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Andersen, Jonas Lohmann Elkjær; Landex, Alex

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Modeling and evaluation of characteristics for on-street Rapid Transit systems

Jonas Lohmann Elkjær Andersen
M.Sc.
Technical University of Denmark, Department of Transport
Bygningstorvet 116B
2800 DK-Kgs. Lyngby
Mail: ja@transport.dtu.dk
Tel: +4545251538
Fax: +45 4593 6412

Alex Landex
Ph.D.
Technical University of Denmark, Department of Transport
Bygningstorvet 116B
2800 DK-Kgs. Lyngby

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Abstract

There is an ongoing discussion about on-street Rapid Transit systems like Light Rail Transit and Bus Rapid Transit in terms of their advantages, their differences, and the impact of their particular characteristics like travel time, headway, capacity, and the so-called rail factor.

System characteristics can be viewed as means to obtain the main objective of introducing a Rapid Transit System, to increase the number of passengers. Variations in the system characteristics have a direct impact on ridership. However, it is difficult to predict the impact of implementing or altering the characteristics. A Rapid Transit system should display sufficient service already in the planning phase. That is why pre-acquired knowledge of the impact of the characteristics on the system performance is valuable. Such knowledge could provide a firm basis for planning the service and operation of a Rapid Transit system.

This article focuses on the performance of on-street Rapid Transit systems by examining core characteristics for these systems, characteristics that are computable through traffic models and are known to differ somewhat from system to system. The article has a case-oriented route choice modeling approach to the investigation of these characteristics. It focuses on the following characteristics for Rapid Transit systems: travel time, headway, rail factor and capacity. It evaluates how the implementation and variation of these characteristics affect the ridership of a case project.

The findings offer a theoretical base for managing the impact of various characteristics when Rapid Transit are considered in urban regions where the effects of such systems are unknown – to show what can be expected and what magnitude the impacts will have. The dependencies between system characteristics and ridership can be used to configure Rapid Transit systems to meet specific ridership objectives.

1 Introduction

In Northern Europe, there is an ongoing discussion about upgrading urban public transport systems. In the past decade, the discussion has particularly revolved around implementing Rapid Transit Systems at street level in cities. On-street Rapid Transit Systems are viewed as a supplemental service in larger cities where the public transport system is already fairly developed with heavy rail and/or metro systems. But even medium sized cities, with populations too small to support urban rail or metro systems, have started discovering the option of upgrading public transport with on-street Rapid Transit Systems. The debate has intensified over recent years, with more and more Scandinavian cities in screening phases to implement Light Rail Transit (LRT) systems (e.g. SSSV 2007 and Bay & Kjærgaard 2009). Light Rail is the rail-bound street level Rapid Transit system which is considered as high quality public transport. In Denmark, there are currently a lot of initiatives to promote Light Rail and a couple of projects are close to being reality. However, no definite Light Rail or Rapid Transit system exists in Denmark and that emphasizes the need for further research of the performance of such systems. Discussions about the less prestigious Bus Rapid Transit (BRT) systems is more moderate but is also going on in some cities. There have been several official review studies of Light Rail Transit projects, but very few about Bus Rapid Transit Projects (see for instance Light Rail Cooperation in Ring 3 2008 and Ministry of Transport 2010).

Studies of Rapid Transit Systems have an obvious focus on their economics. But the performance of the systems and their ability to attract customers are also important. The characteristics of a Rapid Transit System have an impact on both system performance and passenger attraction. They are sometimes referred to as system factors and they are direct planning means for shaping the system configuration. Some of the most important system factors of an operation-ready Rapid Transit System[1] are travel time and headway.

There are also on-going discussions about the differences between rail-bound and road-bound Rapid Transit Systems. Bus Rapid Transit is considered to be a more inexpensive solution, while Light Rail Transit is considered to have greater passenger attraction. This latter is not only due to differences in system characteristics (such differences are common between bus and rail), but also to a higher attractiveness for rail itself. The favoring of rail over bus is considered to be a question of driving comfort and customer perception and is commonly referred to as the rail factor, although it is not something that is directly measurable. Often the impact is seen only when the system has gone into service and the number of passengers exceeds the forecast e.g. seen in many of the LRT systems in French cities (Scherer 2010). Ill-defined, yet present, the rail factor is an important element to include in any analysis aimed at choosing between Rapid Transit Systems.

1.1 Importance of the research

Since the ability to attract customers is an important focal point, pre-acquired knowledge of the system characteristics and their impact on performance is valuable as basis for decision-making in on-street Rapid Transit projects. Knowing how they impact is easy, but how much they impact is more complicated. The settings of the characteristics define not only the configuration of the Rapid Transit System, but also the resulting impact on ridership. Therefore, they can also be viewed as a means to obtain certain ridership objectives.

In this article, we use a case-oriented traffic modeling approach to focus on these system characteristics and how much they impact the ridership. The article is based on an examination that included the important system planning factors, travel time (in-vehicle driving time) and headway/frequency (number of departures). These system factors have a high impact on ridership, they are computable using traffic models and they are known to differ somewhat from system to system.. The rail factor and its impact on ridership are also examined. Finally, the capacity issue is addressed, albeit only in a derived form. The objective is to examine how the implementation and variation of these system characteristics affect the performance of on-street Rapid Transit Systems in general urban conditions. Such findings can form a theoretical basis for planning the service and operation of Rapid Transit systems and for choosing the system itself.

1.2 Approach adopted

The basis for the investigation is a case corridor in the central part of Copenhagen, Denmark. Currently, the examined corridor is a bus corridor, but one it has been proposed to turn into a Rapid Transit corridor. A route choice assignment model was used for the examination and provided distributed passenger volumes for the current bus line in the case corridor (cf. Section 2.1 *The route choice model*). The route choice model was validated by comparing its results with official traffic counts for the bus line (cf. Section 3.1 *Validation of the route choice model* & Section 4.1 *Route choice model validation results*). The model was found trustworthy and a suitable but also conservative base configuration for an on-street Rapid Transit System in the case corridor was planned and laid out (cf. Section 2.3 *The Rapid Transit system* &

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[1] The physical configuration (alignment and stop positioning) are already decided on/fixed

Section 2.4 *Rapid Transit timetable*). Then alterations were made to the system factors – to travel time by making the Rapid Transit faster and to headway by increasing the number of departures. All the alterations to the systems factors were based on reasonable assumptions and thorough knowledge of the general conditions to ensure that the values were realistic for the corridor (cf. Section 3.2 *System factors approach*). Then the rail factor was investigated by altering the model parameters included in the utility function of the route choice, thus giving the rail factor higher impact (cf. Section 3.3 *Rail factor approach*). The impact on ridership of varying system configurations was plotted in graphs and the magnitude of the impacts were evaluated (cf. Section 4.3 *System factor results* & Section 4.4 *Rail factor results*). A catalog including all combinations of the system factors and rail factor to help decide future Rapid Transit configurations was also produced (cf. Section 4.5 *Catalog results*). Finally the capacity of the Rapid Transit system was examined by comparing the highest occupancies with standard vehicle capacities (cf. section 4.6 *Capacity results*). All findings are discussed and a proposed configuration for the specific case corridor is presented (cf. Section 5 *Discussion of results*). Last, conclusions complete the article (cf. Section 6 *Conclusions*).

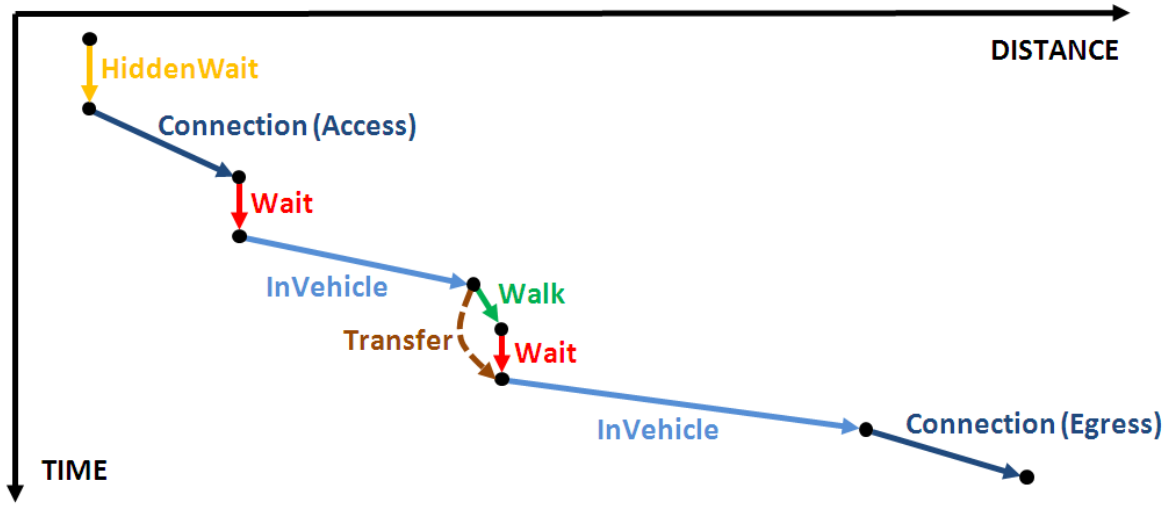
2 Setting the framework

Before any analysis could be performed to examine the impact of the Rapid Transit System, the framework had to be set. This meant setting the preconditions and delimitations of the route choice model, defining the case corridor and configuring the Rapid Transit System itself.

2.1 The route choice model

The traffic model used to evaluate the different Rapid Transit configuration is a schedule-based route choice assignment model based on stochastic utility theory (as described in IMV 2006). It incorporates network and timetables for a typical weekday of all Public Transport lines in the Greater Copenhagen area (for more information about the route choice model see (Nielsen, Hansen & Daly 2001)). The actual route choice assignments were carried out using the Traffic Analyst extension for ArcGIS (Rapidis).

