely populated parts of a region versus regional equality (Portinson Hylander, 2021, pp. 157–158).

Indicators

The success of a public transport system in terms of patronage objectives can be measured in several ways, and there is a plethora of performance indicators related to these objectives (Hirschhorn et al., 2018). Some of the performance indicators focus directly on modal split and patronage per capita, while others relate to financial return or efficiency. Financial efficiency is sometimes mentioned as an objective in itself alongside the other objectives served by patronage (Walker, 2008). Alternatively, using financial efficiency primarily as a performance indicator aligns with a view of economics as a framework for the service planning, encompassing both the patronage and coverage objectives.

In contrast, performance indicators related to the coverage objectives are much less prevalent (Hirschhorn et al., 2018). Typically, coverage is measured as a percentage of the service area or a percentage of residents and jobs within a certain distance from a public transport service (Hirschhorn et al., 2018; Walker, 2008). The area-based indicator does not take into account differing population densities, but is comparatively easier to calculate and illustrate on maps. The population-based indicator, on the other hand, is more accurate in terms of the actual location of residents and jobs, but requires an additional layer of information.

The prescribed maximum distance in these coverage indicators varies, but a common standard is to use 400 m, corresponding roughly to a five-minute walk (Grisé et al., 2021). In contrast to this prescriptive approach, more descriptive approaches are sometimes suggested, in the sense that the indicator should be informed by some understanding of the travel behaviour in different situations (Merlin et al., 2021; Páez et al., 2012). As an example, the distance limit may depend on the quality of the service (Grisé et al., 2021). Walking distances are also longer to regional public transport compared to local public transport, manifested by distance limits ranging from 700 m to 3 km depending on the regional context (Ušpalytė-Vitkūnienė & Ranceva, 2022).

Spatial and temporal dimensions

The singular nature of how coverage is usually measured does not do justice to the versatility of the concept. As an illustration of this versatility, the patronage–coverage dichotomy can be twisted so that the trade-offs are described between different types of coverage, or rather between accessibility on different geographic scales. The tensions may then be described as being between "*intensive* versus *extensive* accessibility" (Portinson Hylander, 2021, p. 241). Intensive accessibility refers to connectivity on the local scale, whereas extensive accessibility refers to regional connectivity, i.e. accessibility between destinations at greater distance from each other. In public transport, intensive accessibility is generally promoted by short access distances and extensive accessibility is promoted by higher speeds. Hence, the trade-off between intensive and extensive accessibility is similar to the trade-off between patronage and coverage in terms of route directness and stop spacing. As an example, tensions between intensive and extensive accessibility may surface when some rural bus stops on a regional bus service are to be removed in order to improve the regional connectivity to the remaining rural bus stops (Pettersson, 2018).

The importance of speed in the trade-off between intensive and extensive accessibility combines the spatial and temporal dimensions of coverage. This emphasises the importance of not only focusing on distances to stops (the spatial dimension) but also including temporal aspects such as if the public transport services at these stops are able to offer reasonable travel times to relevant destinations. Furthermore, the services should be available at times that are suitable for the users to be able to carry out their desired or needed activities, which means that the temporal dimension of coverage also extends to the frequency and operating hours of the public transport services (Vitrano & Mellquist, in press).

These temporal aspects are associated with a certain amount of ambiguity in terms of the patronage–coverage dichotomy: "it is usually misleading to say that a certain part of a service span, or a certain increment of frequency, is attributable to patronage while the rest is not" (Walker, 2008, p. 440). This ambiguity can be discerned in some of the suggested best-practice principles for high-quality services, emphasising frequent all-day operations, but without much detail about the inherent trade-off in this recommendation (Nielsen, 2021; Walker, 2008). Possibly, this is a consequence of a knowledge gap regarding the importance of off-peak services (Simmons & Haas, 2016; Walker, 2008). Nevertheless, it is acknowledged that public transport services in lower density areas tend to focus on frequent peak-period services if they are designed with an emphasis on patronage objectives (Walker, 2008).

Segmentation of networks

While advising against *temporal* segmentation, Walker (2008) argues that *spatial* segmentation of public transport networks can clarify the divergence between patronage and coverage objectives. The idea is that an explicit distinction between *patronage services* and *coverage services* aids conversations about resource distribution, in turn facilitating policy decisions on how resources should be divided between the two categories. Similar categorisations can also be found in other studies into network planning, but with different labels, for instance "premium network" versus "complementary services" (Nielsen, 2021, p. 454) and "trunk routes" versus "more flexible and dispersed services" (Mulley & Nelson, 2021, p. 391; Nielsen et al., 2005, p. 34). With this division, there are thus two levels of the network:

> A major task in network development is to find the right balance between the two types of services, in space and time. A second challenge is to integrate the two levels of the network into a single public transport network that cater for the different demands of the various groups of users. (Nielsen et al., 2005, p. 34)

As a consequence of this categorisation of services, the patronage–coverage dichotomy has received criticism for creating an unnecessary separation of the network rather than supporting the integration that is stressed in the second part of the quote above (della Porta et al., 2019; Mees, 2014). However, regardless of whether and how the services are categorised and labelled, the network planning literature generally supports integrated networks (e.g. Mulley & Nelson, 2021; Nielsen, 2021; Scheurer, 2020). When patronage and coverage services are separated in different categories, they should still be integrated in the network so that they support and strengthen each other. In such integrated networks, the coverage services have a vital feeder and distributor function to the patronage services (Scheurer, 2020). Still, network integration can only reduce the tensions within the patronage–coverage dichotomy, not eliminate them.

Different ethics – different policies

Essentially, the tensions between patronage and coverage objectives can be discussed from the viewpoints of different philosophies of distributive justice. With their focus on net benefits, it can be argued that patronage objectives lean towards a *utilitarian* approach. The utilitarian approach supports actions that maximise overall good, or welfare, generally ignoring distributional effects (Pereira et al., 2017). Utilitarianism underlies much of the current practice of transport project appraisal and forms the ethical foundation for cost-benefit analysis (van Wee & Geurs, 2011). Although cost-benefit analyses are most widely applied in appraisals of large infrastructure investments, and less often in analyses of changes in a public transport service or network (Johansson et al., 2017), the utilitarian approach is still important as a basis for many of the analyses and decisions made in public transport planning. Utilitarian concepts such as value of time and generalised travel costs are used in a wide range of public transport planning and policy applications (Wardman & Toner, 2020).

Objectives served by coverage are more appropriately discussed based on theories that focus on equality and social inclusion, namely *egalitarianism* and *sufficientarianism*. Contrasting these two approaches may contribute to an understanding of how different moral interpretations of fairness can result in the adoption of different policies (Lucas et al., 2016). In the transport field, the egalitarian and sufficientarian approaches both focus on accessibility to key destinations – such as employment opportunities, healthcare, and education services – assuming a value in accessibility itself, not only in the utility of accessibility (Pereira et al., 2017; van Wee & Geurs, 2011). Thus, the trade-offs in public transport service planning should in this context be assessed in terms of people's ability to reach destinations rather than their revealed travel behaviour.

The primary difference between the egalitarian and sufficientarian approaches lies in the view of what is considered a fair level of accessibility. The egalitarian perspective focuses on differences between people and strives for equalising the level of accessibility between different social groups or geographic areas. Consequently, egalitarian evaluations emphasise *relative* accessibility levels and how the distribution of accessibility changes due to different policies (Lucas et al., 2016). In contrast, sufficientarianism focuses on *absolute* (minimum) accessibility levels and assumes that everybody should be provided with accessibility above a certain threshold – a sufficient level of accessibility (Lucas et al., 2016; Pereira et al., 2017). Deciding on a minimum level may be a way of mitigating the challenge of managing the patronage–coverage conflict.

High-quality bus services on a regional scale

Primarily focusing on objectives served by patronage and the structuring effects of public transport, Bus Rapid Transit (BRT) has proven to be an efficient urban public transport concept in many cities the world over (Hidalgo & Muñoz, 2015). However, examples of similar high-quality bus services on a regional scale are still rare. An adaptation of BRT to the regional level, connecting urban areas and the rural areas in-between, has potential to become a cost-efficient alternative for regional high-quality public transport.

Such adaptations of BRT need to take some important differences between the local and regional scales into account. For example, a typical feature of conventional BRT is a high degree of separation from other traffic through bus lanes or busways (Deng & Nelson, 2011), but outside cities there is generally less congestion and thus it is not meaningful to construct new bus infrastructure along the entire route. Also, high capacity is often mentioned as a key aspect of conventional BRT (Hidalgo & Muñoz, 2015), with less importance on the regional scale due to lower passenger volumes in general. High service frequencies are needed to be able to provide the needed capacity in cities, but on regional services the service frequencies are more about balancing operational costs with waiting times (Jiang et al., 2014).

Consequently, with a couple of the key aspects of conventional BRT out of the equation, a relevant question is what the concept of Regional BRT should contain? There are two answers to this question: (1) it depends on the context, and (2) it is yet to be defined.

The first answer refers to the fact that some regional services near cities share many characteristics with urban services, which means that Regional BRT in these cases is similar to conventional BRT. Examples can be found on parts of the so-called *R-Net* around Amsterdam (Dijkstra, 2022; van der Spek, 2009). Guided busways are also used on some routes, with similar characteristics, such as the one in Cambridgeshire, UK (Mills & White, 2018).

The second answer to the question above refers to uncertainty about what Regional BRT, or high-quality public transport in general, should entail in more rural settings. BRT is not a particularly well-defined concept on the whole, but even less so in rural contexts. One of the few examples identified where the term BRT is used in a rural setting is the *VelociRFTA* in Colorado, USA, which includes high-quality buses and stations in combination with branding and relatively high service frequency (Bazley et al., 2014). A more holistic approach was adopted in a Swedish attempt to define the concept of Regional BRT, including a wide range of factors regarding urban planning, infrastructure, vehicles, and operations (Hansson et al., 2016). The ambition was to define a regional high-quality bus concept using the qualities of regional rail services as a source of inspiration. A set of guidelines was created, based on a synthesis of experience from different actors involved in regional public transport planning (Pettersson et al., 2018). However, despite a high degree of unity among the participants during the development of the guidelines, conflicts emerged between different planning actors when the guidelines were to be put into practice (Pettersson, 2018).

These conflicts could essentially be linked to some of the service planning trade-offs described in this thesis. Possibly, the trade-offs and the associated conflicts of interest that are part of all changes to public transport networks – including the introduction of high-quality concepts such as BRT – were not given sufficient attention in the guidelines.

Research design

Orientations of the included papers

This thesis includes four papers with different orientations relative to the overarching aim. Nonetheless, all four papers contribute to some extent to the exploration of each of the three research questions in the thesis.

The titles of the papers along with some brief notes on the contents offer an overview of the topics covered:

1. *Preferences in regional public transport: a literature review.* Establishes a working definition of regional public transport, explores how different quality attributes influence modal choice, demand, and customer satisfaction, identifies potential differences between regional and local public transport, and studies implications on the regional planning perspective.
2. *Replacing regional bus services with rail: Changes in rural public transport patronage in and around villages.* Investigates how public transport usage and catchment areas are affected when new rail services are introduced, with fewer stops than the bus services they replace.
3. *Effects of rural bus stops on travel time and reliability.* Examines how rural bus stops affect average travel times, travel time variability, and on-time performance in comparison with regional bus stops in urban areas.
4. *Patronage effects of off-peak service improvements in regional public transport.* Explores long-term patronage responses and effects on peak hour demand when substantial off-peak service improvements are made.

In Paper 1, a holistic approach to the service planning trade-offs is adopted and differences between regional and local public transport are reviewed, which means that Paper 1 primarily (but not exclusively) targets the first research question of the thesis. Conversely, Papers 2–4 primarily (but not exclusively) target the second and third research questions concerning effects in terms of the patronage–coverage dichotomy and implications for regional high-quality public transport concepts. These papers have a narrower scope, focusing on a couple of specific service planning trade-offs.

Specifically, Papers 2 and 3 explore different aspects of stop spacing on regional services and in Paper 4 the trade-off concerning temporal distribution is approached through an analysis of off-peak service improvements.

To provide a little more detail about the orientations of the papers, the research questions stated in each of them are listed in Table 1. For Paper 1, the research questions are reproduced in a straightforward manner, whereas the questions for Papers 2 and 3 have been adjusted so that they are understandable outside their context. Paper 4 did not include any explicit research question but is represented in the table by an adaption based on the aim expressed in the paper.

The topics of Papers 2–4 were partly deducted from the results of Paper 1, where a set of knowledge gaps was identified regarding the specifics of regional public transport. Two of these knowledge gaps have a particularly strong influence on service planning. First, a need for more research into details about frequency and opening hours was identified, which is in line with the topic of Paper 4. Second, travel time improvements were found to have received surprisingly little attention. Keeping in mind that travel time is a compound of different components such as access trip time, waiting time, and in-vehicle trip time, this can be linked to the focus on stop spacing in Papers 2 and 3. These studies are in turn sequential because the question of the potential effects of removing rural bus stops was raised in the conclusions of Paper 2 and fed into Paper 3.

Table 1 Specific research questions in the papers
Orientation of each of the papers included in the thesis, represented by the research questions.

PAPER	RESEARCH QUESTIONS
1	What similarities and differences between regional and local public transport are evident with regards to important quality attributes?
	Are there any quality attributes whose importance depends on travel time or distance?
	Are there any evident differences between bus and rail services in terms of important quality attributes?
	Do the results of studies into public transport demand and modal choice conform to the results of customer satisfaction studies?
2	Following the opening of a number of rural rail stations, what is the net demand effect of changed travel opportunities in the surrounding rural areas where bus services have been substantially reduced in connection with the introduction of the rail services?
3	On a regional bus service, what are the effects of rural bus stops on average travel times?
	What are the effects of rural bus stops on travel time variability and on-time performance on this bus service?
4	Following substantial off-peak service improvements on a number of regional rail and bus services, what are the patronage effects of the extended supply outside peak hours?

Methodology

Because the papers differ in terms of the width of their scopes, they also differ regarding their methodological approaches. Paper 1 spans many different aspects of regional public transport, whereas Papers 2–4 are aimed at more in-depth analyses of some more specific aspects. The corresponding research approaches can be contrasted as *extensive* versus *intensive* approaches (Swanborn, 2010). The extensive approach in Paper 1 required information from a large number of instances, which was obtained through a survey and a literature review. In contrast, the intensive approaches in Papers 2–4 required more in-depth information from just a few instances in each study.

Considering their intensive research approaches, Papers 2–4 can all be labelled as case studies in the sense that they are investigations within specific contexts (in contrast to Paper 1, in which the empirical material spans various contexts). It is acknowledged that there are varying views on what defines a case study depending on its use in different research traditions and at different levels of inquiry (Swanborn, 2010). Also, the studies in Paper 2–4 can be given different labels depending on which aspects are emphasised (following the subheadings in the following *Methods* section). Nevertheless, the case study label is used here to emphasise the context-specific feature of these studies.

In case studies, the boundaries between the studied phenomena and the contexts are not clearly evident (Yin, 2014). This affects the conditions for the *external validity* of the results, i.e. the domain to which the findings can be generalised. The domain of generalisation cannot be statistically established in case studies, but instead relies on analytical reasoning (Rowley, 2002) and strategic choice of cases (Flyvbjerg, 2006).[5]

Despite this, statistical analyses are central in Papers 2–4 for the purpose of *internal validity*, i.e. for establishing causal relationships within the specific cases (Rowley, 2002). These methods differ between the studies depending on research purpose, questions, theoretical assumptions, and data availability. Similarly, control variables were included in various forms in the different studies, but for the common purpose of dismissing alternative explanations for the causal relationships in order to avoid spuriousness in the data.

[5] The discussion of generalisability is aligned with a positivist approach to research. Alternatively, case studies can be accepted as independent sources of knowledge that leave it up to the readers to apply ideas from the case study into their own experience (Flyvbjerg, 2006; Rowley, 2002).

Methods

The methods used in this thesis have been mainly quantitative, with the exception of Paper 1 in which quantitative and qualitative approaches were combined as described in the following subsection. The methods used in Papers 2–4 involved different types of setups and different types of statistical analyses and are described in the succeeding subsections.

Paper 1: Terminology survey and literature review

The initial survey aimed to explore how the term *regional travel* is perceived by public transport professionals in order to create a working definition. The survey questionnaire was constructed with single-choice questions including open-ended alternatives and comment opportunities, which enabled a combined quantitative and qualitative approach in the analysis. The quantitative part provided an overview of how *regional public transport* and some related terms are perceived in general, while the qualitative part provided an understanding of the nuances of the concept.

Similarly, the quantitative part of the literature review was used as a springboard for the qualitative assessment. The quantitative part indicated which quality attributes have recurringly been discussed as important or that have been found to have major impacts in the reviewed studies. In contrast, the purpose of the qualitative approach was not about general patterns or correlations but was instead aimed at developing a deeper understanding of quality attributes in regional public transport and how they affect customer satisfaction, patronage, and modal choice in certain contexts. The qualitative approach was also suitable for gaining more knowledge about the dynamics in the interplay between different quality attributes, with implications on the service planning trade-offs.

Furthermore, some of the most important results of the literature review were found at the intersection of the quantitative and qualitative assessments. A comparison of the results offered valuable indications of key research gaps. The quantitative assessment pointed to the most important service quality attributes, and these results should ideally correspond to the subjects that are dealt with in the qualitative assessment. Dissimilarities are signs of possible knowledge gaps, i.e. important areas where more in-depth understanding is needed.

The process of selecting relevant literature was inspired by the PRISMA method (Preferred Reporting Items for Systematic reviews and Meta-Analyses) due to its structured, iterative process for identifying a comprehensive set of literature that meets the aim of the study (Moher et al., 2009). The PRISMA method for systematic reviews was originally developed for the field of medicine, but its merits justify application in other fields. However, the method needs to be modified to be able to transfer its benefits to more qualitative research because “it is simply not possible to lift the systematic review template off the shelf and apply it to qualitative work without important modifications” (Prior, 2003, p. 150).

In the literature review in Paper 1, characteristics such as study size, randomness, and representative samples were largely ignored in the selection process. Consequently, the selection of literature included, for instance, case studies, which can be valuable as sources of deeper insights into the processes involved in the studied phenomena. The procedure of narrowing down the selection of literature to include in the review was purely focused on the scope of the study, using only relevance criteria (and no quantitative measures of quality). One relevance criterion was based on the working definition of regional public transport as outlined in the introduction of this thesis so that the reviewed studies reported results explicitly for regional services. The other relevance criteria were based on the study’s focus on the analysis of service quality attributes and the limitation to conventional public transport along fixed routes and with fixed timetables.

Semi-systematic literature reviews combining quantitative and qualitative information are suitable for detecting themes and common issues in research areas that have been variously conceptualised and studied within different disciplines (Snyder, 2019). As a result of this diversity, the reviewed studies differed in terms of nomenclature, structure, and scope. Consequently, a framework was needed to be able to organise the review. The framework in Paper 1 was based on a classification of service quality attributes into nine main areas and a number of subcategories. The framework was an adapted version of the structure presented in the European standard EN 13816:2002 (CEN, 2002).

Paper 2: Quasi-experimental case–control study

The method employed in Paper 2 can be regarded as a quasi-experiment developed around the introduction of new rail services in a number of locations. Quasi-experiments are similar to traditional experiments but lack the random assignment of study objects into the treatment and control groups. Consequently, quasi-experimental designs are used in settings where random assignment is unfeasible, which is usually the case in studies into public transport usage (Werner et al., 2016). The “treatment” of the experiment in Paper 2 was the opening of a new train station and simultaneous reduction of bus services.

The experimental design requires that the development in the case study group (the treatment group) is compared with a control group. In Paper 2, the case and control groups consisted of a number of villages with surrounding rural areas. The villages in the two groups had similar population sizes and were situated at comparable locations in the region. They were also largely similar regarding age distribution, employment rate, household incomes, and car access.

The results of the study focused on the development of the public transport usage between two points in time – pre- and post-treatment – for each of the objects in the case and control groups. The groups were then compared using the Mann–Whitney *U*-test, which is a nonparametric statistical test of differences between two independent groups. The nonparametric feature means that the test does not rely on assumptions of a certain underlying probability distribution. This feature was important for the comparisons in Paper 2 because the two groups contained relatively few observations that could not be assumed to be derived from, for instance, a normal distribution. Statistical significance was tested on the 5% level.

The quasi-experimental design was chosen due to its ability to suggest a cause-and-effect relationship between the introduction of new rail services and changes in public transport usage. Such changes may occur for a number of other reasons, but these should be controlled for through the composition of the case and control groups.

Paper 3: Cross-sectional within-case study

A cross-sectional study design was used in Paper 3 in the sense that it compared different types of bus stops on a single occasion. The "single occasion" in Paper 3 was the aggregated assembly of data over a one-year period. The method can also be described as a within-case analysis (Paterson, 2010), referring to the in-depth exploration of a single bus service. This approach allowed detailed analysis of the rich amount of data that has become commonly available since the introduction of automatic data collection systems on buses (Büchel & Corman, 2020).

The statistical analyses in Paper 3 focused on ordinary least square regression to analyse the effects of individual bus stops and cross-tabulation to analyse the aggregate effects on the bus service. Welch's *t*-test was also used, together with plots, as preparatory steps for the regression analysis. A significance level of 5% was used in the *t*-tests as well as in the regression analyses, but given the large sample size ($N = 67{,}068$), the focus of the analyses was on effect size rather than statistical significance.

The cross-tabulation and the corresponding plots provided in Paper 3 for analysis of the aggregate effects on the bus service contain only descriptive statistics. In other words, this part of the analysis does not offer any inferential statistics. However, the combination of analyses regarding individual bus stops and aggregate effects on the bus service provides a strong indication of the impact of different types of bus stops on travel time and reliability.

Paper 4: Longitudinal cross-case study

In contrast to the cross-sectional feature of Paper 3, a longitudinal study design was employed in Paper 4 with data covering several points in time. The longitudinal design was chosen in order to be able to analyse long-term trends before and after the off-peak service improvements that were the focal point of the study. Furthermore, the study covered four different public transport services, which enabled a cross-case analysis (Mathison, 2005). By including several cases, the results could be synthesised to identify differences and similarities between the individual case studies. It also meant that the four cases could be brought together to create a more robust model for the baseline scenarios, against which the patronage effects were estimated.

This was made possible by an elasticity model estimated through linear mixed regression with a random intercept effect. This means that the model coefficients (elasticities) were estimated based on data from all cases combined, since this model setup allowed differing intercepts (different initial patronage levels) from case to case.

The longitudinal approach was combined with a disaggregate before-and-after comparison, which in practice means that hourly patronage levels were compared between two points in time – namely, before and after the off-peak service improvements.

Data

An overview of the various datasets used in the four papers is shown in Table 2. As can be seen in the table, Paper 1 is standalone in terms of data types. The analyses in this paper rely on the initial survey about perceptions of the term *regional travel* and the set of literature included in the literature review. In the other papers, the datasets can basically be divided into three categories: demand data, supply data, and control variables.

Terminology survey

In order to gather input into the working definition of regional public transport, a survey was conducted on perceptions of the term *regional travel* and some other related concepts. The survey was conducted online and disseminated through various mailing lists and social media groups of public transport planners. The goal was to identify practitioners and academics that in their work use a distinction between local and regional or between regional and interregional public transport.

Table 2 Data types
Overview of the different types of data used in the four papers.

DATA	PAPERS			
Terminology survey	1			
Reviewed literature	1			
Demand data				
Passenger counts		2	3	4
Park-and-ride usage		2		
Travel survey		2		
Supply data				
Timetables		2	3	4
Automatic vehicle location records			3	
Control variables				
Population statistics		2		4
Weather observations			3	
Fuel price				4
Ticket price				4
Introduction of new trains and coaches				4

The sampling method was non-probabilistic (Boisjoly & El-Geneidy, 2017), meaning that the sample was not representative of all public transport professionals. Therefore, the results cannot be generalised to reflect the views of the whole community of practitioners and academics working with public transport. Nevertheless, the survey results were useful to explore the perceptions of a variety of experts, and the findings uncovered clear and homogenous trends. The aim of the study was not to create a general definition to be used for all purposes and in all contexts, but rather to sort the terms and to collect valuable input for further research into regional public transport.

In total, 290 completed questionnaires were collected. The respondents were located in 40 different countries, and all continents were represented in the survey. However, there was a strong concentration of responses in North America (N = 153) and Europe (N = 105), compared to the other continental regions (N = 32). This means that the results have to be interpreted primarily from a North American and European perspective.

Reviewed literature

The empirical material used for the literature review in Paper 1 was based on a set of studies identified through an iterative process. The first step of this process was the initial literature search, based on keywords related to the three concepts of *ridership*, *regional*, and *public transport* (see Paper 1 for the complete list of keywords). Second, the set of literature was narrowed down stepwise by assessing titles, abstracts, and full-text articles, in turn. This assessment was based on a set of inclusion and exclusion criteria that were aligned with the aim of the study in terms of the working definition of regional public transport (exclusion of studies without results regarding regional public transport), service quality attributes (exclusion of studies not covering at least one service quality attribute and its influence on modal split, demand, or customer satisfaction), and conventional bus and rail services (exclusion of studies focusing on paratransit, demand-responsive services, and air services).

The selection process yielded 37 studies for review. Fourteen of the studies were "overviews" comprising evaluations of multiple service quality attributes, while the remaining 23 studies were "specialisations" focused on specific attributes and providing more in-depth information about various aspects of regional public transport networks in different contexts. There was a large variation among the types of data used in the reviewed studies, covering, for example, stated and revealed preference data, customer satisfaction surveys, interviews, and ethnographic observations.

Demand data

The primary source of demand data in Papers 2–4 is passenger counts, on different time scales (before-and-after, cross-section, and longitudinal) and with varying levels of geographical disaggregation (stop level and service level). The regional transport authority supplied these data, originating from three different sources: manual passenger counts, automatic passenger counting systems on-board, and ticket validations.

In Paper 2, the analysis of access trips required more information than what could be retrieved from the passenger counts. To this end, information about park-and-ride usage along with data from a travel survey were added. These data revealed information about actual trip origins, access modes, and access distances. The park-and-ride data were collected in the preparatory phase of the study and the travel survey data were obtained from a recently conducted regional travel survey (Region Skåne, 2019).

Supply data

Timetables were used in Papers 2–4 to obtain information about the public transport supply in terms of frequencies, travel times, and scheduled departure and arrival times. Given the time spans in the different studies, the timetables together extended over roughly 20 years.

In Paper 3, the primary data source was Automatic Vehicle Location (AVL) records. The AVL data contain time logs for arrivals and departures at all bus stops for each bus. AVL systems have become increasingly available, enabling detailed travel time analysis based on large amounts of data (Büchel & Corman, 2020).

Control variables

The analyses of demand and supply data in Papers 2–4 were supplemented with control variables in various forms. These variables were not of direct interest for the aims of the studies, but were controlled for due to their potential influence on the results (Pole & Bondy, 2010).

In Paper 2, the variables were controlled for by verifying the equivalence between the case study group and the control group over the studied time period. These variables comprised population statistics including age distribution, employment rate, household incomes, and vehicle access. The data were retrieved from the regional travel survey and from Statistics Sweden.

In Papers 3 and 4, the control variables were instead included in the statistical analyses. In Paper 3, a dataset of weather observations was added to be able to control for the influence of varying weather conditions on the bus travel times. The weather data were obtained from the Swedish Meteorological and Hydrological Institute and contained observations of temperature, precipitation, wind speed, and snow depth. In Paper 4, panel data consisting of annual patronage and supply observations were supplemented with information about population size, petrol price, ticket price, and times for the introduction of new trains and coaches on the studied services. These data were obtained from Statistics Sweden, the Swedish fuel industry organisation (*Drivkraft Sverige*), and the public transport authority.

Study areas and cases

The global perspective in Paper 1

A global perspective was adopted in the initial terminology survey and literature review, although with a North American and European centre of gravity. Consequently, the studies included in the review were from different contexts, ranging from suburban rail networks around large cities to bus services in rural areas. The different settings allowed us to study patterns beyond the situational conditions as well as specific quality attributes in various contexts.

Scanian cases in Papers 2–4

Papers 2–4 examined different rail, coach, and bus services in the southern Swedish region of Scania (*Skåne*; population 1.4 million, area 11,000 km^2). The region is characterised by a polycentric structure that has increasingly been linked together in recent decades, partly due to major investments in the public transport system. As a consequence, public transport patronage has grown rapidly since the turn of the millennium. This applies not least to regional travel, which has more than doubled (Region Skåne, 2020).

However, despite the investments and the massive patronage growth, conflicts persist between the parts of the region that are well-connected to the trunk network and those that are not (Portinson Hylander, 2021). Even in areas that are subject to planned public transport investments in infrastructure or operations, conflicts may arise around where to focus and how the improvements should materialise. For example, investments extending into rural areas can create tensions between the "rural cores" that would benefit most from the investments and the surrounding rural areas (Pettersson, 2018, p. 38).

The Scanian public transport network is managed by the regional council through the public transport authority *Skånetrafiken*. The regional public transport authority controls the planning of both local and regional public transport, but the services are provided through procured contracts with private operators. These contracts are typically passenger incentive contracts, which means that the remuneration is based on a set amount per boarding passenger in addition to the production costs related to number of vehicles, kilometres, and hours operated (Vigren & Pyddoke, 2020).

The cost coverage is slightly above 50% on average, i.e. roughly half of the costs are covered by ticket revenues and the other half by subsidies from the regional tax funds (Region Skåne, 2020). However, these shares vary considerably between different services. Consequently, service planning trade-offs in Scania are not about profits, they are instead essentially policy issues concerning the distribution of resources in the public transport network.

An outline of the regional public transport network in Scania and the locations of the studied cases are shown on the map in Figure 5. As can be seen in the figure, the study objects are scattered across the region. All of the cases focus on relatively small towns and villages, though with connections to the larger towns and cities (which predominantly are located in the western parts of the region).

The case–control design in Paper 2 included 14 villages in the case-study group and another 14 villages in the control group, with population sizes ranging from 200 to 4000. The daily number of train passengers at the stations in the case study group ranged from 70 to 700 per weekday, with an average of 400 (figures for 2018, boardings and alightings). The daily number of train departures on these stations ranged from 11 to 40 in each direction on weekdays, with an average of 21.

The bus service analysed in Paper 3 is the main public transport connection in the relatively sparsely populated north-easternmost part of the region. Like the cases in

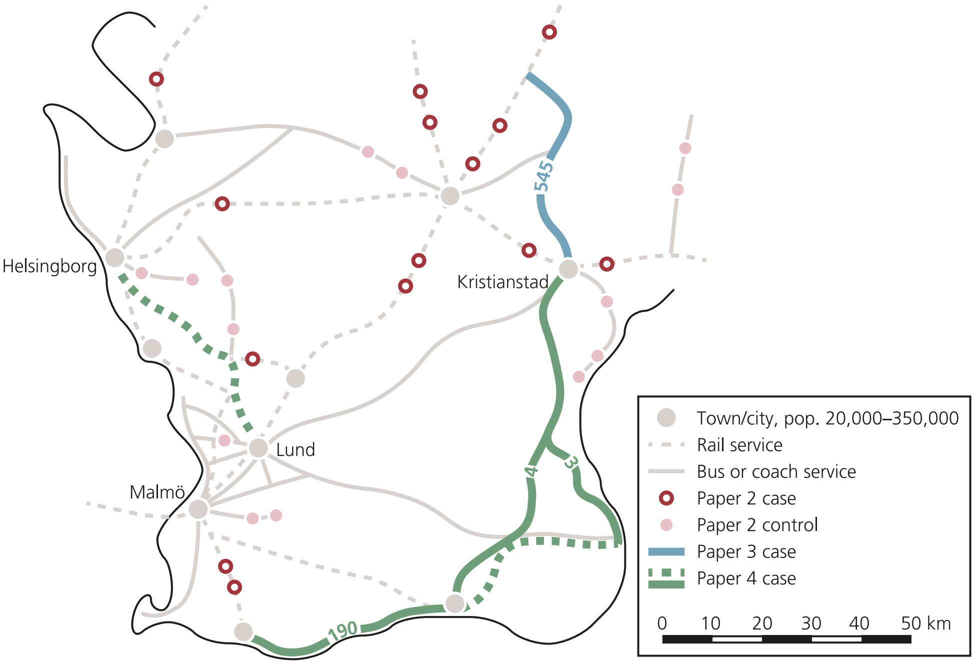

Figure 5 Scanian cases
Map of Scania showing public transport services of regional significance (Region Skåne, 2020) and the locations of the study objects in Papers 2–4. Dashed lines represent rail services and solid lines represent bus and coach services. Service numbers are shown for the bus and coach services studied in Papers 3 and 4 (rail services are unnumbered).

Paper 4, it can be described as a rural and interurban service in the sense that it serves the smaller settlements en route as much as it connects the towns at the ends. Passenger numbers and the daily number of departures on these services are shown in Table 3.

Table 3 Services studied in Papers 3 and 4
Basic information about the services studied in Paper 3 and 4 (figures for 2019). "Passengers" corresponds to the annual number of trips on each service, and "weekday departures" is the daily number of departures in each direction.

PAPER	SERVICE	MODE	PASSENGERS (2019)	WEEKDAY DEPARTURES
3	545 Osby–Kristianstad	Bus	1,100,000	62
4	Helsingborg–Lund*	Rail	1,500,000	19
	Ystad–Simrishamn*	Rail	860,000	20
	3 Kristianstad–Simrishamn**	Coach	280,000	19
	4 Kristianstad–Ystad**	Coach	300,000	20
	190 Trelleborg–Ystad	Bus	310,000	27

* Some newly opened stations and throughgoing trips to other parts of the network were excluded from the analyses in Paper 4. These trips have not been excluded here; the table shows the total number of passengers on each service.

** The coach services from Kristianstad to Simrishamn and Ystad were analysed together because their routes are parallel for about half the distance.

Findings

Paper 1: Preferences in regional public transport

The results of Paper 1 can be divided into four main parts. The first part is about how regional public transport can be defined and separated from local and interregional public transport. Second, the initial quantitative part of the literature review provided an overview of important quality attributes in regional public transport. Third, the qualitative synthesis of the reviewed literature provided more in-depth information about some essential aspects of regional public transport networks. Finally, the quantitative and qualitative parts were brought together in order to identify knowledge gaps.

Definition of regional public transport

The survey about the definition of regional public transport indicated a strong preference for either an administrative or a functional definition depending on the purpose. It was concluded that the two versions of the definition in practice overlap to a large extent and that the functional definition was best suited for the purpose of exploring passenger preferences. This definition is based on the concepts of *urban areas* and *regular travel*.

Urban areas are the basis for the distinction between local and regional, where local travel is defined as within an urban area. Consequently, regional public transport targets passengers travelling between separate urban areas (interurban) or to and from rural areas (rural or rural-urban).

Regular travel is the basis for the distinction between regional and interregional. Unlike interregional public transport, regional public transport is mainly focused on trips made on a regular basis, roughly in the span between daily and weekly. This part of the definition originated from a suggestion based on labour market areas. Based on the survey, the suggestion was modified to extend the scope beyond commuter trips. Consequently, regional public transport may focus on commuter trips as well as regular travel for leisure activities and shopping needs.

Relative importance of quality attributes

Fourteen of the reviewed studies into regional public transport comprised evaluations of the influence of different quality attributes on modal choice, demand, or customer satisfaction. A compilation of these studies is presented in Table 4, showing which categories of quality attributes were commonly discussed as important or that were found to have major impacts in the analyses. As can be seen in the table, three of the categories were found to be of particular importance in most of the studies in which they were included, namely availability, time, and comfort. The categories consist of a collection of more specific quality attributes, the most significant of which are listed in parentheses in the table.

Service frequency was the most common individual attribute of importance in the reviewed studies, followed by reliability, on-board comfort, travel time, and network coverage. These concepts were treated differently in different studies in terms of how the quality attributes were labelled and how the studies focused on specific aspects. For instance, on-board comfort was typically represented by aspects such as crowding, cleanliness, ventilation, and vehicle condition. Similarly, network coverage was represented by different aspects such as walking distance and network structure.

The results largely conformed to the results of similar literature reviews about local public transport (dell'Olio et al., 2018; van Lierop et al., 2018), but there were some essential differences. Most prominently, on-board comfort was more commonly found to be important in regional than in local public transport, and its importance seemed to increase with trip distance. On-board comfort was mentioned among the important quality attributes in all of the reviewed studies into medium and long regional trips (defined in the review as longer than 25 km), but not in any of the reviewed studies into shorter regional trips. Furthermore, attributes concerning network coverage were

Table 4 Important quality attributes

Quantitative assessment of important quality attributes: Number of studies where the attributes were discussed as important and the total number of studies where the attributes were included. The percentage is the quotient between these two figures, i.e. the ratio of studies where each attribute was discussed as important compared to in how many studies it was included. The quantitative assessment is based on 14 items in the set of reviewed literature.

QUALITY ATTRIBUTE	IMPORTANT	INCLUDED	PERCENTAGE
Availability (frequency, network coverage)	10	12	84%
Time (reliability, travel time)	10	13	77%
Comfort (on-board comfort, station facilities)	10	13	77%
Information	4	9	44%
Cost	5	12	42%
Accessibility	2	7	29%
Safety	2	9	22%
Customer care	1	8	13%
Environmental impact	0	2	0%

more pronounced among regional passengers compared to local passengers, possibly as a consequence of the more dispersed nature of regional networks.

Qualitative synthesis of the reviewed literature

The qualitative assessment provided more detail on some of the quality attributes that had been found to be commonly reported as important in the quantitative part. From the list of the most important quality attributes according to the quantitative analysis, the review primarily uncovered more details about reliability, on-board comfort, and network coverage.

Reliability can be defined and measured in a variety of ways, but on-time performance is the most common measure in regional public transport. Lower on-time performance means a higher probability of delays, which significantly impact the level of passenger satisfaction and the probability of choosing public transport (Jiang et al., 2014; Zhou et al., 2017). The importance of the issue increases with low frequencies (Jackson et al., 2012).

The identified literature into on-board comfort generally focused on crowding. This is a critical issue in densely populated areas (Sahu et al., 2018), but where passenger flows are lower, other aspects of on-board comfort become more significant, such as noise, ride comfort, and on-board facilities.

Network coverage has a twofold implication. First, passengers value the possibility to reach a multitude of destinations through integrated networks with timed transfers, which have been proven feasible even in rural regions with very low population densities (Petersen, 2016). Second, short access distances are valued, and it was suggested that stops and stations should preferably be reached within reasonable walking distance. However, the review also revealed that walking distances to regional public transport in many cases can be substantially longer than the conventionally assumed 400 m (Brand et al., 2017; Ker & Ginn, 2003). Moreover, the share of bicycle and car access trips was suggested to increase with the quality of service and with overall trip length (Brand et al., 2017; Hamer, 2010; Vijayakumar et al., 2011).

Knowledge gaps

The literature review revealed a general lack of research into regional public transport. At the intersection between the quantitative and qualitative assessments, a number of areas could be identified as more specific knowledge gaps, including different aspects of on-board comfort, peak and off-peak frequencies, travel time improvements, environmental impacts, and crossed effects between distance and other service attributes.

Paper 2: Rural patronage growth despite bus cuts

In Paper 2, changes in rural public transport usage were studied in a number of villages and their surrounding rural areas where rail services have been introduced. The rail services replaced, at least partially, regional bus services with denser stop spacing, as illustrated in Figure 6. The geographic distribution of access and egress trips was studied in order to analyse changes in rural patronage beyond the immediate surroundings of the train stations. Accordingly, the purpose of the study concerned stop spacing and catchment areas rather than a comparison of bus and rail services.

The results revealed that higher service quality, represented by the rail services, extended the catchment areas by increasing the use of cars and bicycles as access modes (all of the studied train stations were equipped with park-and-ride facilities). On average, 19% of all access trips to the stations were car trips and 10% were bicycle trips. In addition, a couple of the stations were served by feeding bus services, accounting for 7% of the total amount of access trips to the studied stations. The remaining almost two thirds were access trips by foot.

It was estimated that 40% of the bicycles and 81% of the cars at these facilities originated in the rural areas surrounding the villages. Based on the 85th percentiles, which is a commonly used measure of catchment areas, the walking catchments were estimated to extend roughly 860 m from the stations on average, compared to 2.8 km for bicycle catchments and 10 km for cars (Euclidean distances). However, the shape of the catchment area differed from case to case depending on the location of the population, the available infrastructure, and the presence of other nearby stops and stations in the public transport network.

