Transformation to a trunk and feeder network: effects on passenger flows, travel times and reliability

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Transformation to a trunk and feeder network: effects on passenger flows, travel times and service reliability

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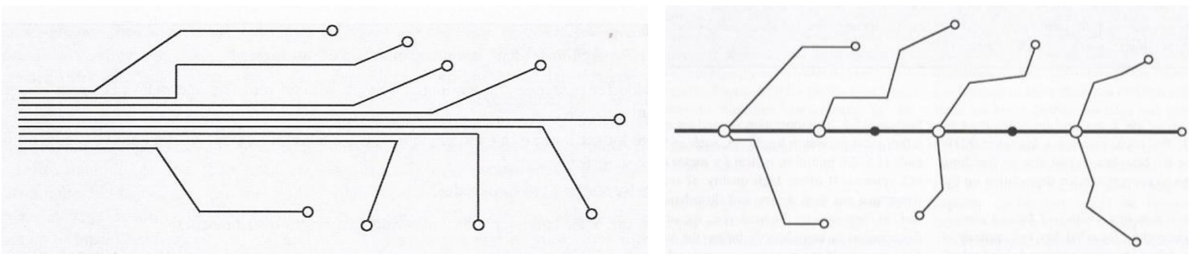
Abstract: *We evaluate a large scale network change in Amsterdam, the Netherlands, where a regional network of many direct bus lines is replaced by a new metro line as a trunk line and buses serving as feeder lines. For the analysis we use realized trip times from automated vehicle location data and ridership details from smart card data. In the new network, we observe a strong shift to the new transfer stations. On the other hand, stops and lines keeping their direct connection in the new feeder network are used more than other stops and lines. From northern direction, the leg on the faster trunk line is too short to compensate for the additional transfer, leading to a slight increase in travel time. From the south, travel time has become shorter: a longer leg is travelled on the new metro line. Finally, all new feeder lines operate more reliably than the former direct lines. These findings can help guide ex-ante evaluations for other networks considering transition to a trunk and feeder system.*

Keywords*:* PT-network design, trunk and feeder networks, passenger flows, smart card data, automated vehicle location data, evaluation study

1. Introduction

For public transportation (PT) networks, trunk and feeder networks have multiple advantages over networks with branches (also called direct networks) (Vuchic, 2005, see Figure 1). Trunk and feeder networks usually have higher frequencies and enable higher performance on the trunk line such as offering a more reliable service. Furthermore, each section can be optimized with respect to mode, vehicle type and schedule. However, trunk and feeder networks also have some disadvantages, like additional transfers for passengers and a need to construct (possibly expensive) transfer stations.

Figure 1 : Conceptual visualisation of a network with branches / direct lines (left) and a trunk and feeder network (right) (Vuchic, 2005)



From the passenger perspective, direct (no-transfer) routes are preferred, but it is usually inefficient from the operators perspective to offer many direct services from most stops. Conversely, the trunk and feeder system is expected to provide a more

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efficient solution, but with some travellers having to make additional transfers. From the travellers perspective, this additional transfer may be compensated by shorter travel times, depending on the valuation of each travel time components by the traveller, like in-vehicle time, wait time and number of transfers (an overview of these valuations is given in Wardman, 2014). According to Weckström et al., 2019, planners often face a dilemma when trying to achieve a careful balance between efficiency and equity (i.e. the traveller's perspective), as a network change might result in an unequal distribution of benefits and burdens for end users.

Fielbaum et al. (2016) established that the optimal transit network structure for a city is a function of the spatial concentration of demand (depending on the structure of the city), transfer penalty and the patronage. Although many studies have compared alternate transit network structures theoretically (Gschwender et al., 2016; Jara-Diaz et al., 2012; Fielbaum et al., 2016), only a few make the comparison for actual large-scale networks. Recently, Weckström et al. (2019) compared the change of a direct bus network to a metro trunk and feeder network in Helsinki in terms of impact on travel time and transfers using timetable (GTFS) data. They found that the impact of the network change was distributed unequally across the network, with the travel time and transfer benefits concentrating around the metro stations, and feeder stops experiencing an increase in travel time and transfers.

In the current study, we evaluate a similar network transformation from branches to trunk and feeder which happened in Amsterdam, capital of The Netherlands. However, in this study we use realized trip times from automated vehicle location (AVL) data, which provides a more accurate evaluation than timetable data. Furthermore, we include information on ridership from smart card. We focus on the regional bus network where direct bus lines were replaced by a 'trunk' metro line and feeder (regional) bus services. The urban PT network of Amsterdam was studied and discussed earlier in Brands et al. (2020).