In the route choice the algorithms seek to maximize the utility of travelers by minimizing the general cost. The utility function implements various weights (based on values of time) for various parts of a public transport journey (see Fig. 2.1), as well as differentiated values of time depending on the mean of transport. The latter is especially favorable in the examination of the rail-factor since the value of time for the case Rapid Transit system can be given a separate choice set.



$$GC = \mu_{HiddenWait} \times HiddenWaitTime + \mu_{Connection} \times ConnectionTime + \mu_{Wait} \times WaitTime + \sum_{ServiceTypes} (\mu_{InVehicle} \times InVehicleTime) + \mu_{Walk} \times WalkTime + \mu_{TransferPenalty} \times NumberOfTransfers$$

Fig. 2.1 – Model components of a public transport journey and their role in the utility function in the route choice

In the route choice model traffic is laid out in the public network from trip matrices. The trip matrices and corresponding zonal structure are based on the Orestad Traffic Model (OTM) version 4.0 (Jovicic & Hansen 2003). The zonal structure and trip matrices cover the Greater Copenhagen area and implement three different trip purposes: Commuting, business and leisure.

The route choice model produces result data such as Level-of-Service and traffic volumes on edges and stops. The traffic volumes are the result data that were used in this examination.

2.1.1 Delimitations in the modeling approach

Since route choice modeling is quite resource demanding in terms of calculation times, the calculation period was delimited to the morning rush hour (7.00-9.00). This is a simplification but can be justified by the fact that 20-25% of the weekday traffic is carried out in this time span (comparing to full weekday trip matrices). Also most of the home-work traffic is carried out in the rush hours and because of the symmetry in travel patterns the morning rush hour will provide an indirect view into the reversed afternoon work-home traffic. The dominant focus of the examination was consequently laid on home-work traffic.

Another delimitation of the examination was the fact that the trip matrices are based on data from year 2000. However, these matrices were found to be some of the newest, best suitable and most trustworthy trip data available for this examination and their rather old origin should not be a considerable limitation for the distribution of traffic.

The route choice modeling itself is solely based on redistribution of existing public transport customers. This means that no transfer from car to Rapid Transit can occur and that no long term effects are implemented. Furthermore, no induced traffic is taken into account which normally can be expected when upgrading to faster and better public transport service.

The listed delimitations have the inopportune impact that they underestimate the level of traffic for the Rapid Transit system. This means that the absolute ridership is expected to be too low and should therefore only be cautiously used in conclusive connections. But since the distribution of traffic should not be affected and since the examination has a comparative approach where increases in ridership are studied rather than absolute ridership numbers, the delimitations were acceptable.

2.2 The case corridor

Copenhagen metropolitan area has a population of around 1.8 million and the current public transport system in the city consists of Metro, heavy urban rail and busses. There have been several proposals for both LRT and BRT solutions in Copenhagen, but no proper street-level Rapid Transit system has yet been introduced to the Copenhagen transport system. This emphasizes the need for examinations like the one described in this paper.

The case corridor chosen for this examination is a radial urban bus corridor primarily in the central part of Copenhagen. It is not the bus corridor in Copenhagen with the highest public transport volumes, but it meets some important requirements as case for the examination since it is:

- Feasible for a street-level Rapid Transit system (regarding customer base, physical conditions etc.)
    - ➢ To ensure realistic needs and solutions
- Typical and relatively uniform in terms of urban functions, activities and transport demands, and thereby comparable to street based radial public transport corridors in other cities
    - ➢ To ensure results and conclusions could be transferred and applied outside Copenhagen and serve a more general purpose
- Only one primary existing bus line operating in the corridor
    - ➢ To make the bus adjustment following the Rapid Transit less complex

The current bus operating the corridor is called line 6A and it is part of the main urban bus system in central Copenhagen. Bus line 6A is actually a dual corridor bus line since it operates both in the western part and the northwestern part of Copenhagen, linking the two together via the city centre. However, it is only the western part – going from Rødovre in west to Nørreport terminal station in the city centre – that constituted the case corridor in this examination (see Fig. 2.2).

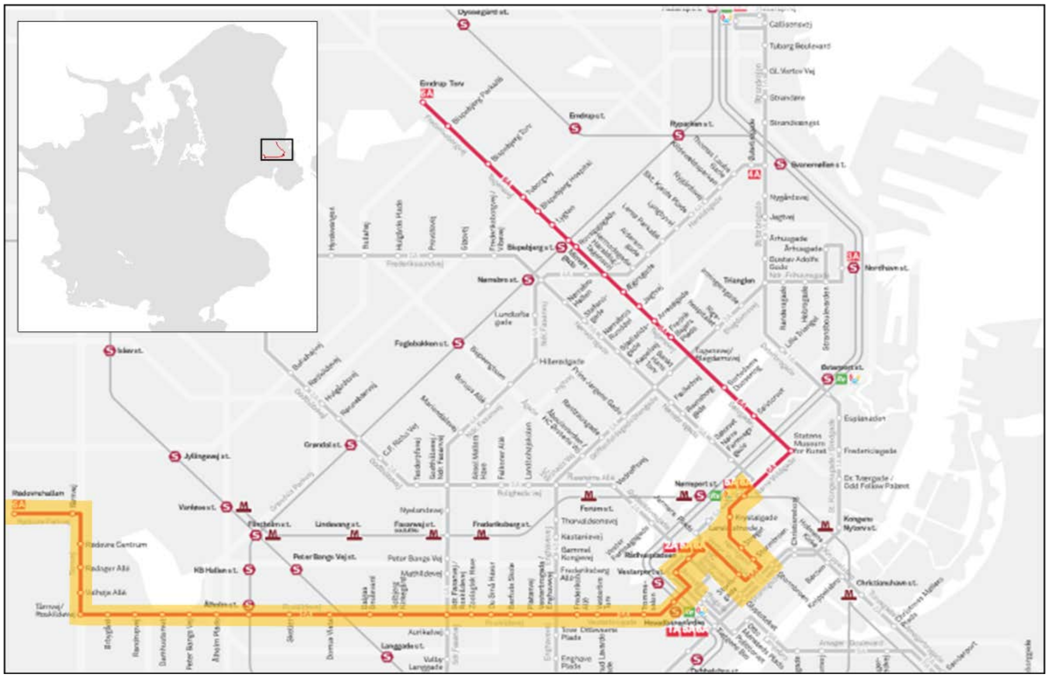


Fig. 2.2 – Bus line 6A in Copenhagen (red line) – Highlighted (with orange) the part from Rødovre to Nørreport station which is the intended corridor for the Rapid Transit

2.3 The Rapid Transit System

In the following sections, a Rapid Transit System is planned and suited to the case corridor. The Rapid Transit configuration is then implemented in the route choice model. The configuration includes the physical layout (alignment and stop positioning) as well as the timetable.

2.3.1 Alignment

The alignment of the Rapid Transit System is planned to be nearly identical with the alignment for the existing bus line. This is justified since the existing bus already follows the main arterial road of the corridor, Rosklidevej/Vesterbrogade. However, in the inner city and the medieval town bus line 6A has a torturous alignment and it was not found suitable for a Rapid Transit System. This is because the narrow streets and sharp turns is problematic for larger vehicles like light rail vehicles or articulated busses, but also because the detour of the alignment and the low speeds especially in the medieval town result in poor travel time. Instead, the Rapid Transit System was laid out in the largest road and most direct route between the central station and the end stop at Nørreport station (see Fig. 2.3).

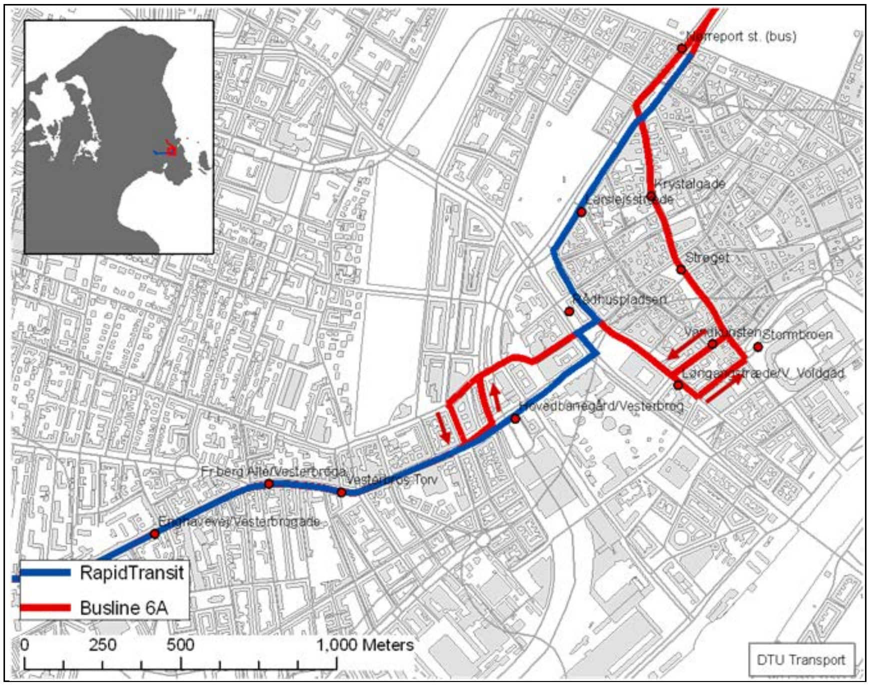


Fig. 2.3 – Rerouting of the Rapid Transit in the inner city

2.3.2 Stop positioning

The existing bus line 6A has in the western part, end stop at Rødovrehallen. This end stop was also found suitable for a Rapid Transit System. In the inner city bus line 6A connects to the large city terminals Copenhagen Central Station, the Town Hall Square and the largest passenger terminal in Denmark, Nørreport station. It was estimated that the Rapid Transit System would gain most passengers if it also connected to these three important terminals. The Rapid Transit System was, therefore, laid out between the western end stop in Rødovre and Nørreport station in the inner city.