Thus, the catchment areas of the stations extended into the rural areas that surrounded the villages where the stations were located. This means that while some travel opportunities were lost due to removal of rural bus stops, new opportunities were gained through the use of a bicycle or car to access a station with a higher level of

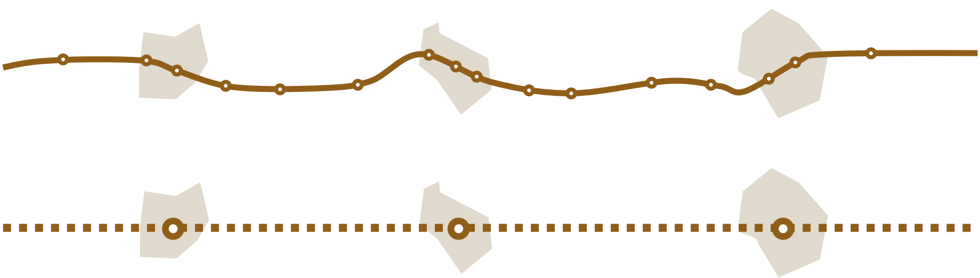

Figure 6 Stop spacing on the studied bus and rail services
Illustration of typical stop spacing on a regional bus service (top) and a regional rail service (bottom). Replacing a regional bus service with rail means replacing several bus stops in and between the villages with a single station in each village.

service. In fact, the results suggest that these new travel opportunities outweighed the former rural bus stops in terms of patronage. This is illustrated by the numbers in Table 5, showing the patronage development in and around villages in the case study group, where rail services replaced bus services, compared to the control group where bus services remained. As can be seen in the table, substantial patronage growth was observed around the villages in the case study group – a significantly more positive development than in the control group (U = 24, z = –3.10, p = .002).

Hence, it was concluded that the introduction of rail services, with the associated bus cuts, led to substantial patronage growth. Furthermore, despite the service reduction at rural bus stops, the rail services did not result in a distortion of the public transport usage between villages and their surrounding rural areas. The relative patronage growth was of equal magnitude in and outside the villages.

There were also differences within the case study group regarding parallel services. In half of the cases, the bus services were suspended completely. In the other half, bus services were retained parallel to the rail services, though with a dramatically reduced supply on the bus services and fewer train departures than in the cases where the bus services were suspended completely. At first glance, a comparison of these groups indicated greater patronage growth if resources were concentrated such that a regular-interval rail service could be provided throughout the day (44% compared to 17% for the cases with bus services parallel to the rail services; the numbers are for villages and the surrounding rural areas together). However, the difference between the groups was not statistically significant (U = 6, z = –1.92, p = .055).

Table 5 Patronage development in and around villages

Patronage development over an eight-year period (on average) in the case study group, where rail services replaced bus services, and in the control group, where bus services remained. The table presents the aggregate change in all cases combined and the share of cases with positive patronage development.

PATRONAGE DEVELOPMENT	CASE STUDY GROUP	CONTROL GROUP
In villages		
Aggregate change	+36%	+8%
Number of cases with patronage growth	12 of 14	8 of 14
In surrounding rural areas		
Aggregate change	+47%	–24%
Number of cases with patronage growth	10 of 13	0 of 13
Total, villages and surrounding rural areas		
Aggregate change	+38%	+4%
Number of cases with patronage growth	12 of 14	6 of 14

Paper 3: Bus stops – a matter of reliability

The effects of different types of bus stops regarding average travel time, travel time variability, and on-time performance were analysed in Paper 3. To this end, three bus stop categories were defined:

1. Main bus stop in an urban area (town or village), typically located in the centre of an urban area and with higher patronage levels than other nearby bus stops.
2. Secondary bus stops in urban areas, i.e. bus stops in towns or villages that are not in category 1.
3. Rural bus stops (outside of urban areas), located en route between villages and towns.

On the studied bus service, the bus stops in category 1 dominated in terms of patronage, despite the fact that they were greatly outnumbered by the bus stops in the other two categories. Conversely, the rural bus stop (category 3) was the most common type of bus stop, but with marginal significance for the total patronage of the service.

The results showed that when buses stopped at a bus stop in category 2 or 3, approximately 40 s were added to the travel time.[6] The length of this added time was relatively insensitive to the number of boardings and alightings because most of it stemmed from deceleration and acceleration, opening and closing of doors, and the waiting time for the bus to merge back into traffic. The added time for a bus stopping at a rural bus stop (category 3) was in general a few seconds longer than for secondary bus stops in urban areas (category 2) due to higher speeds and consequently longer deceleration and acceleration times.

On-call stopping is applied on the studied bus service, which means that buses can bypass stops if there is no boarding or alighting demand. This leads to variation in the stopping rate – the share of buses that stop at an individual bus stop – as illustrated by the numbers in Table 6. The minimum and maximum values reveal some variation within each category on the studied bus service, but at most bus stops the stopping rates are relatively close to the category medians – roughly 95% for the main bus stops in urban areas (category 1), 50% for secondary bus stops in urban areas (category 2), and around 5% for rural bus stops (category 3).

[6] Bus stops in category 1 were not analysed in this part of the study. On the studied bus service, all bus stops in category 1 are time points where early arriving buses are held to adjust to the schedule. This means that part of the dwell time on these bus stops is associated with the delay status, which severely complicates the analysis.

Table 6 Stopping rates

Ranges and median values of the share of bus trips that stop at an individual bus stop, i.e. the stopping rate, in each bus stop category on the studied bus service (Broby–Kristianstad, excluding the termini).

STOPPING RATE	CATEGORY 1 (N = 3)	CATEGORY 2 (N = 8)	CATEGORY 3 (N = 10)
Minimum	29%	23%	0%
Median	94%	50%	4%
Maximum	95%	71%	26%

The low stopping rates at the rural bus stops meant that their average effect on the travel time was less than 3 s per bus stop. The average impact of secondary bus stops in urban areas was greater (18 s per bus stop), but still all of the bus stops in these two categories together accounted for less than 10% of the average travel time on the bus service. Considering the fact that the vast majority of the bus stops on the service belonged to these two categories, this was a rather moderate effect.

However, the fluctuating usage of the bus stops resulted in inconsistent stopping patterns. Out of 21 intermediate bus stops on the studied bus service, the actual number of stops made on a single bus trip varied from 1 to 15 in the sample. This resulted in considerable travel time variability and poor on-time performance.

Stopping rates close to 50% is the worst-case scenario in terms of travel time variability. Stopping rates closer to 0 or closer to 100% imply less variability in the total number of stops made. Consequently, the secondary bus stops in urban areas on the studied service have a larger impact on service reliability than the rural bus stops.

Thus, with such low stopping rates as on the studied service, removal of a few rural bus stops cannot be expected to lead to any substantial quality improvements, neither in terms of average travel time nor reliability. The potential for quality improvements is greater with regard to stop spacing in urban areas. Removing bus stops in urban areas may seem irrational, considering the typically higher levels of patronage there, but not only do these bus stops have a greater impact on service reliability, there are typically also more nearby options available when bus stops are removed.

Paper 4: The importance of off-peak frequency

In Paper 4, long-term patronage effects were studied on four regional public transport services where substantial off-peak service improvements had been introduced some years earlier. The improvements generally resulted in at least hourly all-day services, with weekday service improvements characterised by peak hour frequencies being extended into the midday and evening periods, and the weekend service improvements typically being upgrades from departures roughly every two hours to every hour.

An overview of the estimated patronage effects compared to the relative increase in the daily number of departures is presented in Table 7. As can be seen in the table, the long-term patronage growth was substantial with values close to or, at least on weekdays, even exceeding the relative frequency increase. This means that the cost coverage has increased overall, and this effect was strengthened by the fact that off-peak service improvements can be provided at relatively low cost because the needed vehicles are generally already available (assuming that the patronage growth during peak hours can be managed with existing vehicle capacity).

Comparisons of patronage levels at different times of the day before and after the off-peak service improvements suggest that the patronage growth is not concentrated to the periods where new departures have been introduced. In fact, the off-peak service improvements on weekdays seem to have inflicted substantial patronage growth during peak hours, despite unaltered peak hour frequencies. Making the service available throughout the day seems to be valued even by passengers who normally do not use the off-peak services.

Thus, the results suggest that off-peak service improvements may result in substantial patronage growth even if patronage is low on the specific departures that have been added. In some of the studied cases, patronage growth was even greater during the peak hours, where frequencies were unaltered, than during the off-peak periods. This so-called cross-effect seems to be most apparent between different periods on weekdays. Effects on weekday patronage of improved weekend supply could not be detected, nor vice versa.

A possible interpretation of the results is that an adequate service frequency throughout the day (at least hourly departures in the cases of this study) may be regarded as a basis for public transport to be a viable option. This means that reasonable off-peak service levels are not only valuable for social inclusion objectives, but also for attracting new patronage.

Table 7 Estimated patronage effects

Overview of the estimated long-term patronage effects compared to the relative increase of the daily number of departures. The rate of convergence to the long-term effect varies, but a large part of the effect is in most cases attained within three years.

PATRONAGE / FREQUENCY INCREASE	CASE A	CASE B	CASE C	CASE D
Weekday	40% / 27%	50% / 33%	-	50% / 42%
Saturday	50% / 100%	70% / 100%	60% / 80%	100% / 88%
Sunday	50% / 100%	85% / 100%	90% / 150%	70% / 40%

Discussion

The aim of this thesis was to develop the understanding of the effects of different service planning decisions in regional public transport in terms of different trade-offs and their impacts on the overarching objectives of public transport provision. The aim was framed by three research questions, which are discussed in the following three sections of this chapter. The discussion is then concluded with a review of the methods used along with some suggestions for future research.

A regional perspective on service planning trade-offs

The first research question concerned differences between regional and local public transport and how these differences affect some of the considerations that are at the centre of service planning:

- *In what ways are the service planning trade-offs different in regional public transport compared to local (urban) public transport?*

The findings of this thesis demonstrate that the service planning trade-offs commonly are more complex than they might appear to be (when they are debated) and that there are some important differences between local and regional public transport that add to this complexity. The differences appear in varying shapes in different types of trade-offs. This is further developed in the following subsections through a return to the taxonomy presented in the *Background* chapter (see Figure 4). The taxonomy offers a framework for the discussion and is aimed at aiding the understanding of the different types of trade-offs that service planning entails.

Geographic distribution

Despite the limited amount of research into regional public transport, there seems to be a relatively clear understanding of how networks should be designed to facilitate patronage growth. In short, resources should be concentrated to high-demand corridors between cities and towns, focusing on fast and frequent all-day services with high levels of service reliability. These features are familiar from studies into local public transport (e.g. Grisé et al., 2021; McLeod et al., 2017; Nielsen et al., 2005), but for regional services a high level of on-board comfort should be added to the top priorities on the wish list.

Network coverage is also a more pronounced preference in regional compared to local public transport according to the findings of Paper 1. This is possibly a reflection of the more dispersed nature of regional networks, where the geographic distribution of the network is not a matter of service quality but rather of whether the public transport system is considered available at all.

Importantly, network coverage is a multifaceted concept that involves access and egress distances as well as the possibilities to reach a multitude of destinations (within a reasonable travel time, which means that spatial and temporal dimensions are combined in the concept of network coverage). This means, among other things, that network coordination in terms of integrated ticketing, information, and transport planning is crucial for network coverage. As for passengers' preferences, this implication of network coverage is suggested in Paper 1 to be as important as access distances.

Access distances are also associated with some ambiguity in relation to network coverage, which further adds to the versatility of the concept:

- Accessibility depends on individual characteristics and perceptions of personal capabilities (Ryan & Pereira, 2021), which means that network coverage is perceived differently from the perspectives of different individuals or population groups.
- The results of Papers 1 and 2 show that the availability of different access modes may have a substantial impact on access distances. If the appropriate infrastructure exists – in the form of park-and-ride facilities (for bicycles and cars) and roads suitable for cycling – access trips by bicycles and cars may constitute significant shares of the total patronage. These modes are associated with longer access distances than typical walking distances.
- Many passengers are willing to walk farther to access a public transport service of better quality (El-Geneidy et al., 2014; Mamun & Lownes, 2014; Mulley et al., 2018; van Soest et al., 2020). The review in Paper 1 suggests that this also applies to cycling and driving, i.e. passengers are generally also willing to cycle or drive longer to a better public transport service. Moreover, the results indicate that a higher service quality infers larger shares of access trips by bicycle and car.
- Total trip lengths affect access distances. When total trip lengths increase, the in-vehicle travel times typically increase as well. Access trip times thus constitute

relatively smaller parts of the total travel times, implying the acceptance of longer access distances.

Hence, the trade-off regarding geographic distribution of the network depends largely on how coverage is defined. In regional public transport, the availability of bicycles and cars as access modes need particular consideration, along with the influence of total trip lengths, the quality of the public transport service, and the diversity of capabilities in the population. Also, analogous to the concept of accessibility in general terms, the findings stress the importance of including possibilities to reach various destinations in the concept of coverage, thus avoiding a one-sided focus on access distances.

Transfers

Service frequencies are generally lower in regional compared to urban networks. This poses a greater challenge in achieving the desired network effect, facilitated by short transfer times. Some of the reviewed studies in Paper 1 showed that timed transfers are possible even in low-frequency networks through coordinated planning and so-called pulse timetables. The generally negative perceptions of transfers were suggested to be compensated for by the possibility to increase service frequencies in the peripheral parts of such networks.

Rural areas are characterised by low population density, which generally means that all-day services with adequate service frequencies cannot be provided unless the settlements are concentrated in corridors along interurban routes. Feeding services are required to be able to cover areas outside these corridors through conventional fixed-route services or DRT (demand-responsive transport) feeding to the nearest hub (Mulley & Nelson, 2021; Nielsen, 2021).

Parallel services

As an expansion of the recommendation on feeding services, the results of Paper 1 showed benefits of a network structure with high-quality services as backbones and other services feeding into these backbones rather than operating on parallel direct routes. This is in line with what has been suggested for urban networks, corresponding to the distinction between the ready-made approach and the tailor-made approach (Nielsen et al., 2005).

Limited-stop express services parallel to full-stop services may be beneficial where the demand is sufficient for both, but the results of Paper 2 indicate that such setups must be applied with caution. This is further stressed by the findings of Paper 4, emphasising the value of providing a regular-interval all-day service rather than a limited-stop and a full-stop service, each with insufficient off-peak service frequency.

Temporal distribution

The results of Paper 4 demonstrate that making the service available throughout the day may lead to substantial patronage growth and seems to be valued even by passengers who normally do not use the off-peak services. Despite the typically low demand during midday and evenings, adding departures during these periods to fill gaps in the timetable can result in relatively large patronage growth in total over the course of the day. The results of Paper 4 suggest that the patronage growth may even exceed the relative frequency increase. This is particularly interesting because the patronage response to changes in service frequency otherwise is typically inelastic (Totten & Levinson, 2016; Wallis, 2013).

Hence, off-peak departures should not be assessed in isolation. Although these departures may at first glance be seen as empty vehicles or excess capacity, they can in fact be crucial for the perceived service quality. In effect, off-peak service improvements may be a cost-efficient way to achieve substantial patronage growth and simultaneously reduce social exclusion by expanding the temporal coverage.

Mode

Some of the reviewed studies in Paper 1 suggest a general preference for trains over buses in regional public transport (Hasiak et al., 2016; Jackson et al., 2012), similar to results from urban services (e.g. Scherer, 2010; Werner et al., 2016). This preference for rail may partly be a proxy for higher comfort (Ben-Akiva & Morikawa, 2002; Scherer, 2010; Varela et al., 2018). With the suggested increased importance of comfort with increased trip distances in Paper 1, there is potentially a stronger preference for rail in regional than in local public transport. Longer distances also mean that the in-vehicle travel time constitutes a larger share of the total travel time, pushing the balance towards rail even further due to the typically higher speeds compared to bus and coach services.

Besides the higher costs associated with rail investments and operations, the benefits of rail services must typically also be weighed against wider stop spacing.

Stop spacing

Stop spacing is commonly debated and often assessed as a trade-off between in-vehicle travel time and access time or spatial coverage. However, the findings of Paper 3 show that stop spacing on a regional bus service is not so much about travel time as it is about reliability. This is particularly evident for rural bus stops where the stopping rates are low, i.e. where buses rarely need to stop to pick up or drop off passengers. Also, the coverage aspect of the trade-off is complex, as illustrated by the findings of Paper 2 which suggest that higher service quality extends the catchment area around a stop, not least by increasing the use of bicycles and cars as access modes.

Thus, if bus stops are to be removed, it is important not to assess the bus stops only on passenger activity, even when patronage is prioritised over coverage. Rarely used bus stops (with low stopping rates) have little impact on the overall reliability of the service, and even less impact on the average travel time. Consequently, removing such stops will not lead to any significant service quality improvements. Essentially, stopping rates need to be considered when bus stops are evaluated, along with patronage levels and availability of nearby alternatives.

Directness

The mechanisms in the trade-off between direct routes and proximity to stops are similar to the mechanisms of stop spacing. However, depending on the available options in each particular case, the potential effects on travel time are more tangible. As shown by the findings of Paper 2, if the appropriate infrastructure exists – such as bike paths and park-and-ride facilities – the drawback of longer access distances can be outweighed by a higher quality of service regarding other attributes, at least for the parts of the population who perceive bicycles and cars as viable access modes.

Although empirical evidence on the effects of detours is lacking in this thesis, it can be assumed that the general suggestion for high-quality services in urban areas, to make straight routes (Nielsen, 2021), may have more far-reaching consequences on regional services. On urban services, a straight route instead of a detour typically results in longer walking distances to access the service. On regional services, a major road with bypasses may be located several kilometres from the villages along the route. This not only implies a greater time difference between the straight route and the detour, but a stop on the bypass also means that the villagers are generally referred to cars, bicycles, and potential feeding services to access the service. Consequently, the plausibility to use public transport in these cases depends to a large extent on the quality of the bicycle and car infrastructure and the feasibility of feeding services.

Effects on the patronage–coverage dichotomy

The second research question was directed towards relating the service planning trade-offs to the strategic level through the two conflicting poles of patronage and coverage objectives:

- *What are the effects of the trade-offs in terms of the balance between patronage objectives and coverage objectives?*

This question is approached through a discussion of various perspectives on coverage. With this as a point of departure, the effects of a couple of service planning trade-offs and their projections on the patronage–coverage dichotomy are then discussed in light of the results of the included papers.

The concept of coverage

Crucially, discussions about the patronage–coverage dichotomy depend on how the concept of coverage is understood. The typical performance indicator, measuring the percentage of the service area or the percentage of residents and jobs within a certain distance from the stops in the public transport network (Hirschhorn et al., 2018; Walker, 2008), overlooks the temporal dimension of coverage. Thus, it ignores crucial aspects of public transport accessibility, such as travel time, frequency, and operating hours. Furthermore, as described above in the discussion of the trade-off regarding geographic distribution, access distances vary depending on the quality of the public transport service, total trip lengths, and conditions for bicycles and cars as access modes. Additionally, the diversity of individual characteristics and perceptions of personal capabilities is neglected by indicators with fixed threshold distances.

Even if a specific threshold distance can be defined based on a choice of maximum walking distance, it must be acknowledged that the results of such coverage indicators are not comparable between local and regional public transport. In local public transport, it may be feasible to design networks with stops or stations within some prescribed distance from any part of the urban area. Regional networks are more dispersed, which means that similar coverage indicators will yield much lower coverage percentages there, even if longer threshold distances are applied (Ušpalytė-Vitkūnienė & Ranceva, 2022). This is demonstrated by the left graphic in Figure 7. As illustrated by the pink shaded zones in the figure, large areas will typically remain outside the walking catchment areas even if the stop spacings on the services in the network are dense.

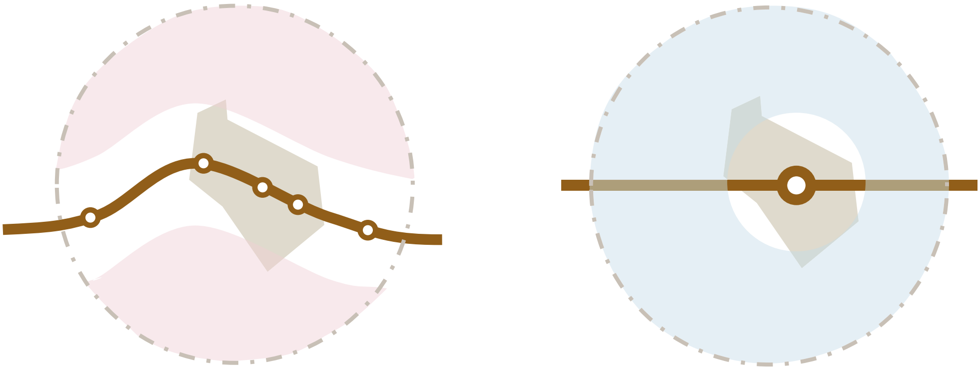

Figure 7 Rural coverage around regional public transport services
Models of spatial coverage in a small town or village (grey area) and a portion of its surrounding rural area (dash-dotted circle) served by a bus service with several bus stops (left) compared to a rail or coach service with just one station (right). The shaded pink and blue areas represent areas outside the typical walking catchment areas, defined as within a certain distance from a bus stop or station. Service quality improvements may have a positive net effect on public transport usage not only within walking distance, but also in relatively large rural areas (represented by the shaded blue area in the right-hand figure) even if the number of stops is reduced.

The perception of coverage is also coloured by the moral principles applied to determine what constitutes a fair distribution of resources. For instance, the utilitarian approach emphasises revealed travel behaviour, whereas the egalitarian and sufficientarian approaches instead emphasise accessibility in terms of opportunities. The egalitarian approach focuses on relative accessibility levels and the distribution of accessibility among the population, whereas the sufficientarian approach instead focuses on absolute accessibility levels in relation to a prescribed minimum level. Applying these approaches to the setting in Paper 2, where regional bus services are compared with rail services with fewer stops, demonstrates how different views on fairness may result in different service planning decisions. The setting is illustrated in Figure 7, displaying catchment areas around a typical bus service compared to a rail service.

The *utilitarian* approach emphasises the actual usage of the service and, even with a strict focus on the rural areas outside villages, the results of Paper 2 demonstrate that higher service quality may improve the utility of the service in relatively large rural areas despite the reduction in the number of stops.

The effects in the *egalitarian* perspective arguably depend on the accessibility levels in the affected area as a whole relative to other parts of the region. Assuming that the rail service will generally improve the accessibility levels in the area, it will lead to more equal accessibility levels if the residents in the area are among the least well-off citizens in the region in terms of accessibility. Conversely, if many residents in the area are already relatively well-off in terms of accessibility, replacing the bus service with rail may exacerbate existing inequalities. This risk is amplified by the fact that the greatest improvements are allocated to the residents in the urban area and the car owners in the surrounding rural area – the presumably already most well-off in the affected area.

From the *sufficientarian* perspective, replacing the bus service with rail would probably be inadvisable, assuming that more people will become socially excluded due to the loss of rural bus stops. However, if feeding DRT services are introduced along with the rail service, and if the combination of DRT and rail services is able to provide a sufficient level of accessibility for the rural population, the rail alternative offers a substantial coverage improvement in the sufficientarian perspective. Similar rural areas will then have similar (and sufficient) levels of service, regardless of whether the area is located en route between urban areas (compare the pink and blue shaded areas in Figure 7). Yet, the sufficientarian approach is burdened by the challenge of defining a sufficient level of accessibility (Lucas et al., 2016; Pereira et al., 2017) and consequently a minimum level of service for the feeding services. Importantly, the minimum level of service should not only be a matter of the number of departures for the feeding services but should also include travel times to relevant destinations.

Problems with the dichotomy

These reasonings about coverage, departing from different moral principles, do not fit into the patronage–coverage dichotomy. With the utilitarian perspective on coverage, there is no conflict between patronage and coverage in this case. Replacing bus services with rail was shown in Paper 2 to have increased the patronage and can also be argued to have increased the spatial coverage. In the egalitarian perspective, it can be argued that the new rail services have resulted in improved rural public transport and likely a more equal level of service compared to the more densely populated parts of the region. However, this argument is only valid for the part of the population with access to a car or residing within cycling distance from a station. In line with the sufficientarian perspective, rural residents near the former bus stops who do not have the ability to get to the new stations experience a loss of travel opportunities and an increased risk of social exclusion. Consequently, the tension is not so much between patronage and coverage as it is between regional equality and social inclusion. Alternatively, the trade-off can be described as a conflict between extensive and intensive accessibility (Portinson Hylander, 2021, p. 241).

The patronage–coverage dichotomy can be further problematised through the findings of Paper 3. These findings suggest that reduced spatial coverage through removal of rural bus stops cannot be expected to lead to any substantial quality improvements or patronage growth. Consolidation of bus stops in urban areas has greater potential. This is then not a simple trade-off between patronage and coverage, not even on the local scale. In general, passengers are willing to walk farther to a better service, which means that it can be argued that the spatial coverage does not deteriorate in proportion to the number of removed bus stops.

Regarding the trade-off between peak hour frequency and temporal coverage, the findings of Paper 4 give another example of how the patronage–coverage dichotomy can be misleading. In this case, there are no real tensions between patronage and coverage objectives. Temporal coverage improvements were associated with increased patronage, despite the fact that the new departures were added during periods of low demand. The findings support the idea that it is inappropriate to attribute certain parts of the service span to patronage and other parts to coverage (Walker, 2008).

To summarise, the findings of this thesis demonstrate that the tensions within some of the service planning trade-offs are not aligned with the patronage–coverage dichotomy. In fact, the dichotomy can be misleading for the understanding of the trade-offs concerning stop spacing and temporal distribution on regional public transport services. The simplicity and clarity of the patronage–coverage dichotomy is appealing, but the dichotomisation has a cost in the loss of nuances.

The findings focus on a couple of the service planning trade-offs on the route level. On the network level, the tensions in the patronage–coverage dichotomy seem more evident, particularly in the trade-off concerning geographic distribution for which the dichotomy was originally described (Walker, 2008). However, discussions about the patronage–coverage dichotomy still depend on how the concept of coverage is understood. This is not only a matter of practical issues, such as prescribed maximum access distances or how accessibility is measured, but also of the underlying moral principles that guide the perceptions of what constitutes a fair distribution of resources.

Implications for regional high-quality services

The third research question addressed the demand for more knowledge into what constitutes a high level of service in regional public transport and how this can be implemented:

- *What are the implications for the development of high-quality public transport concepts on the regional scale, such as Regional BRT?*

Before recommendations on the design of high-quality services can be established, it is crucial to clarify the objectives. A fundamental feature of public transport service planning, as illustrated by the trade-offs described in this thesis, is that it is not possible to make a universally applicable service concept that is able to meet patronage objectives, regional equality, and social inclusion objectives simultaneously. In general, high-quality services refer to so-called patronage services on trunk routes. Thus, to state the obvious, the notion of high quality typically does not include everyone.[7]

The design of the services depends not only on the objectives, but also on the typical trip distances. For example, as was found in Paper 1, longer distances stress the importance of on-board comfort. Also, trip lengths affect access distances. On longer trips, the in-vehicle travel time constitutes a larger share of the total travel time and the access trip time constitutes a smaller share. This affects the ideal stop spacing and directness of the route.

The influence of trip distances also emphasises the importance of acknowledging the different preconditions for service planning in local and regional public transport. Besides the generally longer distances in regional public transport, these differences typically include lower passenger volumes, higher speeds, and more frequent use of bicycles and cars as access modes. As discussed in the previous sections of this chapter, the different preconditions affect the outcomes of the service planning decisions. Consequently, applying planning principles for local public transport (e.g. Grisé et al., 2021; McLeod et al., 2017; Nielsen et al., 2005) to regional public transport without adequate consideration of the differences entails an obvious risk of overgeneralisation. Best-practice principles or guidelines with a pronounced regional perspective seem to be lacking, but the results of this thesis provide some general points of departure.

According to the results of Paper 4, one of the basic requirements for regional high-quality public transport should be a service that is available throughout the day with regular departures from morning to evening (at least hourly departures in the studied cases in Paper 4). Possibly, public transport investments may not reach their full potential if this requirement is not met.

The general preference for rail, suggested by some of the reviewed studies in Paper 1 (Hasiak et al., 2016; Jackson et al., 2012), is an interesting point of departure for the development of rail-inspired bus concepts such as Regional BRT. Presumably, some of the typical differences between bus and rail services depend on different planning traditions rather than technical divergence. If these planning traditions can be set aside, most of the quality attributes suggested to be the most important for regional passengers, according to the results of Paper 1, should be feasible to improve for bus or coach services to levels similar to or better than the typical rail service:

- *Frequency.* Lower operational costs for bus and coach services infer greater opportunities to provide adequate service frequencies throughout the day.

[7] The protests on the Falsterbo Peninsula, described in the prologue, illustrate some of the conflicts of interest that high-quality services may entail. Similar conflicts of interest may also be discerned on the organisational level between different actors involved in the planning process (Pettersson, 2018).

- *Comfort.* On-board comfort is crucial in regional public transport, at least for longer trips, which places high demands on the vehicles. A high level of comfort also entails requirements for road conditions, as well as for bus stop facilities.
- *Reliability.* As was shown by the results of Paper 3, bus stops largely influence the service reliability. Ideally, high-quality services should be operated with fixed stopping regimes or on-call stopping regimes with very low levels of variability in the stopping patterns. The service reliability can also be improved through bus priority measures and swift boarding procedures.
- *Network coverage.* A high quality of service should include access trips. Walking is typically the primary access mode, but the coverage of high-quality services is also dependent on bicycle and car access. This means that appropriate infrastructure for such access trips is required. Network coverage also entails coordination with other services in the public transport network.

However, travel time is a quality attribute for which bus services generally lack the potential of the corresponding rail services because bus services are restricted by the speed limits on the roads. Because buses need to stop at intermediate bus stops, bus trips will always be slower than car trips assuming an uncongested environment where bus priority measures will not imply any substantial time gains. Rail services are generally operated with higher speeds, which means that their ability to compete with car trips in terms of travel time is better. The importance of short in-vehicle travel times increases with the trip distance, as does the travel time difference between buses and (the faster) trains.

Some travel time improvement can be achieved by reducing the number of stops, but the results of Paper 3 suggest that the effects are limited. In particular, removal of rural bus stops cannot be expected to result in any significant travel time improvements. The effects on service reliability are more tangible, but still quite moderate for rural bus stops. In comparison, limiting the number of bus stops in urban areas has greater potential, at least as a general principle. In practice, every stop should be assessed based on its impact on travel time and reliability (e.g. by taking the stopping rate into account), patronage, and the availability of nearby alternatives.

The existence of the rural bus stops also depends on the conditions for access to the nearest station in terms of feeding services (conventional or demand-responsive), bicycle paths, park-and-ride facilities, etc. With a high-quality trunk service and sufficient access options from the surrounding rural area, rural public transport usage can increase compared to a conventional regional bus service with rural bus stops. However, these findings (from Paper 2) are based exclusively on rail services and it is unclear whether the results are transferable to high-quality bus concepts. This uncertainty applies to longer trips in particular, given the typical speed difference between trains and buses described above.

Reflections on the research design and future research

A natural part of research is that it gives rise to new questions. Presumably, this is especially true of doctoral thesis projects, which are learning processes by nature and thus developed gradually with reflections on previous steps in the process. This thesis is no exception.

About public transport modes and passengers

The first reflection on the research design is a follow-up to the end of the previous section, i.e. the fact that the findings of Paper 2 are based exclusively on rail services. Initially, the intention was to also include cases where conventional bus services had been replaced by coach services with fewer stops, but it turned out to be more challenging than expected to find adequate empirical material. Even though such cases do exist in the study area, they have been implemented incrementally over several years, which confounds pre- and post-comparisons. The changes to rail were more distinct, substantially altering the public transport network from one day to the next.

A suggestion for future research is to address this knowledge gap by exploring the use of bus-based park and ride (for bicycles and cars) in rural areas. An interesting approach would be to examine catchment areas for bicycles and cars and how they are influenced by total trip distances because the typical speed difference between trains and buses has been suggested to particularly influence longer trips. Furthermore, the influence of the quality of the bicycle infrastructure would be an interesting topic to include in such studies.

As was also acknowledged in Paper 2, and which may be extended to the entire thesis, the methods used focused on describing *what* has happened, without much detail on *why*. Consequently, the thesis offers a number of potential points of departure for studies delving deeper into reasons and details. Two potentially interesting research subjects are investigations into how removal of rural bus stops affects different groups in the population and how passengers experience temporal coverage in terms of off-peak departures. For instance, a study about passengers' experiences of temporal coverage may provide new insights into why people start using public transport due to off-peak service improvements and to what extent the patronage growth is related to new passengers or to existing passengers making more trips.

A related reflection is that passengers have not been involved directly in any of the included studies. Their preferences have instead been explored through analysis of demand data in Papers 2–4 and through the reviewed studies in Paper 1. However, it should be noted that many of the reviewed studies in Paper 1 are based on stated preference and customer satisfaction surveys. Nevertheless, the absence of direct encounters with passengers in the thesis can be seen as a reflection of its focus on planning. The perspective of public transport planners' decisions (the "street-level bureaucrats" as they are called in the description of the aim of this thesis) is at the centre of the thesis rather than the perspective of passengers. Passengers' perspectives are, of course, still highly relevant.

Generalisability of the results

One of the more obvious avenues for future research is to extend the empirical scope to more cases and to other study areas. This is interesting in relation to the case studies in Papers 2–4 and their external validity.

For instance, bicycle trips are relatively common in Scania compared to many other regions, even in rural areas such as the ones studied in Paper 2. The percentage of bicycle trips to the train stations in the study was 10% on average. The bicycle share of trips to the stations is even larger for residents beyond walking distance, and even though car trips dominate in these areas, the generalisability of the results to regions with lower bicycle shares needs to be studied further.

The case in Paper 3 demonstrates rather distinct differences in stopping rates at rural bus stops compared to bus stops in urban areas, possibly due to the specific population structure along the studied route with a relatively sparse population outside the urban areas. Exploration of how stopping rates vary depending on context may prove useful. In any case, the method presented in Paper 3 is a reasonable point of departure for future studies into bus travel time and how it varies depending on different types of bus stops. The lack of inference statistics on the route level is a soft spot, but this can be overcome, for example, by introducing analysis of variance on the relation between the number of stops made and delays.

Regarding Paper 4, the extended empirical scope may include off-peak service reductions as well as improvements in order to explore whether the patronage effects are symmetric. Furthermore, all of the studied cases in Paper 4 were upgraded with hourly departures throughout the day as a basis. In line with this, another interesting research topic would be to explore whether hourly departures can be regarded as a minimum level of service for public transport to be a viable alternative (a specific threshold frequency for off-peak services). A potential approach could thus be to study whether corresponding effects can be expected with improvements from, for example, occasional daily departures to departures every other hour or from hourly to half-hourly departures.

Financial aspects

Future research should preferably also include elaborations on the financial aspects of the trade-offs in order to provide more in-depth insights into their mechanisms. For instance, the distribution of departures between peak and off-peak periods is not a matter of allocating a fixed number of departures to different time slots. As outlined in the findings of Paper 4, the marginal cost of additional off-peak departures can be considerably lower than corresponding additions during peak hours, given that the off-peak service improvements typically can be managed with the existing vehicle fleet. Similar financial complexities also exist in many of the other trade-offs, e.g. regarding economies of scale in the geographic distribution of services and varying operational costs in the trade-off between bus and rail services.

Main contributions of the thesis

The taxonomy of trade-offs presented in this thesis can serve as a point of reference for future discussions and studies into the balancing act of service planning. Such studies may become valuable complements to the existing body of literature regarding best-practice principles, recommendations, and guidelines, which have been common in previous publications on service planning (e.g. Grisé et al., 2021; McLeod et al., 2017; Nielsen et al., 2005). Because the taxonomy basically has a general approach to public transport services, it can be used as a framework for studies into local as well as regional public transport.

The perspective of the trade-offs highlights the tensions between different quality attributes and their spatial and temporal distribution, and ultimately between different objectives of public transport provision. In this regard, this thesis has shown that the service planning trade-offs cannot be translated into a one-dimensional dilemma in the form of patronage objectives versus coverage objectives. Studies and assessments in public transport planning should adopt a more nuanced view of the various objectives of public transport provision.

The differences between local and regional public transport affect the relationships between the service planning trade-offs and the overarching objectives of public transport provision. A general need for more knowledge about the specifics of regional public transport was outlined in the introduction of this thesis and was also confirmed by the literature review in Paper 1. Previous public transport research has largely been focused on local public transport in cities. Arguably, one of the main contributions of the thesis has been to highlight the regional perspective in public transport planning. It has shed light on some of the relevant aspects, and hopefully it can serve as a starting point for many more studies to come in the regional public transport realm.

Conclusions

This thesis aimed to develop the understanding of the effects of different service planning decisions in regional public transport, in terms of different trade-offs and their impacts on the overarching objectives of public transport provision. Based on a synthesis of the four research papers included in the thesis, it can be concluded that a regional perspective on public transport service planning requires consideration of the differences between the local and regional scales.

To elaborate on this, it is appropriate to begin by returning to the first research question and how it is answered in the thesis:

1. *In what ways are the service planning trade-offs different in regional public transport compared to local (urban) public transport?*

The findings of the thesis demonstrate that service planning trade-offs are more complex than they may seem, and the differences between local and regional public transport add to this complexity. As an example, stop spacing is commonly debated and assessed as a trade-off between travel time and spatial coverage. However, the results of this thesis demonstrate that stop spacing on regional bus services is not so much about travel time as it is about reliability. This is particularly evident for rural bus stops where the stopping rates are low. Also, the coverage aspect of the trade-off is complex because higher service quality extends the walking catchment area around a stop and increases the use of bicycles and cars as access modes.

The effects of these trade-offs on the strategic level in terms of the overarching objectives of public transport provision was approached in the second research question:

2. *What are the effects of the trade-offs in terms of the balance between patronage objectives and coverage objectives?*

It has previously been suggested that most of the overarching objectives of public transport cluster around two conflicting poles: objectives served by patronage and objectives served by coverage. The intention of this dichotomisation was to aid conversations about resource distribution in public transport networks, and it has proven useful for understanding other types of service planning trade-offs as well. However, the findings of this thesis illustrate that the patronage–coverage dichotomy fails at explaining the underlying tensions in some cases. For example, the question of removing rural bus stops in order to improve the quality of service at the remaining stops involves tensions between regional equality and social inclusion objectives, i.e. objectives concerning different aspects of coverage rather than patronage versus coverage. Hence, it is suggested that the patronage–coverage dichotomy implies a loss of nuances and may even be misleading if applied indiscriminately.

Finally, the third research question approached some of the practical implications of the differences between local and regional public transport. Here, the concept of Regional BRT was used as a lens through which the findings of the thesis were viewed:

3. *What are the implications for the development of high-quality public transport concepts on the regional scale, such as Regional BRT?*

The results suggest that it is important to strive for high levels of quality particularly regarding frequency, comfort, reliability, travel time, access and egress trips, and coordination with other services in the public transport network. The basis is set by the frequency and the temporal coverage, with adequate service levels throughout the day, from morning to evening. Also, well-balanced stop spacing is exceptionally important for the reliability of the service, assuming on-call stopping where buses stop only on passenger demand. If bus stops are removed and the quality of service at the remaining stops is adequately improved, park-and-ride facilities (for bicycles and cars) are important for maintaining or even improving the availability of the service in rural areas, at least for the parts of the rural population who perceive bicycle and car access trips as viable options.

With these conclusions as starting points, a number of policy recommendations can be extracted from the thesis:

- Applying experiences from local public transport on regional public transport entails a risk of overgeneralisation. Such extrapolations must be handled with close attention to the differences between the local and regional scales.
- Trade-offs, with associated conflicts of interest, are present in all changes to public transport services and networks. Best-practice principles and guidelines should be interpreted with these trade-offs in mind.
- On the strategic level, the conflicts of interest cannot be easily translated into a simple trade-off between patronage and coverage. A more nuanced view on the objectives of public transport provision is necessary.

- Rail-inspired bus concepts such as Regional BRT may prove valuable for the development of regional bus and coach services with a high level of service. For most of the important quality attributes for regional passengers, it should be feasible to reach quality levels similar to or better than the typical rail service.
- If the quality of service is sufficiently upgraded, the number of stops can be reduced without impairing coverage in terms of patronage in rural areas, provided that appropriate infrastructure for car and bicycle access to the remaining stops is provided. However, the fact that coverage is a multifaceted concept, essentially linked to different ethical perspectives, cannot be overemphasised.
- Appraisals of bus stops must include effects on service reliability, taking stopping rates into account. Bus stops with low stopping rates (i.e. where buses rarely stop) have very limited impact on the overall quality of service, as opposed to moderately used bus stops (with stopping rates close to 50%), which have a much greater impact.
- Despite low patronage levels on some off-peak departures, such departures may contribute substantially to patronage overall. Thus, off-peak services should not be assessed on the basis of patronage on individual departures.

