Station crowd redistribution and pandemic resilience

Access and egress-based solutions to station crowding

by

Johan Klaas Krom, Florian Wilkesmann, Alejandro Montes Rojas, Ziru Zhang, Reddhi Uday Bhatt

Supervisor(s):

Niels van Oort, Wijnand Veeneman, Danique Ton (TU Delft)

Menno de Bruyn, Mark van Hagen (NS)

A Conference Paper Submitted to

European Transport Conference 2021,

held online on 13th-15th of September 2021

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Krom, Johan Klaas; Wilkesmann, Florian; Montes Rojas, Alejandro;
Zhang, Ziru; Bhatt, Reddhi Uday

TU Delft, Delft, The Netherlands

Abstract. The COVID-19 pandemic has had a substantial impact on public transportion. With ridership figures decreasing, it has brought a new sense of urgency to the old problem of crowding. Using a structured design approach, this paper presents the results of a project which set out to reduce crowding in Dutch train stations by absorbing it at the network level. The design which is detailed in this paper uses advance communication of bike parking availability and price incentives on shared bikes as means to stimulate travellers to access or egress the railway system through alternative, uncrowded stations. It is determined that, theoretically, up to 7% of daily travellers in the Amsterdam region might use the system, suggesting that effects on station capacity would be substantial high adoption levels are realised.

Keywords: Public transport · crowding · socio-technical design · COVID19.

1 Introduction

The COVID-19 pandemic revealed several vulnerabilities in the operation of passenger rail services. As infections surged and countermeasures came into effect, transit services in the Netherlands witnessed substantial decreases in ridership as people sought to avoid infection risks. These conditions highlighted a new urgency to the pre-existing challenge of transit crowding. Consequently, to restore people's trust in transit and achieve a return of mass rail transport as a key mode in the modal split, policy measures are needed to reduce the risk of crowding.

Conventional anti-crowding measures in railway systems mainly focus on either temporal redistribution of flows (e.g. peak and off-peak travel) or the physical redesign of public spaces and rolling stock (e.g. increase of capacities). However, these approaches disregard the spatial concentration of flows, with the bulk of travellers entering and exiting the railway network through a limited number of main stations. Access and egress behaviour is generally considered fixed and hard to change. This paper recognises this condition, but responds to it with the view that the COVID19 pandemic created a window of opportunity in which behavioural patterns might be changed. The authors identify the possibility of reducing in-station crowding by redistributing passenger flows from crowded to less crowded stations as the entry and/or exit points to the railway network by using active modes.

2 Literature Review

This literature review sets out the academic base for the design effort in three dimensions:

To get a better understanding of the dynamics at play, the academic literature is reviewed on three points: First, the impact the outbreak of COVID-19 has on travel behaviour. Second, the role of (active) access and egress mode choice in combination with public transport. Third, individual health benefits of using active modes in conjunction with public transport.

2.1 COVID-19 Implications

As travelling by public transport involves entering closed spaces with multiple points of contact, exposing travellers to several instance of infection risk, transit is particularly vulnerable to pandemic-based shocks. although infection risk features across all areas of public transport systems, it holds particularly for moments of traveller action such as boarding, alighting and traferring (Tirachini & Cats, 2020). Similarly, Tan & Ma note that it is of key importance for operators to control the density of passengers on board trains, across platforms and at facility entry or exit points (Tan & Ma, 2020). For instance, the authors suggest that train carriages should be isolated from each other as much as possible to minimise any potential risk to individual batches of travellers. As noted by Das et al. (2021), higher standards of hygiene and cleanliness will also be required. In this vein, operators can require passengers and staff to wear various kinds of personal protective equipment and facilitate cash- and contact-less payments across all operations. Measures which seek to address crowding-based infection risks, mostly focus on well-managed reductions of ridership levels, such as by working from home, or off-peak travel policies may serve to keep transit services safe and accessible for those who need to travel.