The objective of this paper is to identify the main effects of the network transformation on passengers of regional bus services. As recognised by Weckström et al. (2019), the benefits and costs resulting from such network transformations are often distributed unequally amongst users. In this study we further evaluate such distributive impacts. The following research questions are answered by comparing the situation after opening of the metro line with the before situation.

- How do total travel numbers change on the regional bus services?
- How are passengers distributed over feeder lines and direct (branch) lines?
- How do travel times change for regional bus passengers?
- How does the number of transfers change?
- How does the travel time reliability of PT journeys change?

The outline of the remainder of this paper is as follows. In section 2 the case study in Amsterdam is described in more detail. In section 3 the method for data processing and analysis is described. Section 4 contains the major findings for the Amsterdam case study and section 5 summarizes the lessons learned.

2. Case study

In this chapter the case study is described. First the city and PT network of Amsterdam and its surrounding area are described. Next, the evaluated network change is described in more detail.

2.1. Amsterdam and its PT network

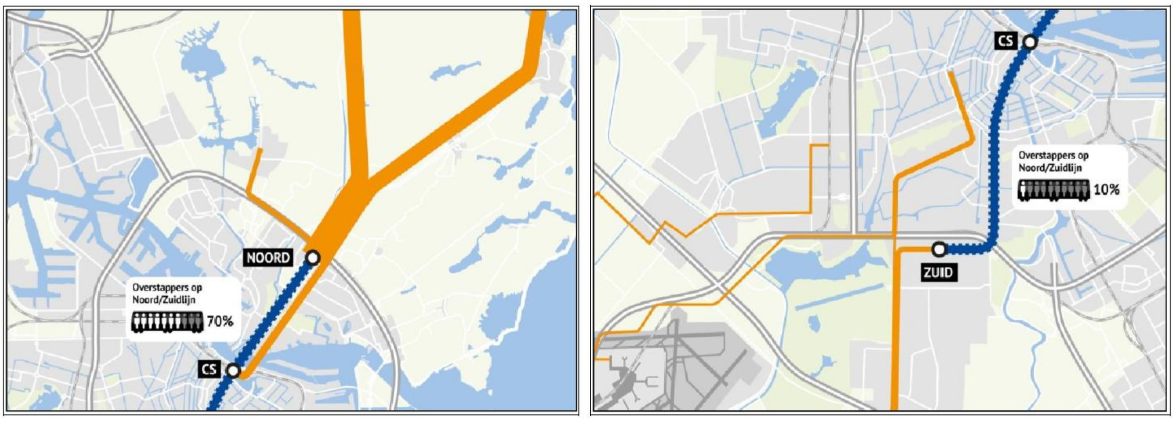
Amsterdam has about 850,000 inhabitants within its municipality borders. The transit authority ‘Vervoerregio Amsterdam’ also covers the surrounding area (with towns like Amstelveen, Hoofddorp, Zaanstad and Purmerend) of 950 km^2 with about 1,500,000 inhabitants (see Figure 2). Before opening of the new metro line, the area was served by 25 train stations, 4 metro lines with 51 metro stations, 15 tram lines and several urban and regional bus lines. The broad river IJ divides the city into two parts, where the city centre is situated in the larger southern part. The northern part of the city was only served by buses; it is also connected to the rest of the city by 6 ferry connections. All metro, tram and bus lines have the same fare system (a fixed start fare combined with a distance based fare). Several towns North of Amsterdam (like Purmerend and Volendam) are connected to the city by bundles of high frequency regional bus lines. Also from the southern direction, the towns of Aalsmeer and Uithoorn are connected to Amsterdam by high frequency regional bus services, which both also serve Amstelveen. Amstelveen is also served by an urban tram line and a metro line.

Figure 2 : Area of the Vervoerregio Amsterdam (Vervoerregio, 2021)

2.2. The north-south metro line

The new north-south metro line in Amsterdam became operational on 22nd of July 2018. It connects the Amsterdam Zuid (south) station to the Noord (north) neighbourhood, passing through the Amsterdam central station and the dense city centre. The opening of the new line was accompanied by changes to the existing bus and tram network to provide feeder services to the new line, as well as to remove duplicate routes. Especially, regional bus services from northern direction (i.e. Purmerend, Volendam) are now connected to the new metro at Noord (north) station, instead of the central station of Amsterdam (Figure 3, left). However, 30% of the buses still run to the central station, making it an interesting case to analyse passenger behaviour in a network with both trunk and feeder lines and direct lines. Similarly, from southern direction regional buses are shortened: the central station is not served any more. Instead, new lines to Zuid station are introduced, to feeder the new metro line (Figure 3, right).