References

Adolphson, M., & Fröidh, O. (2019). Impact on urban form by the localization of railway stations: Evidence from Sweden. *Cities*, *95*, 102362. https://doi.org/https://doi.org/10.1016/j.cities.2019.05.031

Alsger, A., Tavassoli, A., Mesbah, M., Ferreira, L., & Hickman, M. (2018). Public transport trip purpose inference using smart card fare data. *Transportation Research Part C: Emerging Technologies*, *87*, 123–137. https://doi.org/10.1016/j.trc.2017.12.016

Bazley, C., Vink, P., & Blankenship, D. (2014). Survey Results for Rural Bus Rapid Transit (BRT) VelociRFTA and Future Human Factor Considerations. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *58*(1), 1224–1228. https://doi.org/10.1177/1541931214581255

Ben-Akiva, M., & Morikawa, T. (2002). Comparing ridership attraction of rail and bus. *Transport Policy*, *9*(2), 107–116. https://doi.org/10.1016/S0967-070X(02)00009-4

Berg, J., & Ihlström, J. (2019). The importance of public transport for mobility and everyday activities among rural residents. *Social Sciences*, *8*(2). https://doi.org/10.3390/socsci8020058

Berggren, U., Kjær-Rasmussen, T., Thorhauge, M., Svensson, H., & Brundell-Freij, K. (2021). Public transport path choice estimation based on trip data from dedicated smartphone app survey. *Transportmetrica A: Transport Science*, 1–34. https://doi.org/10.1080/23249935.2021.1973146

Berriman, C. (2019, October 20). Hawstead, Lawshall, Nowton and Shimpling villagers concern as axe hangs over thrice-weekly bus service. *Bury Free Press*.

Bertolini, L. (2017). *Planning the Mobile Metropolis: Transport for People, Places and the Planet*. Palgrave.

Bohman, H., & Nilsson, D. (2021). Borrowed sizes: A hedonic price approach to the value of netowrk structure in public transport systems. *Journal of Transport and Land Use*, *14*(1), 87–103. https://doi.org/10.5198/jtlu.2021.1664

Boisjoly, G., & El-Geneidy, A. M. (2017). The insider: A planners' perspective on accessibility. *Journal of Transport Geography*, *64*, 33–43. https://doi.org/10.1016/j.jtrangeo.2017.08.006

Bondemark, A., Johansson, E., & Kopsch, F. (2021). Accessibility and uncertainty: An empirical analysis of option value in transport. *Journal of Transport and Land Use*, *14*(1), 463–477. https://doi.org/10.5198/jtlu.2021.1783

Brake, J., Nelson, J. D., & Wright, S. (2004). Demand responsive transport: towards the emergence of a new market segment. *Journal of Transport Geography*, *12*(4), 323–337. https://doi.org/10.1016/j.jtrangeo.2004.08.011

Brand, J., Hoogendoorn, S., van Oort, N., & Schalkwijk, B. (2017). Modelling multimodal transit networks integration of bus networks with walking and cycling. *2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, 750–755. https://doi.org/10.1109/MTITS.2017.8005612

Büchel, B., & Corman, F. (2020). Review on Statistical Modeling of Travel Time Variability for Road-Based Public Transport. *Frontiers in Built Environment*, *6*, 1–14. https://doi.org/10.3389/fbuil.2020.00070

Buehler, R., Pucher, J., & Dümmler, O. (2019). Verkehrsverbund: The evolution and spread of fully integrated regional public transport in Germany, Austria, and Switzerland. *International Journal of Sustainable Transportation*, *13*(1), 36–50. https://doi.org/10.1080/15568318.2018.1431821

Camporeale, R., Wretstrand, A., & Andersson, M. (2019). How the built environment and the railway network can affect the mobility of older people: Analyses of the southern Swedish region of Scania. *Research in Transportation Business & Management*, *30*, 100368. https://doi.org/10.1016/j.rtbm.2019.100368

CEN. (2002). *EN 13816:2002 Transportation - Logistics and services - Public passenger transport - Service quality definition, targeting and measurement*. European Committee for Standardization.

Chen, J., Currie, G., Wang, W., Liu, Z., & Li, Z. (2016). Should optimal stop spacing vary by land use type? New methodology. *Transportation Research Record*, *2543*, 34–44. https://doi.org/10.3141/2543-04

Chowdhury, S., & Ceder, A. (Avi). (2016). Users' willingness to ride an integrated public-transport service: A literature review. *Transport Policy*, *48*, 183–195. https://doi.org/10.1016/j.tranpol.2016.03.007

Church, A., Frost, M., & Sullivan, K. (2000). Transport and social exclusion in London. *Transport Policy*, *7*(3), 195–205. https://doi.org/10.1016/S0967-070X(00)00024-X

Currie, G. (2006). Bus Transit Oriented Development — Strengths and Challenges Relative to Rail. *Journal of Public Transportation*, *9*(4), 1–21. https://doi.org/10.5038/2375-0901.9.4.1

Currie, G. (2016). Managing on-road public transport. In M. Bliemer, C. Mulley, & C. J. Moutou (Eds.), *Handbook on Transport and Urban Planning in the Developed World* (pp. 471–497). Edward Elgar Publishing. https://doi.org/10.4337/9781783471393.00036

Currie, G., & Loader, C. (2009). High ridership growth from extended transit service hours: An exploration of the causes. *Transportation Research Record*, *2110*, 120–127. https://doi.org/10.3141/2110-15 della Porta, A., Migliori, S., Paolone, F., & Pozzoli, M. (2019). Integrated Transport Planning: The "Rehabilitation" of a contested concept in UK bus reforms. *Journal of Cleaner Production*, *232*, 1297–1308. https://doi.org/10.1016/j.jclepro.2019.05.282

dell'Olio, L., Ibeas, A., de Oña, J., & de Oña, R. (2018). *Public Transportation Quality of Service*. Elsevier.

Deng, T., & Nelson, J. D. (2011). Recent Developments in Bus Rapid Transit: A Review of the Literature. *Transport Reviews*, *31*(1), 69–96. https://doi.org/10.1080/01441647.2010.492455

Dijkstra, J. (2022, January 13). Lijn 300 (Zuidtangent) is 20 jaar: "Goede verbinding tussen Haarlem en Amsterdam" [Line 300 (Zuidtangent) is 20 years old: "Good connection between Haarlem and Amsterdam"]. *NH Nieuws*.

Dodson, J., Mees, P., Stone, J., & Burke, M. (2011). *The principles of public transport network planning: A review of the emerging literature with select examples (Issues Paper 15)*. Urban Research Program, Griffith University.

El-Geneidy, A. M., Grimsrud, M., Wasfi, R., Tétreault, P., & Surprenant-Legault, J. (2014). New evidence on walking distances to transit stops: Identifying redundancies and gaps using variable service areas. *Transportation*, *41*(1), 193–210. https://doi.org/10.1007/s11116-013-9508-z

El-Geneidy, A. M., Strathman, J. G., Kimpel, T. J., & Crout, D. T. (2006). Effects of bus stop consolidation on passenger activity and transit operations. *Transportation Research Record*, *1971*, 32–41. https://doi.org/10.3141/1971-06

El-Geneidy, A. M., & Surprenant-Legault, J. (2010). Limited-stop bus service: an evaluation of an implementation strategy. *Public Transport*, *2*(4), 291–306. https://doi.org/10.1007/s12469-010-0030-9

Fielbaum, A., Jara-Diaz, S., & Gschwender, A. (2020). Beyond the Mohring effect: Scale economies induced by transit lines structures design. *Economics of Transportation*, *22*, 100163. https://doi.org/10.1016/j.ecotra.2020.100163

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363

Geater, P. (2019, July 31). Suffolk rural buses set for axe – but some routes beat county council cut. *East Anglian Daily Times*.

Grisé, E., & El-Geneidy, A. (2018). Where is the happy transit rider? Evaluating satisfaction with regional rail service using a spatial segmentation approach. *Transportation Research Part A: Policy and Practice*, *114*, 84–96. https://doi.org/10.1016/j.tra.2017.11.005

Grisé, E., El-Geneidy, A., & Stewart, A. F. (2021). Planning a high-frequency transfer-based bus network: How do we get there? *Journal of Transport and Land Use*, *14*(1), 863–884. https://doi.org/10.5198/JTLU.2021.1742

Hamer, P. (2010). Analysing the effectiveness of park and ride as a generator of public transport mode shift. *Road and Transport Research*, *19*(1), 51–107.

Hansson, J., Pettersson, F., Ringqvist, S., & Lindblom, P. (2016). *Guidelines för attraktiv regional busstrafik – Regional BRT [Guidelines for attractive regional bus services – Regional BRT]*. K2.

Hasiak, S., Hasiak, F., & Egea, A. (2016). Coach and Train: Differences in Individuals Perception of These Modes. *Transportation Research Procedia*, *14*, 1706–1715. https://doi.org/10.1016/j.trpro.2016.05.136

Heilig, L., & Voß, S. (2015). A Scientometric Analysis of Public Transport Research. *Journal of Public Transportation*, *18*(2), 111–141. https://doi.org/10.5038/2375-0901.18.2.8

Hidalgo, D., & Muñoz, J. C. (2015). Bus rapid transit and buses with high levels of service: a global overview. In R. Hickman, R. Givoni, D. Bonilla, & D. Banister (Eds.), *Handbook on Transport and Development* (pp. 346–362). Edward Elgar Publishing. https://doi.org/https://doi.org/10.4337/9780857937261.00030

Hirschhorn, F., Veeneman, W., & van de Velde, D. (2018). Inventory and rating of performance indicators and organisational features in metropolitan public transport: A worldwide Delphi survey. *Research in Transportation Economics*, *69*, 144–156. https://doi.org/10.1016/j.retrec.2018.02.003

Ibarra-Rojas, O. J., Delgado, F., Giesen, R., & Muñoz, J. C. (2015). Planning, operation, and control of bus transport systems: A literature review. *Transportation Research Part B: Methodological*, *77*, 38–75. https://doi.org/https://doi.org/10.1016/j.trb.2015.03.002

Iseki, H., & Taylor, B. D. (2009). Not all transfers are created equal: Towards a framework relating transfer connectivity to travel behaviour. *Transport Reviews*, *29*(6), 777–800. https://doi.org/10.1080/01441640902811304

ITF. (2021). *ITF Transport Outlook 2021*. OECD Publishing. https://doi.org/https://doi.org/10.1787/16826a30-en

Jackson, J., Johnson, D., & Nash, C. (2012). On the willingness to pay for rural rail service level changes. *Research in Transportation Business & Management*, *4*, 104–113. https://doi.org/10.1016/j.rtbm.2012.06.006

Jacques, C., Manaugh, K., & El-Geneidy, A. M. (2013). Rescuing the captive [mode] user: an alternative approach to transport market segmentation. *Transportation*, *40*(3), 625–645. https://doi.org/10.1007/s11116-012-9437-2

Jiang, X., Guo, X., & Ran, B. (2014). Optimization Model for Headway of a Suburban Bus Route. *Mathematical Problems in Engineering*, *2014*, 1–6. https://doi.org/10.1155/2014/979062

Johansson, E. (2020). *The knowledge problem of public transport policy*. Lund University.

Johansson, E., Winslott Hiselius, L., Koglin, T., & Wretstrand, A. (2017). Evaluation of public transport: regional policies and planning practices in Sweden. *Urban, Planning and Transport Research*, *5*(1), 59–77. https://doi.org/10.1080/21650020.2017.1395291

Jokinen, J.-P., Sörensen, L., & Schlüter, J. (2021). Public Transport in Low Density Areas. In R. Vickerman (Ed.), *International Encyclopedia of Transportation* (pp. 589–595). Elsevier. https://doi.org/10.1016/B978-0-08-102671-7.10628-1

Ker, I., & Ginn, S. (2003). Myths and realities in walkable catchments: The case of walking and transit. *Road and Transport Research*, *12*(2), 69–80.

Khan, J., Hrelja, R., & Pettersson-Löfstedt, F. (2021). Increasing public transport patronage – An analysis of planning principles and public transport governance in Swedish regions with the highest growth in ridership. *Case Studies on Transport Policy*, *9*(1), 260–270. https://doi.org/https://doi.org/10.1016/j.cstp.2020.12.008

Kikuchi, S., & Vuchic, V. R. (1982). Transit Vehicle Stopping Regimes and Spacings. *Transportation Science*, *16*(3), 311–331. https://doi.org/10.1287/trsc.16.3.311

Kwan, S. C., & Hashim, J. H. (2016). A review on co-benefits of mass public transportation in climate change mitigation. *Sustainable Cities and Society*, *22*, 11–18. https://doi.org/10.1016/j.scs.2016.01.004

Landelius, M. (2020, March 22). Näsetborna går samman i protester mot nya superbussen [Näset residents unite in protests against the new superbus]. *Sydsvenskan*.

Landelius, M. (2021, March 15). Näsetborna vann delseger i striden mot superbussen [Näset residents won a partial victory in the battle against the superbus]. *Sydsvenskan*.

Leiva, C., Muñoz, J. C., Giesen, R., & Larrain, H. (2010). Design of limited-stop services for an urban bus corridor with capacity constraints. *Transportation Research Part B: Methodological*, *44*(10), 1186–1201. https://doi.org/10.1016/j.trb.2010.01.003

Lipsky, M. (2010). *Street-level bureaucracy: dilemmas of the individual in public services* (30th anniversary ed.). Russel Sage Foundation.

Loader, C., & Stanley, J. (2009). Growing bus patronage and addressing transport disadvantage—the Melbourne experience. *Transport Policy*, *16*(3), 106–114. https://doi.org/10.1016/j.tranpol.2009.02.001

Lucas, K., van Wee, B., & Maat, K. (2016). A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. *Transportation*, *43*(3), 473–490. https://doi.org/10.1007/s11116-015-9585-2

Luke, D., Steer, J., & White, P. (2018). *Interurban Bus: Time to raise the profile*. Greengauge 21.

Mamun, S. A., & Lownes, N. E. (2014). Access and Connectivity Trade-Offs in Transit Stop Location. *Transportation Research Record: Journal of the Transportation Research Board*, *2466*(1), 1–11. https://doi.org/10.3141/2466-01

Markovich, J., & Lucas, K. (2011). *The social and distributional impacts of transport: a literature review (working paper 1055)*. Transport Studies Unit, School of Geography and the Environment, University of Oxford.

Mathison, S. (2005). Cross-Case Analysis. In *Encyclopedia of Evaluation* (Vol. 1, p. 96). SAGE Publications, Inc. https://doi.org/10.4135/9781412950558.n129

McLeod, S., Scheurer, J., & Curtis, C. (2017). Urban Public Transport: Planning Principles and Emerging Practice. *Journal of Planning Literature*, *32*(3), 223–239. https://doi.org/10.1177/0885412217693570

Mees, P. (2014). A centenary review of transport planning in Canberra, Australia. *Progress in Planning*, *87*, 1–32. https://doi.org/https://doi.org/10.1016/j.progress.2013.03.002

Merlin, L. A., Teoman, D., Viola, M., Vaughn, H., & Buehler, R. (2021). Redrawing the Planners' Circle. *Journal of the American Planning Association*, *87*(4), 470–483. https://doi.org/10.1080/01944363.2021.1877181

Mills, G., & White, P. (2018). Evaluating the long-term impacts of bus-based park and ride. *Research in Transportation Economics*, *69*, 536–543. https://doi.org/10.1016/j.retrec.2018.07.028

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Mohring, H. (1972). Optimization and Scale Economies in Urban Bus Transportation. *The American Economic Review*, *62*(4), 591–604. http://www.jstor.org.ludwig.lub.lu.se/stable/1806101

Mulley, C., Ho, C., Ho, L., Hensher, D., & Rose, J. (2018). Will bus travellers walk further for a more frequent service? An international study using a stated preference approach. *Transport Policy*, *69*, 88–97. https://doi.org/10.1016/j.tranpol.2018.06.002

Mulley, C., Ma, L., Clifton, G., & Tanner, M. (2017). Are network planning guidelines based on equal access equitable? *Transportation Research Record*, *2651*(1), 1–11. https://doi.org/10.3141/2651-01

Mulley, C., & Nelson, J. D. (2009). Flexible transport services: A new market opportunity for public transport. *Research in Transportation Economics*, *25*(1), 39–45. https://doi.org/10.1016/j.retrec.2009.08.008

Mulley, C., & Nelson, J. D. (2021). Public Transport Network Planning. In R. Vickerman (Ed.), *International Encyclopedia of Transportation* (pp. 388–394). Elsevier. https://doi.org/10.1016/B978-0-08-102671-7.10781-X

Murray, A. T., & Wu, X. (2003). Accessibility tradeoffs in public transit planning. *Journal of Geographical Systems*, *5*(1), 93–107. https://doi.org/10.1007/s101090300105

Nielsen, G. (2021). Network planning and design. In C. Mulley, J. D. Nelson, & S. Ison (Eds.), *The Routledge Handbook of Public Transport* (1st ed., pp. 453–467). Routledge.

Nielsen, G., Nelson, J. D., Mulley, C., Tegnér, G., Lind, G., & Lange, T. (2005). *HiTrans Best practice guide 2: Public transport - Planning the networks*. HiTrans.

Páez, A., Scott, D. M., & Morency, C. (2012). Measuring accessibility: positive and normative implementations of various accessibility indicators. *Journal of Transport Geography*, *25*, 141–153. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2012.03.016

Paterson, B. L. (2010). Within-Case Analysis. In A. Mills, G. Durepos, & E. Wiebe (Eds.), *Encyclopedia of Case Study Research* (pp. 971–972). SAGE Publications, Inc. https://doi.org/10.4135/9781412957397.n357

Pereira, R. H. M., Schwanen, T., & Banister, D. (2017). Distributive justice and equity in transportation. *Transport Reviews*, *37*(2), 170–191. https://doi.org/10.1080/01441647.2016.1257660

Petersen, T. (2016). Watching the Swiss: A network approach to rural and exurban public transport. *Transport Policy*, *52*, 175–185. https://doi.org/10.1016/j.tranpol.2016.07.012

Pettersson, F. (2018). Developing a regional superbus concept – Collaboration challenges. *Case Studies on Transport Policy*, *6*(1), 32–42. https://doi.org/10.1016/j.cstp.2017.12.003

Pettersson, F., & Frisk, H. (2016). Soft space regional planning as an approach for integrated transport and land use planning in Sweden – challenges and ways forward. *Urban, Planning and Transport Research*, *4*(1), 64–82. https://doi.org/10.1080/21650020.2016.1156020

Pettersson, F., Westerdahl, S., & Hansson, J. (2018). Learning through collaboration in the Swedish public transport sector? Co-production through guidelines and living labs. *Research in Transportation Economics*, *69*, 394–401. https://doi.org/10.1016/j.retrec.2018.07.010

Pole, J. D., & Bondy, S. J. (2010). Control Variables. In N. J. Salkind (Ed.), *Encyclopedia of Research Design* (pp. 253–254). SAGE Publications, Inc. https://doi.org/10.4135/9781412961288.n77

Portinson Hylander, J. (2021). *Constructing Transit Corridors: The Politics of Public Transport Policy and Planning in Malmöhus and Skåne 1970-2020*. Lund University.

Prior, L. (2003). *Using Documents in Social Research*. SAGE Publications Ltd. https://doi.org/10.4135/9780857020222

Redman, L., Friman, M., Gärling, T., & Hartig, T. (2013). Quality attributes of public transport that attract car users: A research review. *Transport Policy*, *25*, 119–127. http://10.0.3.248/j.tranpol.2012.11.005

Region Skåne. (2016). *Planera för nya stationssamhällen: Införandet av Regionalt superbusskoncept i Skåne [Planning for new station communities: The introduction of the Regional superbus concept in Scania].*

Region Skåne. (2019). *Så reser vi i Skåne: Resvaneundersökningen 2018 [This is how we travel in Scania: Travel survey 2018].*

Region Skåne. (2020). *Trafikförsörjningsprogram för Skåne 2020-2030 [Transport supply programme for Scania 2020-2030].*

Rissel, C., Curac, N., Greenaway, M., & Bauman, A. (2012). Physical Activity Associated with Public Transport Use—A Review and Modelling of Potential Benefits. *International Journal of Environmental Research and Public Health*, *9*(7), 2454–2478. https://doi.org/10.3390/ijerph9072454

Román, C., Martín, J. C., & Espino, R. (2014). Using Stated Preferences to Analyze the Service Quality of Public Transport. *International Journal of Sustainable Transportation*, *8*(1), 28–46. https://doi.org/10.1080/15568318.2012.758460

Rowley, J. (2002). Using case studies in research. *Management Research News*. https://doi.org/10.1108/01409170210782990

Ryan, J., & Pereira, R. H. M. (2021). What are we missing when we measure accessibility? Comparing calculated and self-reported accounts among older people. *Journal of Transport Geography*, *93*, 103086. https://doi.org/10.1016/j.jtrangeo.2021.103086

Sahu, P. K., Sharma, G., & Guharoy, A. (2018). Commuter Travel Cost Estimation at Different Levels of Crowding in Suburban Rail System: A Case Study of Mumbai. *Transportation Research Board 97th Annual Meeting*. https://trid.trb.org/view/1495556

Scherer, M. (2010). Is Light Rail More Attractive to users than bus Transit?: Arguments Based on Cognition and Rational Choice. *Transportation Research Record: Journal of the Transportation Research Board*, *2144*(1), 11–19. https://doi.org/10.3141/2144-02

Scherer, M., & Dziekan, K. (2012). Bus or Rail: An Approach to Explain the Psychological Rail Factor. *Journal of Public Transportation*, *15*(1), 75–93. https://doi.org/10.5038/2375-0901.15.1.5

Scheurer, J. (2020). Public transport network planning. In C. Curtis (Ed.), *Handbook of Sustainable Transport* (pp. 139–149). Edward Elgar Publishing. https://doi.org/10.4337/9781789900477.00026

Sevä, M. (2015). *The decisive role of street-level bureaucrats in environmental management*. Luleå University of Technology.

Shrestha, R. M., & Zolnik, E. J. (2013). Eliminating bus stops: Evaluating changes in operations, emissions and coverage. *Journal of Public Transportation*, *16*(4), 1–23. https://doi.org/10.5038/2375-0901.16.4.1

Simmons, J., & Haas, P. J. (2016). Impact on Bus Ridership from Changes in a Route's Span of Service. *Transportation Research Record*, *2539*(1), 48–54. https://doi.org/10.3141/2539-06

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sørensen, C. H., Pettersson, F., & Hansson, J. (2021). Planning for Bus Priority. In *International Encyclopedia of Transportation* (pp. 254–260). Elsevier. https://doi.org/10.1016/B978-0-08-102671-7.10692-X

Sörensen, L., Bossert, A., Jokinen, J.-P., & Schlüter, J. (2021). How much flexibility does rural public transport need? – Implications from a fully flexible DRT system. *Transport Policy*, *100*, 5–20. https://doi.org/https://doi.org/10.1016/j.tranpol.2020.09.005

Stähli, S. (1990). Zur Entwickliung des Taktfahrplans in der Schweiz [On the development of the regular-interval timetable in Switzerland]. *Schweizer Ingenieur Und Architekt*, *108*(50), 1464–1468.

Šťastná, M., & Vaishar, A. (2017). The relationship between public transport and the progressive development of rural areas. *Land Use Policy*, *67*, 107–114. https://doi.org/10.1016/j.landusepol.2017.05.022

Stewart, C., & El-Geneidy, A. (2016). Don't stop just yet! A simple, effective, and socially responsible approach to bus-stop consolidation. *Public Transport*, *8*(1), 1–23. https://doi.org/10.1007/s12469-015-0112-9

Swanborn, P. (2010). *Case Study Research: What, Why and How?* SAGE Publications, Inc. https://doi.org/10.4135/9781526485168

Taylor, B. D., Miller, D., Iseki, H., & Fink, C. (2009). Nature and/or nurture? Analyzing the determinants of transit ridership across US urbanized areas. *Transportation Research Part A: Policy and Practice*, *43*(1), 60–77. https://doi.org/10.1016/j.tra.2008.06.007

Tirachini, A. (2014). The economics and engineering of bus stops: Spacing, design and congestion. *Transportation Research Part A: Policy and Practice*, *59*, 37–57. https://doi.org/10.1016/j.tra.2013.10.010

Totten, J. C., & Levinson, D. M. (2016). Cross-elasticities in frequencies and ridership for Urban local routes. *Journal of Public Transportation*, *19*(3), 117–125. https://doi.org/10.5038/2375-0901.19.3.7

Trivector. (2010). *Superbussar – ett högklassigt regionalt bussystem i Nordostskåne [Superbuses – a high-quality regional bus system in northeastern Scania] (report 2010:73)*.

Trivector. (2014). *Regional Superbuss i Skåne – kravspecifikation [Regional Superbus in Scania – specification of requirements] (PM 2014:1)*.

Tzieropoulos, P., Emery, D., & Buri, J.-D. (2010). Regular-interval timetables : Theoretical foundations and policy implications. *12th World Conference on Transport Research*, 1–15.

UITP. (2013). *Core Brief: Demographic changes and challenges for regional transport*.

Ušpalytė-Vitkūnienė, R., & Ranceva, J. (2022). Accessibility of Regional Public Transport. In O. Prentkovskis, I. Yatskiv (Jackiva), P. Skačkauskas, R. Junevičius, & P. Maruschak (Eds.), *TRANSBALTICA XII: Transportation Science and Technology* (pp. 726–737). Springer International Publishing. https://doi.org/10.1007/978-3-030-94774-3_70

Utsunomiya, K., & Shibayama, T. (2021). Rail bonus: An empirical study onto relative valuation of railways in Austria. *Transport Policy*, *113*, 37–45. https://doi.org/10.1016/j.tranpol.2020.04.005

van de Velde, D. M. (1999). Organisational forms and entrepreneurship in public transport: classifying organisational forms. *Transport Policy*, *6*(3), 147–157. https://doi.org/10.1016/S0967-070X(99)00016-5

van der Spek, D. (2009). *The Zuidtangent - experiences with BRT in the Amsterdam region*. Stadsregio Amsterdam.

van Lierop, D., Badami, M. G., & El-Geneidy, A. M. (2018). What influences satisfaction and loyalty in public transport? A review of the literature. *Transport Reviews*, *38*(1), 52–72. https://doi.org/10.1080/01441647.2017.1298683

van Soest, D., Tight, M. R., & Rogers, C. D. F. (2020). Exploring the distances people walk to access public transport. *Transport Reviews*, *40*(2), 160–182. https://doi.org/10.1080/01441647.2019.1575491

van Wee, B., & Geurs, K. (2011). Discussing equity and social exclusion in accessibility evaluations. *European Journal of Transport and Infrastructure Research*, *11*(4), 350–367. https://doi.org/10.18757/ejtir.2011.11.4.2940

Varela, J. M. L., Börjesson, M., & Daly, A. (2018). Public transport: One mode or several? *Transportation Research Part A: Policy and Practice*, *113*, 137–156. https://doi.org/10.1016/j.tra.2018.03.018

Vigren, A., & Pyddoke, R. (2020). The impact on bus ridership of passenger incentive contracts in public transport. *Transportation Research Part A: Policy and Practice*, *135*, 144–159. https://doi.org/10.1016/j.tra.2020.03.003

Vijayakumar, N., El-Geneidy, A. M., & Patterson, Z. (2011). Driving to Suburban Rail Stations. *Transportation Research Record: Journal of the Transportation Research Board*, *2219*(1), 97–103. https://doi.org/10.3141/2219-12

Vitrano, C., & Mellquist, L. (in press). Spatiotemporal accessibility by public transport and time wealth. Insights from two peripheral neighbourhoods in Malmö, Sweden. *Time & Society*.

Walker, J. (2008). Purpose-driven public transport: creating a clear conversation about public transport goals. *Journal of Transport Geography*, *16*(6), 436–442. https://doi.org/10.1016/j.jtrangeo.2008.06.005

Wallis, I. P. (2013). *Experience with the development of off-peak bus services (research report 487)*. NZ Transport Agency.

Wardman, M., & Toner, J. (2020). Is generalised cost justified in travel demand analysis? *Transportation*, *47*(1), 75–108. https://doi.org/10.1007/s11116-017-9850-7

Werner, C. M., Brown, B. B., Tribby, C. P., Tharp, D., Flick, K., Miller, H. J., Smith, K. R., & Jensen, W. (2016). Evaluating the attractiveness of a new light rail extension: Testing simple change and displacement change hypotheses. *Transport Policy*, *45*, 15–23. https://doi.org/10.1016/j.tranpol.2015.09.003

White, P. (2016). Rural public transport. In *Public transport: its planning, management and operation* (6th ed., pp. 201–221). Routledge.

Wittmann, T. (2019). *Transit Network Design and Service Tradeoffs Workshop*. Nelson\Nygaard.

Yin, R. K. (2014). *Case study research: design and methods* (5th ed.). SAGE.

Zhou, X., Du, H., Liu, Y., Huang, H., & Ran, B. (2017). Investigating the Intention of Rural Residents to Use Transit in Cixi, China. *Journal of Urban Planning and Development*, *143*(2). https://doi.org/10.1061/(ASCE)UP.1943-5444.0000367

Appendix

List of included papers

Paper 1

Hansson, J., Pettersson, F., Svensson, H., & Wretstrand, A. (2019). Preferences in regional public transport: a literature review. *European Transport Research Review, 11*, 38. https://doi.org/10.1186/s12544-019-0374-4

Authors' contributions

JH conducted the survey, the literature search and assessments, and did most of the writing. FP assisted with the literature assessments and made intellectual contributions to the analyses. HS made intellectual contributions to the analyses. AW assisted in developing the framework and made intellectual contributions to the analyses.

Paper 2

Hansson, J., Pettersson-Löfstedt, F., Svensson, H., & Wretstrand, A. (2021). Replacing regional bus services with rail: Changes in rural public transport patronage in and around villages. *Transport Policy, 101*, 89–99. https://doi.org/10.1016/j.tranpol.2020.12.002

Authors' contributions

JH: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Visualization; Writing – original draft. FP-L: Supervision; Writing – review & editing. HS: Supervision; Writing – review & editing. AW: Supervision; Writing – review & editing.

Paper 3

Hansson, J., Pettersson-Löfstedt, F., Svensson, H., & Wretstrand, A. (2021). Effects of rural bus stops on travel time and reliability. *Public Transport.* https://doi.org/10.1007/s12469-021-00281-1

Authors' contributions

JH: Conceptualisation; Formal analysis; Investigation; Methodology; Visualisation; Writing – original draft. FP-L: Supervision; Writing – review and editing. HS: Supervision; Writing – review and editing. AW: Supervision; Writing – review and editing.

Paper 4

Hansson, J., Pettersson-Löfstedt, F., Svensson, H., & Wretstrand, A. (2022). Patronage effects of off-peak service improvements in regional public transport. *European Transport Research Review, 14*, 19. https://doi.org/10.1186/s12544-022-00543-4

Authors' contributions

JH: Conceptualization; Formal analysis; Investigation; Data Curation; Methodology; Visualization; Writing - original draft. FP-L: Supervision; Writing – review & editing. HS: Supervision; Writing – review & editing. AW: Supervision; Writing – review & editing.

Additional publications

Hansson, J., Pettersson, F., Ringqvist, S., & Lindblom, P. (2016). *Guidelines för attraktiv regional busstrafik – Regional BRT [Guidelines for attractive regional bus services – Regional BRT]*. K2.

Hansson, J., Pettersson, F., Svensson, H., & Wretstrand, A. (2018). *Defining regional public transport (K2 working paper 2018:7)*. K2.

Pettersson, F., Westerdahl, S., & Hansson, J. (2018). Learning through collaboration in the Swedish public transport sector? Co-production through guidelines and living labs. *Research in Transportation Economics, 69*, 394–401. https://doi.org/10.1016/j.retrec.2018.07.010.

Sørensen, C.H., Pettersson, F., & Hansson, J. (2021). Planning for bus priority. In R. Vickerman (Ed.), *International Encyclopedia of Transportation* (pp. 254–260). Elsevier. https://doi.org/10.1016/B978-0-08-102671-7.10692-X

Paper 1

European Transport Research Review

REVIEW Open Access

Preferences in regional public transport: a literature review

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Abstract

The purpose of this article is to analyse quality attributes of regional public transport and their influence on modal choice, demand, and customer satisfaction through a literature review. The review is based on a working definition of regional public transport with boundaries toward local as well as interregional public transport: Regional public transport (i) targets passengers travelling between separate urban areas or to rural areas and (ii) a majority of the trips are made on a regular basis. Our results suggest that preferences of regional travellers mainly conform to the preferences of local travellers, but some important differences have been revealed. Most notably, on-board comfort is a higher priority for regional travellers and is increasingly important with longer travel times. Network coverage and coordination are also more prominent features of regional public transport, presumably due to the more dispersed nature of regional public transport networks. These differences, and the fact that the prerequisites for regional public transport are in general substantially different compared to local and interregional public transport, support continued use of this categorisation in public transport research. We also conclude that there is a requirement for more knowledge about the specifics of regional public transport, as public transport research, thus far, has been largely focused on local travel. Research areas of particular interest are on-board comfort, operational aspects, travel time improvements, how the environmental impact of public transport services affects modal choice, and the influence of trip length on passenger preferences.

Keywords: Public transport, Quality attribute, Service quality, Regional travel, Systematic review

1 Introduction

Settlements in rural areas around cities continue to expand across the developed world [1, 2]. Commuters living in these areas predominantly use private cars to travel to the cities, adding to congestion, parking and environmental problems and putting the city centre's transport network under continuous strain [3].

Also, for issues regarding greenhouse gas emissions and energy consumption in the transport sector, addressing regional travel is of key importance. In general, short trips are more frequent than longer trips, but the total mileage is dominated by medium and long-distance trips. Moreover, this dominance is likely to increase in the coming decades. According to forecasts produced by the International Transport Forum, non-urban travel demand will grow faster than urban travel demand in terms of passenger kilometres [4]. In their baseline scenario, CO_2 emissions from the non-urban passenger land transport sector is expected to double between 2015 and 2050. To be able to prevent this, incentives for modal shift as well as improved rail and bus services are needed alongside fuel efficiency improvements and increased use of alternative fuels [5].

The recent transport policies and policy-related transport research trends, focusing on replacing (passive) car travel with more active modes like walking, cycling and public transport (e.g. [6]) may suggest that there will be increased need for better regional public transport services. Active living and travel policies target older people [7], children and adolescents [8] as well as the average working population and workplace interventions [9]. Sedentary lifestyles thus affect all generations, and regional public transport services with walking and cycling as first and last mile-solutions, may play an ever so important role in the future.

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For many regional trips, walking and cycling are not viable options, meaning that public transport is often the only alternative to the car for such trips. People in rural areas are at a risk of being excluded from participation in normal relationships and activities if they do not have a driver's licence or access to a car [10]. The quality of regional public transport services impact the independent mobility of this group, particularly children and adolescents [11].

Despite this, public transport research is mainly focused on local travel. In a bibliometric analysis, Heilig & Voss [12] give insight into the field from a meta-perspective. Their keyword analysis indicates that there are few publications that exclusively concern regional public transport, at least compared to research into local public transport. Five of the 59 most used keywords contain *urban* (urban planning, urban traffic, urban areas, urban development, and urban area). None of the listed keywords relate directly to regional public transport: keywords containing terms such as *regional*, *rural* or *interurban* are absent.

The underrepresentation of regional public transport studies is also acknowledged by de Oña & de Oña [13] specifically for studies on public transport service quality. While there are numerous publications about service quality analyses in the urban transport sector, as well as for air transport, "the analysis of quality is still found to be waking up in the world of interurban land transport services" ([14], p. 9).

Previous literature reviews have pointed out quality attributes commonly found to be important in local public transport. For customer satisfaction, four quality attributes are of particular importance: frequency, travel time, safety, and punctuality [14]. In addition, costs, staff behaviour, on-board cleanliness and comfort are also commonly discussed as important factors that influence customer satisfaction and loyalty [15]. In terms of attracting car users, though, the factors of importance essentially depend on the context and characteristics of the target group [16]. Modal choice is also considerably affected by factors outside the public transport system, e.g. parking availability in the urban area in question [17].

Public transport mode may also affect the passengers' preferences. For local public transport, rail modes display a more complex pattern of priority areas, compared to bus services, when comparing studies in different settings. For bus services, many studies include similar aspects in the conclusions regarding important quality attributes (see [14]). Bus services are overrepresented in studies into customer satisfaction in local public transport [15], but when comparing the modes, passengers generally prefer rail modes, such as metro and light rail [18]. However, through implementation of high-quality bus concepts such as Bus Rapid Transit, bus services in urban areas can attract as many passengers as light rail and metro, and lead to significant modal shifts similar to those found when implementing rail-based systems [19].

The general characteristics of local travel are different from regional travel (longer distances, often lower service frequencies, fewer stops, etc.), and similarly there are important differences between the regional and interregional levels. These characteristics impact the preferences of potential and existing passengers, e.g. expressed on an urban–interurban scale [20] or a short distance–long distance scale [21].

The aim of this paper is to review research into public transport for regional travel, focusing on important factors for increasing the modal share of public transport in relation to the private car. Because few service quality studies deal explicitly with the effects on modal split, studies concerning demand and customer satisfaction are also included in the review. Customer satisfaction is correlated with demand and modal choice [22], but it is also acknowledged that these are separate concepts, to some extent affected differently by different policies [23]. Furthermore, customer satisfaction is not solely based on the actual conditions of the transport system [24, 25]. The perception of the public transport system is moderated by customer characteristics, situational conditions such as regional or urban setting, and passenger expectations [26]. However, this review includes studies from different contexts in different parts of the world, from suburban rail networks around large cities to bus services in rural settings. We will thereby be able to study patterns beyond the situational conditions, and demonstrate the service attributes that are most commonly found to significantly impact customer satisfaction, demand, and modal choice.

From the review, we will attempt to answer the following research questions:

1. What similarities and differences between regional and local public transport are evident with regards to important quality attributes?
2. Are there any quality attributes whose importance depends on travel time or distance? This question relates to the differences between local and regional public transport but has a broader perspective, aiming to also reveal differences between diverse types of regional travel.
3. Are there any evident differences between bus and rail services in terms of important quality attributes?
4. Do the results of studies into public transport demand and modal choice conform to the results of customer satisfaction studies?

The focus of this review is on conventional bus and rail services (along fixed routes and with fixed schedules) serving regional travellers. It is acknowledged that regional public transport has a very diverse service portfolio [3], ranging from demand-responsive services to high-capacity regional rail systems. However, the vast majority of regional passengers use conventional bus and rail services [27].

2 Definitions

2.1 Service quality attributes

The reviewed studies have different objectives and use different data sources. Consequently, each study assesses different variables. As a framework for structuring the analysis, we have used the categorisation presented in the EU standard EN 13816:2002 [28]. This standard provides an extensive list of service quality attributes, grouped into eight areas:

- **Availability.** Extent of the service offered in terms of geography, transport modes, operating hours, and frequency.
- **Accessibility.** Access to the public transport system including interface with other transport systems.
- **Information.** To assist the planning and execution of journeys, under normal conditions as well as under abnormal conditions such as delays.
- **Time.** Length of trip time. This area also includes adherence to schedules in the form of punctuality or regularity.
- **Customer care.** Customer interface, staff behaviour and attitudes, and ticketing options.
- **Comfort.** Service elements that make journeys relaxing, enjoyable, or productive, e.g. through station facilities, seating and personal space, ride comfort, vehicle condition, atmosphere, and complementary services such as on-board Wi-Fi.
- **Safety.** Sense of personal protection from crime and accidents.
- **Environmental impact.** Environmental impact resulting from the provision of the public transport service.

In order to include in the analysis all internal factors over which public transport managers exercise a certain level of control [29], cost has been added to the framework. **Cost** or fare level is also a commonly discussed policy attribute.

2.2 Local, regional and interregional public transport

This paper explores the differences between various geographic scales: local, regional and interregional. However, the boundaries between these geographic scales are unclear and need to be defined in order to conduct the review.

A previous attempt to define regional travel – and hence local and interregional travel – has been made by the UITP [3]. It notes that a single definition is "difficult to establish due to the great diversity that exists within regional transport" (p. 1), and as a result, its definition is somewhat ambiguous. Interestingly, the notion of *captive riders* is included, possibly indicating the challenge in designing attractive regional public transport services: "Regional public transport covers all collective passenger transport services excluding most public transport within cities and urban centres. In general, regional transport services bring captive riders from lower-density and suburban areas to larger city centres and serve small- and medium-sized cities" ([3], p. 1).