Looking at only the western part of bus line 6A – the examined corridor, the existing bus has average stop spacing at 335 meters. This stop spacing corresponds with the general objective of having 400 meters coverage for bus service in Copenhagen (HT et al. 1998). However, this average stop spacing was considered to be too short for a Rapid Transit System since it results in many stops and thereby poor average speed. Instead a guideline of 500-600 meters in average stop spacing was used for the stop positioning. This could be applied to both BRT (APTA 2010) and LRT (EGIS 2003) and found suitable for the urbanization level in the central Copenhagen (e.g. also Andersen & Landex 2010). This average stop spacing was also found suitable to keep an acceptable degree of coverage to public transport in the corridor once the existing bus line would be closed down. Still the average stop spacing was only a guideline, the stop spacing also strongly depended on the homogeneity of the city; some areas demanded more stops to satisfy the travel demand whereas others may not. Practically, the positioning of the majority of the stops for the Rapid Transit was reused from bus line 6A.

In total, the Rapid Transit configuration obtained average stop spacing at 550 meters. The physical configuration of the Rapid Transit System can be seen in Fig. 2.4.

Distance: 9920m, Number of stops: 19, Avg. stop spacing: 550m

Stops, West -> East:

Rødovrehallen
Rødovre Centrum
Roskildevej/Tårnvej
Randrupvej/Roskildevej
Ålholm Plads
Skellet/Roskildevej
Domus Vista
Dalgas Bvld/Roskildevej
De Små Haver
Platanvej
Enghavevej/Vesterbrogade
Fr.berg Allé/Vesterbrogade
Hovedbanegården/Vesterbrogade
Rådhuspladsen
Larslejsstræde
Nørreport st.

Fig. 2.4 – Rapid Transit alignment and stop configuration including 500m coverage

This physical layout of the Rapid Transit system was maintained fixed during the whole examination.

2.4 Rapid Transit timetable

Contrary to the physical layout of the Rapid Transit system, the timetable was intended to change whenever the system factors were changed. To get a starting point, a base timetable configuration was appointed to the Rapid Transit System. The base configuration was chosen to be realistic yet so conservative that the changing of the system factors all would result in increases in ridership. The base configuration was in this way considered to be the lowest acceptable configuration for a Rapid Transit System in terms of travel time and headway and by that only allowing room for improvement. The base configuration served as the frame of reference for all the examined variations in system factors and rail factor.

2.4.1 Base system travel time

The travel time of the Rapid Transit System was inherited from the existing bus line. However, it had to be reduced because of the rerouting in the inner city and the fewer stops on the Rapid Transit than on the bus. Other than that, the travel time preconditions for the Rapid Transit System were set equal to the existing bus, in accordance to the conservative approach. This meant the travel time appointed to the base configuration of the Rapid Transit System was actually that of a regular bus hence the frame of reference was a regular bus travel time.

The average travel speed for the existing bus in the western part (the examined corridor) is approximately 15.7 km/h in the morning rush hour.[2] The resulting average travel speed for the Rapid Transit System was calculated to 18.4 km/h in the morning rush hour.

2.4.2 Base system headway/frequency

The headway of the existing bus line is 12 departures per hour in each direction during the morning rush hour. This equals 5-minutes frequency (minutes between departures). The headway of the Rapid Transit System was set to 6 departures every hour equal to 10-minutes frequency. The reason was that a 10-minute frequency was considered to be the lowest acceptable headway in the corridor and that the larger capacity of the Rapid Transit vehicles still would be able to handle the passengers.

3 Approach of the examination

With a base configuration for the Rapid Transit System in the case corridor defined, the variations of the system factors for the examination had to be determined. Also the approach to the examination of the rail factor needed to be decided on. Every change in either system factors or rail factor was designed to provide a unique configuration for the Rapid Transit system. Each configuration could then be examined through the route choice modeling. But first a validation of the route choice model was performed to insure the foundation of the examination was solid.

3.1 Validation of the route choice model

Although the route choice model is well proven and has shown its worth in previous projects (e.g. IMV 2006) it was unknown how precise it could describe the conditions in the case corridor. Therefore, an approach was taken to validate assignment results on the existing conditions to see how the existing bus line 6A in the corridor was described by the model. Distributed passengers loads along the existing bus line provided by the route choice model were examined and compared to similar count data provided by the local bus authority.

3.2 System factors approach

The examination of the system factors for the Rapid Transit, which consisted of travel time and frequency, had the following approach.

3.2.1 System travel time approach

Upgrading from a regular bus to a Rapid Transit System should result in a travel time reduction to the system (lower running times and stop times for system vehicles). One reason is the longer average stop spacing commonly applied to Rapid Transit as already accounted for in Section 2.3.2 *Stop positioning*. Another reason is higher traffic priorities for Rapid Transit compared to regular bus. These priorities consist primarily of right-of-way for the Rapid Transit obtained by semi-closed or closed alignments and signal priorities. The higher traffic priorities means that the Rapid Transit can – to a certain extent depending on how much priority it is giving – avoid general road congestion and stopping in intersections. Furthermore, in Copenhagen all entry to busses is through the narrow front door causing somewhat of a bottleneck in the passenger exchange at stops. Having more and wider doors in the vehicles and allowing for both entry and exit at all doors as particularly seen for LRT, but also for BRT, can reduce the passenger exchange time and thereby the dwell times at stops.

Since the system travel time of the base configuration was conservatively set as that of a regular bus, the objective in the examination was to decrease the travel time. The examined travel time of the Rapid Transit System was thereby intended to span from the highest acceptable travel time (regular bus) to the lowest achievable travel time for the Rapid Transit in the corridor.

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[2] The speed varies slightly due to different levels of congestion in different periods.

(HUR 2001) has an overview over the components that make up the travel time for busses in the central Copenhagen. From this it can be seen that 15% of the system travel time is driving in congestion, 5% is exiting from stops (also a result of congestion) and 20% is time spend waiting for green light. Moreover, the dwell time at stops constitutes 20% of the system travel time leaving only 40% for free-flow running time. In regards to the before mentioned assessments of these components in a Rapid Transit system, those four elements are the ones that can be improved when upgrading from regular bus to a Rapid Transit. A closed alignment for a Rapid Transit including segregated stops and full signal priority in all intersections will result in exclusive right-of-way for the total Rapid Transit line. This can result in 40% reduction in travel time when values from (HUR 2001) is projected to the Rapid Transit System. If multiple at-grade doors for both entry and exits are applied the dwell time at stops can presumably be cut in half giving additional 10% in reduction of the total system travel time. Consequently, an exclusive right-of-way Rapid Transit in the central Copenhagen with the appropriate rolling stock can result in a 50% reduction in travel time compared to regular bus.

It is far from always the optimal configuration can be obtained for the upgraded system (some streets can be too narrow to ensure closed or segregated alignment; the traffic volumes of crossing roads can be too high to ensure signal priority etc.). However, the optimal configuration can be an objective to strive for. Realistically, the travel time reduction obtained by a Rapid Transit system compared to the regular urban bus will likely be somewhere in the span of 0%-50% hence a reduction of the travel time for the Rapid Transit at 0% (regular bus configuration = Base – see Section 2.4.1 *Base system travel time*), 10%, 20%, 30%, 40% and 50% was investigated (see Tab. 3.1).

	Travel time reduction [%]	**Average speed** [km/h]
Current bus line - 6A*		15.7
Rapid Transit	0	18.4
	10	20.5
	20	23.0
	30	26.3
	40	30.7
	50	36.9

*Between Rødovre and Nørreport station

Tab. 3.1 – Investigated travel time reductions and corresponding average speeds

18.4 km/h average speed for the base configuration is, as desired, on the low side for a Rapid Transit system. The optimal configuration results in average speed at 36.9 km/h which expectedly is on the high side for an urban corridor with relatively low average stop distances.

Changing the travel time of a public transport line like the Rapid Transit system in the traffic model will affect the route choice in the assignment. Looking at the utility function from Fig. 2.1 it is the part called InVehicleTime that is affected in the route choice when changing the system travel time. This implies that a lower travel time result in a lower general cost everything else being equal and consequently a higher number of passengers in the Rapid Transit System.

3.2.2 System headway/frequency approach

Upgrading from regular bus to Rapid Transit System should not necessarily result in a more frequent transit system. Fact is that the opposite offhand makes more sense due to the higher capacity of the Rapid Transit vehicles. However, there are also other factors that play a role. For instance whether there will be supplemental bus service in the corridor. Generally, it should be avoided to worsen the overall service in the corridor. This means that if there is no supplemental bus service, the Rapid Transit System can be giving the same (or close to the same) frequency as the existing bus to maintain the same level of service. Sometimes an even more frequent system can be applied when upgrading to Rapid Transit if the potential is there; then the initial surplus of capacity can be instantly (due to the improved service itself) and gradually (long term effect) filled with more passengers. Attentions should off course also be given to the fact that a more frequent system in general is more expensive to operate.

In the case corridor the existing bus line 6A is considered to be closed down in the Rapid Transit situation and no supplemental bus service is applied. Even so, the headway of the base Rapid Transit configuration is set to 6 departures per hour (cf. Section 2.4.2 *Base system headway*). This means there is room for improvement and system headway closer to, identical to, and even more frequent than the existing bus has been applied in the examination. In numbers this means 6 (Base), 8, 12 (existing bus) and 24 departures per hour thus applying respectively 10, 7.5, 5 and 2.5 minutes frequencies to the Rapid Transit System.

Changing the frequency of a public transport line like the Rapid Transit System in the traffic model will like the changing of travel time affect the route choice in the assignment. Looking at the utility function from Fig. 2.1 it is primarily the Hidden Wait time that is affected. However, also the Wait time is affected especially the Wait time(s) in transfers. Higher frequencies lead to lower waiting times and thereby lower general cost, everything else being equal, which means more passengers in the Rapid Transit System.

3.3 Rail factor approach

The Rapid Transit of the case corridor was, in the previous sections, deliberately not configured as bus or rail. For the system factors this was unnecessary since a Bus Rapid Transit system can perform just as well as a Light Rail Transit system if giving the same opportunities. However, like mentioned in Section 1 *Introduction*, a rail system can be expected to attract more passengers than a bus system everything else being equal. This is the effect of the so-called rail factor.

The method to examine the impact of the rail factor was to implement different preferences based on perceived attractiveness for different types of public transport means in the traffic model. Looking at the utility function from Fig. 2.1 this is represented by the coefficient multiplied with the InVehicle time ($\mu_{InVehicle}$). This coefficient allows for applying different values and thereby different cost to different means of public transport where lower values result in lower cost/higher utility. In the predefined model this is already applied and the value for heavy urban rail is 20% lower than for bus thus representing a higher attractiveness for rail than for bus and consequently a rail factor contribution implemented in the route choice. The values of time that constitutes the foundation of the coefficient in the model are derived from SP and RP-data and should therefore represent real preferences for different means of transportation (Nielsen 2000).