Figure 3 : Conceptual visualisation of network changes in the regional bus network (orange), in relation to the new metro line (blue) (Stadsregio Amsterdam, 2015)



3. <u>Data and methodology</u>

Four sets of smart card data were analysed. The Dutch smartcard system requires both tapping-in and tapping out and thus provides very good insights into passenger travel patterns (for more information on Dutch smart card data, see Van Oort et al., 2015a). Furthermore, automated vehicle location (AVL) data was used to measure trip time and reliability (for more information on Dutch AVL data see van Oort et al., 2015c). In this section information is given on these datasets. The data sets are chosen such that the same period in the year before opening of the metro line is compared with the situation after opening and school holidays in the Netherlands are excluded. First, the data on northbound buses operated by EBS is described. Second, the data on southbound buses operated by Connexxion is described.

3.1. Northbound buses

The datasets of the northbound buses (operated by EBS) are aggregated for the following time periods:

- 28th of May to 24th of June 2018 (20 working days)
- 3rd of June to 8th of July 2019, excluding 10th of June, a bank holiday (25 working days).

The aggregated smart card data contains the number of trips from stop to stop, depending on day of week, hour of day and line. The number of records is approximately 180,000 and 190,000 respectively for 2018 and 2019 data. The total trips per working day is approximately 34,500 in the 2018 data and 37,000 in the 2019 data. To determine the travel times, the average value was taken from all realized stop to stop trip times in the AM-peak period on working days (7-10AM). As an indicator for service reliability, the standard deviation of travel time (i.e. travel time variability) from stop to stop in the same period is used, as proposed by Van Oort et al. (2015b).

3.2. Southbound buses

The datasets for southbound buses (operated by Connexxion) are available aggregated for working days in whole months. Therefore, the data of June 2019 (19 working days) is compared with June 2018 (21 working days). In June 2018, 4 days of strike are included in the data. On these days, a very limited bus service was provided (roughly 1/8 of regular service). Therefore, we corrected for that by assuming the data represents 17.5 working days.

The aggregated smart card data contains number of trips from stop to stop for working days, depending on line. Only records with at least 10 observations per month were included due to privacy regulations, which resulted in 1.1% to 1.5% of total trips to be excluded. The number of records is approximately 19,000 and 17,000 respectively for 2018 and 2019 data. The total trips per working day is approximately 116,000 in 2018 data and 121,000 in 2019 data. To determine the travel times, the average value was taken from all realized stop to stop trip times on working days (from AVL data). No distinction is made between time of day, since the smart card data contains day totals only. As an indicator for reliability, the standard deviation of travel time (i.e. travel time variability) from stop to stop on working days is used.

4. Results

4.1. Effects on distribution of travellers

The first major finding concerns the effect of the new network on distribution of travellers over stations, lines and stops.

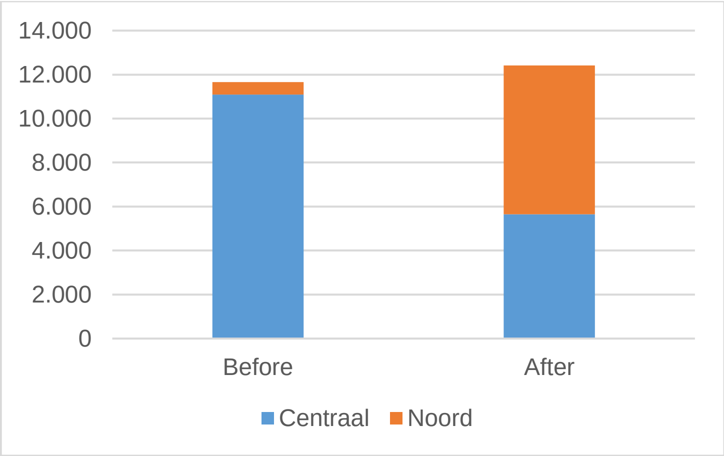
4.1.1. Northbound lines

In Figure 4 the network changes in the Northern part of Amsterdam are shown for the northbound lines. In the after situation, only four regional bus lines serve the central station, instead of 10 lines in the before situation. The other 6, and 1 new one, stop at Noord Station enabling a transfer to the new metro line.