A number of other previous publications touch upon definitions of terms related to regional public transport. White [27] adopts the definition of *rural transport* used in the National Travel Survey in the UK. It concludes that rural areas comprise settlements below 10,000 people or are open countryside. However, White notes that for transport planning purposes, small towns are often also served by rural networks, providing interurban links to larger regional centres of employment, shopping, etc. Village-to-town and town-to-town movements are in many cases served by the same routes.

Exurban is another related term, used by Petersen [30], who writes about public transport for exurban settlements in Australia. He presents two alternative definitions of exurban: "Beyond the suburbs, the Australian exurban region is defined by […] the region surrounding an urban area, bounded on the outer by how far commuters are willing to travel, and on the inner by contiguous urban or suburban development" (pp. 24–25). Alternatively, exurban areas can be defined as "the mainly small town and rural regions within 150 kilometres radius from the state's capital and largest city" ([30], p. 25).

A systemisation of bus services in three categories has been made by Godlund [31], as a tool to describe the development of bus services in Sweden from the early years of the twentieth century to the 1950s. The network is categorised into *α services*, *β services* and *γ services*. The first category, *α services*, include urban and suburban lines, defined by a maximum distance of 6 km from an urban area. *β services* include rural to urban services, interurban services with intermediate rural stops, as well as purely rural services. Finally, *γ services* are interurban express lines.

Interurban bus services have been explored in a number of case studies by Luke, Steer & White [32], describing the current state and future development of such services in the UK. For this purpose, they adopt a working definition of *interurban bus*: "two or more urban areas (typically towns, but might be cities) are linked by a bus service with intermediate stops typically to serve villages en route" (p. 1).

To conclude, existing definitions of regional public transport and related terms such as rural, exurban and interurban are somewhat vague and use various sets of metrics. Besides demographics, the definitions are based on elements such as travel distances or stopping patterns of the public transport services.

In order to sort the terms, we conducted a survey among public transport professionals about their perception of the concept of *regional travel* (see [33]). The results emphasise the importance of maintaining a distinction between functionality and technology, meaning that factors such as vehicle type or speed should not be included in the definition. Instead, the survey indicates a clear preference for either an administrative or a functional definition, depending on the purpose.

In the administrative version, regional travel is defined by administrative boundaries, i.e. on the outer boundary by county limits, or an agglomeration of counties, and on the inner boundary by city, town or municipality limits. The functional definition is, instead, based on the notions of *urban areas* and *regular travel*. Local travel is within an urban area and consequently some portion of a regional trip takes place outside an urban area. For the outer boundary, the functional definition focuses on travel patterns: regional trips are made on a regular basis, daily to weekly in general. This frequency range is based on the survey responses, expressing a need to include also other trip purposes than commuting in the definition of regional travel, such as travel for daily or weekly leisure activities and shopping needs [33].

For practical reasons, trips made on a regular basis can be roughly interpreted as trips within a certain distance or within a certain travel time. However, it is hard to draw a general conclusion about the quantification of such distance or time limits, as they are likely to depend on the national or regional context [33].

For both the (outer) regional-interregional and the (inner) local-regional boundaries, the survey respondents' preferences for the administrative and the functional definitions are roughly equal. One approach could then be to combine these criteria using logical conjunction or disjunction (AND/OR).

In most cases there is a large overlap between the two criteria. As for the regional-interregional boundary, most of the trips made on a regular basis are almost certainly within an administrative unit such as a county or an agglomeration of counties, and vice versa. As for the local-regional boundary, most trips to and from an urban area will cross an administrative boundary such as city, town or municipality limits.

To be able to determine how to combine the criteria, we need to examine what lies outside the overlaps. As for the regional-interregional boundary, the administrative definition will include trips that are not made on a regular basis, especially if the administrative region is large. At the other end of the Venn diagram (see Fig. 1), trips made on a regular basis but crossing a regional (or national) administrative boundary, even between towns just a few kilometres apart, are excluded in the strictly administrative definition.

Since this project focuses on passenger preferences and factors that influence ridership on regional public transport services, it is reasonable to exclude long-distance travel within large administrative regions from the definition of regional travel. However, regular travel that crosses administrative boundaries shares key characteristics with other regular travel, and should therefore be included. This means that a combination of administrative and functional criteria is superfluous. The criterion of regular travel is sufficient in itself, for our purpose, and will, moreover, include a majority of the trips that are regional according to the administrative criterion.

The line of reasoning is similar for the local-regional boundary. Trips that cross an administrative boundary but that are carried out within an urban area are local in terms of passenger preferences. At the other end of the Venn diagram (see Fig. 2), trips which, to some extent, pass outside urban areas but are within a local administrative entity have much in common with other interurban or urban-to-rural trips. Analogous to the outer boundary, this means that the functional criterion is sufficient for our purpose and will also in this case include a majority of the trips that are regional according to the administrative criterion.

Thus, for the purpose of exploring passenger preferences, the following working definitions have been adopted in this review:

- *Local public transport* carries passengers within an urban area. The definition is based on urban areas instead of density or urban centres, implying that travel between different parts of a conurbation (belonging to the same urban area) is local rather than regional.
- *Regional public transport* targets passengers travelling between separate urban areas or to rural areas, and a majority of the trips are made on a regular basis (daily to weekly, in general). This means that regional travel is not defined as being within a certain geographic area, but is instead based on travel patterns in each case.
- *Interregional public transport* targets passengers travelling between regions as defined above. Thus, the majority of the trips are made less frequently than weekly.

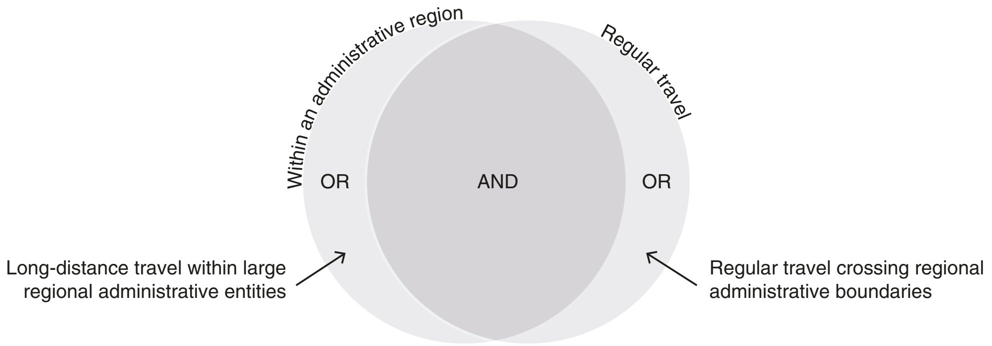

Fig. 1 Venn diagram for the outer boundary of regional travel. Regular travel means that trips are made daily to weekly in general

The definitions focus on travel patterns rather than individual trips. On a regional public transport service, the majority of passengers travel between separate urban areas or to rural areas, and the majority of these trips are made on a regular basis. This implies that most passengers on regional services are frequent travellers, but not necessarily all of them.

3 Method

This study uses the PRISMA method [34] to identify and systematically analyse relevant literature on important service quality attributes in regional public transport. The PRISMA method is chosen due to its structured, iterative process for identifying a comprehensive set of studies that meet the specified aim of this study [34].

The process includes three phases (Fig. 3): First, a set of literature is gathered through an extensive search in Scopus and TRID – Transport Research International Documentation. In the second phase, the identified literature is assessed using a set of inclusion and exclusion criteria. Titles, abstracts, and full-text articles, respectively, are assessed, narrowing down the literature list in each step. Before the full-text assessment, literature found via citation searches is added to complement the literature identified in the database searches. The third and final phase of the process is a qualitative synthesis of the selected literature.

In order to identify relevant search terms, the research subject was broken down into three main concepts: *ridership*, *regional*, and *public transport*. For each of these concepts, synonyms, broader terms, narrower terms, and related terms were identified through a combination of citation searches and using the Transportation Research Thesaurus [35]. The resulting search terms, listed in Table 1, were combined using building block searches. In addition, the searches were limited to literature written in English and published before July 2018 when the search was conducted.

The titles, abstracts, and finally the full-text literature have been assessed using a number of inclusion and exclusion criteria. Besides the language and publication date limitations mentioned above, we have used three

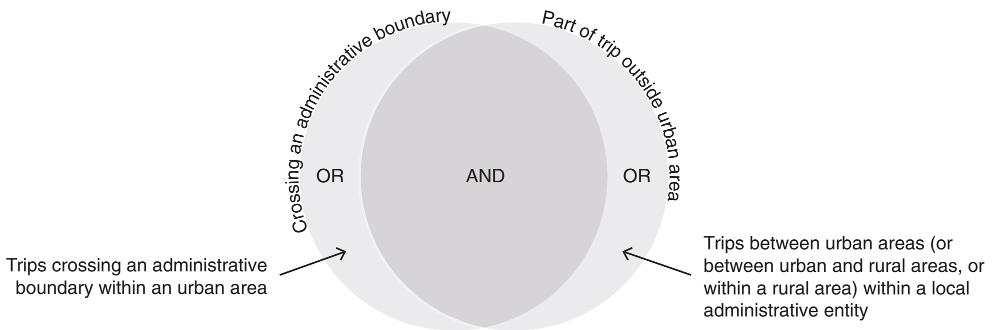

Fig. 2 Venn diagram for the inner boundary of regional travel

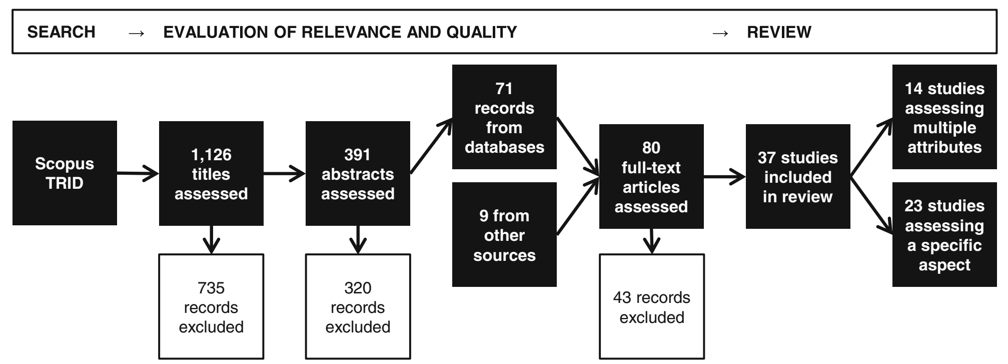

Fig. 3 Process for identification of relevant literature (adapted from [34])

relevance criteria to narrow down the results. Firstly, the study case must be in line with our definition of regional public transport. In studies covering more than just regional public transport, for example, both local and regional public transport in a metropolitan area, results regarding regional travel have to be explicitly reported. Secondly, the study must cover one or multiple service quality attributes and their influence on modal split, ridership, or customer satisfaction. Thirdly, we only include studies about conventional modes of regional public transport, i.e. train and bus services along fixed routes and with fixed timetables. Paratransit and demand-responsive services, as well as air services, have been excluded.

4 Results

Thirty-seven studies were selected for review (references [20, 24, 36–70]). The selection is centred upon recent publications: 31 of the studies have been published during the last 10 years and 23 of them as recently as during the last five-year period. This pattern was also evident in the initial search results, indicating an increasing trend for research into service quality in regional public transport.

Studies from different geographic contexts are included in the review, from the suburbs and rural areas around Mumbai [36–38] and Shanghai [39] to small-town regions in Texas [40] and southern Italy [24]. These differences in city and region size mean different realities in the public transport systems. For instance, crowding is a common issue around large cities (see [38, 41]), while other types of comfort-related attributes are more important in less densely populated areas (see [20, 40, 42, 43]). Geographic context is indicated in the review when relevant.

Fourteen of the selected studies comprise evaluations of multiple quality attributes, enabling suggestions about the relative importance of these attributes. These studies are outlined in section The relative importance of quality attributes, providing an overview of important quality attributes in regional public transport. The focus of this section lies on a quantitative assessment of these 14 studies. The remainder of the studies that were identified in the search process are focused on specific attributes, providing more in-depth information about

Table 1 Search terms, based on the three concepts *ridership*, *regional*, and *public transport*

Ridership		Regional		Public transport
ridership OR	AND (	regional OR	PRE/0	"public transport*" OR
patronage OR		rural OR		transit OR
demand OR		semirural OR		bus OR
quality OR		"semi-rural" OR		coach OR
attitude OR		exurban OR		rail* OR
perception OR		"ex-urban" OR		passenger
satisfaction OR		periurban OR		
improvement OR		"peri-urban" OR		
upgrade		suburban OR		
		interurban OR		
		"inter-urban"		

In Scopus, the concepts *regional* and *public transport* were combined with the operator PRE/0, meaning that the terms must be adjacent. TRID, however, lacks this functionality. Thus, all three concepts were combined with the AND operator. The asterisks are multi-character wildcards, enabling inclusion of various suffixes of the chosen keywords. For example, the search term "public transport*" includes studies using one of the terms "public transport" or "public transportation" various aspects of regional public transport networks. Results from a qualitative assessment of these studies, and of the 14 “overview studies”, can be found in sections Cost to Comfort. The structure of this part of the review reflects the content of the selected studies, sorted into some of the categories used in section The relative importance of quality attributes. In section Research gaps we return to the full framework of attribute categories (see section Service quality attributes) in order to identify gaps in the literature.

4.1 The relative importance of quality attributes

Results from the 14 studies comprising evaluations of multiple quality attributes are summarised in Table 2. In the table the results are visualised through quality attribute categories (see section Service quality attributes) that are discussed by the authors as being important or found to have major impacts in the analyses. In most cases, each category included comprises several more specific quality attributes. For instance, the category “Availability” may for a specific study include attributes concerning frequency as well as attributes about network coverage. To be able to separate these attributes, a more fine-grained analysis have been carried out. For reasons of clarity, however, the results are presented on category level in Table 2. It should also be noted that the notions for similar quality attributes vary between the studies, and in those cases we have made interpretations according to the framework described in section Service quality attributes.

For each publication, public transport modes included in the study are specified, as well as the output variable: modal choice, demand, or customer satisfaction. We have also made rough estimations of average travel distances in the samples, as they are usually not explicitly reported in the studies, and assigned each study to one of the three distance categories: short (less than 25 km, 6 studies), medium (25–50 km, 3 studies), and long (more than 50 km, 4 studies). The three distance categories have been chosen based on the availability of results from the investigated studies. One of the studies covers multiple geographical scales. Thus, it has not been assigned to a distance category.

In addition, the type of data used in each study is also specified in Table 2. The most commonly used data sources in the selection of studies comprise different types of stated preference surveys and customer satisfaction surveys, often in combination. It should be noted that the notion of stated preference is used here as a wide concept, ranging from directly stated importance of different attributes to discrete choice experiments. Revealed preference data is only used in three of the studies, through ridership data or a survey.

Cost, availability, time, and comfort are the most commonly explored categories, covered in almost all of the selected studies. Most of the other categories are also quite well represented, as they are included in at least half of the studies. The exception is environmental impact, which is included in only two of the studies.

Three of the categories are mentioned in the discussion of the most important variables in most of the studies in which they have been included:

- Availability, whereof frequency of service appears to be of particular importance. Frequency is the most common individual attribute in the discussions about important attributes. Another availability attribute commonly discussed is network coverage (and walking distance).
- Time, whereof reliability and punctuality are the most common attributes mentioned in the discussions. Travel time also appears in the discussion about important attributes in more than half of the studies in which it has been included.
- Comfort, which is typically represented by different attributes related to on-board comfort, such as crowding, cleanliness, ventilation, vehicle condition, etc. A number of studies also find station facilities to be of importance.

A couple of the studies include comparisons of local and regional travel. Majumdar & Lentz [40] suggest that the results in rural areas do not differ very much from the results in urban areas. In contrast, Stern [51] concludes that the urban and rural population ascribes different preferences to service attributes. Román, Martín, & Espino [20] find that interurban passengers place more emphasis on comfort, and less on frequency, than urban passengers. In fact, comfort is found to be the most important attribute for interurban passengers, and frequency is a top priority for urban passengers.

A similar pattern is evident in the comparison between short, medium, and long regional trips in Table 2. All studies of medium and long regional trips include some aspect of on-board comfort in the discussion of important attributes. However, in the studies of short regional trips these attributes are absent in the discussion (a couple of these studies instead find station facilities important, which is another aspect of the comfort category). Additional support for this finding is expressed by Bouscasse, Joly, & Peyhardi [36] through a positive crossed effect between travel time and comfort, which means that the value of comfort increases as travel time increases.

In addition, the results indicate that cost is a more important attribute for medium and long regional trips than for short regional trips.

Table 2 Studies about the relative importance of quality attributes in regional public transport

Reference	PT modes	Measure	Study area, case	Travel distance	Data	Cost	Availability	Accessibility	Information	Time	Customer care	Comfort	Safety	Environmental impact
Bouscasse, Joly, & Peyhardi [42]	Bus and rail	Modal choice	Rhône-Alpes Région, France	Long	Stated preference survey among citizens	X				X		X		
Majumdar & Lentz [40]	Bus	Modal choice	Huntsville, Texas, USA	Medium	Stated preference survey among citizens	X	X	i		X	X	X	i	i
Rashedi, Mahmoud, Hasnine, & Habib [43]	Bus and rail	Modal choice	The Greater Toronto and Hamilton Area, Canada	Long	Revealed preference and stated preference survey among citizens	X	i	i	i	i		X		
Zhou, Du, Liu, Huang, & Ran [39]	Bus	Modal choice	Cixi, China	Short	Satisfaction and stated preference survey among citizens	i	X	i	X	X	i	X	i	
Asensio [45]	Rail	Demand	11 suburban rail networks in Spain	N/A	Panel data covering ridership and independent variables at network level	i	X					X		
Berežný & Konečný [46]	Bus	Demand	Žilina, Slovakia	Short	Stated preference survey among passengers, panel data covering satisfaction levels and ridership				X	X	i	i	i	
Román, Martín, & Espino [20]	Bus	Demand	Gran Canaria, Spain	Medium	Stated preference survey among passengers	i	i		i	i	i	X		
Eboli & Mazzulla [24]	Bus	Satisfaction	Cosenza, Italy	Short	Service performance indicators and customer satisfaction survey	i	X		X	X	i	X	i	i
Garrido, de Oña, & de Oña [47]	Bus	Satisfaction	Granada, Spain	Short	Customer satisfaction survey	i	X	i	X	X	i	i	i	
Grisé & El-Geneidy, [41]	Rail	Satisfaction	The Greater Toronto and Hamilton Area, Canada	Medium	Customer satisfaction survey	X	X	X	i	X	i	X	i	
Guirao, García-Pastor, & López-Lambas [48]	Bus	Satisfaction	Madrid–Tres Cantos, Spain	Short	Stated preference and customer satisfaction survey		X	i	i	X	i	i	X	
Ramesh, Rao, & Sarkar [49]	Bus	Satisfaction	Visakhapatnam, India	Medium	Stated preference and customer satisfaction survey	i	X	X		X		X	X	
Rojo, Gonzalo-Orden, dell'Olio, & Ibeas [50]	Bus	Satisfaction	Castilla y León, Spain	Long	Customer satisfaction survey	X	X		i	i		X	i	
Stern [51]	Bus	Satisfaction	Northern Negev, Israel	Short	Stated preference survey among citizens	i	X			X				

Results are summarised in the table with quality categories included in the analysis (marked by i) and discussed by the authors as being important (X). In most cases, each category included comprises several more specific quality attributes. Results regarding these more specific quality attributes are not shown in the table, but are described in the text

The opposite could be said for information, which is found to be important in all but one of the studies of short regional trips (where included), but in none of the studies of medium and long regional trips. A similar tendency is also found for frequency and reliability, although not as pronounced.

In terms of differences between bus and rail services regarding the relative importance of quality attributes, no conclusions can be drawn from the studies in Table 2 due to the low number of such studies that focus entirely on rail services.

The results of studies into modal choice and demand largely conform to the results of the customer satisfaction studies. A couple of differences can be discerned: more emphasis is placed on frequency and reliability in the customer satisfaction studies. However, these differences are not convincingly transparent and there is also an overrepresentation of customer satisfaction studies regarding short regional trips and bus users. Hence, it is hard to determine whether the differences relate to the type of study, travel distances, public transport mode, or to all of those.

4.2 Cost

Firstly, it is important to note that cost cannot be seen as an isolated entity, it is rather the relationship between quality and price that affects users the most [50].

In terms of price elasticity, the demand for regional public transport services is inelastic, i.e. typically between -1 and 0 [37, 45, 52], and the demand adjusts very quickly after any change in fare levels [37]. Price elasticity differences between bus and rail services are found to be minimal [36, 52] and no significant difference has been detected between elasticities of demand for day and season tickets [52]. Furthermore, Stark [52] found that price elasticities may vary with distance – absolute elasticity values fell with increasing distance up to around 20 km and then rose again. However, it should be noted that the number of cases in this study was too low for a more general conclusion to be justified.

Integrated local–regional fare systems are crucial in order for users to access a coherent public transport network at a reasonable cost. Rashedi, Mahmoud, Hasnine, & Habib [43] revealed that eliminating additional costs for regional transit users when using local transit for access or egress is an effective strategy for improving the modal share of public transport for regional commuting trips.

4.3 Availability and accessibility

4.3.1 Planning and organising regional public transport networks

The coordination of public transport systems, not only through integrated fares but also through integrated ticketing and coordinated transport planning, marketing, and customer information, is a foundation for providing an attractive alternative to the car. Buehler, Pucher, & Dümmler [53] suggest that such coordination, in the form of so-called Verkehrsverbund, is a part of the explanation of why the modal share of private cars has fallen since 1990 in many German, Austrian, and Swiss metropolitan areas. In all six of their case studies, they argue that the integrated public transport associations have increased the quality and quantity of services, attracted more passengers, and reduced the proportion of costs covered by subsidies.

Coordination is also a key element for making public transport attractive and cost-effective outside the most densely-populated areas. Despite low frequencies, it is possible to create an attractive public transport network through rigorous coordination and central network planning [54]. Integrated timed-transfer systems with pulse timetables can operate with more than adequate levels of cost recovery and vehicle occupancy even in rural regions with very low population densities [55]. Demand-responsive services may enable larger areas to be covered, to meet planning objectives of ensuring a minimum of level of service. However, conventional interurban services between towns can provide a more cost-effective way of serving rural areas in which smaller settlements are concentrated along corridors [55, 56].

4.3.2 Regional public transport modes: bus versus rail

The coordination of public transport networks also includes the coordination of modes. Brown & Thompson [57] argue that the combination of a rail service backbone and a multi-destination service strategy – feeder services to rail stations rather than parallel direct services – is a prosperous approach. Easy and well-timed transfers are fundamental to making this strategy successful [54, 55, 57].

A couple of studies indicate that trains are preferred to buses in general, or that bus or coach services are considered to complement rail services [58, 59]. There are exceptions in which coaches can achieve comparable trip times to rail [59] though the perception of the modes is not only based on performance and cost criteria. There are also other more subjective criteria related to travel emotions or sensory aspects that might explain the differences in perception [58].

Bazley, Vink, & Blankenship [60] describe the concept of “Rural Bus Rapid Transit” as an alternative to rail in rural settings. Such a concept was inaugurated in 2013 between Aspen and Glenwood Springs, USA, covering a distance of approximately 70 km with 13 bus stations. The concept comprises high standards of operations as well as vehicles and station facilities. A few months after introduction, ridership had increased by 22% and, according to a customer satisfaction survey, this is mainly due to station locations, frequency, bus comfort and safety.

4.3.3 Access and egress

Integration of local and regional public transport networks is described above as an important factor for the availability of the system. In the design of the system, this needs to be balanced with other modes of access and egress to regional public transport stations. For instance, Akbari, Mahmoud, Shalaby, & Habib [61] suggest that the number of bus stops should be limited within the walking catchment area of a station, for the benefit of walking access. They define the walking catchment area as an 800-m radius around the station.

Four hundred or eight hundred meters, roughly a 5- or 10-min walk, are conventionally assumed distances for walking catchment areas, but there are studies which demonstrate that many passengers are willing to walk substantially further. For instance, data from regional buses around Amsterdam show that the 90-percentile of the walking access distance is somewhere in the range of 1,200–1,500 m [62]. Walking distances to suburban rail stations in Perth, Australia, are even longer, with significant numbers of passengers walking as far as 2–3 km to the stations [63]. However, it should be noted that characteristics of the built environment significantly affect trip production by walk access [61].

Higher speed and frequency of public transport services increase the catchment area, although this effect is not as apparent for walking as it is for cycling. The 90-percentile of the catchment radius for high-quality bus services around Amsterdam ("R-Net") is almost double the catchment radius for conventional services ("Comfortnet"), 3,000 m vs 1,500 m. For walking access, the differences are not as evident. Also, the bicycle is a more important access mode for the high-quality system than for conventional bus services. The mode share of the bicycle is significantly higher for access to "R-Net" than for access to "Comfortnet" [62].

For car access there are also indications of a positive relationship between quality of service and catchment area. Higher frequencies mean that people are willing to drive longer distances [64]. Additionally, driving distances to stations are affected by overall trip lengths, i.e. longer public transport trips mean longer average driving distances to stations [64].

In general, the importance of car parking at stations, or park-and-ride facilities, increases with distance from the destination [65, 66]. Accessible and inexpensive car parking at stations can encourage motorists to shift to public transport modes for part of their trip [65] and make daily travel easier for many commuters. However, offering passengers free parking at stations also has negative consequences and, in most cases, free park-and-ride cannot be assumed as a measure of reducing traffic volumes or greenhouse gas emissions from traffic [66]. Traffic volumes may even increase if a park-and-ride facility occupies a site which has an alternative use that could contribute to less transport demand and traffic, or if the park-and-ride facility means car journeys replace walking, cycling or using public transport to access the station [66].

Monetising parking at stations will stop some regional travellers from using public transport. Nevertheless, it is a way of managing parking demand and improving access times for park-and-ride users [43]. Reasonable daily parking charges (compared to the cost of driving to considerably more expensive parking facilities at the destination) can also provide sufficient capital to build and operate new park-and-ride capacity without subsidies from other revenue sources [67].

4.4 Time

4.4.1 Reliability

In many of the reviewed studies reliability is equalled with punctuality, even though reliability often is understood as a wider concept. The EU standard EN 13816:2002 [28] (see section Service quality attributes) separates punctuality – on-time performance – from regularity – maintaining headways – but this differentiation is absent in the reviewed studies. However, there are some cases where the concept of reliability is diversified in other ways. Reliability of connections is sometimes separated from general punctuality, and it is shown that reducing the probability of delays is particularly important for passengers with transfers [46, 59]. Another aspect is the occurrence of cancelled runs, which self-evidently may come out as an important facet of reliability in studies where it is separated from on-time performance [24]. In a broader sense, reliability can also be affiliated with concepts such as permanence and simplicity, implying a general preference for carefully planned, fixed public transport routes combined in a stable network [55].

Still, punctuality is the most common measure of reliability, and it is shown that delays significantly impact the level of passenger satisfaction [68]. Higher probability of delays also decreases the probability of choosing public transport modes [39, 43]. The importance of the issue increases with low frequencies [59]. Also, evidence from the suburban railway network in Paris suggests that passengers travelling for other purposes than commuting value punctuality even more than commuters [69]. A related issue is communicating information about service disruptions, which is highly valued among all passengers [41, 69]. Specifically, explicit information about the expected duration of delays is particularly appreciated [69].

4.5 Comfort

The notion of comfort covers a wide range of quality attributes, for example, station facilities, crowding, noise, ride comfort, etc. In general, on-board facilities have a higher impact on perceived service quality in regional public transport than station facilities [68]. Complementary services such as on-board Wi-Fi may also significantly impact modal choice in favour of public transport [70].

Depending on passenger flows, crowding is an important factor to take into account when designing regional public transport services. In rural areas, passenger flows are generally relatively low. Thus, frequencies are largely determined by other aspects, i.e. balancing operational costs and waiting times [43]. In more densely populated areas, however, crowding is a critical factor. As the level of crowding increases, the total perceived in-vehicle travel time increases [38]. Females tend to perceive a higher reduction in utility due to crowding than males. Similar preferences are observed for higher income groups [38]. However, the effects of crowding are not inherently or unavoidably negative. A crowd can be a source of entertainment, fun, and friendship [36]. Thus, it is important to understand the specifics of the crowd, such as the density, passenger perceptions and culture.

4.6 Research gaps

Returning to the framework of quality attribute categories (see section Service quality attributes), cost, availability, time, and comfort are the most commonly explored categories, covered by more than half of the reviewed studies (Table 3).

Availability is the most widely covered category, with a focus on modes (bus vs rail) and network (coordination, transfers, access and egress). However, elaborations of the operational aspect of availability, i.e. operating hours and frequency, are missing.

Regarding the time category, the reviewed studies focus on reliability. Elaborations of travel time, for example, studies about travel time improvements in regional public transport, are absent.

The reviewed studies on comfort are mainly centred on crowding. As mentioned above (section Comfort), there are many further aspects of comfort that are yet to be investigated.

Attributes regarding accessibility, information, customer care, security, and environmental impact are touched upon in some publications, but without any further elaboration. The least explored category, environmental impact, and its effect on modal choice, ridership or customer satisfaction, is mentioned in only three of the 37 publications.

5 Discussion

The objectives of this review were framed in four research questions, discussed in the following sections, together with some suggestions for future research. Many of the results from this review are indicative rather than conclusive, due to the little amount of previous research in the topic. The fact that the reviewed studies differ in methods used and factors controlled for also limits the possibility for solid conclusions. Still, the review provides an overview of quality studies conducted in regional public transport and demonstrates some quality attributes that are recurringly found to be important in these studies.

It should be noted that there is a variation in the reviewed studies regarding how quality attributes are defined and used. This complicates the assessment, but through transformation to the framework presented in section Service quality attributes we have been able to compare studies and reveal some overall patterns. The discussion and conclusions are based on this framework, but the original studies might use different notations.

5.1 Comparison of regional and local public transport

This review has shown that frequency, comfort, reliability, travel time, and network coverage are particularly important quality attributes in many studies into regional public transport. Comparing this result with similar reviews about local public transport [14, 15], the general impression is that the preferences of regional travellers mainly conform to the preferences of local travellers. This is also suggested by Majumdar & Lentz [40]. However, our review also highlights some important differences.

Frequency is among the highest ranked attributes in both local and regional public transport, though the results also indicate that the importance of frequency is less pronounced among regional travellers. Instead, in this group, comfort is a higher priority [20].

Attributes concerning network coverage or walking distance are seemingly more frequent in discussions about important attributes in regional public transport than in local public transport. A probable explanation is the more dispersed nature of regional public transport networks, together with the challenge of designing coherent networks in which frequencies are typically low. A proven remedy, however, is easy and well-timed transfers, achieved through rigorous coordination and central network planning [54, 55, 57]. In addition, the conditions for access and egress to and from stops and stations need attention, including beyond the conventionally assumed catchment areas of 400 or 800 m. Many passengers are willing to walk substantially further if the appropriate infrastructure exists [62, 63], even if these results depend on sociodemographic characteristics (such as age) and characteristics of the built environment (such as walkability). Cycling also has the potential to be an important access mode, especially for high-quality regional services, increasing the catchment area to several kilometres [62]. Moreover, park-and-ride facilities can improve access to the public transport network in cases where overall trip lengths are relatively long [65, 66].

In contrast to comfort and network coverage, attributes concerning security and staff do not appear to be as highly prioritised in regional public transport as in local public transport.

The notions of local and regional public transport are rarely used in the literature. Urban, rural, and interurban are more common concepts and substantial parts of the review are based on studies using these notions. As regional is not synonymous with rural or interurban, all parallels need to be handled with care. However, with the definition of regional public transport that we have adopted in this review, which is based on urban areas rather than administrative boundaries, studies of rural and interurban travel, in most cases, will fall within our definition of regional. This is illustrated in the Venn diagram in Fig. 2, in which the right-hand circle corresponds to our working definition. Furthermore, we have assessed each case study to confirm that it is in line with our definition.

5.2 The influence of trip length

Our results indicate that there are quality attributes whose importance depends on trip length. Based on the availability of results from the investigated studies, three distance categories have been defined – short (less than 25 km), medium (25–50 km), and long (more than 50 km). Passenger preferences appear to differ between short regional trips compared to medium and long regional trips. Unsurprisingly, the results reveal that these differences are essentially in line with the differences found between local and regional travel.

The most pronounced differences appear in attributes regarding on-board comfort, the importance of which quite logically appears to increase with travel distance. Comfort in terms of station facilities is reported to have less impact on perceived service quality in regional public transport [68], although the results of our review suggest that this conclusion might require modification. On-board comfort is clearly important for medium and long regional trips, but there are indications that station facilities are more important for short regional trips.

Also in line with local–regional differences, the importance of frequency and reliability appear to decrease somewhat with travel distance. A possible explanation for this is that as travel distance increases, in-vehicle travel time increases, meaning that waiting time and potential delays constitute relatively smaller portions of the total travel time. It should be noted, however, that frequency and reliability still are among the top priorities also for long regional trips.

More surprisingly, price appears to be less important for short regional trips than for local trips and for medium and long regional trips. This finding is principally based on patterns appearing when comparing results from studies carried out in different settings regarding travel distances. Only one of the studies uses a comparative method, observing a decrease in price elasticity up to around 20 km, from where it starts increasing again [52]. This result is in line with the overall pattern, but it should be noted that it is based on relatively few observations.

As there are many similarities between the local–regional comparison and the short–long trip comparison, a relevant question is whether the segmentation between local, regional, and interregional is necessary. Is segmentation based on trip lengths, or travel times, more suitable? Indeed, the relative importance of different quality attributes probably depends more on travel times and trip lengths than on the urban or regional context. However, the prerequisites for regional public transport are generally significantly different compared to local public

Table 3 Inclusion of quality attribute categories in the reviewed studies

Category	Number of studies in which a quality attribute in the category is included		
	"Overviews" ($N = 14$)	"Specialisations" ($N = 23$)	Total ($N = 37$)
Cost	12	7	19
Availability	12	17	29
Accessibility	7	8	15
Information	9	4	13
Time	13	8	21
Customer care	8	2	10
Comfort	13	6	19
Security	9	2	11
Environmental impact	2	1	3

"Overviews" correspond to the studies included in Table 2, and "specialisations" comprise the remainder of the studies that were identified in the search process and included in the review transport, so the separation of geographical scales is still relevant. We suggest using a combination where possible, separating short from long trip lengths, or travel times, within each category (e.g. short local trips, long local trips, short regional trips, long regional trips). A similar approach is also reasonable for interregional public transport, separating it from regional public transport based on trip regularity (in line with our working definition, see section Local, regional and interregional public transport) and, where possible, also keeping track of the influence of trip length or travel time.

5.3 Bus versus rail

We have not been able to find any differences between bus and rail services in terms of how quality attributes are prioritised. Comparisons are aggravated by the fact that passenger satisfaction levels are moderated by their expectations [26] and expectations differ between the modes based on subjective criteria related to travel emotions or sensory aspects [58]. Nevertheless, there are indications of a general preference for trains over buses [58, 59]. Thus, the development and evaluation of rail-inspired bus concepts such as "Rural Bus Rapid Transit" [60] or "R-Net" [62] could be an interesting and potentially prosperous way forward for regional bus and coach services.

Compared to local public transport (outlined in the introduction), there are similarities in terms of how bus services are overrepresented in studies into customer satisfaction. Also, rail is generally favoured compared to buses in both local and regional public transport. For local public transport, this gap in perception can be bridged through high-quality bus services such as Bus Rapid Transit, which has been implemented in many cities and now becoming a well-established concept the world over [19]. Efforts for developing similar high-quality bus concepts on a regional scale are, however, rare.

5.4 Modal choice, demand, and customer satisfaction

As outlined in the introduction, customer satisfaction, demand, and modal choice are intertwined concepts, each impacting the other. In this review, we have been unable to find any substantial differences, in terms of important quality attributes, in the conclusions of customer satisfaction studies compared to studies on demand or modal choice. A couple of minor dissimilarities were indicated in the results, but it is difficult to draw robust conclusions in this regard. This is due to a risk of spuriousness between type of study and other factors such as trip length and public transport mode.

Analogous to studies into local public transport, customer satisfaction studies predominantly focus on bus services. A possible explanation is that bus generally is the least favoured mode, yet constituting significant parts of the public transport networks in many cities and regions, implying that many transport authorities would benefit from increasing customer satisfaction among bus users [15].

5.5 Directions for future research

As outlined in the introduction, public transport research has largely been focused on local travel and there are relatively few publications that exclusively concern regional public transport [12–14]. There is a need for more knowledge about the specifics of regional public transport and, based on our results regarding important quality attributes, combined with identified gaps, we can offer some suggestions about the direction of future research:

- On-board comfort is a top priority for many regional travellers, but this is a multifaceted attribute and more research is needed into the impact of different aspects of on-board comfort, e.g. seating, ride comfort, and complementary facilities.
- Frequency is also acknowledged to be an attribute of great importance, but the reviewed studies have not revealed many details of operational aspects such as peak and off-peak frequencies or operating hours.
- Surprisingly little attention has been paid to travel time improvements, regarding in-vehicle travel time in particular, given that in-vehicle travel time generally constitutes a relatively large proportion of the total travel time in regional public transport.
- Little is known about how the environmental impact of public transport services affects modal choice for regional travel, as this attribute is rarely included in such studies.
- Our review suggests that trip lengths or travel times affect passenger preferences, but the mechanisms are still largely unclear. Further studies that include the crossed effects between trip length or travel time and other service attributes are desirable.

6 Conclusions

For the purpose of exploring passenger preferences, the following working definition of regional public transport can be adopted, with boundaries towards local as well as interregional public transport. Regional public transport (i) targets passengers travelling between separate urban areas or to rural areas and (ii) a majority of the trips are made on a regular basis. The second part of the definition implies that most passengers on regional public transport services are frequent travellers, and hence, our results mainly target frequent travellers.

Quality attributes commonly reported as priorities for regional travellers are frequency, comfort, reliability, travel time, and network coverage. Some important differences with regard to local public transport are suggested. Firstly, on-board comfort is a higher priority for regional travellers, becoming increasingly important with longer travel times. Secondly, network coverage and co-ordination are also more prominent features in regional public transport, presumably because of the more dispersed nature of regional public transport networks. In relation to this, it has been concluded that catchment areas for walking and cycling to high-quality regional public transport services can be substantially larger than the conventionally assumed 400 or 800 m radius.

These differences, and the fact that the prerequisites for regional public transport are, in general, substantially different compared to local and interregional public transport, support continued use of this categorisation in public transport research. Where applicable, we also suggest inclusion of the impact of trip length or travel time within each category.

Trains are generally found to be preferred to buses and we therefore suggest further development and evaluation of rail-inspired bus concepts. However, we have not found any differences between bus and rail services regarding quality attribute priorities.

Our review does not indicate any substantial differences in terms of important quality attributes in the conclusions of customer satisfaction studies compared to studies into demand or modal choice.

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Authors' contributions
JH conducted the survey, the literature search and assessments, and did most of the writing. FP assisted with the literature assessments and made intellectual contributions to the analyses. HS made intellectual contributions to the analyses. AW assisted in developing the framework and made intellectual contributions to the analyses. All authors read and approved the final manuscript and agree with its submission to *European Transport Research Review*.

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Competing interests
The authors declare that they have no competing interests. We confirm that this manuscript has not been published elsewhere and is not under consideration by another journal. Section Local, regional and interregional public transport in the manuscript is a summary of a previously published working paper (cited in the manuscript and available on-line).