If a Bus Rapid Transit system is chosen for the corridor, the coefficient to apply already exists in the model. But if a Light Rail Transit system is chosen no exact coefficient can directly be applied since there is not any Light Rail Transit system in Denmark. This means no real knowledge of LRT attractiveness and consequently no corresponding preference values are applied in the model. For forecasting scenarios including Light Rail projects a combination of the bus coefficient and the heavy urban rail coefficient has been used. In Denmark, the combination has generally consisted of 1/3 bus value and 2/3 heavy rail value thus indicating an impact that lies between bus and heavy urban rail but slightly more towards heavy urban rail. This combination is here considered to be the unofficial Danish attractiveness to apply to LRT, but it has no survey data to support it up and is merely based on estimates. However, the combination concept can be developed further and that is done in this examination. The assumption is, that both the attractiveness from bus and heavy urban rail can be applied to the Rapid Transit System respectively as the lowest (none) and highest estimate, and the span in between is an interval for plausible impacts. This assumption has given the combination sets of rail value and bus values that have been implemented in the examination to represent differences in attractiveness and induce a rail factor – see Fig. 3.1

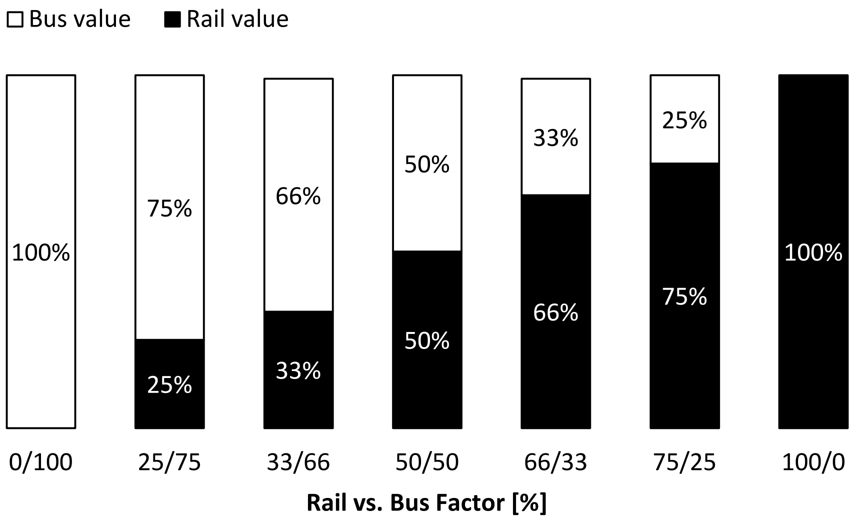


Fig. 3.1 – Bus in-vehicle value and rail in vehicle value combinations to simulate different attractiveness levels for the Rapid Transit system and induce rail factor – Span from Bus Rapid Transit (Bus value) to heavy urban rail (Rail value)

The examination of the rail factor has an implicit system choice applied since it is only relevant to talk about rail factor when the system is rail-bound. The examination of the rail factor is therefore based on the assumption that the Rapid Transit system of the case corridor is a Light Rail Transit system.

3.4 Catalog approach

All characteristics of the Rapid Transit system were examined separately to isolate their impact. In reality they are all open for changing simultaneously and it was desirable to examine the impact on ridership when changing several characteristics at the same time. For instance, what happens if the travel time can be reduced by 50% and the headway is best suited to 5 minutes frequency and/or the attractiveness level is estimated to be the same as for heavy urban rail? To examine this all combinations of the defined span of system factors and rail factor was calculated in the route choice model and the results could serve as a look-up catalog for different configurations of the Rapid Transit system.

3.5 Capacity approach

Upgrading from regular bus to Rapid Transit will usually result in higher vehicle capacity since larger vehicles are deployed to the system. This could be articulated busses or Light Rail vehicles. But the capacity of the system also coincides with the frequency and the number of passengers that choose to ride the system.

The applied route choice model does not operate with capacity restraints. This means that all laid-out passengers can board the mean of transport they wish in accordance to the utility function no matter how packed the vehicle may be. This is of course not realistic and ignores that large capacity problems can lead to alternative route choices. To examine whether a public transport line has sufficient capacity a derived path has to be taken where the highest occupancies in the vehicles are examined and then compared to standard vehicle capacities. In the examination, such an approach accounted for the capacity issue of all configurations of the Rapid Transit, system factors as well as rail factor.

3.6 Approach summary

The examination of the Rapid Transit system in the case corridor included system factors and rail factor and their variations, plus the affect on capacity as described in this section. Tab. 3.2 gives an overview of what has been examined and the terms that are used to present them.

System Factors			Rail Factor
System Travel Time		**System Headway**	**Rail vs. Bus factor**
Reduction [%]	(Average speed)	Minutes between departures	[%]
0	(18.4 km/h)	10	0/100
10	(20.5 km/h)	7.5	25/75
20	(23.0 km/h)	5	33/66
30	(26.3 km/h)	2.5	50/50
40	(30.7 km/h)		66/33
50	(36.9 km/h)		75/25
			100/0

Capacity
Passenger per vehicle

Tab. 3.2 – The Rapid Transit configurations that were included in the examination – Highlighted (with orange) is the base

4 Results of the examination

The Rapid Transit base configuration was implemented in the route choice model and subsequently all the configurations based on the variations of the characteristics that constitute the examination were implemented also. Then route choice assignment was performed for the morning rush hour on each configuration of the Rapid Transit System that applied to the particular characteristic setting. To obtain the more general approach so that results can be compatible to other corridors than the case corridor, and so that the comparability is emphasized, the ridership results are in the following presented as relative to the base ridership. The results are presented using plots and tables for clarity

4.1 Route choice model validation results

The validation of the route choice models ability to describe the existing conditions of the case corridor provided the results seen in Fig. 4.1 where the distribution of passengers for the existing bus line 6A is compared to official passenger counts.

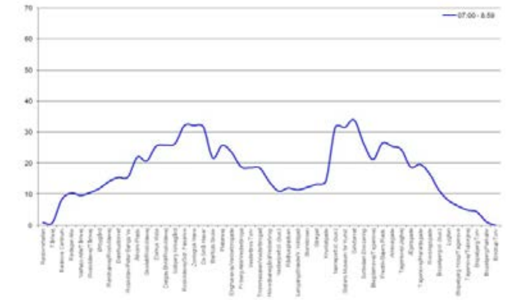
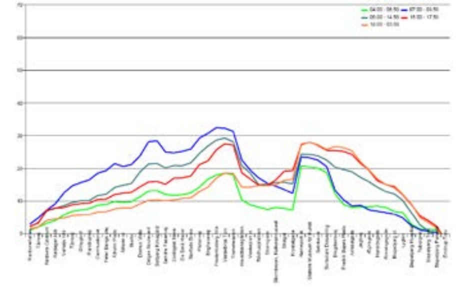
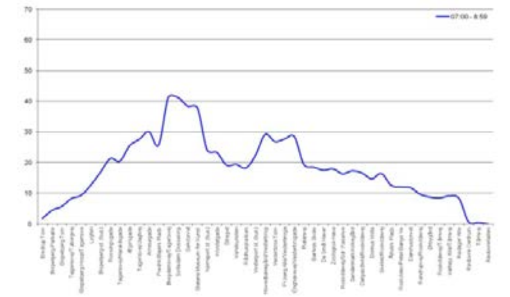
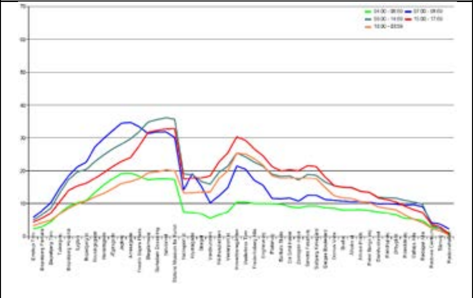
	Route choice model results	Passenger counts
Direction 1 Rødovre -> Emdrup		
Direction 2 Emdrup -> Rødovre		

Fig. 4.1 – Passenger volume per trip for the existing bus line 6A in the case corridor – Route choice model results left and passenger counts right. The blue line represent the morning rush hour.

Since the route choice assignment was performed on the morning rush hour the results should be compared to the morning rush hour counts which are represented by the blue line in the passenger count column in Fig. 4.1. Note that it is the whole existing bus line 6A that has been examined and not only the western part that constitutes the case corridor. From Fig. 4.1 it can be seen that the passenger distribution looks fairly alike and the models ability to describe the existing conditions in the corridor appear sufficient. The results were found trustworthy enough for further examination.

4.2 Base results

First the frame of reference, the result of the base configuration for the Rapid Transit, had to be determined. The examination provided the result of 1,977 passengers in the Rapid Transit system during the morning rush hour. Depending on how this is numbered, it adds up to a weekday ridership at 7,900-9,900 passengers. It seems as a low estimate and is also lower than the existing bus in the corridor. There are several reasons for that, and some of them are already described as delimitations (cf. Section 2.1.1 *Delimitation in the modeling approach*). First, the base configuration of the Rapid Transit system is not much faster than the existing bus but have substantial longer distances between stops which result in poorer accessibility to the system. This effect is seen both when comparing to traffic counts and to modeling of the existing situation. Second, since the trip matrices are based on relatively old data and there has been an increase in traffic since then, the level of traffic laid-out in the route choice is lower than present. Third the delimitations of the trip matrices to morning rush hour may decrease the daily number of passengers since urban corridors with a lot of activities tend to have a higher share of leisure and other travel. Fourth, since the route choice modeling is solely based on redistribution of existing public transport customers, no induced traffic, no transferring of car travel and no long term impact is taking into account. This may be of concern for the base configuration but concurrently with the improved configurations of the Rapid Transit in the examination this will pose a larger problem. All in all the lower level of traffic was expected and it should not affect the purpose of the examination since it has a comparative approach.