2.2 Access and Egress

The multi-modal combination of active modes and public transport is increasingly recognised as a highly complementary modal chain (Ton, Shelat, Nijënstein, et al., 2020; van Oort, 2020). Prior to the COVID-19 pandemic, cycling featured as part of multi-modal trip chains between 1.2 and 5.2 days per week in the Netherlands. This illustrates that the bike-train combination is a fairly established mode combination among train passengers (Olafsson, Nielsen, & Carstensen, 2016). A study by Jonkeren, Kager, Harms, & te Brömmelstroet found that the majority of multimodal passengers are commuters (Jonkeren et al., 2019). In the Netherlands, active mode preferences differ between access and egress-ends: cycling is preferred as an access mode, whereas walking is preferred for egress travel (Brand, Hoogendoorn, Van Oort, & Schalkwijk, 2017). Furthermore, as found by Arendsen familiarity with bike sharing systems enhances train travellers' willingness to adopt such systems for egress travel. One of the reasons which causes walking to be the preferred mode to egress from train stations is the uncertainty about the availability of shared bike options at the activity-end of trips (La Paix & Geurs, 2016). Other research suggests that passengers who use bikes for both their access and egress legs are willing to cycle up to the fourth closest station to avoid transfers in the train leg of their journey (Van Kampen, Jayaraj, Pauwels, Van Der Mei, & Dugundji, 2020). In the case of public transport users, the on-time performance of the service plays a vital role (Yang, Zhao, Wang, Liu, & Li, 2015). Whereas when the main egress mode is on foot, commuters who use motorized modes for access are more concerned about the walking environment. Commuters who opt for a non-motorised commute for access, consider the availability of walking space as an important factor (Yang et al., 2015).

Overall, these findings indicate the importance of service connectivity and frequency in multimodal station choice (Chakour & Eluru, 2014). As found by Ton, Shelat, Nijënstein, et al., the presence of adequate bike parking facilities at access stations increases people's willingness to cycle further. Additionally, walking distance is weighted more negatively compared to cycling (Ton, Shelat, Nijënstein, et al., 2020). Prior research by Givoni & Rietveld indicates that if for access travel the station is located within 3 km (radius) of the user's location, a higher preference is given cycling (Givoni & Rietveld, 2007). As such, following Kager, Bertolini, & Te Brömmelstroet, it can be concluded that multimodal trips encompassing bike and train provide a system for access and egress travel that is both flexible and fast (Kager et al., 2016). Improving bike access to stations may as such provide an effective option to increase public transport usage overall. However, in terms of station choice there is evidence that station utility decreases as the access time and distance to the station, in-vehicle travel time, the number of transfers and fares increase, or available frequencies deterioriate (Young, Blainey, Young, & Blainey, 2018). Some authors, such as van Mil, Leferink, Annema, & van Oort caution that the success of multimodal bike-train combinations is highly context-dependent and remains contingent on various local conditions (e.g., weather, employment, demography) (van Mil et al., 2020).

2.3 Health benefits and active modes

For commuters, trips to and from work represent a significant part of their daily physical activity (Laverty, Millett, & Majeed, 2020). This activity can be expected to have a positive effect on their health. This is especially the case when involving active modes within the commute (Laverty et al., 2020). Martin, Panter, Suhrcke, & Ogilvie find that the people who use public transport for commuting are less likely to be obese than those using (motorised) private modes (Martin et al., 2015; Sener, Lee, & Elgart, 2016). Moreover, a large body of research notes that the use of public transport is not only positively linked to increases in physical activity, but also has potential health benefits (Sener et al., 2016). Additionally, as noted by Laverty et al., increased car usage results in the opposite: detrimental effects on population health, in addition to other negative external effects such as air pollution (Laverty et al., 2020). Studies indicate that the adoption of public transport and the active modes has a positive impact on health. For example, there is evidence suggesting that the body mass-index and obesity rate is lower for non-motorised vehicle users as compared to motorised vehicle users (Margozzini, Ryan, & Mu, 2020).