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References

1. EEA, European Environment Agency. (2016). *Urban Sprawl in Europe (EEA Report No 11/2016)*. https://doi.org/10.2800/143470.
2. WHO & UN, World Health Organization & United Nations. (2010). *Hidden cities: Unmasking and overcoming health inequities in urban settings*. Geneva: WHO Retrieved from https://apps.who.int/iris/handle/10665/44439.
3. UITP, International Association of Public Transport. (2013). *Demographic changes and challenges for regional transport (Core brief)*. Brussels: Author.
4. ITF, International Transport Forum. (2017). *ITF transport outlook 2017*. Paris: OECD Publishing. https://doi.org/10.1787/9789282108000-en.
5. Chen, G., & Benezech, V. (2018). Non-urban passenger travel demand and CO_2 emissions: A global perspective. *Transportation Research Board 97th Annual Meeting*. https://trid.trb.org/view/1496014.
6. Petrunoff, N., Rissel, C., & Wen, L. M. (2016). The effect of active travel interventions conducted in work settings on driving to work: A systematic review. *Journal of Transport & Health, 3*(1), 61–76. https://doi.org/10.1016/j.jth.2015.12.001.
7. Aguiar, B., & Macário, R. (2017). The need for an elderly centred mobility policy. *Transportation Research Procedia, 25*, 4355–4369. https://doi.org/10.1016/j.trpro.2017.05.309.
8. Mehdizadeh, M., Mamdoohi, A., & Nordfjaern, T. (2017). Walking time to school, children's active school travel and their related factors. *Journal of Transport & Health, 6*, 313–326. https://doi.org/10.1016/j.jth.2017.01.012.
9. Commissaris, D. A., Huysmans, M. A., Mathiassen, S., Srinivasan, D., Koppes, L. L., & Hendriksen, I. J. (2016). Interventions to reduce sedentary behavior and increase physical activity during productive work: A systematic review. *Scandinavian Journal of Work, Environment & Health, 42*(3), 181–191. https://doi.org/10.5271/sjweh.3544.
10. Lucas, K. (2012). Transport and social exclusion: Where are we now? *Transport Policy, 20*, 105–113. https://doi.org/10.1016/j.tranpol.2012.01.013.
11. Berg, J., & Ihlström, J. (2019). The importance of public transport for mobility and everyday activities among rural residents. *Social Sciences, 8*(2), 58. https://doi.org/10.3390/socsci8020058.
12. Heilig, L., & Voss, S. (2015). A Scientometric analysis of public transport research. *Journal of Public Transportation, 18*(2), 111–141. https://doi.org/10.5038/2375-0901.18.2.8.
13. de Oña, J., & de Oña, R. (2015). Quality of service in public transport based on customer satisfaction surveys: A review and assessment of methodological approaches. *Transportation Science, 49*(3), 605–622. https://doi.org/10.1287/trsc.2014.0544.
14. dell'Olio, L., Ibeas, A., de Oña, J., & de Oña, R. (2018). *Public transport quality of service*. Amsterdam: Elsevier.
15. van Lierop, D., Badami, M. G., & El-Geneidy, A. M. (2018). What influences satisfaction and loyalty in public transport? A review of the literature. *Transport Reviews, 38*(1), 52–72. https://doi.org/10.1080/01441647.2017.1298683.
16. Redman, L., Friman, M., Gärling, T., & Hartig, T. (2013). Quality attributes of public transport that attract car users: A research review. *Transport Policy, 25*, 119–127. https://doi.org/10.1016/j.tranpol.2012.11.005.
17. Tyrinopoulos, Y., & Antoniou, C. (2013). Factors affecting modal choice in urban mobility. *Eur Transp Res Rev, 5*, 27–39. https://doi.org/10.1007/s12544-012-0088-3.
18. Varela, J. M. L., Börjesson, M., & Daly, A. (2018). Public transport: One mode or several? *Transportation Research Part A, 113*, 137–156. https://doi.org/10.1016/j.tra.2018.03.018.
19. Ingvardson, J. B., & Nielsen, O. A. (2018). Effects of new bus and rail rapid transit systems – an international review. *Transport Reviews, 38*(1), 96–116. https://doi.org/10.1080/01441647.2017.1301594.
20. Román, C., Martín, J. C., & Espino, R. (2014). Using stated preferences to analyze the service quality of public transport. *International Journal of Sustainable Transportation, 8*(1), 28–46. https://doi.org/10.1080/15568318.2012.758460.
21. Börjesson, M., & Eliasson, J. (2014). Experiences from the Swedish value of time study. *Transp Res A Policy Pract, 59*, 144–158. https://doi.org/10.1016/j.tra.2013.10.022.
22. van Lierop, D., & El-Geneidy, A. M. (2018). Is having a positive image of public transit associated with travel satisfaction and continued transit usage? An exploratory study of bus transit. *Public Transportation, 10*(2), 241–256. https://doi.org/10.1007/s12469-018-0175-5.
23. Rojo, M., Gonzalo-Orden, H., dell'Olio, L., Ibeas, Á., & Ibeas, T. (2012). Relationship between service quality and demand for inter-urban buses. *Transportation Research Part A: Policy and Practice, 46*(10), 1716–1729. https://doi.org/10.1016/j.tra.2012.07.006.
24. Eboli, L., & Mazzulla, G. (2011). A methodology for evaluating transit service quality based on subjective and objective measures from the passenger's

point of view. *Transport Policy, 18*(1), 172–181. https://doi.org/10.1016/j.tranpol.2010.07.007.
25. Friman, M., & Fellesson, M. (2009). Service supply and customer satisfaction in public transportation: The quality paradox. *Journal of Public Transportation, 12*(4), 57–69. https://doi.org/10.5038/2375-0901.12.4.4.
26. Mouwen, A. (2015). Drivers of customer satisfaction with public transport services. *Transportation Research Part A: Policy and Practice, 78*, 1–20. https://doi.org/10.1016/j.tra.2015.05.005.
27. White, P. (2016). Rural public transport. In *Public transport: Its planning, management and operation* (pp. 201–221). Oxford: Routledge.
28. CEN, European Committee for Standardisation. (2002). *Transportation - Logistics and services - Public passenger transport - Service quality definition, targeting and measurement (EN 13816:2002)*. Brussels: Author.
29. Taylor, B. D., Miller, D., Iseki, H., & Fink, C. (2009). Nature and/or nurture? Analyzing the determinants of transit ridership across US urbanized areas. *Transportation Research Part A: Policy and Practice, 43*(1), 60–77. https://doi.org/10.1016/j.tra.2008.06.007.
30. Petersen, T. (2012). *Public transport for exurban settlements (PhD thesis)*. Melbourne: The University of Melbourne.
31. Godlund, S. (1954). Verksamhets-, varaktighets- och miljöformerna inom billinjetrafiken. Tätortsavgränsingen. [Operational, durability and environmental forms within bus traffic. The urban area delimitation.]. In *Busstrafikens framväxt och funktion i de urbana influensfälten [The growth and function of bus traffic in the urban influence fields]* (pp. 27–42). Lund: C.W.K. Gleerup.
32. Luke, D., Steer, J., & White, P. (2018). Interurban bus: Time to raise the profile. Greengauge, 21. http://www.greengauge21.net/wp-content/uploads/GG21_IBR_A4P_WEB.pdf.
33. Hansson, J., Pettersson, F., Svensson, H., & Wretstrand, A. (2018). *Defining regional public transport (K2 working papers 2018:7)*. Lund: K2.
34. Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine, 6*(7). https://doi.org/10.1371/journal.pmed.1000097.
35. Transportation Research Board. (2018). Transportation Research Thesaurus. Retrieved March 20, 2018, from http://trt.trb.org/trt.asp?.
36. Hirsch, L., Thompson, K., & Every, D. (2017). Frustrations, fights, and friendships: The physical, emotional, and behavioural effects of high-density crowding on Mumbai's suburban rail passengers. *Qualitative Report, 22*(2), 550–566 Retrieved from https://nsuworks.nova.edu/tqr/vol22/iss2/12.
37. Rahman, S., & Balijepalli, C. (2016). Understanding the determinants of demand for public transport: Evidence from suburban rail operations in five divisions of Indian Railways. *Transport Policy, 48*, 13–22. https://doi.org/10.1016/j.tranpol.2016.02.006.
38. Sahu, P. K., Sharma, G., & Guharoy, A. (2018). Commuter travel cost estimation at different levels of crowding in suburban rail system: A case study of Mumbai. *Transportation Research Board 97th Annual Meeting*. https://trid.trb.org/view/1495556.
39. Zhou, X., Du, H., Liu, Y., Huang, H., & Ran, B. (2017). Investigating the intention of rural residents to use transit in Cixi, China. *Journal of Urban Planning and Development, 143*(2). https://doi.org/10.1061/(ASCE)UP.1943-5444.0000367.
40. Majumdar, S. R., & Lentz, C. (2012). Individuals' attitudes toward public transit in a rural Transit District. *Public Works Manag Policy, 17*(1), 83–102. https://doi.org/10.1177/1087724X11421953.
41. Grisé, E., & El-Geneidy, A. (2017). Where is the happy transit rider? Evaluating satisfaction with regional rail service using a spatial segmentation approach. *Transportation Research Part A: Policy and Practice, 114*(A), 84–96. https://doi.org/10.1016/j.tra.2017.11.005.
42. Bouscasse, H., Joly, I., & Peyhardi, J. (2016). *Estimating travel mode choice, including rail in regional area, based on a new family of regression models* (GAEL Working Paper 2016–04). Retrieved from https://hal.archives-ouvertes.fr/hal-01847227.
43. Jiang, X., Guo, X., & Ran, B. (2014). Optimization model for headway of a suburban bus route. *Math Probl Mathematical Problems in Engineering, 2014*. https://doi.org/10.1155/2014/979062.
44. Rashedi, Z., Mahmoud, M., Hasnine, S., & Habib, K. N. (2017). On the factors affecting the choice of regional transit for commuting in Greater Toronto and Hamilton Area: Application of an advanced RP-SP choice model. *Transportation Research Part A: Policy and Practice, 105*, 1–13. https://doi.org/10.1016/j.tra.2017.08.008.
45. Asensio, J. (2000). The success story of Spanish suburban railways: Determinants of demand and policy implications. *Transport Policy, 7*(4), 295–302. https://doi.org/10.1016/S0967-070X(00)00030-5.
46. Berežný, R., & Konecný, V. (2017). The impact of the quality of transport services on passenger demand in the suburban bus transport. *Procedia Engineering, 192*, 40–45. https://doi.org/10.1016/j.proeng.2017.06.007.
47. Garrido, C., De Oña, R., & De Oña, J. (2014). Neural networks for analyzing service quality in public transportation. *Expert Systems with Applications, 41*(15), 6830–6838. https://doi.org/10.1016/j.eswa.2014.04.045.
48. Guirao, B., García-Pastor, A., & López-Lambas, M. E. (2016). The importance of service quality attributes in public transportation: Narrowing the gap between scientific research and practitioners' needs. *Transport Policy, 49*, 68–77. https://doi.org/10.1016/j.tranpol.2016.04.003.
49. Ramesh, A. V., Rao, K. R., & Sarkar, A. K. (1998). The LOS index: An evaluation of regional bus services in Andhra Pradesh, India, using fuzzy set theory. *Science, Technology and Development, 16*(2), 112–123.
50. Rojo, M., Gonzalo-Orden, H., dell'Olio, L., & Ibeas, Á. (2011). Modelling gender perception of quality in interurban bus services. *Proceedings of the Institution of Civil Engineers: Transport, 164*(1), 43–53. https://doi.org/10.1680/tran.9.00031.
51. Stern, E. (1981). An innovative regional transit system in Israel. *Urban Development and Urban Renewal*, 125–132. https://www.scopus.com/record/display.uri?eid=2-s2.0-0019696952&origin=inward&txGid=10ee73d2069ba4715f8fcb4cecb90270.
52. Stark, D. C. (1981). *Time series analysis of Glasgow suburban rail patronage (supplementary report 649)*. Crowthorne: U.K. Transport & Road Research Laboratory.
53. Buehler, R., Pucher, J., & Dümmler, O. (2018). Verkehrsverbund: The evolution and spread of fully integrated regional public transport in Germany, Austria, and Switzerland. *International Journal of Sustainable Transportation*. https://doi.org/10.1080/15568318.2018.1431821.
54. Petersen, T. (2009). Network planning, Swiss style: Making public transport work in semi-rural areas. *32nd Australasian Transport Research Forum* Retrieved from https://atrf.info/papers/2009/2009_petersen.pdf.
55. Petersen, T. (2016). Watching the Swiss: A network approach to rural and exurban public transport. *Transport Policy, 52*, 175–185. https://doi.org/10.1016/j.tranpol.2016.07.012.
56. White, P. (2016). The roles of 'conventional' and demand-responsive bus services. In C. Mulley & J. D. Nelson (Eds.), *Paratransit: Shaping the Flexible Transport Future* (pp. 307–330). https://doi.org/10.1108/S2044-994120160000008015.
57. Brown, J. R., & Thompson, G. L. (2009). Express bus versus rail transit: How a marriage of mode and mission affects transit performance. *Transportation Research Record, 2110*(1), 45–54. https://doi.org/10.3141/2110-06.
58. Hasiak, S., Hasiak, F., & Egea, A. (2016). Coach and train: Differences in individuals perception of these modes. *Transportation Research Procedia, 14*, 1706–1715. https://doi.org/10.1016/j.trpro.2016.05.136.
59. Jackson, J., Johnson, D., & Nash, C. (2012). On the willingness to pay for rural rail service level changes. *Res Transp Bus Manag, 4*, 104–113. https://doi.org/10.1016/j.rtbm.2012.06.006.
60. Bazley, C., Vink, P., & Blankenship, D. (2014). Survey results for rural bus rapid transit (BRT) VelociRFTA and future human factor considerations. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting*, 1224–1228. https://doi.org/10.1177/1541931214581255.
61. Akbari, S., Mahmoud, M. S., Shalaby, A., & Habib, K. M. (2018). Empirical models of transit demand with walk access/egress for planning transit oriented developments around commuter rail stations in the greater Toronto and Hamilton area. *Journal of Transport Geography, 68*, 1–8. https://doi.org/10.1016/j.jtrangeo.2018.02.002.
62. Brand, J., Hoogendoorn, S., Van Oort, N., & Schalkwijk, B. (2017). Modelling multimodal transit networks integration of bus networks with walking and cycling. In *2017 5th IEEE international conference on models and Technologies for Intelligent Transportation Systems (MT-ITS)* (pp. 750–755). https://doi.org/10.1109/MTITS.2017.8005612.
63. Ker, I., & Ginn, S. (2003). Myths and realities in walkable catchments: The case of walking and transit. *Road and Transport Research, 12*(2), 69–80.
64. Vijayakumar, N., El-Geneidy, A. M., & Patterson, Z. (2011). Driving to suburban rail stations: Understanding variables that affect driving distance and station demand. *Transportation Research Record, 2219*, 97–103. https://doi.org/10.3141/2219-12.
65. Hamer, P. (2010). Analysing the effectiveness of park and ride as a generator of public transport mode shift. *Road and Transport Research, 19*(1), 51–107.
66. Hanssen, J. U., Tennøy, A., Christiansen, P., & Øksenholt, K. V. (2016). How can P & R facilities contribute to reduced emissions of greenhouse gases?

European Transport Conference Retrieved from https://aetransport.org/public/downloads/ljecn/4819-57e51951a4f4c.pdf.
67. Niles, J., & Pogodzinski, J. M. (2016). *Bus Transit Operational Efficiency Resulting from Passenger Boardings at Park-and-Ride Facilities (MTI report 12–60)*. San José, CA: Mineta Transportation Institute Retrieved from http://transweb.sjsu.edu/PDFs/research/1401-park-and-ride-bus-passenger-boarding-efficiency.pdf.
68. Monsuur, F., Enoch, M., Quddus, M., & Meek, S. (2017). The impact of train and station types on perceived rail service quality. *Transportation Research Record, 2648*, 51–59. https://doi.org/10.3141/2648-06.
69. Kroes, E., Kouwenhoven, M., Duchateau, H., Debrincat, L., & Goldberg, J. (2007). Value of punctuality on suburban trains to and from Paris. *Transportation Research Record, 2006*, 67–75. https://doi.org/10.3141/2006-08.
70. Mahmoud, M. S., Shalaby, A., Habib, K. N., & Shalaby, A. (2016). Application of RP/SP data to the joint estimation of mode choice models: Lessons learned from an empirical investigation into cross-regional commuting trips in the greater Toronto and Hamilton area. *Transportation Research Board 95th Annual Meeting* Retrieved from https://trid.trb.org/view/1393247.

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Replacing regional bus services with rail: Changes in rural public transport patronage in and around villages

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ABSTRACT

Removing bus stops is often a prerequisite for introducing faster, more reliable, and more frequent rail or coach services in rural areas. Despite the potentially higher quality of service through trains or coaches, however, the bus-stop removals often become stumbling blocks. It is sometimes feared that the alterations to the public transport network will pose a threat to the possibilities of living in rural areas outside villages. In this study, we investigate how travel by public transport is affected in areas where bus services are substantially reduced in connection with the introduction of rail services with fewer stops. Through an analysis of access trips from rural areas surrounding the train stations, we are able to study the development of public transport patronage in these areas in comparison with a control group with retained rural bus services. A total of 28 villages with surrounding rural areas in southern Sweden are included in the study. Our results reveal a significantly larger patronage increase around new train stations compared to areas where regional bus services are kept, and importantly, the patronage increase does not only occur in the immediate surroundings of the stations. Outside the villages, in the rural areas where public transport services have been cut, the increase is of equal magnitude. Hence, our results oppose the idea of distortion between the villages and their surrounding rural areas, at least in terms of net effect on public transport usage.

1. Introduction

Due to low population density, and consequently, limited travel demand, providing high-quality public transport in rural areas is challenging (ITF, 2015; White, 2016a). Also, since rural travel is characterised by relatively long distances (Litman, 2018), walking and bicycling are, in general, not viable options either. This leads to a high car dependence among rural residents (Berg and Ihlström, 2019), even in the peri-urban areas surrounding cities (Hickman and Banister, 2014).

The absence of transport options affects the independent mobility of all rural residents with limited or no access to a car, for instance in households where multiple car ownership is financially impossible (Farrington and Farrington, 2005). As a consequence, the ability to perform everyday activities is restricted. Children, adolescents (Berg and Ihlström, 2019), and older people (Ward et al., 2013) are particularly exposed population groups, whose accessibility is largely affected by poor public transport. Recent research has also shown that older people tend to move to the countryside after retirement. For the 'younger older', this may not be a problem, but driving cessation among older seniors in areas with poor or non-existent public transport services will inevitably result in increased social costs (Camporeale et al., 2019).

Also, high-quality public transport is often seen as a means for rural development (Šťastná et al., 2015). Such development aims may be an important objective for investing in improved public transport (Pettersson, 2018). These improvements make it possible for residents to remain in the rural areas, as public transport becomes a viable option for commuting to work or school and for reaching amenities in the region's towns and cities (Šťastná and Vaishar, 2017).

The notion of high-quality services contains a combination of factors. In regional public transport, the most important quality attributes discussed in the literature are frequency, comfort, reliability and travel time (Hansson et al., 2019). Network coverage (the geographical range and extent of the public transport services) is also commonly reported to be among the top priorities for regional travellers, with a twofold implication: First, passengers value the possibility to reach a multitude of destinations, stressing the importance of interconnected services with

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easy and well-timed transfers (Petersen, 2016). Second, short access distances are considered to be vital, preferably so that the stops can be reached with a short walk (Akbari et al., 2018).

In practice, there is a contradiction between short access distances and some of the other quality attributes, primarily travel time and reliability. Short access distances imply that stop distances should be kept short, but on the other hand, too many stops will make the public transport services slow and travel times less predictable. This in turn may also have a negative effect on frequency (Stewart and El-Geneidy, 2016). Hence, balancing stop spacing is an important and delicate issue.

Crucially, there is an interesting dynamic in this balance, as quality of service improvements increase the acceptance of longer access distances (Brand et al., 2017; El-Geneidy et al., 2014; Vijayakumar et al., 2011). This means that quality of service improvements increase the catchment areas around the stops, and thereby also increase the population base for the services. Accordingly, concentrating resources to high-demand routes and stops has proven to be an effective strategy for increasing patronage (Dodson et al., 2011; Nielsen et al., 2005).

In regional networks, this strategy means that bus services are replaced by faster, more reliable, and more frequent rail or coach services. Reducing the number of stops is a prerequisite for such quality of service improvements, but leads to critique from residents in the rural areas who face longer distances to their nearest bus stop or station. Thus, removing bus stops is a much debated issue in this type of public transport improvement projects. Fewer bus stops lead to decreased area coverage, and some politicians and the general public have expressed fears that this will possibly pose a threat to the possibilities of living in rural areas outside the rural cores (Pettersson, 2018). The rural cores are the villages that gain improved public transport services, i.e. where the remaining stops or stations are located.

At the same time, new travel opportunities arise in these areas, through the possibility to travel by bicycle or by car to stations where the public transport quality of service has been significantly improved. Eventually, it can be expected that new travel patterns are established, in which multimodal trips, where bicycles and cars are used to access a public transport node, might play a substantial role (Brand et al., 2017; Hamer, 2010). However, there is currently a lack of knowledge about to what extent such multimodal trips are made in rural areas, in comparison with the former number of bus trips at the removed bus stops (Berg, 2017).

In this study, we aim to investigate how travel by public transport is affected in rural areas where bus services are substantially reduced in connection with introduction of rail services. The following question forms the point of departure for the study:

- What is the net demand effect of the changed travel opportunities in such rural areas?

The study is based on an analysis of how public transport travel has developed around 28 villages in Scania, southern Sweden. In half of the villages (control group), bus services have remained unchanged, with several bus stops in each village as well as in the surrounding areas. In the other half of the villages (case study objects), train stations have been opened and regional rail services have replaced most of the former bus services. We use a combination of patronage statistics, geographical information about vehicles at the park-and-ride facilities, and travel survey data to analyse multimodal trips in the rural areas surrounding the stations.

2. Literature review

New rail services generally attract more passengers than the bus services they replace (Scherer, 2010; Werner et al., 2016). This increased patronage can only partly be explained by improvements of basic service quality attributes such as travel time and frequency, and therefore many studies suggest a so-called rail factor or rail bonus (Scherer and Dziekan, 2012; Utsunomiya and Shibayama, 2020; Varela et al., 2018). The rail factor can be understood as a compound of intangible quality attributes, such as perceived reliability, information availability, comfort, and safety. Some scholars argue that if these attributes are taken into account, there is no evident preference for rail travel (Ben-Akiva and Morikawa, 2002). However, at least in some cases, there may also exist a general preference for rail beyond performance and cost criteria. In fact, a considerable proportion of the rail factor may be based on emotional and social aspects (Hasiak et al., 2016; Scherer and Dziekan, 2012). In addition to the rail factor, at least for regional travel, rail services typically also mean higher speeds, and consequently, shorter in-vehicle travel times.

However, rail services typically require longer stop distances than the bus services they replace, so (besides the economic aspects) the potential benefits of the rail service need to be balanced with longer access distances. This balance of stop spacing has been dealt with in many studies applied on urban bus systems (e.g. El-Geneidy et al., 2006; Mamun and Lownes, 2014; Murray and Wu, 2003; Shrestha and Zolnik, 2013; Stewart and El-Geneidy, 2016; Tirachini, 2014). Most of these studies conclude that bus services can be improved through longer stop distances, and that many passengers are willing to walk longer distances to access a stop with a public transport service of better quality (El-Geneidy et al., 2014; Mamun and Lownes, 2014; Mulley et al., 2018; van Soest et al., 2019). However, it is acknowledged that bus stop removals can be met with considerable resistance from residents, and are likely to spark conflicts in the planning process (Pettersson, 2018; Stewart and El-Geneidy, 2016). Thus, it is important to understand what the impacts of widespread removal of bus stops will be.

All of the identified studies into stop spacing have been carried out in urban contexts, where walking generally is the dominant access mode. In regional public transport, where travel distances generally are longer, bicycles and cars are more prominent access modes (Hamer, 2010; Martens, 2004; Vijayakumar et al., 2011). Besides the overall trip length, the quality of the public transport service also affects the characteristics of the access trips. A higher quality of service typically means larger shares of access trips by bicycle or by car, and a higher quality of service also attracts people to travel longer distances to access the bus stop or train station (Martens, 2004; Midenet et al., 2018; Vijayakumar et al., 2011). In practice, this means larger catchment areas for services with higher quality of service. Also, the increasing use of pedal electric bicycles as a feeder mode further extends the bicycle catchment area (Midenet et al., 2018).

To sum up, an extensive set of previous research has looked into differences between bus and rail in terms of passenger preferences and patronage. However, these differences have not been connected to the longer stop distances that typically are required when bus services are replaced with rail. Also, studies into stop spacing have focused on urban bus systems, where the conditions and effects are widely different from rural areas. An important difference is the more widespread use of bicycles and cars to access bus stops and train stations in rural areas, especially for high-quality regional public transport services.

The present study contributes to the literature by looking into effects of longer stop distances in rural areas. This is done by analyses of multimodal trips, where bicycles and cars are used in combination with public transport in a rural setting. The study also addresses a previously identified research gap in the field of regional public transport (Hansson et al., 2019), as the subject is closely connected to different travel time components. In principle, longer access trip times are balanced against quality-of-service improvements, including drastically reduced in-vehicle trip times. The study is based on a number of cases where bus services are replaced by rail, but the question of whether changes in patronage levels are a result of introducing rail services, or if they rather reflect general improvements of the level of service, is beyond the scope of the study.

3. Case study objects and control group

The 28 villages in the study are located in Scania, the southernmost county in Sweden (total county population 1.4 million). The population sizes of the villages range from 200 to 4000. New train stations have recently been opened in 14 of the villages: the case study objects. There, regional rail services have been introduced, replacing most of the former bus services. In the other 14 villages, the control group, bus services have been retained. The locations of the villages are shown in Fig. 1.

The case study objects are scattered along several regional rail lines. The stations were opened between 2011 and 2016, at least partly replacing regional bus services with several bus stops in each village as well as in the surrounding rural areas. The new rail services have drastically reduced station-to-station travel times compared to the former bus services, which together with improved ride comfort have entailed significant quality of service improvements, at least for trips between the central parts of the villages and the nearest towns.

Fig. 2 shows the service supply (in terms of numbers of departures per weekday) in the case study villages, before the stations were opened compared to 2018. The opening year differs from station to station, from 2011 to 2016 (see Table 1). As can be seen in Fig. 2, three different types of network setup exist in terms of how train and bus services are combined:

1. Suspended bus services (6 stations). In this group the rail service is the only available public transport option in and around the village. The total number of departures per day has increased at all these stations in comparison with the former bus services.
2. Parallel bus services (6 stations). In this group, bus services have been retained (or reintroduced after a couple of years) parallel to the rail services, though with a dramatically reduced supply. Rail services are less frequent than the former bus services, but buses and trains together make the number of departures per day roughly equal to the situation before train services were introduced.
3. Feeding bus services (2 stations). Two of the stations have catchment areas stretching relatively far, also covering other villages. The network setup in these cases includes bus routes feeding to the stations (the feeding services are not included in the bars in Fig. 2). At one of these stations, the bus service running parallel to the railway has also been retained.

Studying changes in patronage only at these 14 case study objects would limit the possibilities to draw solid conclusions, particularly as there are several years between the observations. Changes in public transport usage might occur for a number of reasons, not necessarily as a result of the new rail services. Thus, the study was designed as a quasi-experimental case–control study (Werner et al., 2016). This means that changes in public transport usage were also studied in and around a number of villages of similar sizes and locations as the case study objects, but where bus services have remained practically unchanged: a control group.

For the control group, 14 villages were chosen across the regional bus network. During the time span studied, the number of bus stops on the bus routes serving these villages was relatively stable: Roughly, just one in twenty bus stops was removed. Also, the service supply was stable or increased on all bus routes in the control group: The average number of departures per weekday in each direction increased from 38 to 44 (+15%). The corresponding average for the case study objects increased from 20 to 28 (+40%, buses and trains together), over an analogous time span.

The villages are listed in Table 1, with information about studied time span in each case. As can be seen in the table, the time spans differ from village to village. This is due to the availability of patronage data on bus stop level. On most bus services, that data is collected by the public transport authority through manual passenger counts, conducted roughly every five to ten years on each route. As the timing of these passenger counts differs between the routes, the points in time for pre- and post-treatment differs from case to case. However, the variation is similar in both groups, with an average time range of eight years for the case study objects as well as in the control group.

The population sizes in Table 1 are for 2018. Over the studied time period, the population in the villages has increased in both groups, in total by 5% in the case study group and by 6% in the control group. We have also controlled for other variables (not shown in the table), such as

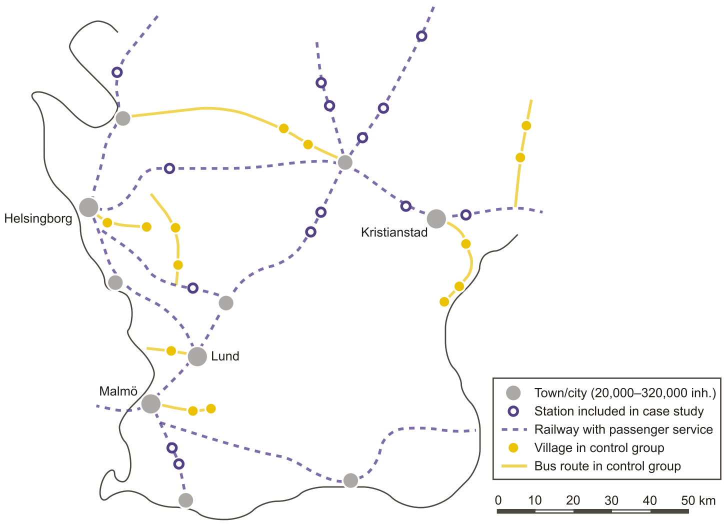

Fig. 1. Map of Scania, southern Sweden, indicating the locations of the 14 stations included in the case study, as well as the 14 villages in the control group.

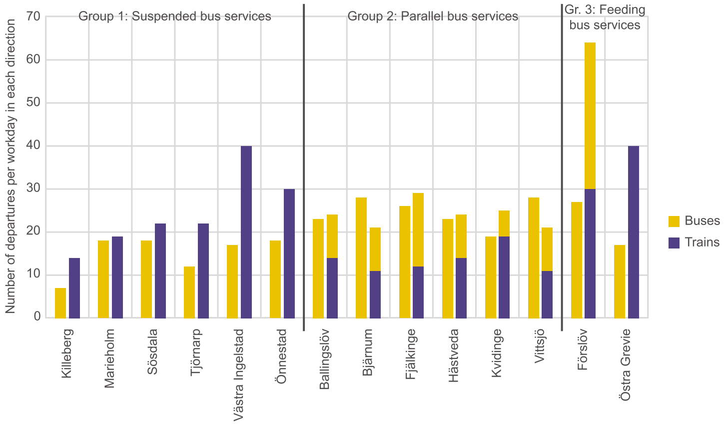

Fig. 2. Service supply before the opening of each station (left bar; opening years are listed in Table 1) compared to 2018 (right bar). Only bus routes parallel to the railways are included in the chart; feeding services are not included.

Table 1
Population sizes and studied time spans of the villages included in the case study and in the control group.

Case study village	Population	Station opened	Studied time span	Control group village	Population	Studied time span
Bjärnum	2800	2013	2009–2018	Svalöv	4000	2010–2015
Förslöv	2300	2015	2015–2018	Bara	3800	2006–2014
Fjälkinge	1900	2013	2010–2018	Ekeby	3400	2005–2018
Kvidinge	1900	2014	2009–2018	Bårslöv	2800	2005–2018
Sösdala	1900	2011	2009–2018	Klågerup	2100	2006–2014
Vittsjö	1900	2013	2009–2018	Jämshög	1600	2007–2017
Hästveda	1700	2013	2009–2018	Kågeröd	1600	2010–2015
Marieholm	1600	2016	2009–2018	Näsum	1300	2007–2017
Önnestad	1400	2013	2009–2018	Rinkaby	800	2012–2016
Tjörnarp	900	2014	2008–2018	Yngsjö	600	2012–2016
Västra Ingelstad	900	2015	2015–2018	Flädie	300	2005–2014
Östra Grevie	800	2015	2015–2018	Furuboda	300	2012–2016
Killeberg	600	2013	2012–2018	Hörja	200	2008–2017
Ballingslöv	400	2013	2009–2018	Röke	200	2008–2017
Average	**1500**		**8 years**		**1600**	**8 years**

age distribution, employment, household income, and vehicle access. No crucial differences were found: the case study group and the control group are largely similar in these respects.

4. Method

To analyse the effects of replacing rural bus services with rail, we

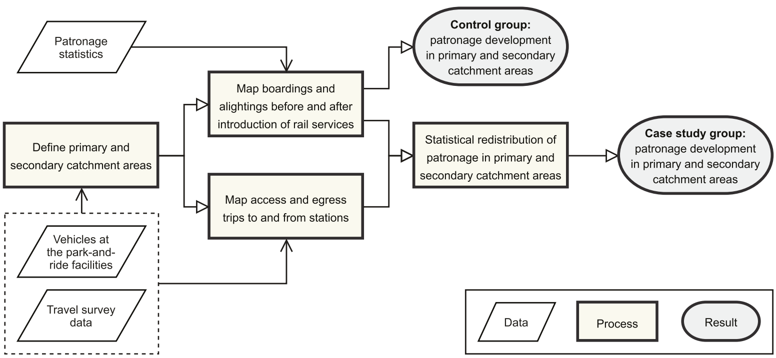

Fig. 3. Analysis flow.

adapted a quasi-experimental case–control study design (Werner et al., 2016) applied on two principal metrics. First, the impact on patronage in the entire catchment areas was analysed, i.e. including trips to and from the villages as well as the surrounding rural areas. Second, we focused specifically on the rural areas where public transport services have been cut, i.e. excluding the immediate surroundings of the stations.

The analysis flow is illustrated in Fig. 3. As a first step, to be able to address our aims, we needed to distinguish 'the immediate surroundings' of the stations (where the public transport quality of service have been improved) from 'the surrounding rural areas' (where services have been cut). Hereinafter, these are referred to as the primary and secondary catchment areas, respectively. Based on these demarcations, we mapped boardings and alightings in each area. However, for the case study group, we needed more information than what is given in the patronage data about the origins and destinations of the trips. To that end, we also examined access and egress trips to and from the train stations. Finally, the analysis was concluded with what can be described as a statistical redistribution of origins and destinations.

The different parts of the analysis are described more in detail in the following subsections. The first three subsections are about collecting and processing each of the different types of data used (patronage statistics, vehicles at the park-and-ride facilities, and travel survey data). The last two subsections describe the part of the analysis where these different types of data are brought together: first to define primary and secondary catchment areas, and then to determine changes in public transport usage in these areas.

4.1. Patronage statistics

The basis of the analysis is patronage statistics on bus-stop or train-station level, on two points in time: before and some years after the introduction of new rail services. Due to the availability of the data, the time span differs between the cases, but the average time range is eight years for the case study objects as well as in the control group (for details, see Table 1).

The data was retrieved from the regional public transport authority Skånetrafiken, who in turn uses two different data collection methods. On most bus services, stop-level data is collected through manual passenger counts, conducted roughly every five to ten years on each route. The passenger counts are made for five consecutive weekdays on similar dates each time (usually mid-October or mid-March). The regional trains, however, are equipped with automatic passenger counting systems. After subtracting movements of the train personnel, this data was compared with earlier manual passenger counts to verify that there are no structural differences between the outcomes of the two methods.

4.2. Vehicles at the park-and-ride facilities

To gain more information about actual origins and destinations of the train trips, we conducted screenings of the numbers of bicycles and cars at the park-and-ride facilities. In addition to these numbers, geographical information about where cars and motorcycles were registered was obtained through the vehicle registry at The Swedish Transport Agency. The screenings were conducted once at each facility, between 9 a.m. and 2 p.m. on weekdays in November 2018 (one station was screened in May 2019).

All in all, 293 bicycles and 328 cars (including motorcycles and mopeds) were counted at the 14 stations. Of the 328 cars, 289 had valid addresses in the vehicle registry. Furthermore, 15 cars were excluded because they were registered less than 200 m from a station, indicating that the park-and-ride facilities in these cases were used for residential parking. In addition, 16 cars were excluded because they were registered more than 25 km away from the stations, for instance at leasing companies. The 200 m and 25 km limits were chosen based on the travel survey data (see section 4.3). In the end, 258 valid addresses were used in the analysis, corresponding to 79% of all cars at the park-and-ride facilities.

None of the bus stops in our study was equipped with a park-and-ride facility, so the screenings were only conducted at the train stations.

4.3. Travel survey data

To be able to convert numbers of vehicles to numbers of trips, and to analyse access distances to stations, we used data from a regional travel survey, conducted 2018 (Region Skåne, 2019). Disaggregate trip modes are registered in the survey, hence allowing analyses of access and egress trips preceding or following train trips. Unfortunately, disaggregate trip distances are not recorded, but the distance from each respondent's home and workplace to the nearest train station could be used instead.

Table 2 lists the filters used on the travel survey data for retrieving the needed information, and for making the selection of cases similar to the conditions in our case study group. The first step filtered out all trips not starting at home or ending at work or school, as these are the only trips for which we could estimate access and egress distances. The second and third steps were used to select train trips with single access modes. Some of the trips filtered out had multiple access modes, not suitable for our analysis, and some of them had no registered access mode at all, as access trips are occasionally omitted by the respondents. The fourth step filtered out long-distance trips, as our study focuses on regional travel. For this, we used a distance limit of 100 km, a reasonable limit in the context of our study area and also an accepted practice in Sweden (Swedish Ministry of Enterprise and Innovation, 2010). In the final step, we selected cases similar to the conditions in our case study, i.e. trips to or from rural areas including villages with up to 4000 inhabitants.

In the region, there are 35 stations located in villages with less than 4000 inhabitants. As a comparison to our sample size, roughly 15,000 daily trips were made to and from these stations, in total. To compensate for response distortion, the survey results were weighted with regard to gender, age, marital status, country of birth, and place of residence.

Access trip distances are given as Euclidean distances in the travel survey, and consequently, Euclidean distances were also used in our analysis. Actual network distances are longer.

4.4. Defining the primary and secondary catchment areas

For the primary catchment area, two different definitions were used. First, the analysis was conducted with the primary catchment area equalling a typical catchment area for walking access. Based on the travel survey data, the walking catchment areas were defined as buffers around the stations with radii corresponding to the 85th percentile of walking distances to rural train stations. The 85th percentile is a commonly used measure of catchment areas, and it has been proven that it can differ substantially from the conventionally assumed 400 or 800 m, for instance depending on the type and standard of the public transport service (El-Geneidy et al., 2014; O'Connor and Caulfield, 2018; van Soest et al., 2019). As an alternative to the walking catchment area, the analysis was also conducted with the primary catchment area equalling the village where the station is located. Urban areas (including villages) are delimited by Statistics Sweden, applying a definition of an urban area as a contiguous built-up area with at least 200 residents and no more than 200 m between houses (Statistics Sweden, 2019).

Table 2
Filters used on the travel survey data, and remaining number of trips (N).

Filter	N
All trips in the travel survey	75,373
1. Origin at home or destination at workplace or school	41,613
2. Train is the main trip mode	3707
3. Single trip mode used for access/egress	2531
4. Regional train trips, maximum 100 km	2177
5. Nearest station in village with less than 4000 inhabitants	372

The secondary catchment area was defined as the part of a station's catchment area outside the primary catchment area, where access trips typically are made by bicycle, by car, or by feeder bus. We acknowledged that the extent of the catchment area might differ between the longitudinal and lateral directions. In the longitudinal direction, we assumed that the catchment area extends halfway to the next station. In the lateral direction, the catchment area might extend further, depending on the public transport network structure. However, to avoid overlapping catchment areas, cars registered nearer to stations on other routes were excluded from the analysis.

4.5. Patronage in the primary and secondary catchment areas

Total patronage was calculated by simply adding up boardings and alightings at all stops in the area of interest, the primary and secondary catchment areas together. This was made for two points in time for each case. Transfers were accounted for so that such trips are not double counted.

In the control group, division of the patronage into the primary and secondary catchment areas was a straightforward procedure: Bus stops in a village were assorted to the primary catchment area, and bus stops outside the villages constituted the secondary catchment areas. The alternate definition of the primary catchment area, based on buffers around train stations, is not applicable in the control group.

To account for longer access trips to train stations, and the fact that cars and bicycles are more prominent access modes there, division of the patronage into the primary and secondary catchment areas required what can be described as statistical redistribution of origins and destinations. For example, in areas where all bus services have been suspended, all boardings and alightings take place at the new train station. In those cases, the patronage data does not reveal any information about how origins and destinations are divided between the primary and secondary catchment areas. For this, results from the analysis of travel survey data and vehicles at the park-and-ride facilities were applied. In practice, this means that some portion of the patronage at each station was subtracted from the primary catchment area, and added to the secondary catchment area. The size of this portion depends on the numbers of bicycles and cars at the particular location. In other words, the total number of public transport trips was determined by the patronage data, and the origins and destinations of these trips were estimated by an analysis of access and egress trips.