4.3 System factors results

When the frame of reference was defined the route choice assignments of the different characteristics and their variations could begin, and the results could be assessed. First off were the system factors, travel time and frequency.

4.3.1 System travel time impact on ridership

The examination of the system travel time and the reduction of the travel time for the Rapid Transit in the case corridor provided the results seen in Fig. 4.2.

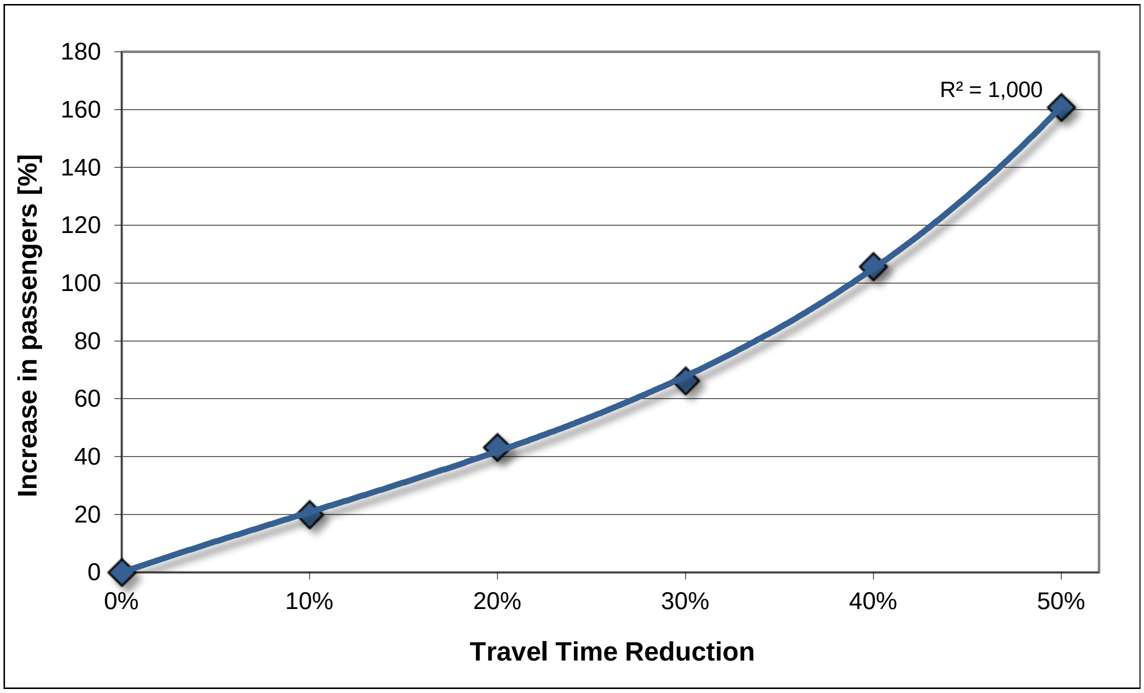


Fig. 4.2 – Travel time reduction – impact on ridership

From Fig. 4.2 it can be seen that the ridership increases when the travel time decreases just as expected. If the optimal solution regarding traffic priorities for the Rapid Transit can be obtained which consequently decrease the travel time by 50% (from average speed at 18.4 to average speed at 36.9 km/h), an increase in passengers at around 160% can be expected. Ensuring the traffic priorities for the Rapid Transit often goes prior to the actual constructing of the system. The desired service level and restrictions of the corridor determine beforehand the obtainable travel speed and time. This means that the travel time often is more or less fixed when the system is in service and decisions of this system factor must be made already in the planning phase. Apart from potential higher constructions cost to ensure the traffic priorities; the changing of the travel time does not have any negative consequence for the Rapid Transit. If anything, faster operation only leads to lower operating cost and need for rolling stock.

4.3.2 System headway/frequency impact on ridership

The examination of the system headway and the increase in frequency for the Rapid Transit in the case corridor provided the results seen in Fig. 4.3.

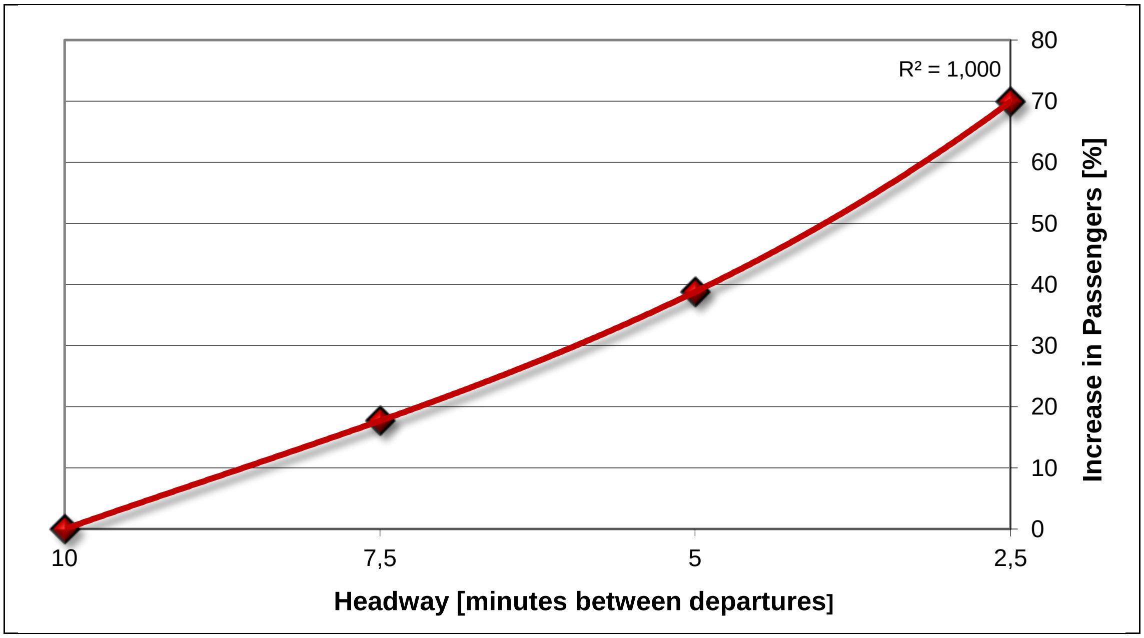


Fig. 4.3 – Headway (increase in frequency) – impact on ridership

From Fig 4.3 it can be seen that an increase in frequency as expected result in a higher number of passengers. Having 2.5 minutes between departures will result in 70% more passengers than having 10 minutes between departures. Contrary to the travel time, the headway can relatively easy be changed when the system is in operation (but it can result in a larger rolling stock). However, changing the frequency, directly affects the operation of the Rapid Transit where higher frequencies lead to higher operating cost. Going from 10 minutes between departures to 2.5 minutes between departures (6 departures per hour to 24 departures per hour) will result in four times more departures overall. Consequently, the operating cost will approximately increase by 400%. This high increase in operation cost may be justified by a larger number of passengers due to the higher service level, or it may not. In order to know, the operating cost must be compared to the number of passengers at each frequency level. Therefore, an estimate of the operating cost for the Rapid Transit was calculated based on the total operating time and a fixed cost per vehicle hour and then normalized with the number of passengers. The result can be seen in Fig. 4.4.

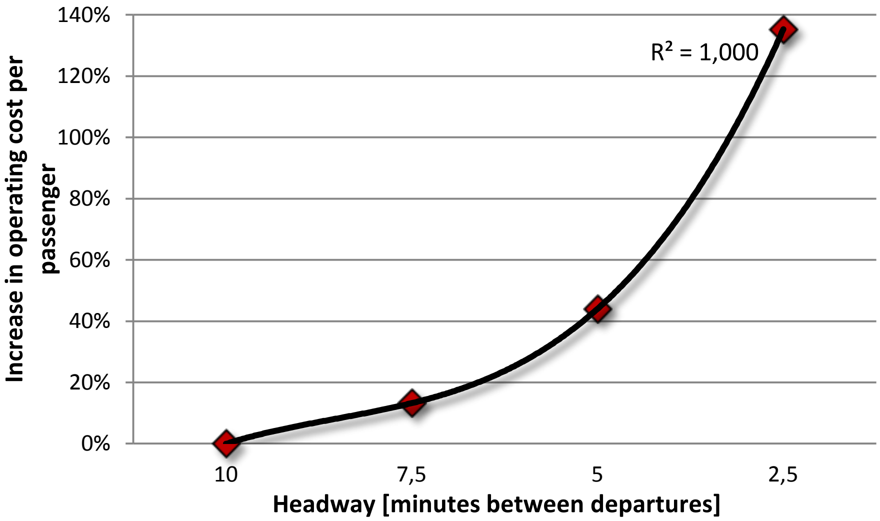


Fig. 4.4– Operating cost normalized with the number of passengers at each examined headway level

From Fig. 4.4 it can be seen how much it affects the operating cost to increase the frequency, especially when minutes between departures become very low. What the Rapid Transit will gain in passengers as result of the increased service can not compensate for the high operating cost when frequencies become as high as 2.5 minutes between departures.