Figure 4 : Detail of the network before (left) and after (right) opening of the north-south line. For the central station and Noord station the line numbers serving the stations are shown

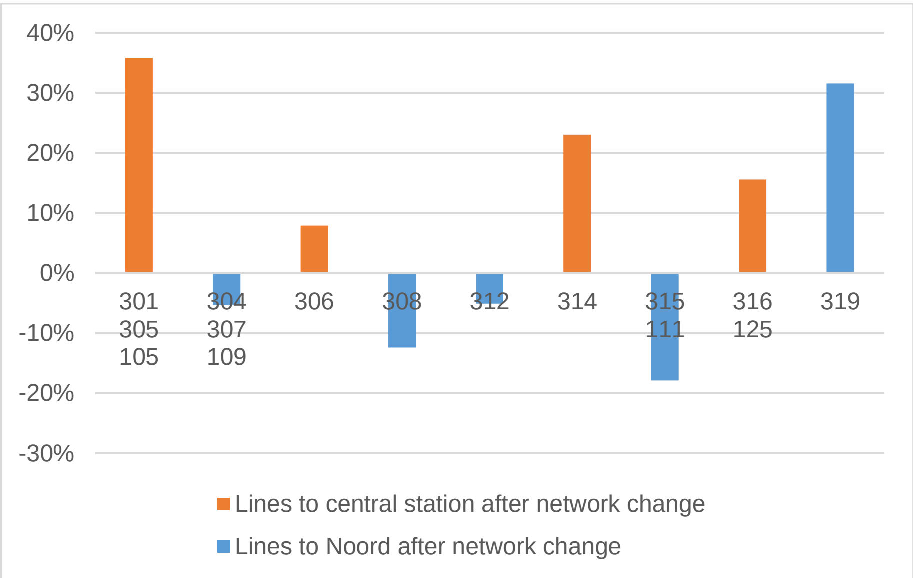
As expected, the distribution of passengers between the central station and Noord station has strongly shifted to Noord metro station (Figure 5). In the before situation, a small proportion (5%) of travellers alighted at the bus stop in Noord (Buikslotermeerplein), having a destination around this stop. 95% of travellers alighted at Amsterdam central station. In the after situation, the share of passengers at Noord station is 54%. This is less than the share of vehicles, which is 66%: slightly lower than the targeted value of 70%. The total number of passengers has increased by 6.4%, likely due to the increased parking fares in the inner city of Amsterdam, since this increase cannot be explained by the travel time effects (see section 4.2.1).

Figure 5 : Number of travellers on regional bus services alighting at the central station and Noord station, before and after opening of the new network.



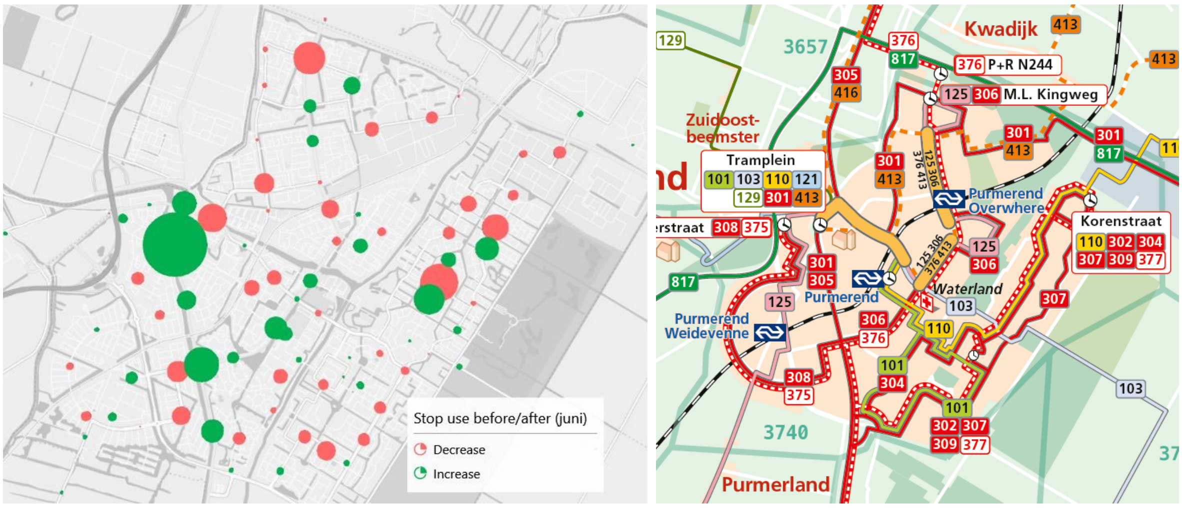
The higher share of the central station in passenger number is also reflected in the line use (Figure 6). Lines which run to the central station (305, 306, 314 and 316) or ferry terminal (301) show increased ridership, while the other lines (which have metro station Noord as their terminal station) show decreased ridership. Exception is line 319 (Landsmeer – Amsterdam), which has increased ridership because its route serves a larger area in the new network.