5. Results

5.1. Catchment areas

As described in section 4.4, we defined the primary catchment area of a station either as the walking catchment area or as the extent of the village where the station is situated.

Fig. 4 shows distance decay curves for access trips by foot and by bicycle, based on the travel survey. For access trips by foot, there seems to be a threshold around 1.0 km. The 85th percentile is found at 860 m, so the walking catchment area is approximated by a 860 m limit around each station.

The distance decay curve for bicycle access trips in Fig. 4 shows that the share of bicycle trips shorter than 860 m is 30%. This means that if the primary catchment area is defined as the walking catchment area, the majority of the bicycle access trips originate in the secondary catchment area. However, the travel survey data also indicates that roughly 60% of the bicycle trips originate in the village where the station is located. Hence, if the primary catchment area is instead defined as the extent of the village, most of the bicycle access trips originate in the primary catchment area.

The extent of the secondary catchment area is defined by car access trips. The geographical data about cars at the park-and-ride facilities revealed that our assumption that the catchment area in the longitudinal direction extends halfway to the next station proved plausible. This has implications also for the control group, and for the case study objects before the train stations were opened: The secondary catchment area includes all bus stops halfway to the next village. The halfway distances range from 1.5 to 7.0 km in the case study group (between stations) and from 2.0 to 8.4 km in the control group (between village centres). The average halfway distance is 4.2 km in both groups.

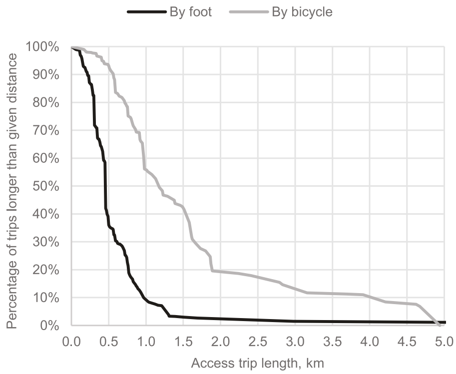

Fig. 4. Distance decay curves for access trips to train stations in rural areas, by foot (N = 159) and by bicycle (N = 94), based on the travel survey. Euclidean distances are used.

An example of a catchment area is displayed in Fig. 5, showing the village of Marieholm and its surroundings. The contour of the secondary catchment area is defined by the 11 cars that were parked at the park-and-ride facility and registered at addresses where Marieholm is the closest available station. As can be seen in the figure, the catchment stretches much further north than the halfway distances to the neighbouring stations that limit the catchment area to the east and west. This irregular shape is typical for most stations in our study, and the secondary catchment areas stretch as far as 16 km from a station. The average value is 8 km.

Fig. 6 shows distance decay curves for access trips by car, based on two different datasets: travel survey data and cars at the park-and-ride facilities. The two curves are similar, indicating that the car access trips in our study are typical for rural access trips by car in the county, a sign of validity of the data. As can also be seen in the figure, a considerable share of the trips are longer than the halfway distances between stations (1.5–7.0 km). This is mainly a result of catchment areas extending further in the lateral direction than in the longitudinal direction. Moreover, as much as 17% of the cars could not be assigned to the catchment areas, as they were registered closer to other stations than the ones where they were parked. This is why the distance decay curve extends further than the 16 km identified as the maximal distance in the catchment areas in the study.

Of the 214 cars that were assigned to the catchment areas, 10% were registered less than 860 m from the station. In addition, 9% were registered more than 860 m from the station but in the same village. The remaining 81% of the cars were registered in the rural areas surrounding the villages.

5.2. Total patronage in the primary and secondary catchment areas

With the catchment areas established, we were able to start analysing the development of public transport patronage in and around the villages. As a first step, we analysed total patronage in the primary and secondary catchment areas together, based on patronage data from all bus stops within halfway distances to neighbouring villages or stations.

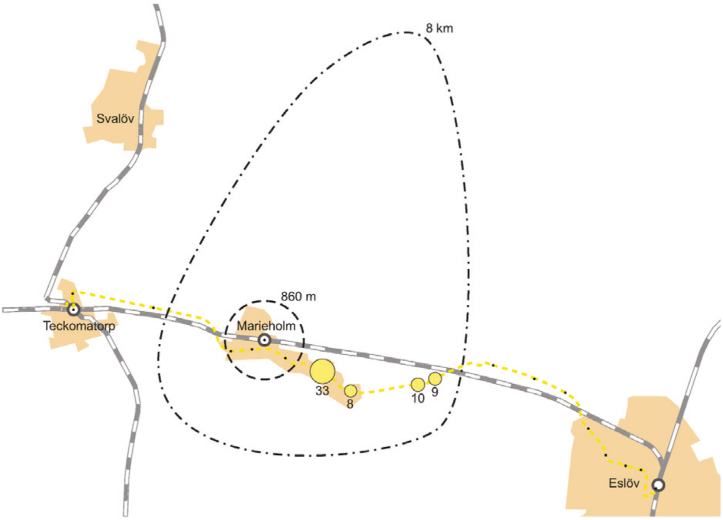

Fig. 5. Primary (dashed circle) and secondary (dash-dotted line) catchment areas around the station in Marieholm. The former bus route is shown as a yellow dashed line, with yellow circles indicating the former daily patronage at bus stops in the secondary catchment area. The patronage at these stops added up to 60 trips per day in 2009. In addition, there were three bus stops within the 860 m circle, with a total of 260 daily trips in 2009. In 2018, two years after the bus service was replaced, patronage had increased to 430 daily trips, all at the new train station. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

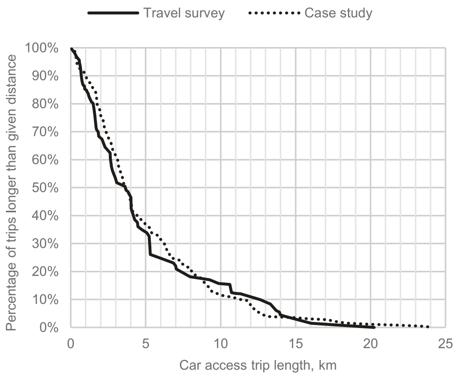

Fig. 6. Distance decay curves for access trips by car, according to the travel survey (N = 78) and for cars at the park-and-ride facilities (N = 258).

Fig. 7 shows a comparison of how patronage developed in the control group and the case study objects over a time period of eight years on average in both groups. The percentage numbers are totals for the entire catchment areas, i.e. including trips to and from the villages as well as the surrounding rural areas. As shown in the figure, patronage increased in and around all but two of the case study villages. In the control group, however, patronage decreased in and around as many villages as where it increased.

In total numbers, patronage increased in the control group from 5500 to 5700 trips per weekday (+4%). In the case study group, total patronage started from roughly the same level, but the increase is substantially larger: from 5700 to 7800 trips per weekday (+38%). The 7800 trips are the sum of 5600 train trips, 1500 bus trips on parallel routes, and 700 non-transfer trips on feeding bus services.

To analyse whether the difference between the groups is statistically significant, a Mann-Whitney U test was conducted. The test shows that patronage increased significantly more around the new stations than in the areas where bus services have remained ($U = 32$, $z = -3.03$, $p = .002$). The median value in the case study group ($n = 14$) is +35%, compared to −1% in the control group ($n = 14$).

5.3. *Patronage in the secondary catchment areas*

The secondary catchment area is the part of the catchment area that is either (1) more than 860 m from the station, or (2) outside the village where the station is located. The results in this section are first presented for the first definition, and are then converted to the second definition to be able to make a comparison with the control group.

To be able to estimate the number of car trips originating in the secondary catchment area, vehicles had to be converted into trips. All in all, 214 of the cars at the park-and-ride facilities were registered in the catchment areas. 192 of these cars were registered more than 860 m from a station. To account for missing data, this number was multiplied by 1.2 (328/273), assuming that vehicles missing in the registry or registered more than 25 km from a station are divided similarly as the other vehicles in the dataset. Furthermore, the travel survey revealed 0.6 car passenger trips for each trip as a car driver (including motorcycles and mopeds), implying 1.6 travellers per car. Assuming that each car makes a return trip to the station, this means 3.2 daily driver and passenger trips per car. So, accounting for missing data and passengers per car together add up to 3.8 trips per car. The 192 cars in the secondary catchment area then correspond to 730 daily trips.

For bicycles, the procedure is simpler but also less precise, as there is no vehicle registry to utilise in that case. The analysis is instead based on the numbers of bicycles at each station, and the distance decay curves derived from the travel survey data. Assuming that each bicycle corresponds to a return trip to the station, the 293 bicycles at the stations correspond to 586 daily access and egress trips. Based on the travel survey, we estimated that 70%, equalling 410 bicycle trips, have origin or destination more than 860 m from the station.

After estimating the numbers of passengers accessing the stations by car, by bicycle, and also by bus, we could determine that the remainder of the train passengers access the stations by foot. At most stations, this is

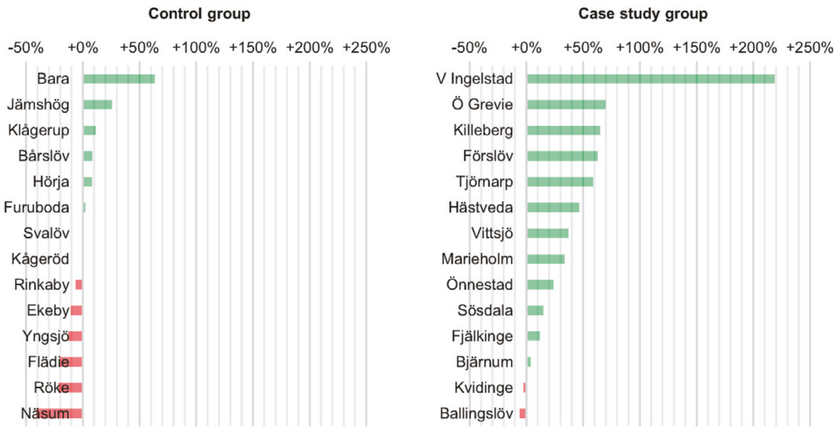

Fig. 7. Development of public transport patronage in and around the villages in the control group, where bus services have remained, and the case study villages, where a large part of the bus services have been replaced by rail services.

the dominant access mode. In total, roughly two thirds of the 5600 train trips are accessed by foot. As the primary catchment area is defined by the 85th percentile of walking distances, 15% of the access and egress trips by foot, equalling 540 trips, have origin or destination more than 860 m from the station.

The calculation of patronage in the secondary catchment areas (beyond 860 m from the stations) is summarised in Table 3. The first row in the table presents straightforward sums of boardings and alightings at bus stops in the secondary catchment areas. Unsurprisingly, as the bus services were substantially reduced, the number of boardings and alightings decreased in the secondary catchment areas after the introduction of rail services. The following rows in the table demonstrate the statistical redistribution, accounting for access trips to train stations originating in the secondary catchment area. With this redistribution, the result in the secondary catchment area shifts from a decrease to a considerable increase in patronage.

Table 4 shows the calculated total number of trips with origin or destination in the primary and secondary catchment areas, before and after the introduction of rail services. In percentages, the increase in the secondary catchment areas is roughly of equal magnitude as in the primary catchment areas. This is a result of larger catchment areas around the train stations compared to the previous bus services.

To be able to make comparisons with the control group, the results need to be converted from ‘within and beyond 860 m’ into ‘in and around villages’. For that conversion, we transferred bus stops more than 860 m from a station but in the same village to the primary catchment area. Also, the redistribution of origins and destinations was recalculated. The car becomes a more dominant access mode in the secondary catchment area in this case, as most of the car access trips originate outside the villages. Simultaneously, most of the bicycle access trips and practically all of the access trips by foot are in this case distributed to the primary catchment area.

Table 3
Calculation of patronage in the secondary catchment areas, beyond 860 m from stations in the 14 villages in the case study group. The numbers are trips per weekday with origin or destination in the area of study.

	Before rail (2008–2015)	With rail (2018)
Boardings and alightings at bus stops	1905	1125
Car access trips to train stations	0	733
Bicycle access trips to train stations	0	410
Access trips by foot to train stations	0	540
Sum of trips to and from secondary catchment areas	**1905**	**2808**

Table 4
Number of daily trips with origin or destination in the primary and secondary catchment areas in and around the 14 villages in the case study group.

	Before rail (2008–2015)	With rail (2018)	Change
Primary catchment area, within 860 m	3764	5030	+33%
Secondary catchment area, beyond 860 m	1905	2808	+47%
Total	**5673**	**7838**	**+38%**

The outcome of the conversion is that a larger portion of the trips have origins or destinations in the primary catchment areas. Still, in terms of increase percentages, the results are virtually unaltered.

A comparison of the results is illustrated in Fig. 8. The size of the bars in the figure represent the share of trip origins and destinations in the primary and secondary catchment areas. As shown in the figure, roughly one third of all trips originate or end more than 860 m from a station. One fifth of the trips originate or end outside the village where the station is located. These shares remain practically unchanged by the introduction of rail services.

For individual case study objects, the results for the rural areas outside the villages are generally based on relatively few trips. As a consequence, the results vary considerably. However, the general trend is clear: 10 cases display positive results, compared to 3 negative. The remaining case (Kvidinge) did not have any bus stops in the secondary catchment area outside the village.

In the control group, the trend is opposite. There, 13 cases display decreased patronage outside the villages. The remaining case (Yngsjö) did not have any bus stops in the secondary catchment area. In total, patronage outside the villages in the control group decreased with 24%. In contrast, patronage at bus stops in the villages increased with 8% during the same time period.

To analyse whether there is a statistically significant difference between the groups regarding patronage outside the villages, a Mann-Whitney U test was conducted. The test shows that there has been a

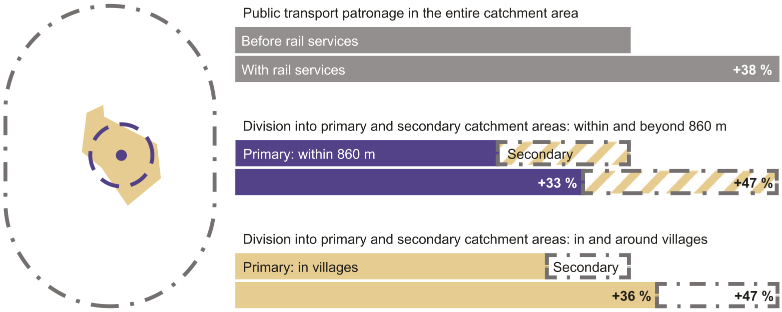

Fig. 8. Development of public transport patronage, from before (top bar in each pair) to after (bottom bars) the introduction of rail services, with different definitions of the primary catchment area.

significantly more positive patronage development in the rural areas around villages with new stations than in the rural areas where bus services have remained ($U = 24$, $z = -3.10$, $p = .002$). The median value in the case study group ($n = 13$) is +64%, compared to −28% in the control group ($n = 13$).

We also made a comparison of the different strategies for combining rail and bus services in the case study group. In total numbers, patronage increased more in areas where bus services were suspended in favour of increased rail service supply than in areas where some bus services were retained in parallel with the rail services. This applies to the primary and secondary catchment areas together (+44% and +17%, respectively), as well as the secondary catchment areas alone (+145% and +24%, respectively). However, the difference is not statistically significant (on the 95% level) in this case, due to the small number of observations for each strategy (for the primary and secondary catchment areas together $U = 6$, $z = -1.92$, $p = .055$; for the secondary catchment areas alone $U = 7$, $z = -1.46$, $p = .14$).

6. Discussion

In our study of public transport patronage in and around 28 villages in south Sweden, we found a clear and statistically significant difference around new train stations compared to areas where regional bus services have been kept. In total, patronage has increased in both groups, but the magnitude of the increase differs considerably: +38% at the new stations compared to +4% in the control group. The study hence confirms that concentration of public transport resources to high-demand routes and stops is an effective strategy for increasing patronage (Dodson et al., 2011; Nielsen et al., 2005), and shows that this can be valid also in rural areas. The drawback with longer access distances to the stations is generally outweighed by the quality of service improvements offered through the new rail services.

Interestingly, we also found that the patronage increase does not only occur in the immediate surroundings of the stations, but also outside the villages, in the rural areas where public transport services have been cut. Despite the loss of bus services, the number of public transport trips with origins or destinations in these areas increased in the period studied. Simultaneously, in the control group with retained bus services, patronage instead decreased in the rural areas around the villages. Hence, there is a clear and statistically significant difference between the rural areas around the new train stations and the rural areas in the control group. Overall, the new rail services are attracting passengers from larger catchment areas than the previous bus services.

Our results oppose the idea of distortion between the rural cores and their surrounding rural areas (Pettersson, 2018), at least in terms of public transport usage. In fact, our results suggest that there are equal magnitudes of patronage increase in the villages where the stations are located (the rural cores) and in the rural areas outside these villages. In absolute numbers, passenger flows are dominated by trips to and from the rural cores, but surprisingly, this dominance is not boosted by the removal of bus stops. It is particularly surprising since the trend in the control group is a clear decrease in public transport usage outside the villages, despite the fact that stopping patterns and service supply have remained practically unchanged in those cases.

However, this does not mean that projects involving reduction of bus services in favour of new rail services should not be questioned or debated. Our results show that an aggregate positive net effect will be a probable outcome, but the advantages and the disadvantages might not be evenly distributed among different population groups. Many access trips from the rural areas surrounding the villages are car trips, so for rural residents without access to a car the new rail or coach services will probably lead to deteriorating conditions for their independent mobility. It is possible that the accessibility of children, adolescents, older people and people with disabilities suffer to the benefit of other population groups.

One way to provide more transport options for access to the stations, and thereby improve accessibility for rural residents with no or limited access to a car, the rail services could be supplemented by feeding bus services, demand-responsive services, minibuses, taxis, school buses, and special transport services for older people and people with disabilities (Nielsen et al., 2005). For improved efficiency, there is in many cases scope for better coordination of these different transport services (ITF, 2015). Where such coordination is possible and where population density is adequate, conventional feeding bus services is generally the most efficient option (White, 2016b). In areas with lower population density, the feeding services may be offered as demand-responsive transport, i.e. pre-ordered services with flexible routes depending on the demand. There has been some interesting recent developments in this area, such as the Danish concept *Plustur*, specifically directed at connecting rural areas to the public transport network through demand-responsive services to the nearest bus stop or train station (Pettersson, 2019). Finally, it is also important to acknowledge the importance of better bicycling connections to the stations, as a means for improving multimodal accessibility in rural areas (Litman, 2018).

An important note in this respect is that feeding bus services differ from parallel bus services. Parallel bus services supplement the rail services by offering direct services in time slots between trains, not by feeding to the trains. Our results indicate that increasing the supply (frequency and operating hours) on the rail service is more efficient, in terms of patronage, than keeping parallel bus services. Patronage has increased more in areas where rail is now the only public transport option compared to areas where resources are distributed between parallel rail and bus services. However, these results are inconclusive; there is a clear difference between the groups in total numbers, but the number of observations is too small (six stations of each type) to draw a statistically sound conclusion.

The method presented in this paper may be useful for practitioners facing similar evaluations of changes in the regional network structure, where bus stops are removed in rural areas. The method requires only a limited amount of data collection, since much of the needed data generally already exists at the public transport authorities: patronage statistics and travel survey data. In addition, information about vehicles at park-and-ride facilities is also needed. Compared to our study, however, it is possible to simplify this data collection by omitting the geographical information about each vehicle, and what remains is then just to count the number of cars and bicycles at each station. The geographical information can be replaced by distance distribution numbers for access trips in the travel survey data.

In the control group, we observed a clear decrease in public transport usage outside the villages, despite practically unchanged service supply and stopping patterns. The results do not offer any explanation to this decrease, as the present study is focused on describing what has happened, not why. Possible reasons for the decrease could be an interesting topic for further investigations.

It would also be of value to conduct research into cases where conventional bus services are replaced by coach services with fewer stops. Travel time gains, and probably also other quality of service improvements, are generally not as prominent when new coach services are introduced, compared to rail services. In addition, there are indications of a general preference for trains over coaches and buses. Because of this, it is unclear whether our results are transferable to coach services.

7. Conclusions

This study has shown a significantly larger patronage increase in rural areas where regional bus services are replaced by rail services, compared to areas where regional bus services are kept. Moreover, the patronage increase does not only occur in the immediate surroundings of the stations. Outside the villages, in the rural areas where public transport services have been cut, the increase is of equal magnitude. Hence, our results oppose the idea of distortion between the villages and their surrounding rural areas, at least in terms of net effect on public transport usage.

For future research, we identify three important issues where more knowledge is needed. First, there is the question of whether similar results can be expected for coach services. The effects of removing stops is in this case largely unclear, in terms of travel time and reliability improvements and in the end in terms of effects on overall accessibility. Second, it would be interesting to see if the decrease in public transport usage outside the villages in the control group is part of a general trend, and to study the reasons for this decrease. Third, more research is also needed into how the removal of bus stops affects different population groups. This study has shown that a positive net effect is probable, but a study of the accessibility effects for different groups of the rural population is saved for future research.

Authors' contributions

Joel Hansson: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Visualization; Writing - original draft

Fredrik Pettersson-Löfstedt: Supervision; Writing - review & editing

Helena Svensson: Supervision; Writing - review & editing

Anders Wretstrand: Supervision; Writing - review & editing

Declaration of competing interest

None.

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References

Akbari, S., Mahmoud, M.S., Shalaby, A., Habib, K.M., 2018. Empirical models of transit demand with walk access/egress for planning transit oriented developments around commuter rail stations in the Greater Toronto and Hamilton Area. J. Transport Geogr. 68, 1–8. https://doi.org/10.1016/j.jtrangeo.2018.02.002.

Ben-Akiva, M., Morikawa, T., 2002. Comparing ridership attraction of rail and bus. Transport Pol. 9, 107–116. https://doi.org/10.1016/S0967-070X(02)00009-4.

Berg, J., 2017. En studie om effektiva och innovativa lösningar för kollektivtrafik på landsbygd - Slutrapport av regeringsuppdrag (VTI Rapport 955). Swedish National Road and Transport Research Institute (VTI), Linköping. www.vti.se.

Berg, J., Ihlström, J., 2019. The importance of public transport for mobility and everyday activities among rural residents. Soc. Sci. 8, 58. https://doi.org/10.3390/socsci8020058.

Brand, J., Hoogendoorn, S., Van Oort, N., Schalkwijk, B., 2017. Modelling multimodal transit networks integration of bus networks with walking and cycling. In: *2017* 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), pp. 750–755.

Camporeale, R., Wretstrand, A., Andersson, M., 2019. How the built environment and the railway network can affect the mobility of older people: analyses of the southern Swedish region of Scania. Res. Transp. Bus. Manag. 30, 100368. https://doi.org/10.1016/j.rtbm.2019.100368.

Dodson, J., Mees, P., Stone, J., Burke, M., 2011. The Principles of Public Transport Network Planning: A Review of the Emerging Literature with Select Examples (Urban Research Program, Issues Paper 15). Griffith University, Brisbane. www.griffith.edu.au/urp.

El-Geneidy, A., Strathman, J.G., Kimpel, T.J., Crout, D.T., 2006. Effects of bus stop consolidation on passenger activity and transit operations. Transport. Res. Rec. 32–41. https://doi.org/10.3141/1971-06.

El-Geneidy, A., Grimsrud, M., Wasfi, R., Tétreault, P., Surprenant-Legault, J., 2014. New evidence on walking distances to transit stops: Identifying redundancies and gaps using variable service areas. Transportation 41, 193–210. https://doi.org/10.1007/s11116-013-9508-z.

Farrington, J., Farrington, C., 2005. Rural accessibility, social inclusion and social justice: towards conceptualisation. J. Transport Geogr. 13, 1–12. https://doi.org/10.1016/j.jtrangeo.2004.10.002.

Hamer, P., 2010. Analysing the effectiveness of park and ride as a generator of public transport mode shift. Road Transp. Res. 19, 51–107.

Hansson, J., Pettersson, F., Svensson, H., Wretstrand, A., 2019. Preferences in regional public transport: a literature review. Eur. Transp. Res. Rev. 11, 38. https://doi.org/10.1186/s12544-019-0374-4.

Hasiak, S., Hasiak, F., Egea, A., 2016. Coach and train: differences in individuals perception of these modes. Transp. Res. Proc 14, 1706–1715. https://doi.org/10.1016/j.trpro.2016.05.136.

Hickman, R., Banister, D., 2014. Affluent rurality and car dependence (Oxfordshire). Transport, Climate Change and the City. Routledge, Abingdon, pp. 141–175.

ITF, 2015. International Experiences on Public Transport Provision in Rural Areas (International Transport Forum Policy Papers, No. 14). OECD Publishing, Paris. https://doi.org/10.1787/5jlwvz97dbbs-en.

Litman, T., 2019. Rural Multimodal Planning: Why and How to Improve Travel Options in Small Towns and Rural Communities. Victoria Transport Policy Institute retrieved from. https://www.vtpi.org/rmp.pdf.

Mamun, S.A., Lownes, N.E., 2014. Access and connectivity trade-offs in transit stop location. Transport. Res. Rec. 2466 https://doi.org/10.3141/2466-01.

Martens, K., 2004. The bicycle as a feedering mode: experiences from three European countries. Transport. Res. Transport Environ. 9, 281–294. https://doi.org/10.1016/j.trd.2004.02.005.

Midenet, S., Côme, E., Papon, F., 2018. Modal shift potential of improvements in cycle access to exurban train stations. Case Stud. Transp. Policy 6, 743–752. https://doi.org/10.1016/j.cstp.2018.09.004.

Mulley, C., Ho, C., Ho, L., Hensher, D., Rose, J., 2018. Will bus travellers walk further for a more frequent service? An international study using a stated preference approach. Transport Pol. 69, 88–97. https://doi.org/10.1016/j.tranpol.2018.06.002.

Murray, A.T., Wu, X., 2003. Accessibility tradeoffs in public transit planning. J. Geogr. Syst. 5, 93–107. https://doi.org/10.1007/s101090300105.

Nielsen, G., Nelson, J.D., Mulley, C., Tegnér, G., Lind, G., Lange, T., 2005. *HiTrans Best Practice Guide 2: Public Transport - Planning The Networks,* HiTrans, Oslo.

O'Connor, D., Caulfield, B., 2018. Level of service and the transit neighbourhood - observations from Dublin city and suburbs. Res. Transport. Econ. 69, 59–67. https://doi.org/10.1016/j.retrec.2018.07.014.

Petersen, T., 2016. Watching the Swiss: a network approach to rural and exurban public transport. Transport Pol. 52, 175–185. https://doi.org/10.1016/j.tranpol.2016.07.012.

Pettersson, F., 2018. Developing a regional superbus concept – collaboration challenges. Case Stud. Transp. Policy 6, 32–42. https://doi.org/10.1016/j.cstp.2017.12.003.

Pettersson, F., 2019. An International Review of Experiences from On-Demand Public Transport Services (K2 Working Paper 2019:5). K2, Lund.
Region Skåne, 2019. *Så reser vi i Skåne: Resvaneundersökningen 2018*. Region Skåne, Malmö.
Scherer, M., 2010. Is light rail more attractive to users than bus transit? Arguments based on cognition and rational choice. Transport. Res. Rec. 2144, 11–19. https://doi.org/10.3141/2144-02.
Scherer, M., Dziekan, K., 2012. Bus or rail: an approach to explain the psychological rail factor. J. Public Transp 15, 75–93. https://doi.org/10.5038/2375-0901.15.1.5.
Shrestha, R.M., Zolnik, E.J., 2013. Eliminating bus stops: evaluating changes in operations, emissions and coverage. J. Public Transp. 16 https://doi.org/10.5038/2375-0901.16.4.1.
Statistics Sweden, 2019. *Localities and urban areas*, Statistics Sweden, viewed 20 December 2019. https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/land-use/localities-and-urban-areas/.
Stewart, C., El-Geneidy, A., 2016. Don't stop just yet! A simple, effective, and socially responsible approach to bus-stop consolidation. Public Transp 8, 1–23. https://doi.org/10.1007/s12469-015-0112-9.
Swedish Ministry of Enterprise and Innovation, 2010. Ny Kollektivtrafiklag (Prop. 2009/10:200). Swedish Ministry of Enterprise and Innovation, Stockholm.
Šťastná, M., Vaishar, A., 2017. The relationship between public transport and the progressive development of rural areas. Land Use Pol. 67, 107–114. https://doi.org/10.1016/j.landusepol.2017.05.022.
Šťastná, M., Vaishar, A., Stonawská, K., 2015. Integrated transport system of the south-moravian region and its impact on rural development. Transport. Res. Transport Environ. 36, 53–64. https://doi.org/10.1016/j.trd.2015.02.012.
Tirachini, A., 2014. The economics and engineering of bus stops: spacing, design and congestion. Transport. Res. Part A Policy Pract. 59, 37–57. https://doi.org/10.1016/j.tra.2013.10.010.
Utsunomiya, K., Shibayama, T., 2020. Rail bonus: an empirical study onto relative valuation of railways in Austria. Transport Pol. https://doi.org/10.1016/j.tranpol.2020.04.005.
van Soest, D., Tight, M.R., Rogers, C.D.F., 2019. Exploring the distances people walk to access public transport. Transport Rev. https://doi.org/10.1080/01441647.2019.1575491.
Varela, J.M.L., Börjesson, M., Daly, A., 2018. Public transport: one mode or several? Transport. Res. Part A Policy Pract. 113, 137–156. https://doi.org/10.1016/j.tra.2018.03.018.
Vijayakumar, N., El-Geneidy, A., Patterson, Z., 2011. Driving to suburban rail stations: understanding variables that affect driving distance and station demand. Transport. Res. Rec. 2219, 97–103. https://doi.org/10.3141/2219-12.
Ward, M.R.M., Somerville, P., Bosworth, G., 2013. "Now without my car I don't know what I'd do": the transportation needs of older people in rural Lincolnshire. Local Econ. 28, 553–566. https://doi.org/10.1177/0269094213495232.
Werner, C.M., Brown, B.B., Tribby, C.P., Tharp, D., Flick, K., Miller, H.J., Smith, K.R., Jensen, W., 2016. Evaluating the attractiveness of a new light rail extension: testing simple change and displacement change hypotheses. Transport Pol. 45, 15–23. https://doi.org/10.1016/j.tranpol.2015.09.003.
White, P., 2016a. Rural public transport. In: Public Transport: its Planning, Management and Operation. Routledge, Oxford, pp. 201–221.
White, P., 2016b. The roles of 'conventional' and demand-responsive bus services. In: Mulley, C., Nelson, J.D. (Eds.), Paratransit: Shaping the Flexible Transport Future (Transport and Sustainability, vol. 8. Emerald Group Publishing Ltd., London, pp. 307–330. https://doi.org/10.1108/S2044-994120160000008015.

Paper 3

Public Transport
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ORIGINAL RESEARCH

Effects of rural bus stops on travel time and reliability

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Abstract

Due to relatively low patronage levels, rural bus stops are sometimes questioned in order to improve travel time and reliability on regional bus services. Previous research into stop spacing has focused on urban areas, which means that there is a lack of knowledge regarding the effects of bus stops in regional networks, with longer distances, higher speeds, and lower passenger volumes, in general. The present study addresses this knowledge gap by analysing the effects of bus stops on a regional bus service regarding average travel times, travel time variability, and on-time performance. This is done by statistical analysis of automatic vehicle location (AVL) data, using a combination of methods previously used for analysis of rail traffic and urban bus operations. The results reveal that bus stops that are only used sporadically have a limited impact on average travel times, in general. In contrast, they are all the more influential on travel time variability, and, in turn, on on-time performance. On the studied bus service, the number of stops made have a far greater impact on travel time variability than any of the other included variables, such as the weather or traffic conditions during peak hours. However, the results suggest that rural bus stops have a much lower impact than what we define as secondary bus stops in urban areas. Consequently, by primarily focusing on bus stop consolidation in urban areas, it is possible to significantly improve service reliability without impairing rural coverage.

Keywords Regional public transport · Rural accessibility · Stop spacing · Delays · Travel time variability · Bus service planning

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1 Introduction

Bus stop locations and stop spacing are central elements in public transport planning. Essentially, stop spacing implies a trade-off between coverage and patronage (Walker 2008). A reduction in the number of stops will make the service inaccessible to some citizens along the route; more stops will make the service slower and travel times less predictable. Increased travel time and reduced reliability in turn lead to decreased patronage. The trade-off is far from trivial, as there are many aspects to consider as well as a complex dynamic in the interplay between these aspects. For example, the primary effects of stop spacing on travel time and reliability in turn affect operating cost and fleet size. Alternatively, lower costs can be converted to a higher quality of service, for example in the form of higher service frequencies (Stewart and El-Geneidy 2016). These so-called secondary effects occur at increasing scale as the primary effects on travel time and reliability increase (Currie 2016). Interestingly, there is also a loop back to coverage, as changes in travel time, reliability, and frequency affect access distances. A higher quality of service means that passengers are willing to accept longer access distances to reach the public transport service (Mulley et al. 2018; van Soest et al. 2020; Hansson et al. 2021).

Previous research into stop spacing has focused on urban areas, typically studying either the effects of bus stop consolidation (e.g. El-Geneidy et al. 2006; Shrestha and Zolnik 2013) or developing methods for assessing optimal stop locations (e.g. Murray and Wu 2003; Tirachini 2014; Stewart and El-Geneidy 2016). The importance of taking different land use types and densities into account is acknowledged (Chen et al. 2016), but still within the urban realm. The perspectives of rural areas and regional public transport seem to be overlooked. The primary effects in question—network coverage, travel time, and reliability—are commonly all among the top priorities for regional passengers (Hansson et al. 2019). However, based on the identified set of literature, the trade-off between these attributes, in terms of stop spacing, is not particularly well understood in regional networks, which cover both urban and rural areas.

The regional scale and rural setting mean different preconditions for the trade-off. Longer distances, higher speeds, and lower passenger volumes are typical features distinguishing regional from urban public transport (Luke et al. 2018). All of these features have important implications for stop spacing. First, long trip distances imply longer access distances in general, and that cars and bicycles are more prominent access modes to bus stops (Martens 2004; Nielsen et al. 2005; Vijayakumar et al. 2011; Midenet et al. 2018). Second, high maximum speeds mean that each stop has a greater impact on travel times and delays, due to longer deceleration and acceleration times. Third, low passenger volumes affect the consistency of stopping patterns. Stops with passenger activity (boardings or alightings) only on a small proportion of the available bus trips will cause travel time fluctuations, which may in turn cause decreased reliability (Stewart and El-Geneidy 2016).

The purpose of this study is to increase knowledge regarding the impact of rural bus stops. An example of a rural bus stop is shown in Fig. 1. The bus stops

Fig. 1 An example of a rural bus stop on the studied bus service

in question are located between villages and towns on regional bus services. The existence of these bus services often depends on interurban trips, but they commonly also serve rural areas along the route as well as local collection and distribution of passengers in urban areas (White 2016). Many rural bus stops are characterised by relatively low levels of passenger activity, but may still be crucial for maintaining a certain level of coverage in rural areas. This coverage is essential for parts of the rural population who depend on public transport for their everyday mobility (Berg and Ihlström 2019), and it may also be associated with symbolic values regarding the possibility to live in rural areas outside the rural cores (Pettersson 2018). These symbolic values are possibly associated with so-called non-use values, whose importance depends on the number of available transport options (Bondemark and Johansson 2017). Consequently, the potential removal of bus stops can cause considerable resistance among residents and their local politicians, regardless of the low levels of passenger activity. A natural argument with this resistance is the assumption that rural bus stops hardly affect overall travel times, as buses rarely need to stop there.

The aim of the present study is to explore this assumption, and thus increase knowledge about the trade-off between coverage and patronage on regional bus services, by looking into the effects of rural bus stops regarding different aspects of travel time and reliability:

- What are the effects on average travel times?
- What are the effects on travel time variability and on-time performance?

The analyses are carried out at two different scales to be able to discern the effects of individual stops as well as aggregated effects on the route level. This is done by combining a method previously used for investigating rail traffic delays (Palmqvist et al. 2017) with another method developed for detailed statistical analysis of service reliability in bus operations (El-Geneidy et al. 2011), and summary statistics concerning stop patterns and on-time performance. The present study makes use of an adaption of these methods, specifically for exploring the impact of different types of bus stops.

2 Methods

To be able to discern the effects of different types of bus stops, the analysis is based on a categorisation regarding the location and function of the stops. Three categories are defined and used, of which category 3 corresponds to the rural bus stops that are the focal point of the analysis:

1. Main bus stop in an urban area (town or village). Bus stops in this category are typically located in the centre of an urban area, and they also typically have higher levels of passenger activity than other nearby bus stops do.
2. Secondary bus stops in urban areas, i.e. bus stops in towns or villages that are not in category 1.
3. Rural bus stops (outside urban areas), located en route between villages and towns.

A key notion in the categorisation is ‘urban areas’, which may have slightly varying meanings from an international perspective. The present study was done in a Swedish context, where an urban area is defined as a contiguous built-up area with at least 200 residents and no more than 200 m between houses (Statistics Sweden 2020).

Travel time is a compound of different components, such as access trip time, waiting time, and in-vehicle trip time. The analysis in this article is centred on the operational equivalent of in-vehicle trip time: bus travel time. Bus travel time is the amount of time it takes a bus to travel along its route, and it can be divided into two main components: run time and dwell time (Büchel and Corman 2020).

Reliability is assessed through measures of travel time variability and on-time performance. Travel time variability is the variability in travel time between different bus trips on the same route. In this study, travel time variability is evaluated through the reliability buffer index, which is the relative difference between the 95th percentile of travel time and the average travel time (Hu and Shalaby 2017). In contrast, on-time performance is a timetable-based measure of reliability, measured by the fraction of services with schedule deviation within some defined threshold values (Zhao et al. 2013). In this study, on-time performance is measured by the percentage of buses arriving less than 3 min later than scheduled arrival. The measure in this study is only used for arrival times at the terminus, so early arriving buses and buses arriving up to 3 mins behind schedule are considered to be on time. The 3-mins threshold is commonly used in the regional context of the case analysed in this article.

To evaluate bus travel times and on-time performance, the core of the analysis is based on automatic vehicle location (AVL) data. The AVL data used in this study contain time logs at each bus stop along the route, with scheduled and actual arrival and departure times. As such, it represents a typical, commonly available AVL dataset, offering the possibility to analyse large amounts of bus trips (Büchel and Corman 2020). To supplement the AVL data, two other datasets were added. First, in order to include passenger activity (boardings and alightings) in the analysis, information was retrieved from automatic passenger counting systems (APC) on-board. Second, a dataset of weather observations was added to include the effects of weather conditions.

To be able to measure the impact of different types of bus stops, both in detail and on an aggregated level, assessments were carried out at two different scales: at the time-point segment level and at the route level. As illustrated in Fig. 2, a time-point segment is a route segment between two consecutive time points, i.e. major bus stops where early arriving buses are held to adjust to the schedule. Time points are typically category 1 bus stops according to the categorisation used in this study. As dwell time at time points is excluded at this level of analysis, bus travel times are not blurred by schedule adjustment time. This enables the use of detailed statistical analysis to understand the causes of travel time variability (El-Geneidy et al. 2011). The route level analysis, on the other hand, relies on summary statistics to illustrate the aggregate effects of stop pattern consistency on travel time variability and on-time performance.

The time-point segment analysis is based on a method previously developed for analysing delays in rail traffic (Palmqvist et al. 2017), using a combination of *t*-tests, plots for different explanatory variables against average bus travel times, and multivariate regression models. First, Welch's *t*-test was used to gain an initial understanding, depicting statistical significance and effect size of the explanatory variables on bus travel time between time points. To this end, for each *t*-test, the dataset was segmented into two groups based on the value of the explanatory variable, e.g. temperatures above or below zero. Second, to get a more nuanced picture, each explanatory variable was binned into a larger number of bins and plotted against average bus travel time. With one exception, these plots are not presented in the article, but the main results are reproduced in text. The results of the *t*-tests and the plots serve as a basis for the selection and transformation of appropriate variables to include in the final step of the time-point segment analysis, the ordinary least square regression models. Three different regression models were estimated, for three different dependent variables:

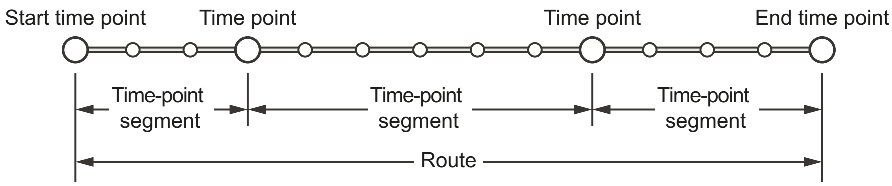

Fig. 2 Schematic diagram of the two levels of analysis: time-point segment and route

- *bus travel time*, to be able to compare the influence of bus stops with other factors
- *run time*, to determine additional time for deceleration and acceleration at bus stops en route
- *dwell time at bus stops along the segment*, to produce separate estimates of technical dwell time and dwell time related to passenger activity.