3 Methodology

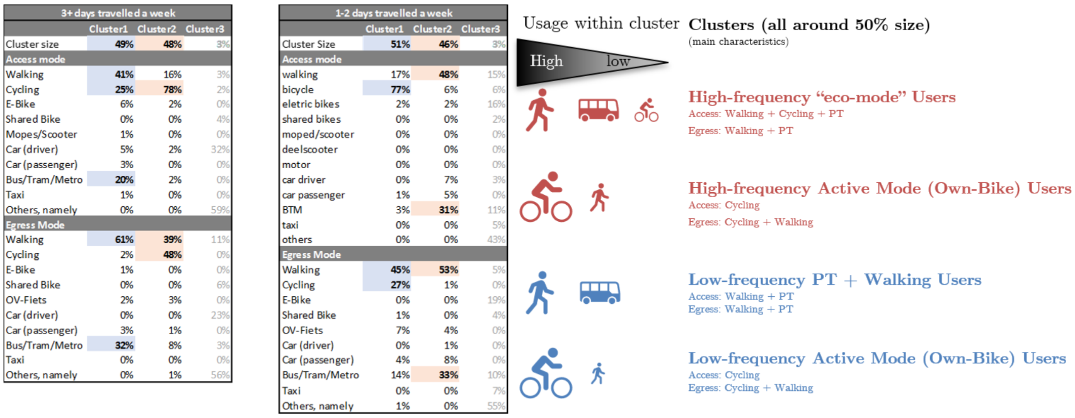
The design process is divided into two stages: requirements analysis and design development. The former is performed to demarcate the available solution space by means of a set of objectives and constraints, the latter encompasses the construction of the design itself.

3.1 Requirements analysis

The requirements analysis conducted by the authors relies on two sources: first, data from a series of surveys by NS and TU Delft among train travellers on their perception of train travel under pandemic conditions. Encompassing over 10,000 responses, these surveys provide a comprehensive view of travellers' sensitivities and changes therein in the incipient, peak and post-peak stages of the first wave of the COVID19-pandemic in the Netherlands. Second, a stakeholder analysis consisting of a series of qualitative interviews with various operator-related stakeholders.

To identify preference categories among travellers, a latent class analysis (LCA) is performed upon the survey data. This method classifies groups within a dataset by maximising homogeneity within clusters and heterogeneity between clusters (i.e. gathering similar travel patterns within a group) (McCutcheon, 1987). To identify what elements of transit are dominant in traveller's reluctance to travel by train, and what modes they would accept as (partial) substitutes, this analysis' focus lies on indicators related to travel frequency and purposes.

The final results show 3 clusters for each frequency group (who travel by train 1-2 days a week as low frequent users and equal or more than 3 days as high frequent group), and therefore 6 clusters in total. For each analysis, two classes emerge representing similar proportions of the overall sample size. For the group of low frequent travellers, one cluster (51% of all respondents) prefers cycling for access travel and walking as egress mode. Only 27% of this cluster use a bike as an egress mode. It might be reasoned that these travellers use their own bikes as access modes, but don't own a bike at the activity-end of their trip and therefore walk instead. The other cluster (46% out of all respondents) shows a preference towards both walking and BTM for both access and egress trips. The share of these two modes similar for access and egress mobility: around 50% choose walking and 30% choose BTM. In the results of the final LCA regarding high frequent travellers, a cluster similar to the one of the low frequency travellers is found, with a cluster size 48%, of which the travellers use their own bikes as access mode (at 78%) while are also likely to walk when egress (39%) thought still quite some people choose bicycle (48%). The other cluster, with a size of 49% out of the sample, presents a relatively diverse preference for access mobility, with walking, cycling and BTM at 41%, 25% and 20%, respectively. Walking dominates as the egress mode (making up of 61%) and BTM usage stands at 30%, thus taking over the share of bicycle (only 2%). This might also attribute to the reason mentioned before that these respondents use their own bikes for access trips while they do not have access to bikes for egress mobility. This group covers a range of green transport modes and therefore could be labelled as 'eco-mode users'.



3+ days travelled a week			
	Cluster1	Cluster2	Cluster3
Cluster size	**49%**	**48%**	3%
Access mode			
Walking	**41%**	16%	3%
Cycling	**25%**	**78%**	2%
E-Bike	6%	2%	0%
Shared Bike	0%	0%	4%
Mopes/Scooter	1%	0%	0%
Car (driver)	5%	2%	32%
Car (passenger)	3%	0%	0%
Bus/Tram/Metro	**20%**	2%	0%
Taxi	1%	0%	0%
Others, namely	0%	0%	59%
Egress Mode			
Walking	**61%**	**39%**	11%
Cycling	2%	**48%**	0%
E-Bike	1%	0%	0%
Shared Bike	0%	0%	6%
OV-Fiets	2%	3%	0%
Car (driver)	0%	0%	23%
Car (passenger)	3%	1%	0%
Bus/Tram/Metro	**32%**	8%	3%
Taxi	0%	0%	0%
Others, namely	0%	1%	56%