4.3.3 Synergy in system factors

Ignoring any rail factor impact, the best achievable configuration for the Rapid Transit system regarding travel time (50% reduction) yielded an increase in passengers at 161% compared to the base configuration. The best achievable configuration regarding headway when solely looking at the impact for passengers (2.5 minutes between departures) yielded an increase in passengers at 70%. However, when looking a the best achievable configuration for the Rapid Transit regarding both travel time and headway the result is 301% increase in passengers which is 70% more passengers than the sum of the two independent results. This indicates that a synergy can be achieved when combining reduction in travel time with increase in headway. This synergy was investigated further and a correlation can be viewed in Fig. 4.5:

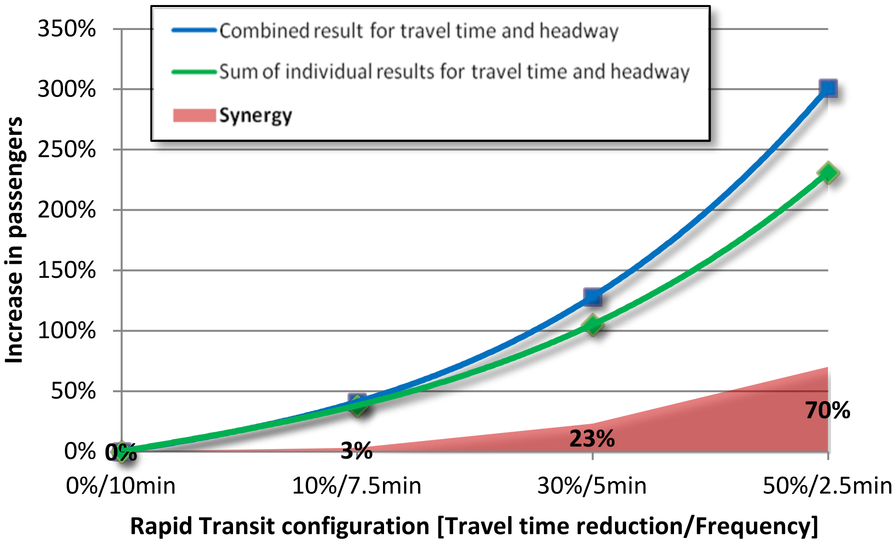


Fig. 4.5 – Impact on ridership when combining reduction in travel time with increase in headway

Targeting more elements in the route choice utility function at the same time will lead to an overall lower travel time for the public transport journey, resulting in lower a generalized cost. This effect consequently results in more passengers choosing the Rapid Transit system over other public transport lines.

4.4 Rail factor results

The examination of the rail factor for the Rapid Transit system in the case corridor provided the results seen in Fig. 4.6.

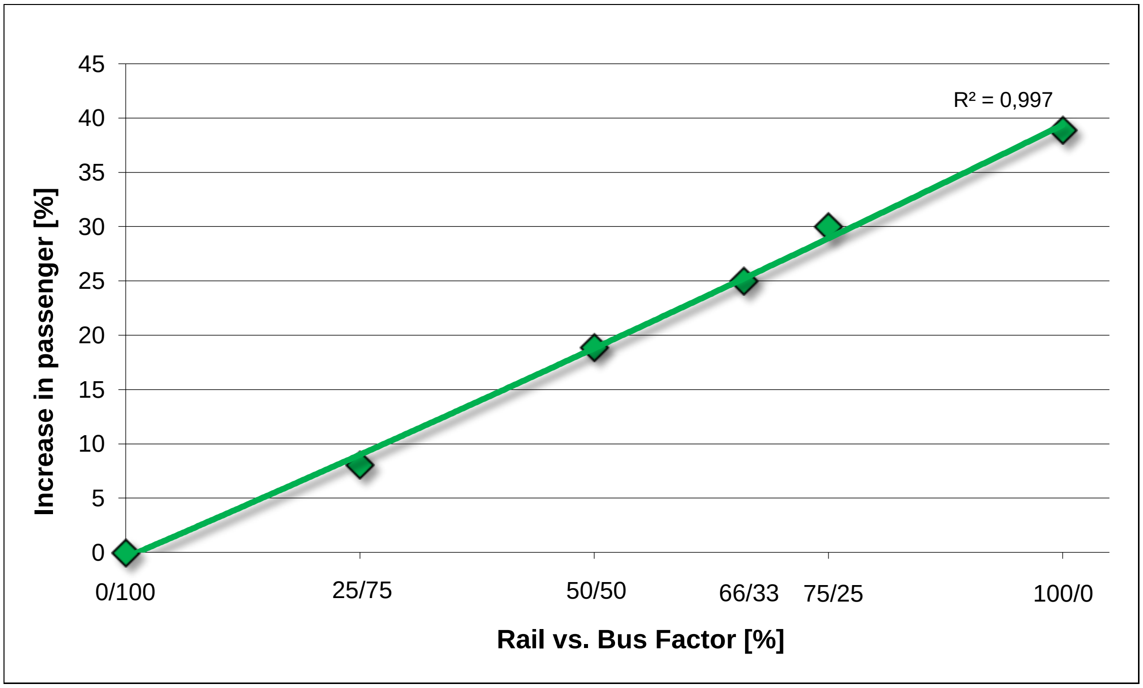
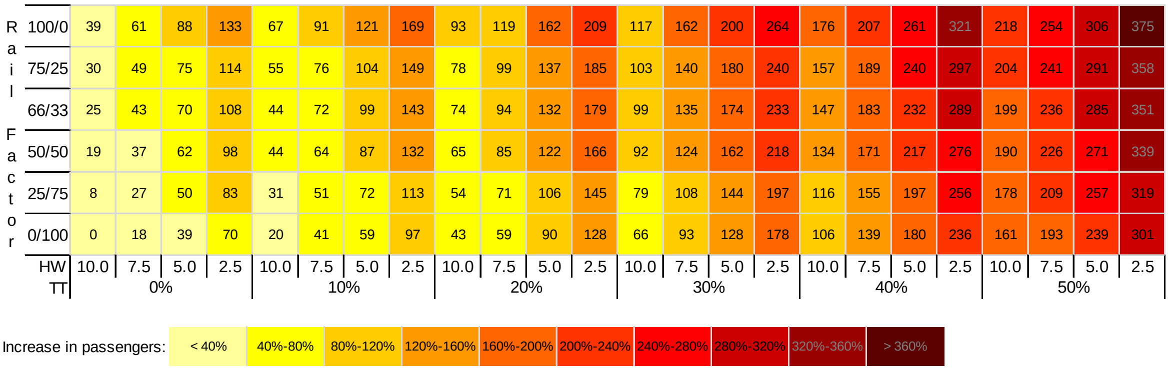


Fig. 4.6 – Rail factor - impact on ridership

From Fig. 4.6 it can be seen that the rail factor has a near linear impact. If the Rapid Transit System is perceived to be as attractive as heavy urban rail the impact of the rail factor will result in a 40% increase in passengers compared to a Bus Rapid Transit system. If the perception of the attractiveness of the Rapid Transit is somewhere in the middle of bus and heavy urban rail the increase in passengers at around 20% can be expected. The unofficial Danish Light Rail attractiveness (Rail/bus = 66/33) will result in a rail factor impact at 25% increase in passengers,

4.5 Catalog results

The examination of all combinations of the system factors and the rail factor provided the look-up catalog seen in Fig. 4.7.



Rail Factor	100/0	75/25	66/33	50/50	25/75	0/100
TT 0%, HW 10.0	39	30	25	19	8	0
TT 0%, HW 7.5	61	49	43	37	27	18
TT 0%, HW 5.0	88	75	70	62	50	39
TT 0%, HW 2.5	133	114	108	98	83	70
TT 10%, HW 10.0	67	55	44	44	31	20
TT 10%, HW 7.5	91	76	72	64	51	41
TT 10%, HW 5.0	121	104	99	87	72	59
TT 10%, HW 2.5	169	149	143	132	113	97
TT 20%, HW 10.0	93	78	74	65	54	43
TT 20%, HW 7.5	119	99	94	85	71	59
TT 20%, HW 5.0	162	137	132	122	106	90
TT 20%, HW 2.5	209	185	179	166	145	128
TT 30%, HW 10.0	117	103	99	92	79	66
TT 30%, HW 7.5	162	140	135	124	108	93
TT 30%, HW 5.0	200	180	174	162	144	128
TT 30%, HW 2.5	264	240	233	218	197	178
TT 40%, HW 10.0	176	157	147	134	116	106
TT 40%, HW 7.5	207	189	183	171	155	139
TT 40%, HW 5.0	261	240	232	217	197	180
TT 40%, HW 2.5	321	297	289	276	256	236
TT 50%, HW 10.0	218	204	199	190	178	161
TT 50%, HW 7.5	254	241	236	226	209	193
TT 50%, HW 5.0	306	291	285	271	257	239
TT 50%, HW 2.5	375	358	351	339	319	301

Increase in passengers:	< 40%	40%-80%	80%-120%	120%-160%	160%-200%	200%-240%	240%-280%	280%-320%	320%-360%	> 360%

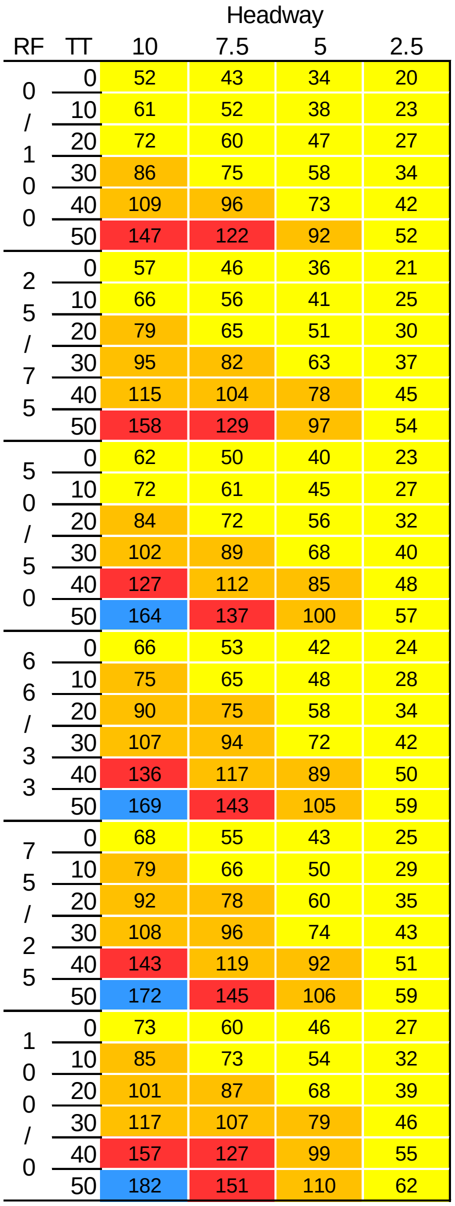
Fig. 4.7 – Catalog for all combinations of system factors and rail factor impact on ridership

From Fig. 4.7 it can be seen that the ridership increases with higher frequency, lower travel time and higher attractiveness as expected. The best achievable system factor configuration and the highest impact of rail factor corresponding to heavy urban rail will result in 375% increase in passengers for the Rapid Transit system compared to the base configuration. In absolute numbers the best achievable configuration for the examined corridor will result in 9,390 passengers using the Rapid Transit system in the morning rush hour. If this number is added up the same way as the base result in Section 4.2 *Base results*, it yields 37,550-46,930 passengers in a weekday for the Rapid Transit in the case corridor.