The variables included in the analyses are described in Table 1. The focal relationship in the study is between the number of stops made and travel time. The actual number of stops made on a specific bus trip depends on the passenger activity at the intermediate bus stops, since buses do not stop at intermediate bus stops without any boardings or alightings. In other words, the focus of the study is on how the variability of the actual number of stops made affects the travel time variability. To be able to compare the impact of the bus stops with other factors, and to control the influence of these factors on the focal relationship, variables concerning day type, time of day, delay status, weather conditions, and passenger activity were included in the analyses. The selection of explanatory variables is based on previous studies on travel time variability (El-Geneidy et al. 2011; Palmqvist et al. 2017), combined with data availability considerations. Infrastructure variables were not included, due to the small number of time-point segments and, consequently, a

Table 1 Description of variables used in the time-point segment analyses. Bus travel time, run time, dwell time, and excess bus travel time are the dependent variables

Variable	Unit	Description
Bus travel time	s	Time between departure from a time point and arrival at the subsequent time point
Run time	s	Time spent between bus stops, i.e. bus travel time excluding dwell time
Dwell time	s	Time spent at bus stops along the segment
Excess bus travel time	–	Ratio between bus travel time and free-flow run time
Free-flow run time	s	Minimum run time, estimated through division of distance by speed limit
Day type	–	Workday (1–5), Saturday (6), or Sunday (7)
Time of day	–	Hour of planned arrival at the end of the segment
Schedule deviation at start	s	Deviation from the schedule at the beginning of the time-point segment, where negative values indicate early departures and positive values indicate delayed departures
Temperature	°C	Air temperature, measured hourly
Precipitation	mm/h	Amount of rain or snowfall during 1 h
Wind	m/s	Average wind speed over a 10-min period, measured hourly
Snow	m	Snow depth, measured daily
Stops made	–	Number of stops made at intermediate bus stops, in total or per bus stop category
Boardings	–	Number of boarding passengers at intermediate bus stops
Alightings	–	Number of alighting passengers at intermediate bus stops

too small variability of the infrastructure conditions. However, the effects of varying traffic conditions are captured by the day type and time of day variables.

To be able to analyse travel times across different time-point segments with differing lengths and speeds, the free-flow run time on each of the segments was used as a basis for the analyses on this level. The free-flow run time corresponds to the minimum run time on the segment, in no-traffic conditions and without any intermediate stops. To keep the calculations simple, the free-flow run time in this study was estimated for each time-point segment through division of distance by speed limit. In practice, there are more factors to take into account, such as turns where buses need to slow down. However, the simple estimate was deemed accurate enough for the purpose of this study.

The route level analysis was carried out to understand the aggregate effects over several time-point segments. First, the variability in stopping patterns on the route level was analysed through descriptive statistics of central locations and variability, in each bus stop category and in total. Second, the influence of this stopping pattern variability on the travel time variability was assessed by calculating the reliability buffer index depending on the number of stops made. Third, the effects on on-time performance were evaluated in a similar manner, to assess also how on-time performance varies with the number of stops made. On-time performance is measured for arrivals at the end time point on the route.

3 Case

The bus service analysed in this study, route 545, is a 50 km long connection between the southern Swedish towns of Osby (population 7700) and Kristianstad (population 41,300). A map of the route is shown in Fig. 3. Through trips between Osby and Kristianstad are rare on the bus service, as both towns are connected through the rail network, which offers a faster alternative. Thus, the main purpose of route 545 is to provide connections to the five smaller towns and villages en route. The main bus stops (bus stop category 1) in these five urban areas constitute the time points on the service, which means that there are six time-point segments.

The bus stops along the route are located around every 400–1000 m in urban areas, but are more widely spaced outside of urban areas, depending on the location of population. All in all, there are 34 bus stops along the route. As shown in Fig. 4, almost half of them are located outside urban areas (category 3). However, the passenger activity (number of boardings and alightings) at these bus stops corresponds to just 2% of the total amount of passenger activity along the route. Thus, roughly 98% of the passenger activity takes place at the 19 bus stops located in urban areas. Of these, the seven main bus stops (category 1, including the two termini) dominate in terms of passenger activity, despite the fact that they are outnumbered by the secondary bus stops (category 2).

The bus stop categories differ not only in terms of numbers and passenger activity, but also regarding infrastructure conditions. The main bus stops (category 1) are generally terminals, separated from other traffic (with one exception: Bjärlöv, where the main bus stop is located on the shoulder of the main road). The other

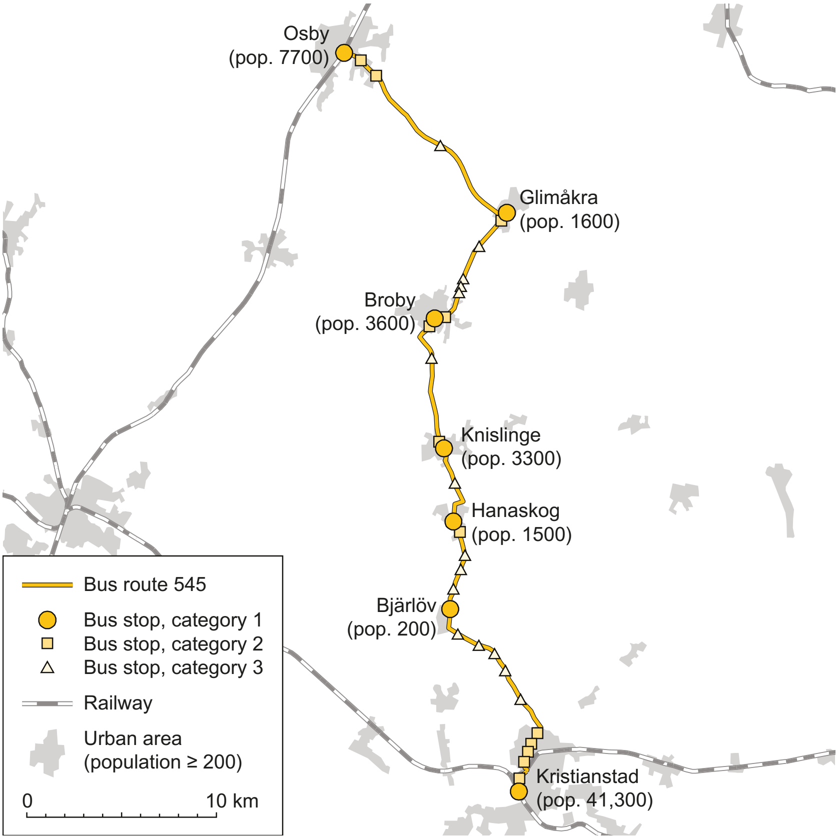

Fig. 3 Map of the analysed bus service. The bus stops in category 1 are also time points

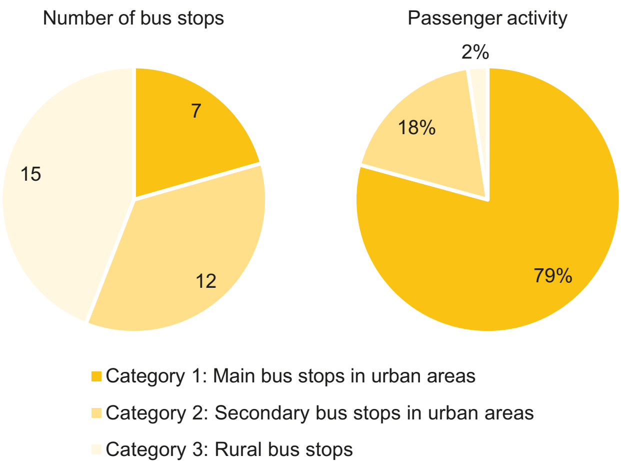

Fig. 4 Number of bus stops and passenger activity per bus stop category

bus stops (category 2 and 3) are typically bus bays, or in some cases in-lane bus stops, with important differences between the bus stop categories regarding speed limits. The secondary bus stops in urban areas (category 2) are located along roads with speed limits 40–60 km/h, and the rural bus stops (category 3) are located along roads with higher speed limits, 80–90 km/h. All roads along the route are generally uncongested.

The choice of route 545 as the case for this study was not only based on the distinctive features of the different bus stop categories, but also on the relatively generous frequency. A high frequency means that an extensive set of data is available for analysis. Buses between Osby and Kristianstad depart hourly all days of the week, and every half hour during peak hours. On the section between Broby and Kristianstad (approximately 30 km), the frequency is more than doubled, overall. There, buses depart every 10 min during peak hours.

Southbound bus trips made during 2019 were chosen for the analysis, corresponding to a total of 17,471 bus trips and 84,865 observations on the time-point segment level. The AVL data were subjected to a detailed scan to remove records with errors at one or several bus stops along the segment ($N=17{,}775$) as well as extremes with bus travel times more than twice as long as the scheduled travel time ($N=22$). This means that 67,068 time-point segment observations (79%) remained in the sample for further analysis, whereas 24,944 records (29% of the total sample) were associated with APC equipped buses and could thus be linked to data on passenger activity.

To be able to include as many bus trips as possible in the route level analysis, this part of the study focuses on the common section for both trip patterns in the timetable: Broby–Kristianstad. Analogous to the time-point segment level, records with errors at any of the bus stops along the route were removed ($N=6825$) together with extremes with bus travel times more than twice as long as the scheduled travel time ($N=1$). This means that 10,645 route level observations (61%) remained in the sample for further analysis. The larger share of missing AVL data at the route level is explained by a larger risk of data errors at intermediate bus stops, simply due to a larger number of bus stops on the route than on any of the individual time-point segments.

4 Results

4.1 Time-point segment analysis

Statistics for the analysed time-point segments are shown in Table 2. As can be seen in the table, the time-point segments differ substantially in terms of distances and average travel times. The numbers of observations also vary, depending on a more frequent service on the four southernmost segments and varying amounts of missing data. However, the travel time variability is relatively stable across the different time-point segments, expressed in the table by the reliability buffer index (RBI)—the relative difference between the 95th percentile and the average travel time.

Table 2 Summary statistics for the analysed time-point segments

Time-point segment	Sample size	Distance	Free-flow run time	Average travel time	RBI
Osby–Glimåkra	4714	12.9 km	722 s	831 s	16.6%
Glimåkra–Broby	6303	7.3 km	424 s	504 s	17.0%
Broby–Knislinge	14,494	7.8 km	426 s	566 s	16.8%
Knislinge–Hanaskog	15,315	4.4 km	279 s	349 s	16.0%
Hanaskog–Bjärlöv	14,816	5.0 km	253 s	306 s	21.4%
Bjärlöv–Kristianstad	11,426	12.4 km	668 s	915 s	18.4%

To ease comparison across different time-point segments, bus travel time was transformed in the *t*-tests and plots to a variable called *excess bus travel time*, defined as the ratio between bus travel time and free-flow run time. As an example, a value of 1.3 means that the bus travel time is 30% longer than the free-flow run time. The average free-flow run time in the sample is 416 s, so each percentage point corresponds to roughly 4.2 s on average.

The *t*-test results are reported in Table 3, comparing the mean value and standard deviation of excess bus travel time for different groups of the sample based on the values of each of the explanatory variables. As can be seen on the *p*-values in the table, the *t*-tests indicate that all the studied variables have a statistically significant impact on the excess bus travel time (on the 5% level), but due to the large sample size, statistical significance can be found even for weak effects (Lin et al. 2013). The difference between the means is relatively small in some cases, resulting in low estimates of the effect size. The effect size, i.e. the amount of impact a variable has on the excess bus travel time, is in the table estimated through Cohen's *d*. As a rule of thumb, *d* values of 0.8, 0.5 and 0.2 represent large, medium, and small effect sizes, respectively (Fritz et al. 2012). Thus, the results indicate that the number of stops made has a large amount of impact, with a substantially higher *d* value than any of the other studied variables.

Table 3 Results of Welch's *t*-test, using excess bus travel time as dependent variable

Variable	Value	Mean	*SD*	Value	Mean	*SD*	*t*	*p*	Cohen's *d*
Day type	1–5	1.273	0.148	6–7	1.234	0.141	26.4	<0.001	0.26
Time of day (hour, weekdays only)	7	1.320	0.162	$\neq 7$	1.268	0.146	22.8	<0.001	0.35
Schedule deviation at start (s)	>0	1.270	0.147	≤ 0	1.247	0.150	14.8	<0.001	0.16
Temperature (°C)	≤ 0	1.271	0.153	>0	1.266	0.147	2.4	0.016	0.03
Precipitation (mm/h)	>0	1.271	0.147	0	1.266	0.148	3.7	<0.001	0.04
Wind (m/s)	>2	1.269	0.149	≤ 2	1.263	0.146	5.6	<0.001	0.04
Snow (m)	>0	1.283	0.154	0	1.265	0.147	7.8	<0.001	0.12
Stops made	>0	1.332	0.142	0	1.203	0.124	124.5	<0.001	0.96

However, as *t*-tests are limited to comparing two groups at a time, these results merely represent the first step of the analysis. To obtain a more nuanced picture, excess travel time was also plotted against each of the variables.

An example is presented in Fig. 5, illustrating how bus travel times vary over the course of the day. As shown in the diagram, there are distinct peaks at 7 a.m. and 4 p.m. Furthermore, travel times drop significantly after 7 p.m. Analogous plots for Saturdays and Sundays reveal that travel times are more stable during weekends, at levels similar to weekdays after 7 p.m. As a result, the day type and time of day variables were transformed into three dummy variables in the regression models: a.m. peak (weekdays 07:00–07:59), p.m. peak (weekdays 16:00–16:59), and off-peak (weekdays from 19:00, Saturdays, and Sundays). The reference category can be interpreted as inter-peak hours (weekdays before 7 p.m. except peak hours).

The impact of deviation from the schedule at the beginning of the time-point segment is also more complex than what is revealed by the *t*-tests. The shortest bus travel times are found around zero deviation, i.e. when buses depart on time. Both early and delayed departures are associated with longer travel times. To fit the linear regression models, this variable was therefore split into two separate variables: one with early departures (negative values, otherwise zero) and one with actual delays at departure (positive values, otherwise zero).

The weather variables seem to have less of an impact on the bus travel time. Based on the plots for these variables, precipitation, wind, and snow were all assumed to be linearly related to bus travel time. The exception is temperature, which was replaced by a dummy variable for temperatures at or below zero.

Boardings and alightings were not included in the *t*-tests, as that would not add any useful information, but the plots indicate decreasing time spent for each

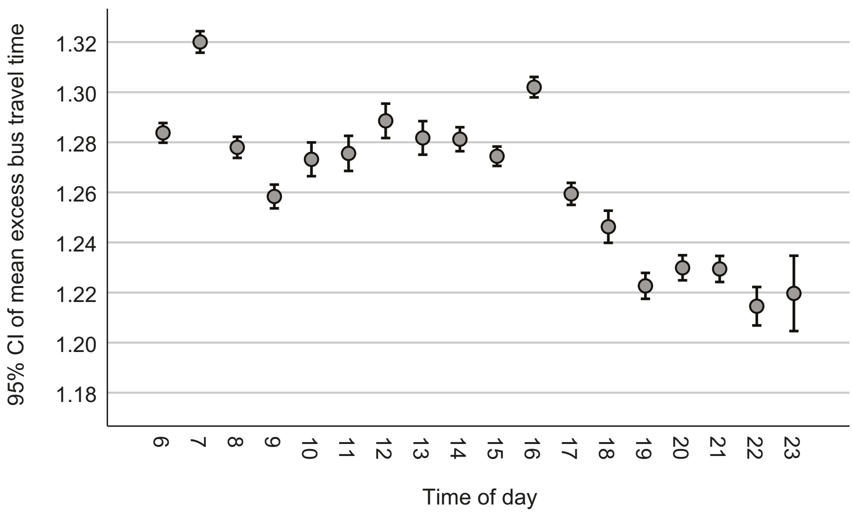

Fig. 5 Mean excess bus travel time against time of day on weekdays. Excess bus travel time is the ratio between bus travel time and free-flow run time. Error bars represent 95% confidence intervals of the mean values

additional passenger. To deal with this non-linear feature, squared terms for boardings and alightings were added to the regression analysis.

The variables, in some cases transformed according to the results of the *t*-tests and plots, were then incorporated in three regression models with different dependent variables: bus travel time, run time, and dwell time. Analogous to the *t*-test results, many of the explanatory variables have low *p*-values in the regression models, due to the large sample size. This means that when interpreting the results, it is important to keep in mind the difference between statistical and practical significance (Lin et al. 2013). Consequently, the description of the results is focused on coefficients (b), variability of the explanatory variables, and standardised coefficients (β). The standardised coefficients refer to how many standard deviations the dependent variable will change per standard deviation increase in the explanatory variable. Furthermore, 95% confidence intervals for the unstandardised coefficients are reported in the regression result tables, adding information about the ranges for the actual magnitudes of the parameters of interest.

The first model, the bus travel time model, is presented in Table 4. As a basis, a coefficient (b) of 1.15 for free-flow run time means that the average bus travel time will be 15% longer than the calculated free-flow time if all other variables are held at zero. The other variables then explain the travel time variability on each time-point segment. For example, bus travel times during the a.m. peak are on average 20 s longer than off-peak travel times if all other variables are held at their average

Table 4 Regression results with bus travel time (in seconds) as the dependent variable

	b	95% CI	β	t	p
Constant	9.016	[7.480, 10.552]	–	11.5	<0.001
Free−flow run time (s)	1.149	[1.146, 1.152]	0.821	718.8	<0.001
Period (ref.: inter-peak)					
a.m. peak	13.535	[11.976, 15.093]	0.016	17.0	<0.001
p.m. peak	11.321	[9.723, 12.918]	0.013	13.9	<0.001
off-peak	− 5.993	[− 6.954, − 5.032]	− 0.012	− 12.2	<0.001
Schedule deviation at start					
Early (s)	− 0.585	[− 0.613, − 0.557]	− 0.038	− 41.0	<0.001
delayed (s)	0.031	[0.027, 0.034]	0.017	18.5	<0.001
Temperature (ref.: >0 °C)					
≤0 °C	2.705	[1.281, 4.128]	0.004	3.7	<0.001
Precipitation (mm/h)	0.964	[0.282, 1.646]	0.003	2.8	0.006
Wind (m/s)	0.274	[− 0.004, 0.551]	0.002	1.9	0.053
Snow (m)	62.581	[45.397, 79.765]	0.007	7.1	<0.001
Stops made					
Category 2	39.637	[39.163, 40.111]	0.191	164.0	<0.001
Category 3	42.351	[41.183, 43.519]	0.068	71.1	<0.001

Model statistics

$F=96{,}018$; $p<0.001$; $N=67{,}068$; adjusted $R^2=0.945$

b = unstandardised coefficient; 95% CI = 95% confidence interval for b; β = standardised coefficient

values. Buses departing from a time point ahead of schedule are slower than buses departing on time. Buses departing behind schedule are also somewhat slower. The weather variables have a relatively limited impact. For example, bus travel times are roughly 3 s longer if the temperature is below zero. Rain or snowfall will typically cause even less additional travel time, except for some rare cases with exceptionally heavy rainfall. Maximum precipitation in the sample is 18 mm during 1 h, which would correspond to 17 s additional travel time according to the regression model. Snow depth has a larger coefficient, but the maximum snow depth in the sample is 0.16 m, so the impact is still relatively limited.

Each stop made at a bus stop on the time-point segment increases bus travel time by 40 s on average for secondary bus stops in urban areas (category 2), and by 42 s on average for rural bus stops (category 3). These variables have the highest values regarding the standardised coefficient (β) among the variables that determine the travel time variability on each time-point segment. This indicates that bus stops along the time-point segments, in particular for category 2, have a greater impact on the travel time variability than any of the other variables.

In the second model, the run time model shown in Table 5, the coefficients (b) for number of stops made correspond to the average time needed for deceleration and acceleration. As the bus stops in category 3 are located along roads with higher speed limits, the coefficient is larger for category 3 (26 s) than for category 2 (19 s).

Table 5 Regression results with run time (in seconds) as the dependent variable

	b	95% CI	*β*	*t*	*p*
Constant	8.266	[6.835, 9.696]	–	11.3	< 0.001
Free-flow run time (s)	1.153	[1.150, 1.156]	0.891	774.5	< 0.001
Period (ref.: inter-peak)					
a.m. peak	14.289	[12.837, 15.741]	0.018	19.3	< 0.001
p.m. peak	12.802	[11.315, 14.290]	0.016	16.9	< 0.001
off-peak	– 6.897	[– 7.792, – 6.001]	– 0.015	– 15.1	< 0.001
Schedule deviation at start					
Early (s)	– 0.602	[– 0.628, – 0.576]	– 0.042	– 45.2	< 0.001
Delayed (s)	0.026	[0.023, 0.029]	0.016	17.0	< 0.001
Temperature (ref.: > 0 °C)					
≤ 0 °C	2.368	[1.042, 3.694]	0.003	3.5	< 0.001
Precipitation (mm/h)	0.721	[0.086, 1.356]	0.002	2.2	0.026
Wind (m/s)	0.112	[– 0.147, 0.370]	0.001	0.8	0.398
Snow (m)	64.068	[48.062, 80.074]	0.007	7.8	< 0.001
Stops made					
Category 2	19.176	[18.735, 19.617]	0.100	85.2	< 0.001
Category 3	25.901	[24.813, 26.989]	0.045	46.7	< 0.001

Model statistics

$F = 94{,}510$; $p < 0.001$; $N = 67{,}068$; adjusted $R^2 = 0.944$

b = unstandardised coefficient; 95% CI = 95% confidence interval for b; β = standardised coefficient

All other variables have similar coefficients as in the first model, meaning that they affect bus travel time and run time similarly.

Finally, the third model, presented in Table 6, suggests that dwell time at bus stops along the time-point segment is defined primarily by the number of stops made and by the passenger activity at these stops. The coefficient for stops made in this case represents the technical dwell time, i.e. the time for opening and closing doors, and the waiting time for the bus to merge back into traffic. The average technical dwell time is 9 s per stop at bus stops in category 2 and 10 s per stop at bus stops in category 3. A boarding passenger adds approximately 8 s to the dwell time, an alighting passenger adds about 2 s, and the negative squared terms indicate that the time associated with passenger boardings and alightings decreases with each additional passenger. All buses on the studied service are low-entry buses, which is a contributing factor to the relatively short boarding and alighting times.

The variables for the number of stops made, boardings, alightings, and their squared terms are correlated, causing potential multicollinearity issues in the dwell time model, indicated by a maximum variance inflation factor (VIF) score of 6.0.

Table 6 Regression results with dwell time (in seconds) as the dependent variable

	B	95% CI	*β*	*t*	*p*
Constant	− 0.549	[− 1.062, − 0.035]	–	− 2.1	0.036
Period (ref.: inter-peak)					
a.m. peak	− 2.049	[− 2.854, − 1.244]	− 0.020	− 5.0	< 0.001
p.m. peak	− 1.740	[− 2.549, − 0.930]	− 0.016	− 4.2	< 0.001
Off-peak	1.702	[1.301, 2.104]	0.033	8.3	< 0.001
Schedule deviation at start					
Early (s)	0.065	[0.052, 0.078]	0.037	9.8	< 0.001
Delayed (s)	0.000	[− 0.001, 0.001]	0.000	0.0	0.979
Temperature (ref.: > 0 °C)					
≤ 0 °C	0.215	[− 0.418, 0.848]	0.003	0.7	0.505
Precipitation (mm/h)	0.132	[− 0.148, 0.412]	0.003	0.9	0.355
Wind (m/s)	0.098	[− 0.028, 0.225]	0.006	1.5	0.128
Snow (m)	− 2.847	[− 11.212, 5.517]	− 0.003	− 0.7	0.505
Stops made					
Category 2	9.118	[8.682, 9.554]	0.302	41.0	< 0.001
Category 3	9.694	[9.016, 10.372]	0.114	28.0	< 0.001
Passenger activity					
Boardings	8.237	[8.010, 8.464]	0.640	71.1	< 0.001
Boardings squared	− 0.213	[− 0.226, − 0.200]	− 0.215	− 31.2	< 0.001
Alightings	2.074	[1.694, 2.455]	0.099	10.7	< 0.001
Alightings squared	− 0.112	[− 0.155, − 0.068]	− 0.038	− 5.1	< 0.001

Model statistics

$F = 3039$; $p < 0.001$; $N = 24{,}944$; adjusted $R^2 = 0.646$

b = unstandardised coefficient; 95% CI = 95% confidence interval for b; β = standardised coefficient

Therefore, a sensitivity analysis was conducted by removing the squared terms for boardings and alightings from the model. As a consequence, the maximum VIF score decreased to 2.7, suggesting a low risk of multicollinearity (Zuur et al. 2010). The resulting coefficients for boardings and alightings also decreased (to 5.3 and 0.5, respectively), which could be expected, as the decreasing effect for each additional passenger had been removed. The coefficients for the number of stops made instead increased somewhat (to a value of 12 for both bus stop categories), and this modest change suggests relatively stable results. The effect on all other coefficients was negligible. Due to higher explanatory power in the original model, the squared terms are included in the regression results reported in Table 6. Furthermore, because the potential multicollinearity issues were related to boardings and alightings, no multicollinearity issues were detected in the travel time and run time models (maximum VIF score 1.7 in both models).

The sensitivity analysis was also extended to include crossed terms between the time of day and the number of stops made. The results showed no substantial effect from the crossed terms, neither on the other coefficients nor on the explanatory power of the models. For the sake of simplicity, these crossed terms are therefore omitted in the reported regression models.

To sum up, the number of stops made has a substantial effect on travel time variability on the studied bus service, a seemingly greater effect than any of the other variables, such as the weather or traffic conditions during peak hours. Moreover, added bus travel time due to deceleration, acceleration, and technical dwell time far exceeds the average dwell time related to passenger activity. A typical stop with one boarding passenger means approximately 40 s additional bus travel time, but only about 8 of those 40 s stem from the boarding process.

4.2 Route level analysis

The part of the bus service that is in focus for the route level analysis (Broby–Kristianstad) includes 21 intermediate bus stops. However, all these 21 stops are never used simultaneously on a single bus trip in the sample. The distribution of the number of stops made is shown in Fig. 6. As can be seen in the figure, the actual number of stops made vary from 1 to 15, and on an average bus trip, only seven of the 21 bus stops are used.

In order to further explore the variability in stopping patterns, stop distributions for each bus stop category are presented in Table 7. In category 1, almost all buses stop at two of the three bus stops between Broby and Kristianstad (excluding the termini). The third bus stop in this category is less frequented, resulting in an average of 2.3 stops per bus trip. The relatively high level of usage, together with the fact that they are few in numbers, mean that bus stops in category 1 affect overall variability to a comparatively small extent.

In contrast, the number of stops made at bus stops in category 2 vary considerably. The share of bus trips that stop at an individual bus stop in this category, the stopping rate, ranges from 20 to 70%, but is close to 50% at most bus stops in this category. The stopping rates are higher during peak hours and lower during

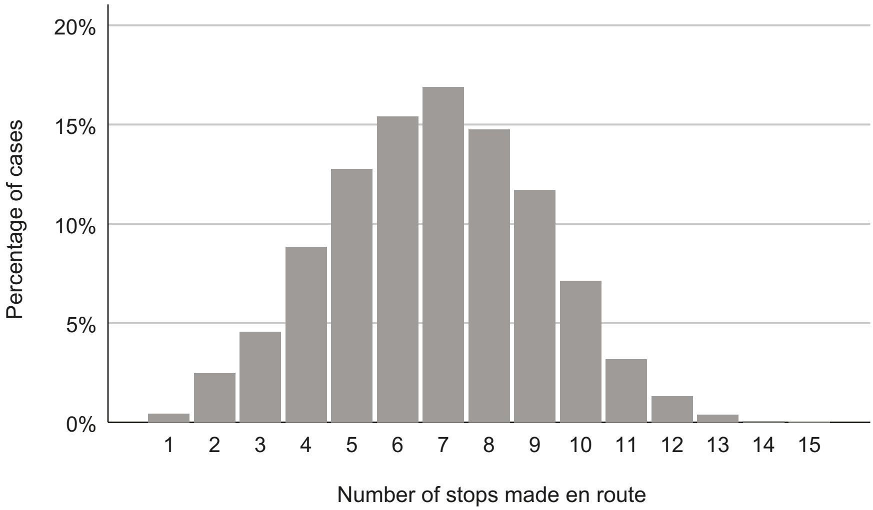

Fig. 6 Distribution of the number of stops made en route, excluding the two termini ($N = 10{,}645$)

Table 7 Statistics of number of stops made en route per bus stop category, excluding the two termini ($N = 10{,}645$)

	Category 1	Category 2	Category 3	Total
Scheduled stops	3	8	10	21
Stops made				
Maximum	3	8	5	15
Mean	2.3	3.9	0.6	6.8
Standard deviation	0.5	1.8	0.8	2.3
Percentiles				
5th percentile	2	1	0	3
Median	2	4	0	7
95th percentile	3	7	2	11

off-peak, and as a result, the total number of stops made at bus stops in this category vary from none to all eight of them. The standard deviation of the number of stops made in this category is considerably higher than in the other two categories.

Category 3 bus stops make up almost half of all scheduled intermediate stops, but they are so infrequently used that it is rare for more than two of them to be used on a single bus trip. The stopping rates in this category range from fractions of a percentage to 30%, with typical values around 5%. As a result, most bus trips do not stop at any of the category-3 bus stops. Nevertheless, they do affect overall variability, but to a considerably smaller extent than the category-2 bus stops.

By combining the results from the time-point segment analysis with the average number of stops made at route level, it is possible to estimate the effects on average travel time. These turn out to be rather moderate. The eight bus stops in category 2 cause an average of 144 s added travel time and the ten bus stops in category 3 cause an additional 26 s. This is a little less than 3 mins in total. As a comparison, the scheduled travel time, as well as the average travel time in the sample, is 38 min.

The effect on travel time variability is more tangible. This is illustrated by the line chart in Fig. 7, where the reliability buffer index is plotted against the number of stops made en route. In this case, the reliability buffer index compares the 95th percentile of travel time in each class with the average travel time in the total sample. Cases with 1–2 stops and cases with 11–15 stops have been binned in order to create large enough groups for the analysis. As can be seen in the chart, the risk of travel times that are substantially higher than average increases as the number of stops made increases, at least if the number of served stops exceeds three. Considering the distribution of the number of stops made together with the high index scores to the right in the chart, cases with many stops are very influential on the travel time dispersion in the total sample. Consequently, the reliability buffer index of the entire sample is as high as 11.6%. Still, it is lower than on the individual time-point segments (see Table 2), due to the possibility of adjusting the schedule at the intermediate time points at the route level.

As a consequence of the travel time variability, the on-time performance of arrivals at the terminus also depends on the number of stops made en route. The proportion of buses arriving less than 3 mins delayed is 74% in the sample, overall; but for buses stopping at four or fewer bus stops it is well above 90%. On the other end of the spectrum, the on-time performance for cases stopping at more than ten bus stops is as low as 30%. This is illustrated in Fig. 8, where on-time performance is plotted against the number of stops made en route. Also, the distribution of the number of stops is included in the figure, through the width of the bars, allowing the influence of each class to be assessed.

With the scheduled travel time roughly equal to the average travel time, there is an obvious relation between the reliability buffer index and the on-time performance. For cases with more than three stops en route, there is a clear drop in on-time performance for every additional stop made.

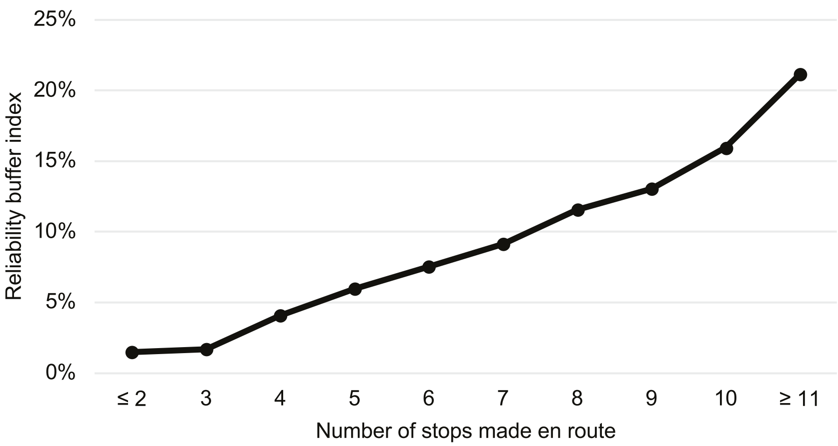

Fig. 7 Reliability buffer index against the number of stops made en route, depicting the relative difference between the 95th percentile of travel time in each class and the average travel time in the total sample ($N = 10{,}465$)

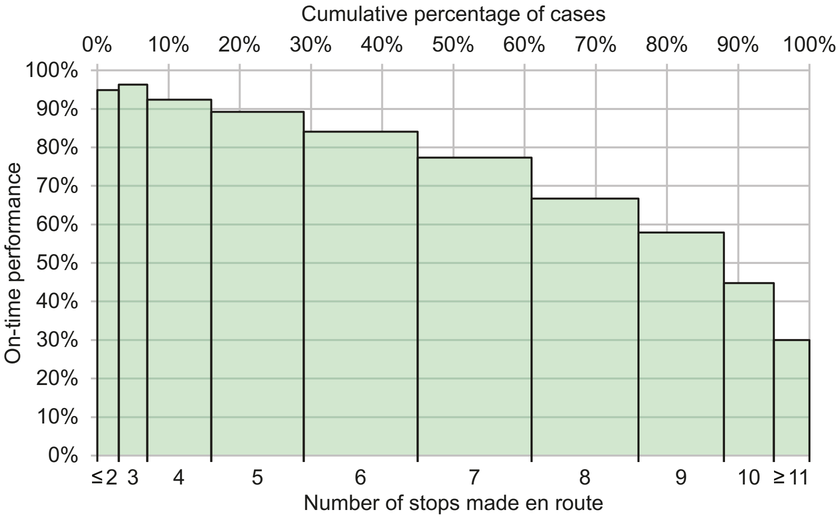

Fig. 8 On-time performance (percentage of arrivals less than 3 mins delayed) against number of stops made, where the width of the bars correspond to the distribution of the number of stops made ($N = 10{,}465$)

5 Discussion

The overall purpose of this study was to increase knowledge about the impact of rural bus stops on average travel times as well as reliability. To this end, bus stops on a regional bus service were categorised with regard to the location and function of the stops, using three categories: main bus stops in urban areas, secondary bus stops in urban areas, and rural bus stops (outside urban areas).

Regarding average travel times, the results from the chosen, fairly rural, study district suggest that rural bus stops have very little impact. Every stop adds, on average, about 40 s to the travel time of a bus trip, but rural bus stops are normally used so infrequently that their impact on the average travel time is practically negligible overall. On the studied bus service, a typical rural bus stop adds just 2–3 s to the average travel time. In comparison, secondary bus stops in urban areas are used more frequently, so their impact on average travel time is more substantial. Still, the impact is relatively moderate in comparison with total travel time.

However, the impact on reliability is much more tangible. Many stops with sporadic usage imply a large variability in actual stopping patterns, which in turn impacts on travel time variability. The results of the time-point segment analysis indicate that the number of stops made has a far greater impact on travel time variability than any of the other included variables, such as the weather or traffic conditions during peak hours. It is acknowledged that the included variables do not cover all aspects with a possible impact on travel time variability. For example, driver experience may have a statistically significant impact, but is omitted in this study due to a lack of data. However, its level of impact is expected to be relatively small (El-Geneidy et al. 2011). In a more congested area, the impact of traffic conditions is likely to increase, but the results suggest that stopping patterns would still in any case be very important to consider in order to improve reliability.

The results of the route level analysis illustrate the impact of travel time variability on overall on-time performance. The probability of arriving on time clearly depends on the number of stops made.

Thus, the results suggest that stop spacing on regional bus services largely implies a trade-off between coverage and reliability rather than between coverage and travel time. This means that approaches for assessing bus stops based only on travel time are too simplistic and risk ignoring the most substantial effects. Reliability is commonly among the top priorities for regional passengers, as is travel time (Hansson et al. 2019), which means that poor on-time performance cannot generally be solved through increased margins in the timetable. The timetable margins also affect operational costs, further stressing the importance of minimising travel time variability (El-Geneidy et al. 2006).

Analogous to the impacts on average travel times, the results suggest that rural bus stops have less of an impact on reliability than secondary bus stops in urban areas. On the studied bus service, the proportion of buses stopping are typically around 50% at the secondary bus stops in urban areas. This is the worst-case scenario for travel time variability. Stopping rates closer to 0, or closer to 100%, imply less variability in the total number of stops made.

Consequently, in order to improve reliability, it would be reasonable to, first and foremost, focus on secondary bus stops in urban areas. This may seem irrational, as rural bus stops generally have lower levels of passenger activity and are therefore more often disputed. However, not only do the secondary bus stops in urban areas have a larger impact on reliability, they are also usually located relatively close to other bus stops. This means that removing such a bus stop will not make the service entirely inaccessible, and the consequence for most people will rather be limited to longer access distances. In addition, the results of the regression analyses show that most of the added travel time at a stop is related to deceleration, acceleration, and technical dwell time. This further stresses the fact that it may be beneficial to concentrate passenger activity (boardings and alightings) on fewer bus stops. The longer access distances may be compensated with a higher level of service (van Soest et al. 2020), in terms of improved reliability.

Outside of urban areas, the trade-off between coverage and reliability is more clear-cut. Access distances there generally become too long when a bus stop is removed, unless remaining stops are upgraded in terms of service quality as well as car and bicycle access (Hansson et al. 2021). This can be crucial for the parts of the rural population who are dependent on public transport in their everyday lives (Berg and Ihlström 2019), but also important for others, whose mobility options become restricted to car travel (Bondemark and Johansson 2017). In general, the impact of rural bus stops on travel time variability is also less substantial, which means that several of them need to be removed in order to achieve an improvement in the same order of magnitude as from removing a single secondary bus stop in an urban area. Thus, by focusing on bus stop consolidation in urban areas, despite the generally higher levels of passenger activity, it is possible to significantly improve reliability without impairing coverage in rural areas.

In cases where the rural bus stops are more frequented or more densely spaced, their level of impact will increase. In those cases, it is reasonable to place greater emphasis on the rural bus stops. Nevertheless, unless the preconditions are widely different from the case studied in this article, it is likely that secondary bus stops in urban areas will still have a more substantial impact. They are also in most cases less crucial in terms of coverage.

As for analyses and impact assessments of different types of bus stops in different contexts, the method presented in this article offers a feasible approach. By combining methods previously used for analysis of rail traffic and urban bus operations, this article demonstrates a relatively simple and useful approach to analyse large volumes of data about bus movements on a regional bus service. The time-point segment analysis and the route level analysis can be used either in combination or separately, depending on whether the study focuses on details about dwell times, etc. or aggregate effects regarding on-time performance.

In practice, an application of the method is neither limited to regional bus services, nor to the specific bus stop categories used in this article. Future implementations may therefore include other types of services, with bus stop categories adapted to the purpose of the specific study.

6 Conclusions

This study shows that bus stops that are only used sporadically have limited impact on average travel times, but are more influential on travel time variability. These types of bus stops, that are common on regional bus services, lead to inconsistent stopping patterns. The results show that this inconsistency has a major impact on the reliability of the bus service.

Furthermore, the results suggest that rural bus stops have a lower impact on reliability than what we define as secondary bus stops in urban areas. Consequently, in order to improve reliability, it would be reasonable to initially focus on secondary bus stops in urban areas. This may seem irrational, as rural bus stops generally have lower levels of passenger activity and are therefore more often disputed. However, not only do the rural bus stops have a lower impact on reliability, they are also generally more crucial for the coverage of the bus service. By focusing primarily on bus stop consolidation in urban areas, it is possible to maintain coverage in rural areas and still significantly improve service reliability. Broadly, this would mean longer access distances for some, but improved reliability for all passengers.

The study also demonstrates a method for analysing bus travel times, specifically adapted for assessing different types of bus stops. The method is primarily based on automatic vehicle location (AVL) data on a bus-stop level, which offer a large number of bus trips to be included in the analysis. The large amount of data, in turn, enables a detailed understanding of the causes of travel time variability.