Figure 6 : Shift in passenger flows per line number for northbound lines



Another way to observe this shift is to look at the passenger numbers per stop (Figure 7 shows the stops of a suburban town north of Amsterdam). Most stops served by lines to the central station show increased ridership, while most stops served by lines to Noord station show a decrease. This indicates that perhaps a proportion of travellers have increased access distance (walking or bicycle) to board a direct bus service to the central station, to minimize their total perceived journey time (Brand et al. 2017).

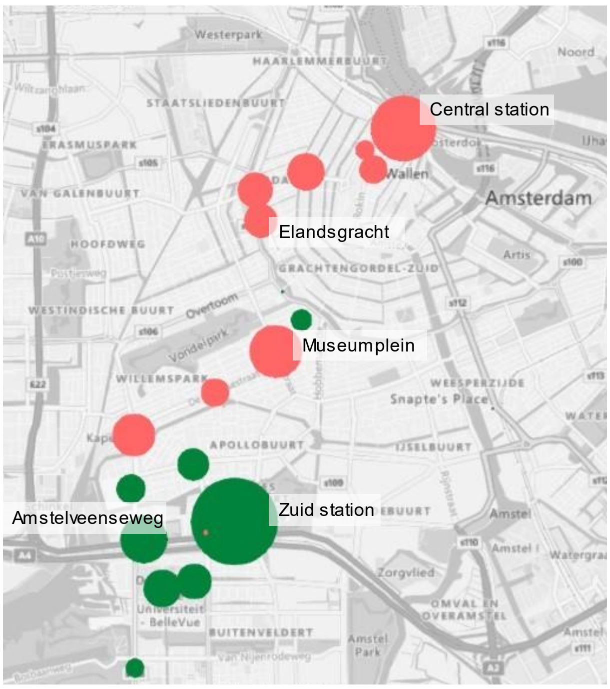
Figure 7 : Shift in passenger flows through stops in the town of Purmerend (left), due to the network changes (right: lines 305 and 306 run to the central station in the after situation)



4.1.2. Southbound lines

In the before situation only lines 347 and 357 were operated from Aalsmeer and Uithoorn to the central station of Amsterdam. In the after situation, these two lines were shortened to Elandsgracht (near the city centre), meaning these lines do not serve the central station any more. At the same time, lines 348 and 358 are introduced between Aalsmeer / Uithoorn and Zuid station. The effect of this change on stop use in Amsterdam is shown in Figure 8.

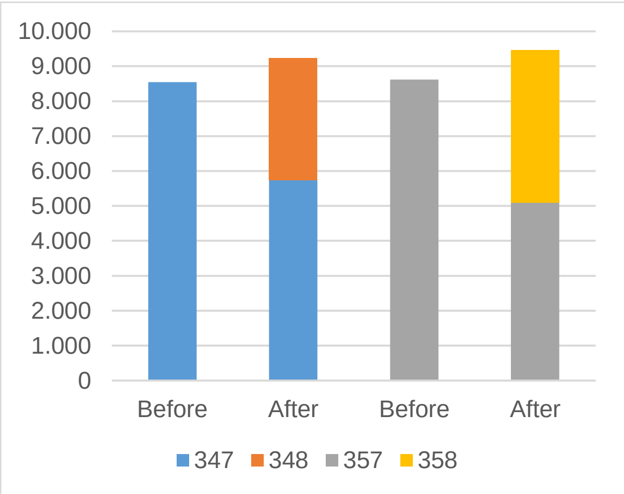
Figure 8 : Shift in passenger flows through stops over Amsterdam for southbound lines



The largest decline in passengers can be observed at the central station, and the largest increase at Zuid station. Also the other stops between the central station and Elandsgracht show decreases, since these are not served any more by these lines. On the stops between Museumplein and Amstelveenseweg a shift of passengers can be observed due to a temporal rerouting of the lines due to engineering works in the after situation.