The catalog also reveals a synergy when combining system factor improvement with higher rail factor impact that is even larger than for the system factors alone. The best independently configuration gives summarized 270% increase in passengers and the assignment result including them all simultaneously gives as mentioned 375%. This is an over 100% increase in passenger-synergy for the best Rapid Transit configuration.

4.6 Capacity results

Due to the nature of capacity and the desire to compare occupancies to standard vehicle capacities, the results of the capacity examination are presented in absolute values. It is thereby specific to the examined corridor and not directly transferable to a general system. However, it gives an idea of what to expect. The capacity of all combinations of the system factors and the rail factor provided the results seen in Fig. 4.8.



		Headway			
RF	TT	10	7.5	5	2.5
0/100	0	52	43	34	20
	10	61	52	38	23
	20	72	60	47	27
	30	86	75	58	34
	40	109	96	73	42
	50	147	122	92	52
25/75	0	57	46	36	21
	10	66	56	41	25
	20	79	65	51	30
	30	95	82	63	37
	40	115	104	78	45
	50	158	129	97	54
50/50	0	62	50	40	23
	10	72	61	45	27
	20	84	72	56	32
	30	102	89	68	40
	40	127	112	85	48
	50	164	137	100	57
66/33	0	66	53	42	24
	10	75	65	48	28
	20	90	75	58	34
	30	107	94	72	42
	40	136	117	89	50
	50	169	143	105	59
75/25	0	68	55	43	25
	10	79	66	50	29
	20	92	78	60	35
	30	108	96	74	43
	40	143	119	92	51
	50	172	145	106	59
100/0	0	73	60	46	27
	10	85	73	54	32
	20	101	87	68	39
	30	117	107	79	46
	40	157	127	99	55
	50	182	151	110	62

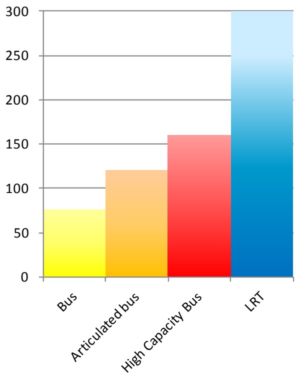


Fig. 4.8 – Highest average occupancies (passengers) in a Rapid Transit vehicle (during morning rush hour) and the standard vehicle capacity (passengers per vehicle) (based on Zhang 2009) that has sufficient capacity to handle the occupying passengers if they are uniformly distributed during the morning rush hour

As seen in Fig. 4.8 most of the Rapid Transit configurations do not have higher occupancies than standard bus vehicle capacity is sufficient to meet the demands, especially when operating with high frequency. However, in low frequencies, where the travel time has been reduced by 50% and the rail factor impacts a little more than a bus, Light Rail capacity is required. The passenger numbers in Fig. 4.8 are based on a uniform distribution of passengers in the morning rush hour. However, there may be peaks within the morning rush hour that will result in a higher number of passengers per vehicle. It should be added that the low level of traffic provided from the trip matrices (cf. Section 4.2 *Base results*) and the lack of induced traffic and transferred car travels underestimate the occupancies and that corridors with higher customer foundation than the base corridor would result in higher occupancies, consequently leading to larger demands for vehicle capacity. Furthermore, the standard vehicle capacities provided by (Zhang 2009) includes both seats and standing spaces so if seating for all passengers is desired the vehicle capacity must be even larger (but it may be acceptable with standees in the morning rush hour). It should also be noted that LRT can obtain even higher vehicle capacity at the same frequency through coupling of vehicles if necessary.

5 Discussion of results

All plots and tables containing the ridership results for the different Rapid Transit characteristics in the examinations are (in combination with similar future examinations) planned to be used as look-up catalogs. In that way a given Rapid Transit configuration can be tested to see what ridership can be expected compared to a regular bus solution. In the following the implications and significance of the results are discussed and evaluated. But first a crucial precondition for the examination namely the validation of the route choice model is addressed.

5.1 Route choice model – implications of results

From previous studies that have used the applied route choice model (e.g. (IMV 2006)) it was already evident that the model was able to produce trustworthy results of the public transport system in the Copenhagen area. Furthermore, the route choice model was tested on the existing conditions to see how well it could describe the case corridor. The results proved solid and trustworthy albeit there were some problems with attaining the right level of traffic due to some delimited input data. The route choice model delivered authentic passengers distributions that were pretty close to official passenger counts for the existing bus line in the corridor. The route choice model was, therefore, found reliable and trustworthy enough to apply in this examination and there are no major concerns in applying its results in conclusions of real-life projects. Off course with that general reservation that models never can describe the reality perfectly.

5.2 System factors – implications of results

The system factors consisting of travel time and headway have been examined separately and in combinations with each other. The examination has provided interesting results.

5.2.1 System travel time implications

The results of the ridership impact when reducing the travel time of the Rapid Transit system (Fig. 4.2) actually indicate a strong correlation. Even minor reductions in travel time result in a significant increase in passengers. The in-vehicle travel time is generally the most time consuming component in the public transport journey, so reducing this will have a very positive impact on competitiveness and thereby attract more customers. If reductions in travel time up to 50% from regular bus can be achieved, the impact is even larger due to the potential growth. A 50% reduction in travel time will lead to 161% increase in passengers.

The results are based on the case corridor and the traffic priorities that were assumed achievable here, but in other corridors and in other cities where congestion slows the bus service these traffic priorities are likely to produce the same reductions in travel time. Since the travel time is such an important element of the public transport journey it seems conceivable that the travel time impact on ridership from this examination is transferable to other corridors and other cities. The results strongly emphasize the importance of the system travel time. It should be a crucial focal point when planning Rapid Transit Systems and it should always be of high priority to increase the average system speed and thereby decrease the travel time. It also underlines the importance of passability projects to decrease travel time for existing systems.

5.2.2 System headway/frequency implications

The system headway impact on ridership is also fairly strong (Fig. 4.3); a more frequent system leads to higher number of passengers. The correlation is, however, less significant than for the travel time impact, and it is doubtful how much more there is to gain if the frequency becomes even higher than 2.5 minutes between departures. There is a good 70% increase in passengers going from 10 minutes frequency to 2.5 minutes frequency but the resulting increase in operating cost is approximately 400%. The operating cost per passenger (Fig. 4.4) suggests that 2.5 minutes frequency is a little too high since the resulting gain in passengers cannot compensate for the higher operating cost. For LRT system frequencies of 5-10 minutes are common but it can be even higher. BRT systems often have even higher frequencies than 2.5 minutes between departures. However, busses are usually considerable more inexpensive to operate than Light Rail vehicles, and their capacity is lower.

Overall the system headway may not seem as an equally important focal point in the planning of Rapid Transit systems as travel time (supported by the fact that the frequency can relatively easy be changed when the system is in operation) when it comes to ridership. However, there are some thresholds regarding the headway that are crucial to be aware of. Going too low or too high on frequency can have a very strong negative impact on service level, capacity and operating cost of the system.

5.2.3 Lack of induced traffic implications

Generally for the system factors but especially for the travel time reduction it is believed that the lack of induced traffic in the examination plays a non-insignificant role. This is both theoretical founded since it is time savings from improved public transport service that leads to induced traffic and it was also indicated (however not documented) by test assignments. Induced traffic was, as described in Section 2.1.1 *Delimitations in the modeling approach*, omitted from the examination. The consequence for the absence of induced traffic is an underestimation of not only the level of traffic in the Rapid Transit system but also for the increases in passengers. There is therefore sound reason to believe that particularly the travel time reduction could show even higher increases in passengers if induced traffic was included in the examination and it would thereby only strengthen the tendency. To determine the exact impact on ridership caused by induced traffic will require further work and could serve as a future refinement of the examination.

5.3 Rail factor – implications of results

The examination of the rail factor has been performed separate from the system factors, but also in combination with the system factors. The sole rail factor impact on ridership (Fig. 4.6) has a clear tendency; the higher attractiveness the Rapid Transit is given, the higher number of passengers, and the correlation is near linear. If having the same attractiveness as heavy urban rail the Rapid Transit could expect to obtain 40% more passengers than if it was a bus. If having 66% heavy urban rail and 33% bus attractiveness as previous used in Danish traffic modeling of Light Rail Transit, the Rapid Transit could expect to gain around 25% more passengers. Since no rail-bound Rapid Transit has been implemented in Denmark it is difficult to know whether that setting is trustworthy and how that attractiveness actually should be fixed. Everything is rarely being equal between bus and Light Rail Transit systems and therefore the rail factor is difficult to observe. From (Scherer 2010) it can be seen how the findings of the rail factor can vary depending on the different studies and their methodology. However, the summarized findings in (Scherer 2010) have a rail factor span of 15%-45% increase in passengers and that coincides very well with the results from this examination as seen both in Fig. 4.6 and Fig. 4.7. It is therefore conceivable that the rail factor impacts found in this examination can be trustworthy and transferable to other corridors and other cities and that the results can be used to understand what can be expected when different levels of attractiveness are applied.

5.4 Synergy – implications of results

The merging of system factor variations where improvement of travel time and headway was examined in combination revealed a surprisingly high synergy in the impact on ridership (see Fig. 4.5). Also the rail factor impact added to the increase of the synergy (see Fig. 4.7). There is therefore an even larger return of investment if improvement in more than just one system characteristics can be made, and a higher rail factor will also contribute to this. The additional increase in passengers when combining the improvement of system factors and rail factor can reach up to 100% as described in Section 4.5 *Catalog results*. This synergy is a hidden benefit that also should be taking into account when planning a Rapid Transit system.