Authors' contributions JH: Conceptualisation; Formal analysis; Investigation; Methodology; Visualisation; Writing—original draft. FP-L: Supervision; Writing—review and editing. HS: Supervision; Writing—review and editing. AW: Supervision; Writing—review and editing.

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Availability of data and material The data used and analysed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

References

Berg J, Ihlström J (2019) The importance of public transport for mobility and everyday activities among rural residents. Soc Sci 8:58. https://doi.org/10.3390/socsci8020058

Bondemark A, Johansson E (2017) Optionsvärden i kollektivtrafiken (K2 working papers 2017:2). K2, Lund

Büchel B, Corman F (2020) Review on statistical modeling of travel time variability for road-based public transport. Front Built Environ 6:1–14. https://doi.org/10.3389/fbuil.2020.00070

Chen J, Currie G, Wang W, Liu Z, Li Z (2016) Should optimal stop spacing vary by land use type? New methodology. Transp Res Rec 2543:34–44. https://doi.org/10.3141/2543-04

Currie G (2016) Managing on-road public transport. In: Bliemer M, Mulley C, Moutou CJ (eds) Handbook on transport and urban planning in the developed world. Edward Elgar Publishing, Cheltenham, UK, pp 471–497

El-Geneidy AM, Strathman JG, Kimpel TJ, Crout DT (2006) Effects of bus stop consolidation on passenger activity and transit operations. Transp Res Rec 1971:32–41. https://doi.org/10.3141/1971-06

El-Geneidy AM, Horning J, Krizek KJ (2011) Analyzing transit service reliability using detailed data from automatic vehicular locator systems. J Adv Transp 45:66–79. https://doi.org/10.1002/atr.134

Fritz CO, Morris PE, Richler JJ (2012) Effect size estimates: current use, calculations, and interpretation. J Exp Psychol Gen 141:2–18. https://doi.org/10.1037/a0024338

Hansson J, Pettersson F, Svensson H, Wretstrand A (2019) Preferences in regional public transport: a literature review. Eur Transp Res Rev 11:38. https://doi.org/10.1186/s12544-019-0374-4

Hansson J, Pettersson-Löfstedt F, Svensson H, Wretstrand A (2021) Replacing regional bus services with rail: changes in rural public transport patronage in and around villages. Transp Policy 101:89–99. https://doi.org/10.1016/j.tranpol.2020.12.002

Hu WX, Shalaby A (2017) Use of automated vehicle location data for route- and segment-level analyses of bus route reliability and speed. Transp Res Rec 2649:9–19. https://doi.org/10.3141/2649-02

Lin M, Lucas HC, Shmueli G (2013) Too big to fail: large samples and the p-value problem. Inf Syst Res 24:906–917. https://doi.org/10.1287/isre.2013.0480

Luke D, Steer J, White P (2018) Interurban Bus Time to raise the profile. Greengauge 21

Martens K (2004) The bicycle as a feedering mode: experiences from three European countries. Transp Res Part D Transp Environ 9:281–294. https://doi.org/10.1016/j.trd.2004.02.005

Midenet S, Côme E, Papon F (2018) Modal shift potential of improvements in cycle access to exurban train stations. Case Stud Transp Policy 6:743–752. https://doi.org/10.1016/j.cstp.2018.09.004
Mulley C, Ho C, Ho L, Hensher D, Rose J (2018) Will bus travellers walk further for a more frequent service? An international study using a stated preference approach. Transp Policy 69:88–97. https://doi.org/10.1016/j.tranpol.2018.06.002
Murray AT, Wu X (2003) Accessibility tradeoffs in public transit planning. J Geogr Syst 5:93–107. https://doi.org/10.1007/s101090300105
Nielsen G, Nelson JD, Mulley C et al (2005) HiTrans best practice guide 2: public transport - planning the networks. HiTrans, Oslo
Palmqvist CW, Olsson NOE, Hiselius L (2017) Delays for passenger trains on a regional railway line in southern Sweden. Int J Transp Dev Integr 1:421–431. https://doi.org/10.2495/TDI-V1-N3-421-431
Pettersson F (2018) Developing a regional superbus concept—collaboration challenges. Case Stud Transp Policy 6:32–42. https://doi.org/10.1016/j.cstp.2017.12.003
Shrestha RM, Zolnik EJ (2013) Eliminating bus stops: evaluating changes in operations, emissions and coverage. J Public Transp 16:1–23. https://doi.org/10.5038/2375-0901.16.4.1
Statistics Sweden (2020) Localities and urban areas. https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/land-use/localities-and-urban-areas/. Accessed 22 Dec 2020
Stewart C, El-Geneidy A (2016) Don't stop just yet! A simple, effective, and socially responsible approach to bus-stop consolidation. Public Transp 8:1–23. https://doi.org/10.1007/s12469-015-0112-9
Tirachini A (2014) The economics and engineering of bus stops: spacing, design and congestion. Transp Res Part A Policy Pract 59:37–57. https://doi.org/10.1016/j.tra.2013.10.010
van Soest D, Tight MR, Rogers CDF (2020) Exploring the distances people walk to access public transport. Transp Rev 40:160–182. https://doi.org/10.1080/01441647.2019.1575491
Vijayakumar N, El-Geneidy AM, Patterson Z (2011) Driving to suburban rail stations: Understanding variables that affect driving distance and station demand. Transp Res Rec 2219:97–103. https://doi.org/10.3141/2219-12
Walker J (2008) Purpose-driven public transport: creating a clear conversation about public transport goals. J Transp Geogr 16:436–442. https://doi.org/10.1016/j.jtrangeo.2008.06.005
White P (2016) Rural public transport. Public transport: its planning, management and operation, 6th edn. Routledge, Oxford, pp 201–221
Zhao J, Frumin M, Wilson N, Zhao Z (2013) Unified estimator for excess journey time under heterogeneous passenger incidence behavior using smartcard data. Transp Res Part C Emerg Technol 34:70–88. https://doi.org/10.1016/j.trc.2013.05.009
Zuur AF, Ieno EN, Elphick CS (2010) A protocol for data exploration to avoid common statistical problems. Methods Ecol Evol 1:3–14. https://doi.org/10.1111/j.2041-210x.2009.00001.x

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ORIGINAL PAPER

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Patronage effects of off-peak service improvements in regional public transport

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Abstract

The purpose of this study is to look into patronage effects of extended supply outside peak hours on regional public transport services. Previous studies have shown that the service frequency is an attribute of great importance for regional passengers, but little is known about the details regarding peak and off-peak frequencies or service hours. The present study addresses this knowledge gap, departing from the hypothesis that additional off-peak supply means more flexibility for the passengers in terms of departure time options, and possibly also a sense of security for passengers who are uncertain about the time of their (return) trips. Essentially, the added off-peak departures may attract more passengers even if they normally do not or only occasionally use the off-peak services. The patronage effects are explored through four case studies from the region of Scania in southern Sweden. The cases include regional rail and bus services where substantial improvements have been made outside peak hours, resulting in at least hourly all-day services. The results of the study provide new insights into the fundamental planning policy trade-off between maximum frequency and span of public transport services in urban peripheries and rural areas. Importantly, the results suggest that improved time coverage may lead to substantial patronage growth, and this growth is evident also during peak hours, despite unaltered peak hour frequencies. Hence, off-peak departures cannot be assessed only through patronage levels in isolated time periods, let alone on the individual departures.

Keywords: Public transport, Rural accessibility, Regional bus, Regional rail, Timetable planning, Service hours, Daily variation

1 Introduction

The relatively low population density in urban peripheries and rural areas means that it is generally not considered feasible to provide high-frequency public transport services throughout the day in these areas. The regional bus and rail services that constitute the backbone of the rural public transport network are typically focused on commuter trips to school or to work [8, 19], with limited supply off-peak unless they operate along corridors linking nearby and highly populated urban areas. As a result, regional public transport services are, in general, not particularly well adapted for travel purposes other than commuting or for commuters with flexible working hours. By extension, there is a risk that an overly one-sided focus on commuter trips will contribute to social exclusion [7].

It is sometimes argued that such demand-oriented planning also leads to inefficient use of vehicles, with a large part of the fleet being idle during off-peak periods [17]. This means that all-day services can be introduced at lower marginal costs and that relatively high off-peak service levels may be feasible even in rural regions with low population densities [9]. By improving the time coverage, the idea is to make the public transport service available at any time, "much like the private car" [17, p. 12]. This may also be referred to as temporal availability [1].

The present study departs from the hypothesis that improved temporal availability means more flexibility for the passengers in terms of departure time options, and possibly also a sense of security for passengers who are

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uncertain about the time of their (return) trips. Essentially, the added off-peak departures may attract more passengers even if they normally do not or only occasionally use the off-peak services, provided that people are aware of these departures. If this hypothesis holds true, more frequent off-peak services would lead to increased patronage also during peak hours, at least after some time when new travel patterns begin to settle.

However, the results of previous studies into off-peak frequencies do not provide much evidence to support this hypothesis. Totten and Levinson [15] found that cross-effects between peak and off-peak periods are weak or non-existent. Currie and Loader [2] conclude that such effects do exist, specifically that extended evening services affect daytime travel, but suggest that the phenomenon can be explained by the fact that extended evening services enable daytime outbound-from-home trips with evening return trips. Furthermore, this pattern is more apparent on Saturdays and Sundays than on weekdays, where the increase in daytime patronage is relatively small. Similar findings are reported by Simmons and Haas [13], suggesting that extended service span leads to patronage growth during unaltered hours, albeit with relatively small percentages.

It should be noted that the aforementioned studies analysed short-term effects, ranging from a few months up to a year. This time horizon is supported by Wallis [18], who concludes that most of the patronage growth due to extended off-peak services occurs within the first year. Continued growth can be expected also after the first year, but at a considerably lower rate. However, with more extensive improvements 'across the board', e.g. establishing reasonable service levels throughout the day, considerable patronage growth can be detected several years after the improvement [6].

Consequently, there is a need for more research into cross-effects between peak and off-peak periods in such cases [18], particularly studies using panel data in order to analyse the longer-term effects [13]. Adding to this, previous studies have predominantly been conducted in urban contexts, with higher frequencies than those typically found on regional public transport services. Low frequencies may imply significantly different results compared to the identified previous studies [15].

Frequency is an attribute of great importance for regional passengers, but little is known about the details regarding peak and off-peak frequencies or service hours in regional contexts [5]. The present study addresses this knowledge gap by examining patronage effects of extended supply outside peak hours on regional public transport services. The results of the study may thereby provide new insights into the fundamental planning policy trade-off between maximum frequency and span of public transport services in urban peripheries and rural areas.

2 Material and methods

2.1 Study design

In this study, the patronage effects of improved off-peak frequency were explored through case studies, where patronage levels were analysed before and after changes in the off-peak supply. By using case studies, it is possible to study the changes and their effects in detail, and at the same time explore the contexts in which the changes take place [12]. The cases included regional rail and bus services with the purpose of offering public transport connections to some small towns and villages and their surrounding rural areas. Substantial improvements in the off-peak supply were made a few years ago on these services, but peak hour frequencies remained unchanged.

The study made use of panel data with annual patronage measurements, covering ten years or more, in order to analyse long-term trends before and after the off-peak service improvements. To control for other factors with a potential influence on the patronage levels, such as population growth and ticket prices, an elasticity model was estimated through linear mixed regression with a random intercept effect. This means that the model could be fitted to the observations from all cases combined, despite the differing patronage levels from case to case. Based on the model, counterfactual scenarios with unaltered service levels were projected. These scenarios provided baseline estimates against which the actual patronage levels were compared. The model is further described in Sect. 3.

In addition, the weekday patronage levels before and after the service improvements were compared on an hourly basis in order to analyse changes at different times of the day. By paralleling these changes with the corresponding timetable alterations, potential cross-effects could be discerned. Weekdays were in these analyses divided into four periods: morning peak (from the start of services, generally between 5 and 6 a.m., to 9 a.m.), midday (from 9 a.m. to 3 p.m.), afternoon peak (from 3 to 6 p.m.), and evening (after 6 p.m.). Peak hours are the morning peak and the afternoon peak combined. The midday and evening periods are off-peak.

2.2 Data

The principal data source used in the study was manual passenger counts, typically conducted on nine consecutive days (two weekends and the five weekdays in-between, on similar dates each time), resulting in stop-level information about boardings and alightings for each departure. In the past few years, the manual passenger counts have gradually been replaced with automatic passenger counting systems on-board, but the studied off-peak improvements were all made during the 'manual era'. The data were collected annually on the regional trains until 2016, and to avoid potential influence of the changed data collection method, the timelines terminate in 2016 for the rail services included in the study. For the bus services, the stop-level data were collected less frequently. To be able to create continuous time series in these cases, the stop-level data were supplemented with patronage statistics at the route level based on ticket validations.

2.3 Study area and case selection

The cases examined in this study are located in the region of Scania in southern Sweden. The regional public transport authority controls the planning of both regional and local public transport in Scania and provides the services through procured contracts with private operators. The number of regional trips in the public transport network is roughly equal to the number of local trips within towns and cities [11]. The share of costs covered by subsidies is slightly below 50% in a normal year, though with considerable variation within the network.

Since the turn of the millennium, there has been a rapid growth in public transport patronage in the region [11]. This growth has enabled, and is partly also a result of, continuous development of the supply in a gradually increasing part of the network. These gradual improvements follow a set of established guidelines, defining minimum frequencies and service hours for different types of services depending on their function in the regional network [11]. Most of the improvements have been incremental, typically comprising just one or two additional departures from one year to the next. However, this study focuses on some exceptional cases with more dramatic improvements for the purpose of producing as clear a picture as possible of the patronage effects of improved off-peak services.

Consequently, the selection of cases was information oriented in order to benefit from as much information as possible from each case [3]. The selection process consisted of three criteria. First, and most important, the off-peak improvements must have been quite extensive, resulting in at least hourly all-day services. Second, the improvements must have been made a few years ago to be able to study effects over several years. Third, no other substantial changes must have taken place within the time span studied. This includes, for example, unaltered peak hour frequencies and travel times.

Following the selection process, four cases that met all of the criteria could be identified. The locations of the cases are indicated in the map in Fig. 1. The four cases include rail and bus services that cover distances ranging roughly from 40 to 80 km. All of them can be described as interurban services, between towns, with intermediate stops that typically are located in smaller settlements en route [19]. The cases display similar patterns of settlement structure and population development, with yearly population growth stable around 1% during the studied period [14]. The parts of the region where the cases are situated are also similar in terms of modal split: the share of motorised trips made by public transport has increased from roughly 15% to 20% during the last decade in the municipalities where the studied services are located [10]. During the corresponding time span, car ownership has been stable around roughly 550 cars per 1000 inhabitants in all of the areas around the studied

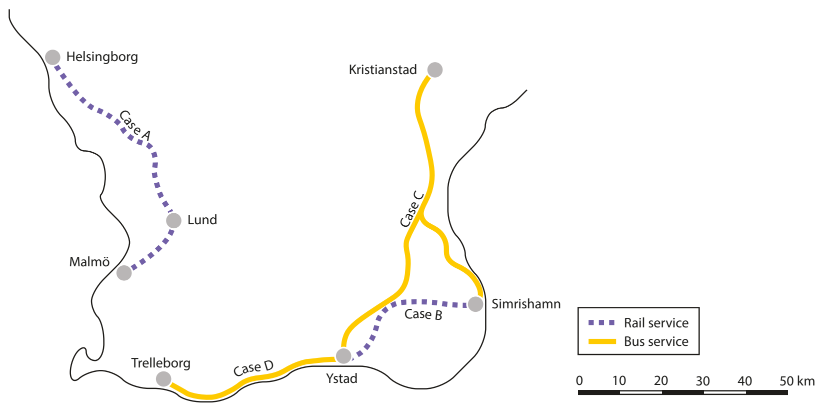

Fig. 1 Locations of the analysed cases in the region of Scania in southern Sweden

services [16]. Each of the cases, denoted A through D, is portrayed in more detail in the description of the results in Sect. 4.

3 Model for patronage effect estimations

3.1 Baseline model

The dataset contains weekday, Saturday, and Sunday patronage numbers for each of the four cases, resulting in twelve subsets of annual observations spanning 10–14 years. These twelve subsets were combined in a linear mixed model to form the basis of the patronage effect analyses. In order to avoid complex lags or ramp-up profiles in the model, observations within three years after major service improvements were removed from the sample in the model estimation process. The three-year limit was chosen based on an initial analysis of the subcases, together with findings presented by Wallis [18]. After this time, the average effect on the number of trips will typically be just a few percent per year. A total of 110 observations remained for the regression analysis.

A simple log-log model was formulated [4] using the number of departures, population, ticket price, and petrol price as predictors. Due to correlation between ticket price and petrol price, together with the small number of observations stressing the importance of limiting the number of predictors, these variables were combined into a price ratio variable. Also, a dummy variable representing the introduction of new trains or coaches was added. The resulting equation can be written as

$$\ln\left(\hat{y}_{ij}\right) = \beta_0 + u_{0j} + \beta_1 \ln\left(x_{1ij}\right) + \beta_2 \ln\left(x_{2ij}\right) + \beta_3 \ln\left(x_{3ij}\right) + \beta_4 x_{4ij}$$

where $\hat{y}_{ij}$ is the predicted daily number of trips in year i and subcase j, $\beta_0 + u_{0j}$ is the intercept for subcase j, x_{1ij} is the number of daily departures, x_{2ij} is the population in urban areas en route, x_{3ij} is the ratio between ticket price and petrol price, x_{4ij} is a dummy variable for the introduction of new vehicles, and $\beta_1, \beta_2, \beta_3$ and β_4 are fixed-effect coefficients whose estimates are presented in Table 1.

Based on this model, patronage levels were estimated for the counterfactual scenarios, without off-peak service improvements, by holding the daily departures variable constant. The dummy variable for new vehicles was also held constant in cases where new vehicles and improved off-peak services were introduced simultaneously. The estimated effect of new vehicles was then subtracted in the next step of the analysis.

3.2 Ramp-up profiles

The observations after the off-peak service improvements were compared to the counterfactual baseline estimates by fitting the differences to ramp-up profiles. The ramp-up profiles take into account that the patronage effects are not immediate, but rather build up over time, which is particularly evident after substantial service improvements [6]. A saturation growth function was assumed for the ramp-up profiles [18]:

$$\hat{z} = A \frac{t}{B + t}$$

where $\hat{z}$ is the patronage growth (in percent) at time t (in months after the service improvement) and A and B are parameters representing the long-run patronage effect and the rate of convergence, respectively.

In the figures showing the patronage development in Sect. 4, the ramp-up profiles have been added to the baseline model in order to illustrate the overall model fit. The differences between the observations and the model in the figures represent random errors. The patronage effects are illustrated by the difference between the ramp-up model estimates and the counterfactual baseline estimates.

Table 1 Estimated coefficients with 95% confidence intervals

Predictor	Coefficient	Estimate	95% CI
Ln daily departures	β_1	0.80	[0.65, 0.95]
Ln population	β_2	0.40	[− 0.09, 0.89]
Ln price ratio	β_3	− 0.35	[− 0.73, 0.03]
New vehicles	β_4	0.17	[0.09, 0.24]

Ln denotes the natural logarithm

4 Results

4.1 Case A: Rail service Råådalsbanan

Råådalsbanan in the northwestern parts of Scania serves a number of small towns and villages (population ranging from 500 to 2000) with connections to some of the larger towns in the region. Råådalsbanan used to be the main line from north to south in this part of Scania, but following the opening of a new railway in 2001 most of the through trips were relocated there. Råådalsbanan was retained as a rural railway, with hourly departures on weekdays, though with a few gaps, and every other hour on Saturdays and Sundays. Three new stations were opened in 2001, but these stations were excluded from the analysis to make sure that the effects of the new openings did not influence the results.

In June 2006, the gaps in the weekday timetable were filled so that the trains started to run on an unbroken hourly schedule from 6 a.m. to midnight. This meant an increase from 15 to 19 daily departures (+27%). The new departures were at 11 a.m., 2 p.m., 9 p.m., and 11 p.m. In other words, two new departures during the midday period and two new departures in the evening.

The sparser frequency on Saturdays and Sundays continued until December 2014, when the number of weekend departures was doubled, resulting in an hourly service from 8 a.m. to midnight on Saturdays and to 11 p.m. on Sundays.

The patronage development from 2002 to 2016 is shown in Fig. 2. As can be seen in the figure, the introduction of an all-day hourly service on weekdays in 2006 was followed by a notable increase in the weekday patronage. The patronage growth after one year was estimated to be 27%, which is on par with the frequency increase, and the growth continued before levelling off at roughly 40% after three to four years. The Saturday and Sunday patronage was relatively stable in this time span, without any signs of cross-effects from the increased frequency on weekdays. New trains were introduced in 2010, resulting in additional growth but to a smaller extent.

Further along on the timeline, the doubled frequency on weekends from 2014 to 2015 led to a roughly 50% increase in patronage on both Saturdays and Sundays. With only two observations after the weekend improvement, it is not possible to estimate the ramp-up parameters, but in contrast to the 2006 improvement, the increase after 2014 seems to have levelled off already after one year. This is confirmed by statistics for the years after 2016, indicating no further patronage increase, neither on Saturdays nor on Sundays. Also, the improved weekend service did not seem to have any notable effect on the weekday patronage.

A more detailed picture of the patronage growth following the 2006 improvement is presented in Fig. 3, showing the number of trips over the course of the day in 2005 and 2008. To facilitate comparison, the values have been averaged over a moving three-hour period. The most conspicuous increase is in the morning peak, where the number of trips increased by 42%, despite the unaltered frequency in that period. The increase in the afternoon peak is less prominent, and taken together the number of off-peak trips increased more than the number of trips during peak hours (+36% off-peak compared to +28% peak). However, trips during peak hours increased more in absolute numbers (+200 peak trips compared to +170 off-peak trips).

4.2 Case B: Rail service Österlenbanan

Österlenbanan is a railway between Ystad (pop. 20,000) and Simrishamn (pop. 6800), via Tomelilla (pop. 7200) and some smaller settlements en route, in the southeastern parts of Scania. The railway was electrified in 2001–2003, and after the reopening the service was operated with departures every two hours. Supplementary departures in the morning and in the afternoon meant that an hourly service was offered on weekdays 6–8 a.m. and 4–6 p.m.

The span of the hourly service was extended in January 2009 to 5–8 a.m. and 2–8 p.m., an increase from 12 to 15 daily departures (+25%). Two and a half years later, in August 2011, another five daily departures were added

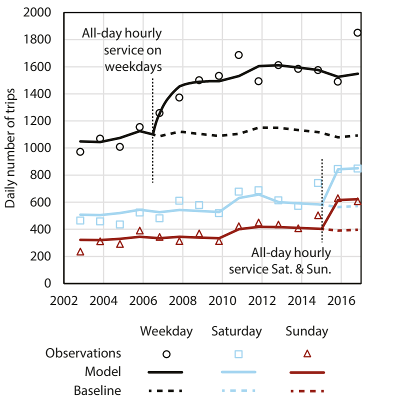

Fig. 2 Patronage development in case A, Råådalsbanan (excluding the new stations opened in 2001), showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

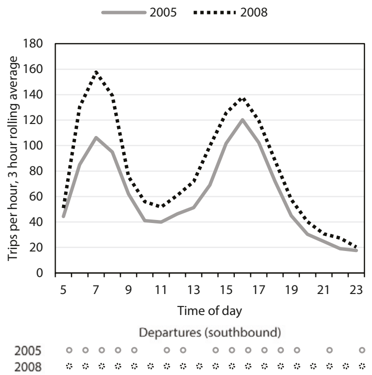

Fig. 3 Centred three-hour rolling average of trips per hour on Råådalsbanan (case A) on a typical weekday in 2005 and 2008. The circles below the chart represent departure times

on weekdays (+33%), resulting in an hourly service from 5 a.m. to midnight. Simultaneously, the frequency on Saturdays and Sundays was doubled to be able to introduce an hourly service all days of the week (from 6 a.m. to midnight on Saturdays and from 7 a.m. to 10 p.m. on Sundays).

Since the reopening in 2003, the trains on Österlenbanan have continued from Ystad towards the more densely populated western parts of the region. However, to avoid any influence from events in other parts of the network, trips passing through Ystad have been excluded from the analysis. Consequently, the number of trips in the analysis corresponds to the number of boarding passengers on eastbound trains, from Ystad to Simrishamn, and to the number of alighting passengers on westbound trains, from Simrishamn to Ystad.

The patronage development from 2004 to 2016 is shown in Fig. 4. The first extension of the hourly service in 2009 appears to have resulted in an increase in weekday patronage of approximately 16%.

The response to the introduction of the all-day hourly service in 2011 is more tangible. As in case A, the estimated patronage growth on weekdays exceeded the relative frequency increase already after the first year. The long-term effect was estimated to be 50%, most of which was attained after three to four years.

The growth was greater on Saturdays and Sundays, although it did not quite reach the corresponding increase in frequency in this case. The doubled frequency was estimated to result in a roughly 70% increase in patronage on Saturdays and an 85% increase on Sundays. In contrast to the patronage growth on weekdays, the weekend patronage seems to have grown faster but to have levelled off considerably already after one to two years.

Patronage growth at different times of the day is shown in Fig. 5. The extended span of the hourly service in 2009 seems to have primarily affected the afternoon peak, with a substantial patronage growth in the early afternoon. This is followed by a clear increase over all times of the day after the introduction of the all-day hourly service in 2011. The increase is particularly evident in the midday period, where the number of trips appears to have more than doubled from 2010 to 2013. The increase is less prominent during peak hours, but still substantial despite the unaltered frequency in those periods. The number of trips made during peak hours increased by 24% from 2010 to 2013, compared to a 75% increase during off-peak hours. In absolute numbers, the increase in off-peak trips was approximately twice as large as the increase in peak trips (+ 330 off-peak trips compared to +160 peak trips).

4.3 Case C: Coach services Kristianstad–Simrishamn/Ystad

The main public transport connections from north to south in the eastern parts of Scania are the coach services from Kristianstad (pop. 41,000) to Simrishamn (pop. 6800) and to Ystad (pop. 20,000). The services are called SkåneExpressen 3 and SkåneExpressen 4, but despite being branded as express services they have quite dense stopping patterns so that they also cover the rural

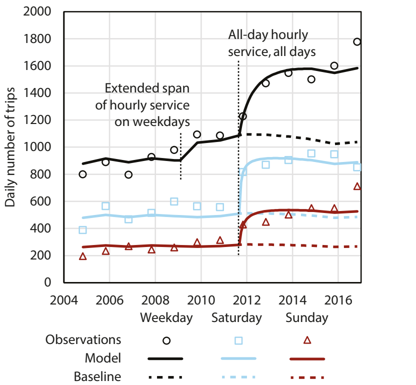

Fig. 4 Patronage development in case B, Österlenbanan (excluding trips with origins or destinations in other parts of the network), showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

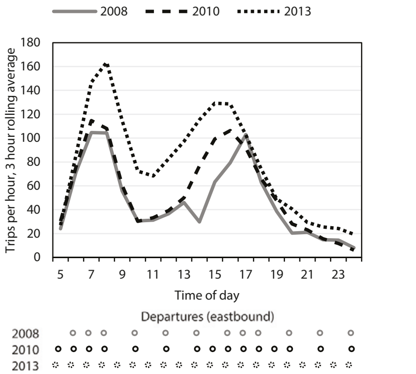

Fig. 5 Centred three-hour rolling average of trips per hour on Österlenbanan (case B) on a typical weekday in 2008, 2010, and 2013. The circles below the chart represent departure times

settlements en route. The services were analysed together because their routes are parallel for about half the distance on the northern section.

Both services run on hourly schedules, supplemented during peak hours by a couple of additional bus services running parallel on the busiest sections. These bus services were also included in the analysis.

The hourly schedules used to only apply on weekdays but were extended to include Saturdays and Sundays in December 2014. This was a dramatic improvement, from 10 to 18 departures in each direction on Saturdays (+80%) and from 6 to 15 departures on Sundays (+150%). The improvement was made possible by integrating the timetables, thus enabling transfers instead of operating on parallel routes. The weekday schedules were also adjusted in December 2014, largely without any notable changes in the supply, except for some additional evening departures on the Ystad branch.

The patronage development from 2010 to 2019 is shown in Fig. 6. As can be seen in the figure, the weekday patronage was relatively stable across the entire time span. In contrast, a swift increase was seen on Saturdays and Sundays as a response to the service improvements at the end of 2014. The long-term effects were estimated to be a roughly 60% patronage increase on Saturdays and a 90% increase on Sundays. These levels were reached already after one to two years.

Changes in patronage over the course of the day on weekdays were also analysed. Except for a slight increase in evening patronage due to the additional evening departures, the results did not reveal any substantial changes that could be related to the improvements of the off-peak frequencies.

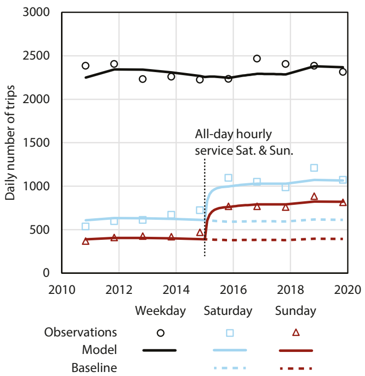

Fig. 6 Patronage development in case C, coach and bus services from Kristianstad to Simrishamn and Ystad (SkåneExpressen 3 and 4 together with route 337 and 573), showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

4.4 Case D: Bus service Trelleborg–Ystad

Bus service 190 operates along the southern Scanian coast between Trelleborg (pop. 31,000) and Ystad (pop. 20,000). The operations in their present form began in 2008, when a couple of previous services were combined to form a coherent route along the coast. Until 2015, the timetable was irregular, with a strong focus on the morning and afternoon peaks. During roughly two hours in the morning and two hours in the afternoon, there were at least two buses per hour in each direction. At other times of the day and during the weekends, the departures were much more sporadic.

In December 2015, a regular-interval timetable was introduced with at least hourly departures on weekdays from 5 a.m. to 8 p.m. At the same time, the departures during peak hours were redistributed so that half-hourly services could be offered 5–9 a.m. and 2–6 p.m. In effect, this meant that the span of the peak hour frequency was extended. All in all, the number of departures on weekdays increased from 19 to 27 (+42%), but the number of departures during peak hours was held constant, and the entire increase took place during the midday period and in the evening.

The hourly service was also extended to Saturdays, with an increase from 8 to 15 daily departures (+88%). On Sundays, however, the new schedule was limited to departures every other hour, which meant a less dramatic improvement, from 5 to 7 daily departures (+40%).

The patronage development from 2010 to 2019 is shown in Fig. 7. The data for this case suggested a relatively slow rate of convergence after the off-peak service improvements. The patronage growth exceeded the relative frequency increase on weekdays as well as on Saturdays and Sundays within three years or so and appears to have continued after that as well. The estimated long-term patronage growth effects were roughly 50% on weekdays, 100% on Saturdays, and 70% on Sundays.

Patronage growth at different times of the day is shown in Fig. 8. The largest increases occurred in the late morning and late afternoon in the transitions from peak hours to midday and evening hours, respectively. This is in line with the extended span of the peak hour frequency, resulting in less sharp peaks. The number of off-peak trips increased more than the number of trips during peak hours in relative terms (+39% off-peak compared to +28% peak). However, trips during peak hours increased more in absolute numbers (+140 peak trips compared to +120 off-peak trips).

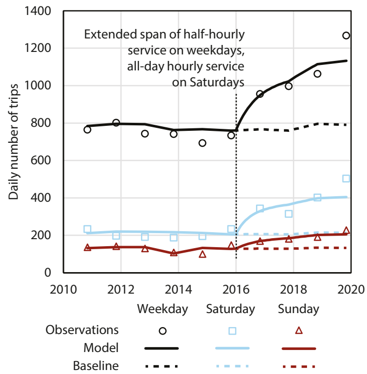

Fig. 7 Patronage development in case D, the bus service between Trelleborg and Ystad, showing annual autumn measurements and model estimations of the patronage development with and without off-peak service improvements (the latter corresponds to the counterfactual baseline scenario)

5 Discussion

In this article we have examined patronage effects of extended supply outside peak hours on regional public transport services. This was done by exploring four cases that have been subject to substantial improvements in the off-peak frequency, generally resulting in at least hourly services throughout the day. All four cases clearly demonstrated considerable patronage growth following the improvements. It has previously been suggested that half-hourly or better service frequencies are needed to be able to attract new patronage [6]. However, that conclusion was drawn in an urban context. By the same logic, our results suggest that the corresponding minimum standard in regional public transport is an hourly all-day service.

The cases with off-peak improvements on weekdays showed notable increases in peak hour patronage, despite unaltered peak hour frequencies. These results contradict the findings presented by Totten and Levinson [15], who concluded that midday and evening frequencies do not have any noticeable effects on peak hour patronage. However, there are a couple of important differences between the studies. First, Totten and Levinson studied urban local routes. The geographical context may in itself affect the results, but the higher frequencies on these services are probably even more influential. The regional services in the present study generally had less frequent than hourly services during off-peak periods before the upgrades. Increasing the frequency to hourly departures is then a drastic improvement in the availability of the service compared to, for example, moving from departures every 30 minutes to every 15 minutes. Second, Totten and Levinson studied short-term elasticities with a one-year horizon, while the results of the present study indicate that patronage levels may continue to increase for several years, particularly on weekdays. It is possible that the cross-period effects are results of a relatively slow process, meaning that the patronage during peak hours only begins to increase after a while, allowing some time for new travel patterns to be established.

The increased peak hour patronage as a result of improved off-peak services in the present study can be viewed as an addition to the results presented by Currie and Loader [2], who focused on extended evening services. However, their hypothesis that the effects can be explained by daytime outbound-from-home trips with evening return trips proves insufficient in a couple of the cases in the present study. The results for cases A and D demonstrate larger increases in the number of trips during peak hours than in off-peak hours. This implies that it is not possible to link all new trips during peak hours to outbound or return trips during the midday and evening periods. This finding supports the hypothesis outlined in the introduction that improved off-peak frequency may attract more passengers even if they normally do not or only occasionally use the off-peak departures. Plausibly, this effect can only be fully achieved with proper marketing of the service upgrade, so that people become aware of the added flexibility in terms of departure time options. Again, it is important to note the longer time perspective in the present study compared to the study

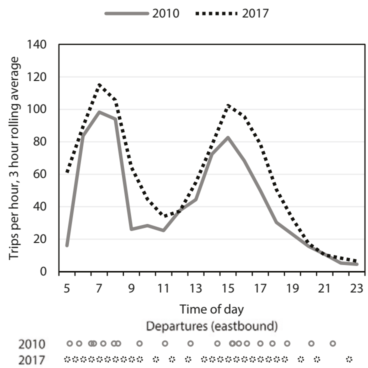

Fig. 8 Centred three-hour rolling averages of trips per hour on the bus service between Trelleborg and Ystad (case D) on a typical weekday in 2010 and 2017. The circles below the chart represent departure times. Some departures in 2010 were very close to each other and thus are difficult to distinguish in the figure

by Currie and Loader [2]. The suggested hypotheses are not mutually exclusive, and it is possible that they come into effect at different stages after a service improvement.

Because no additional vehicles are required, off-peak service improvements may offer a cost-effective option for substantially increasing public transport patronage and at the same time reducing social exclusion. In the region studied, capital costs make up about a quarter of the bus operating costs and about half of the train operating costs. This means that the marginal costs for off-peak service improvements are considerably lower than the relative increase in frequency. Interestingly, if these values are applied to the cases in this study, the marginal cost increase is typically exceeded by the patronage growth within a couple of years. This means that the share of the operating costs covered by ticket revenues increased and that the service improvements could be implemented with very limited impact on the amount of subsidies needed.

The main contributions of this study in relation to previous research into off-peak frequencies are the regional perspective and the use of panel data, which facilitated the analysis of long-term effects. Due to the strict requirements placed on these data in the selection process, the analysis was limited to four cases. This enabled detailed exploration of the off-peak service improvements and their effects in the specific context of each case, but at the same time it is a numerically weak basis for drawing generalisable conclusions. Consequently, a suggestion for future research is to expand the basis with more cases in other regions. Another interesting research direction would be to adopt a qualitative approach focusing on the passengers' experiences. In addition, studies into effects on different types of users and trip purposes would be helpful in deepening the understanding of the importance of off-peak frequencies.

6 Conclusions

The results of this study suggest that the span and frequency of off-peak services are important service quality aspects in regional public transport. Making the public transport service available throughout the day with regular, at least hourly, departures from morning to evening is in all of the studied cases succeeded by substantial patronage growth. In some cases, the growth continues for several years to levels considerably higher than the short-term effects that are recognised during the first year.

The results also suggest that off-peak service improvements on weekdays affect travel demand during peak hours. In fact, the patronage growth during peak hours may be larger than in the off-peak periods, despite unaltered peak hour frequency. Hence, off-peak departures cannot be assessed only through patronage levels in isolated time periods, let alone on the individual departures.

All four of the analysed cases demonstrate substantial growth of the weekend patronage after improvements in the Saturday and Sunday services. However, in contrast to the interaction between peak and off-peak periods on weekdays, there are no signs of cross-effects between weekends and weekdays.

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Author contributions
JH: Conceptualization; Formal analysis; Investigation; Data Curation; Methodology; Visualization; Writing—original draft. FPL: Supervision; Writing—review and editing. HS: Supervision; Writing–review and editing. AW: Supervision; Writing—review and editing. All authors have approved the manuscript for submission.

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Availability of data and materials
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Declarations

Competing interests
The authors declare that they have no competing interests.

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References

1. Cass, N., Shove, E., & Urry, J. (2005). Social exclusion, mobility and access. *The Sociological Review, 53*(3), 539–555. https://doi.org/10.1111/j.1467-954X.2005.00565.x
2. Currie, G., & Loader, C. (2009). High ridership growth from extended transit service hours: An exploration of the causes. *Transportation Research Record, 2110*, 120–127. https://doi.org/10.3141/2110-15
3. Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry, 12*(2), 219–245. https://doi.org/10.1177/1077800405284363
4. Greer, M. R., & van Campen, B. (2011). Influences on public transport utilization: The case of Auckland. *Journal of Public Transportation, 14*(2), 3. https://doi.org/10.5038/2375-0901.14.2.3
5. Hansson, J., Pettersson, F., Svensson, H., & Wretstrand, A. (2019). Preferences in regional public transport: A literature review. *European Transport Research Review, 11*(1), 1–16. https://doi.org/10.1186/s12544-019-0374-4
6. Loader, C., & Stanley, J. (2009). Growing bus patronage and addressing transport disadvantage—The Melbourne experience. *Transport Policy, 16*(3), 106–114. https://doi.org/10.1016/j.tranpol.2009.02.001

7. Markovich, J., & Lucas, K. (2011). *The social and distributional impacts of transport: A literature review (working paper 1055)*. Transport Studies Unit, School of Geography and the Environment, University of Oxford.
8. Metelka, S., & Janoš, V. (2021). Demand variation in regional transport. *Smart City Symposium Prague (SCSP), 2021*, 1–5. https://doi.org/10.1109/SCSP52043.2021.9447373
9. Petersen, T. (2016). Watching the Swiss: A network approach to rural and exurban public transport. *Transport Policy, 52*, 175–185. https://doi.org/10.1016/j.tranpol.2016.07.012
10. Region Skåne. (2019). *Så reser vi i Skåne: Resvaneundersökningen 2018*.
11. Region Skåne. (2020). *Trafikförsörjningsprogram för Skåne 2020–2030*.
12. Rowley, J. (2002). Using case studies in research. *Management Research News*. https://doi.org/10.1108/01409170210782990
13. Simmons, J., & Haas, P. J. (2016). Impact on bus ridership from changes in a Route's span of service. *Transportation Research Record, 2539*(1), 48–54. https://doi.org/10.3141/2539-06
14. Statistics Sweden. (2021). *Folkmängd per tätort efter region och vart 5:e år*.
15. Totten, J. C., & Levinson, D. M. (2016). Cross-elasticities in frequencies and ridership for Urban local routes. *Journal of Public Transportation, 19*(3), 117–125. https://doi.org/10.5038/2375-0901.19.3.7
16. Trafikanalys. (2022). *Personbilar: Antal i trafik per 1000 invånare efter år, län och kommun*.
17. Tzieropoulos, P., Emery, D., & Buri, J.-D. (2010). Regular-interval timetables : Theoretical foundations and policy implications. In: *12th World conference on transport research* (pp. 1–15).
18. Wallis, I. P. (2013). *Experience with the development of off-peak bus services (research report 487)*. NZ Transport Agency.
19. White, P. (2016). Rural public transport. In *Public transport: Its planning, management and operation* (6th ed., pp. 201–221). Routledge.

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