In Figure 9 the distribution of passengers over lines 347 and 348 (Uithoorn – Amsterdam) and lines 357 and 358 (from Aalsmeer to Amsterdam) is shown. The total number of users on these lines has increased by 9%, which is a little higher increase than the network wide increase of 6%. This may be related to the additional travel opportunities of the new lines to Zuid station. However, when comparing passenger numbers for lines 347 (Uithoorn – Elandsgracht) and 348 (Uithoorn – Zuid station), line 347 is clearly used more (63% of travellers). This indicates that travellers still have a preference for direct destinations in the city of Amsterdam over the opportunity to transfer to the north-south metro line at Zuid station. When comparing lines 357 and 358 (from Aalsmeer) this effect is less strong (54% of travellers for line 357), which can be explained by the fact that line 357 is longer: it serves more stops in Aalsmeer.

Figure 9 : Shift in passenger flows per line number for southbound lines



4.2. Effects on travel times

The second major finding concerns the effect of the new network on travel times and service reliability on regional bus services to and from Amsterdam.

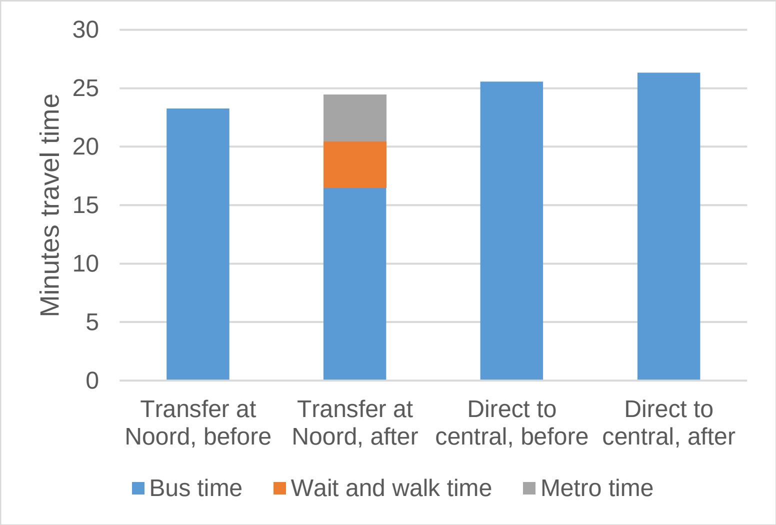
4.2.1. Northbound lines

The AVL data shows that regional bus lines which run to Noord station in the after situation on average have approximately 7 minutes shorter trip time compared to the trip time to the central station in the before situation. Reaching the central station by metro from Noord takes 4 minutes in-vehicle time, on average 3 minutes wait time (headway of 6 minutes) and 1 minute walk/transfer time. Concluding, travellers transferring at Noord station on average have 1 minute longer travel time than in the before situation (see Figure 10).

Lines which run to the central station in the after situation on average have approximately 0.5 minute longer trip time than in the before situation (see Figure 10).

One reason for that could be the increased occupation of lines to the central station, making the boarding and alighting process more time consuming. Another possibility is increased congestion on the network, which is also intensively used by cars and (crossing) bicycles.

Figure 10 : Average travel times to the central station on northbound buses (before only bus time and after also including transfer and metro time for routes with a transfer at Noord station)



For the average AM-peak, regional travellers from northern direction have slightly longer travel times and therefore travel time losses on average. Important assumption here is that travellers have the central station as their destination. Travellers with a destination further in the city may have travel time gains instead of losses.

From the AVL data we observe that trip time reliability has slightly improved for lines to Noord (excluding the effect of the additional transfer to metro): trip time standard deviation has decreased by 0.5 minutes. The lines to the central station show less reliable results in the after situation (2 minutes increase in standard deviation).