5.5 Capacity – implications of results

Capacity evaluations based on the assignment results of all combinations of system factors and rail factor (Fig. 4.8) indicated no demand for higher vehicle capacity than a LRT vehicle unit can provide. In fact, in most configurations bus vehicle capacity would be sufficient. It is, however, believed that the occupancies in the Rapid Transit vehicles were underestimated and that higher vehicle capacity was actually needed in the rush hour. Nevertheless, when the desired system factors are decided on and when the rail factor impact of the system is imposed it is crucial to make capacity reflections to insure that the Rapid Transit system can handle the passenger demand.

5.6 System choice

In the examination of the travel time and headway all variations could be applied to both BRT and LRT systems because they can perform equally when given the same opportunities. In reality everything is rarely being equal between bus and Light Rail systems and some system factor values are more commonly applied to bus than rail and vice versa. There are also other factors than implemented in this examination that differentiate the systems. In favor of LRT are e.g. urban development, noise and particle pollution and concept retention. In favor of BRT is e.g. flexibility. These outside factors overall tend to favor LRT systems. Nevertheless, a carefully planned BRT system can match a LRT system on nearly all performance levels including travel time, headway, accessibility etc. and consequently the construction cost will also be near identical (all though a full LRT solution will still be more expensive). But even if the same opportunities are given, there are still two important areas where the systems differ and those are capacity and rail factor. So if the system choice stands between a carefully planned BRT and a LRT system, equally in nearly all performance levels, the system choice must address those two areas.

From Fig. 4.8 the case corridor does not seem to call for a Light Rail capacity but since the level of traffic in the modeling is underestimated the need for higher capacity is probably there. Further scrutiny of this should be performed including the elements that can lead to higher occupancies. However, 10 minutes frequency can seem reasonable for the case corridor and in that case Light Rail capacity is most likely needed. But given the results from the examination the capacity will not be an issue in the system choice. Then there is the rail factor which naturally favors the rail-bound LRT system. Depending on the perceived attractiveness for LRT systems, the rail factor can increase the number of passengers up to 40%. These up to 40% extra passengers plus the other factors that favors LRT should then justify the extra cost for the LRT system compared to BRT. Whether the up to 40% extra passengers justifies the extra cost must be closer assessed for the individual project along with the evaluation of the other factors that favors LRT which tend to be quite subjective.

5.7 Suggestion for the corridor

The examination has mostly had a general approach so that findings could be transferable to other corridors and other cities. But given the fact that the whole examination is actually based on one specific case corridor it is of interest to propose a configuration for the Rapid Transit in the corridor using the findings from the examination. This could also serve as an example of how to use the appeared results to actually choose a specific configuration.

To be on par with the current discussion climate in Copenhagen and to obtain the extra benefits for urban development and reduction in pollution, a Light Rail solution would make sense in the corridor. If it is considered that the desired LRT system will achieve an attractiveness equal to what has been used in previous Danish studies with the route choice model (Rail vs. bus value at 66/33), the configuration span will look as in Fig. 5.1.

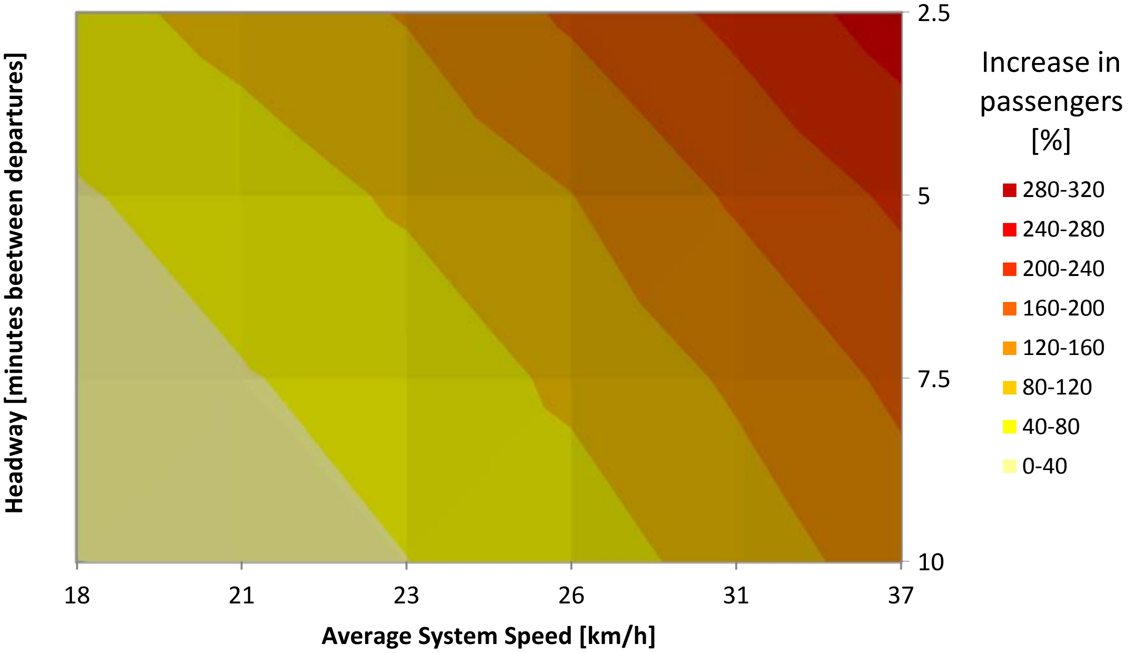


Fig. 5.1 – Configuration span for the Rapid Transit in the case corridor when the attractiveness is fixed to the unofficial Danish LRT attractiveness (Rail vs. Bus = 66/33)

Due to space restraints in the corridor it is not believed that full traffic priority for the LRT can be obtained. It is believed, however, that semi-closed alignment in the middle of the street is obtainable. This should eliminate extra time for exiting from stops. Also the dwell time at stops should be cut in half by providing better access to the LRT vehicles. Close to full signal priority is probably also achievable. Keeping the congestion level of the corridor in mind, the overall reduction in travel time could possibly be 30%-40% compared to a regular bus configuration (equal to average speed at 26-31 km/h).

From a capacity perspective, the frequency would most likely be sufficient at a 10-minutes rate of departure as in the base configuration of the Rapid Transit system when high capacity LRT vehicle are deployed. However, no supplemental bus service is intended in the corridor once the Rapid Transit is implemented. Going from the current bus line 6A and its 5-minutes frequency to a Rapid Transit frequency at 10 minutes would have a negative impact on the waiting times and will result in a degradation of the overall service in the corridor. Totally closing of supplemental bus service may in this regard seem as a poor solution (also since the stop spacing is higher for the Rapid Transit than for the existing bus) but such solution may very well be reality since a costly Rapid Transit system often leads to economizing on the bus service. Preferably, the whole bus system should be reconsidered and adjusted to the Rapid Transit system which actually could entail an overall better public transport system at lower expenses. However, given the fact that no large bus adjustment has been made in this examination, the Rapid Transit system must fully cover for the loss of bus service in the corridor. The Rapid Transit system is able to that, but it requires a higher frequency than the 10 minutes departure rate. A 2.5 minutes frequency is, however, considered too high when looking at the cost per passenger (Fig. 4.4) and the existing and calculated passenger level in the corridor do not seem to support such a high frequency either. Consequently a frequency of 5 to 7.5 minutes between departures is desirable.

Looking at Fig 5.1 the described assumptions for the Rapid Transit configuration in the case corridor will yield an increase in passengers at 80%-160% compared to the base regular bus solution. In absolute numbers this will mean 4,640-6,560 passengers in the Rapid Transit system in the morning rush hours which adds up to 18,560-32,800 passengers on a week day. Expectedly on the low side for a LRT solution, but not unfeasible and the numbers are, as previous mentioned, underestimated.

6 Conclusions

In the preceding sections it has been shown how a route choice model can be applied to examine a Rapid Transit system and how it performs in terms of ridership with different configurations. The findings from the examination have shown some interesting results.

It was estimated that up to 50% reduction in travel time is achievable when upgrading from a regular bus to a Rapid Transit system and the span from 0-50% reduction was examined. The reduction of travel time proved to have a significant impact on ridership and the correlation had a potential growth where the maximum reduction in travel time at 50% compared to a regular bus resulted in 161% more passengers. This shows that the travel time is a very important system factor and that large effort should be put in to minimize this when planning Rapid Transit systems.

It was estimated that frequency ranging from 10 to 2.5 minutes between departures was applicable to a Rapid Transit system. The increase in frequency resulted in an increase in ridership. Going from 10-minutes frequency to 2.5 minutes frequency resulted in a 70% increase in passengers. The examination of the frequency also illustrated its potential growth correlation to the operating cost, and high frequencies like 2.5 minutes between departures resulted in very high operating cost that could not be compensated by the higher number of passengers due to the higher service level. In the planning phase of a Rapid Transit system, special attention must be paid to very high or very low frequencies since they can have a strong negative impact on the system.

Different levels of attractiveness were applied to the Rapid Transit system ranging from that of a regular bus to that of heavy urban rail. The corresponding induced rail factor displayed a near-linear impact where the highest attractiveness resulted in 40% increase in passengers. The unofficial Danish applied attractiveness to LRT was found to result in 25% increase in passengers. The rail factor findings proved to be consistent with other studies of the rail factor and should be included in the system choice of Rapid Transit systems.

The examination of the system factors and the rail factor revealed to have an embedded synergy when combining the different characteristics for instance by improving both travel time and headway at the same time. This synergy is significant – especially for large improvements – due to its potential growth correlation. The best Rapid Transit configurations in combination implied that up to 70% (over 100% with rail factor included) extra passengers can be expected as a result of the combination alone. This is a hidden benefit that should be taken into account when planning Rapid Transit Systems.

System choices are based on many other factors than the examined and may be very subjective. However, the findings of the examination can offer assistance in the system choice for instance by showing the impact of the rail factor or by showing the impacts of system factors commonly applied to certain type of systems. Such assistance can prove very valuable.

We believe that the findings in this examination have a general application and that the results can be used to provide more reliable demand predictions when choosing configuration for Rapid Transit system. The result plots and look-up catalogs for ridership can be used as theoretical base to configure Rapid Transit system to achieve certain ridership objectives. In that way, the findings of the examination can be applied and utilized in the planning phase for future Rapid Transit systems like Bus Rapid Transit or Light Rail Transit in Denmark, Northern Europe or anywhere else.

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