1-2 days travelled a week			
	Cluster1	Cluster2	Cluster3
Cluster Size	**51%**	**46%**	3%
Access mode			
walking	17%	**48%**	15%
bicycle	**77%**	6%	6%
eletric bikes	2%	2%	16%
shared bikes	0%	0%	2%
moped/scooter	0%	0%	0%
deelscooter	0%	0%	0%
motor	0%	0%	0%
car driver	0%	7%	3%
car passenger	1%	5%	0%
BTM	3%	**31%**	11%
taxi	0%	0%	5%
others	0%	0%	43%
Egress Mode			
Walking	**45%**	**53%**	5%
Cycling	**27%**	1%	0%
E-Bike	0%	0%	19%
Shared Bike	1%	0%	4%
OV-Fiets	7%	4%	0%
Car (driver)	0%	1%	0%
Car (passenger)	4%	8%	0%
Bus/Tram/Metro	14%	**33%**	10%
Taxi	0%	0%	7%
Others, namely	1%	0%	55%

Fig. 1. Results of the latent class analysis for both high- and low-frequent travellers

The results indicate that a substantial segment of respondents already use active modes. Of these, they express a preference for cycling and walking on access legs, while mostly walking on egress. This echoes the pattern found Arendsen that walking is mostly preferred for the egress leg, which might change depending on implemented policies (Arendsen, 2019). This reveals the possibility to develop a design solution targeting a change in the mode usage for the egress legs as an opportunity to increase active mode usage. Combined, the requirements analysis resulted in a shortlist of objectives and constraints. This list serves as input for the subsequent development of the design.

3.2 Design development

Based on the defined requirements, a structured design process is applied to develop design solutions which would fit into the solution space. This process is structured by means of an options table and complemented by a valuation approach based on the best-worst method (see Rezaei for a description of the best-worst method (Rezaei, 2015)). First, a long list of potential basic designs was developed, which then was subsequently reduced to a shortlist and a final selection. The general approach is illustrated in Figure 2.

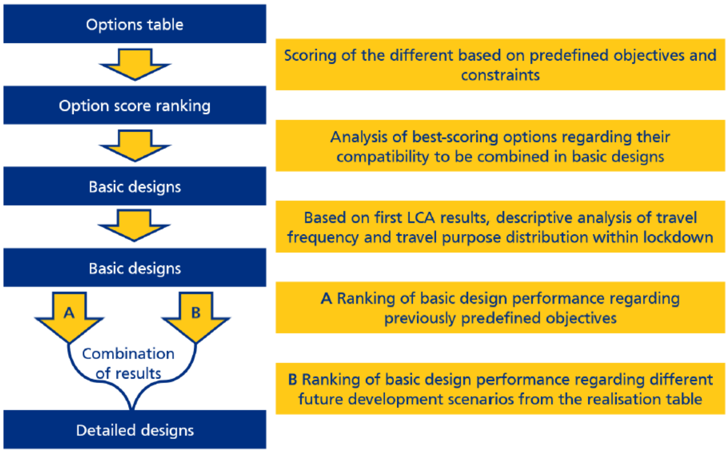


Fig. 2. Design Process

During the process different means (options) are compared against a defined list of aims and ranked for their efficacy. Different combinations of options, again, permit for the conceptual testing of several potential integrated conceptual design solutions, without requiring in-depth development (Smith, 2007). To do so, the overall solution space is decomposed into three options categories, which are defined based on the objectives and constraints defined previously: first, providing information to users. Second, defining a route choice priority, and third, incentivising people's adoption of the design. The provision of information answers to the need of transmitting certain information (according to the design) to the passengers. It allows them to know of its existence, how it works and what it provides, so that they can use it as intended. The route choice definition function deals with the necessity of motivating changes in passengers' route planning process. It considers the availability and use of route planners within different smartphone apps, and proposes different prioritisation systems depending on the available incentives. Finally, the incentive describes the approach to encourage people to use the design, and thus to avoid crowded stations if possible. Its definition includes both the basis to provide the incentive (the mode) and what can be obtained as an incentive (the benefit).