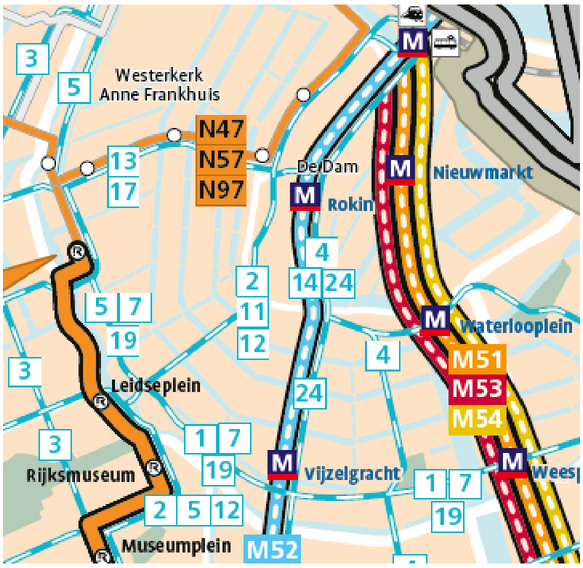
4.2.2. Southbound lines

From southern direction, AVL data shows that regional bus lines on average had 21 minutes shorter trip time to Zuid station in the after situation than to the central station in the before situation. Reaching the central station by metro from Zuid station takes 10 minutes in-vehicle time, on average 3 minutes wait time (headway of 6 minutes) and 1 minute walk/transfer time. Concluding, travellers to the central station transferring at Zuid station on average have 7 minutes shorter travel time than in the before situation (see Figure 11).

Figure 11 : Average travel times to the central station on southbound buses (before only bus time and after also including transfer and metro time)

Also from this direction, not all former travellers have the central station as their destination. Travellers to destination stops between Elandsgracht and the central station have to search for another route in the new network (shown in Figure 12). Travellers to the city centre can now use Damrak metro station, which is close to the former bus stops. Travel time gain for these travellers is expected to be similar as for travellers to the central station. However, travellers with a more western destination stop now have to transfer to a tram service (or walk further to their destination).

Figure 12 : The network south of the central station in the after situation. The new metro line (M52) is shown in light blue, the remaining regional bus in orange. In the before situation, the regional bus ran to the central station using the thin orange route (N47)



From the AVL data we observe that trip time reliability has improved for lines to Zuid (excluding the effect of the additional transfer to metro): trip time standard deviation has decreased by 3.3 minutes. The lines to the Leidseplein show slightly less reliable results in the after situation (0.7 minutes increase in standard deviation). This is an expected result, since lines to Zuid station in the after situation avoid the busy city centre.

5. Conclusions

In the case study for Amsterdam, a direct regional bus network was replaced by a new (trunk) metro line and feeder bus services. Overall, we observed a strong shift in ridership to new (metro) transfer stations, as expected. On the other hand, the (few) northbound lines retaining their direct connection to the central station in the 'after' network had a higher usage than the rest of the lines, implying a passengers preference for direct (branch) lines over trunk and feeder lines.

From the northbound direction, the travellers now experience an additional transfer and slightly (approximately 1 minute) longer travel time to the central station for the trunk and feeder alternative compared to the situation before the network change, as only a small part of the total trip is travelled on the trunk line. The advantages of the trunk line (like higher travel speed and comfort) do not appear to fully compensate for the disutility of making a transfer in this case. From the southbound direction, we observe a 7 minute shorter travel time for the trunk and feeder network in the after situation: a longer leg of the trip is travelled on the new metro line, leading to substantially shorter travel times, although an additional transfer is still required.

The effect of the new network on service reliability is positive: the standard deviation of trip times has decreased slightly for northbound lines and it has decreased by more than 3 minutes for southbound lines. This enables more effective and efficient services.

In agreement with some other studies (like Weckström et al., 2019), we found that the impacts of the network transformation were distributed unevenly amongst users. Therefore, a lesson learned for future network transformations from this case study is that, from a passenger perspective, the trunk line should replace a substantial leg of the passenger journey to achieve enough travel time gain to compensate for the disutility of making a transfer. The advantage of more reliable service on trunk and feeder networks was confirmed by this case study.

A drawback of this study is that it did not take capacity of the network into account: the higher capacity of the metro line is an important advantage in the busy city centre of Amsterdam. For further research, it would be interesting to take crowding and its impact on traveller choice behaviour into consideration in the evaluation. Related to capacity, this study did not evaluate the network transformation in terms of network operations (optimizing each section with respect to mode, vehicle type and schedule). Furthermore, a more detailed analysis of effects on user groups could shed more light on the extent to which the effects of the new network are desired from an equity perspective.

Acknowledgments
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