Based on literature, topical knowledge and exploration, several options are proposed per category. These are then subsequently combined into multiple hypothetical designs. Using the best-worst method, each design is subsequently evaluated on an per-objective or -constraint-basis. Based on the resulting scores a list of basic designs is constructed. However, different designs suit different operational and contextual circumstances. To achieve a robust solution able to offer adequate functionality under a wide range of possible conditions, the basic designs are tested against a realisations table representing potential future uncertainties the design solutions might have to deal with.

4 Proposed Designs

Upon completion of the design development process, two designs were selected for further detailing: first, a points collection-based scheme and second, a bike-based access and egress system. This paper will briefly introduce the first design, but only work out the second design in full. For the detailed description of the first design, please refer to the project report (Bhatt, Krom, Montes Rojas, Wilkesmann, & Zhang, 2021).

4.1 General concepts

Design 1: Points collection, This design gives travellers the incentive to perform certain types of desirable behaviour by granting them points for each instance in which they perform said behaviour. Following a principle of delayed gratification, travellers who have accumulated a given number of points can use these to purchase benefits. This can be considered as a complement to existing discount arrangements such as NS' existing off-peak discount scheme. This design permits for the main aim of relieving crowding through redistribution of passengers across stations, by awarding points whenever the railway system is accessed or exited through stations which are less crowded. This design in essence targets all train travellers who possess a personalised transit smartcard, which is needed in order to track behaviour and manage point balances. In addition to reducing crowding, this design may serve as an incentive for people to obtain a personalised smartcard or even shift (back) to train travel for their travel needs. Overall, the proposed design resembles the 'BahnBonus' system of the Deutsche Bahn (MyOV, 2021), or systems used by frequent flyer programs in the airline industry. The system is broadly similar to the 'MyOV' concept which was conservatively trailed by NS on some trajectories between 2016 and November 2019 (NS, 2016) (MyOV, 2019). The difference between this scheme and the design proposed here is that MyOV was aimed at reducing in-train crowding, while the present design aims to affect the location of network entry or exit, as well as active mode choice behaviour (Nederlandse Spoorwegen, 2018). Taking a wider scope, the system is relatively flexible and can easily be adjusted to suit the operator's business strategy.

Design 2: Bike access and egress The overall aim of this design is to more evenly distribute passengers over available stations by stimulating travellers to access or egress the railway network at other stations than they normally would, by giving them the incentive to cycle to/from such alternative stations. The overarching idea consists of showing prospective travellers which of their travelling options will lead them through stations with lower levels of crowding, and offering immediate gratification incentives to nudge people to use these options. This design seeks to leverage the relative bike-orientedness of urban transport in Netherlands.

The design can be divided into a network-access and network-egress part: For network access, prospective travellers who use their private bikes are nudged to access the train service at stations with ample excess bike parking space. This effect is achieved by giving an indication of the number of (un)available bike stands for candidate access stations in the operator's journey planner application. Here, bike stand availability serves as proxy for station crowding. Additionally, the application includes projected bike parking time as part of the overall travel time. In cases of extreme crowding, travellers who use alternative (uncrowded) stations may be given additional benefits, such as free first-class upgrades. For the egress-side of the design, the system seeks to achieve a more tactical use of NS' own brand station-based shared bike system, OV-fiets. Under this design, train travellers are stimulated to disembark their train at another (less-crowded) station in the destination region and take a shared bike from that station at a significantly reduced cost. Conversely, in cases of extreme crowding, fees for shared bikes at busy stations are increased to reduce such station's attractiveness as egress location.

4.2 Station choice algorithm

To adequately redistribute travellers away from crowded to less-crowded stations, two complementary definitions are needed: first, an indicator which determines which stations are too crowded and are in need of additional measures to mitigate traveller flows. Second, an algorithm which determines which alternative stations are available in a traveller's origin or destination region to absorb part of the excess flow. For implementation, these two definitions need to be combined by a set of logical rules. To enhance compatibility, the project decided to largely adopt the commissioner's current crowding management measures and systems whenever possible. The commissioner currently defines crowding using the common level-of-service measure based on the principles posited by Fruin (Fruin, 1971). This measure indicates the level of crowding of a given area by calculating the number of persons per square meter of any demarcated pedestrian space within the station area. Mathematically, this expresses the number of persons per square meter of a given area, and is specified as the ratio of the horizontal space mean speed S, and the mean flow rate P as defined in Equation 1 (Fruin, 1971). To control for high levels of crowding, the crowding indicator is compared to an operator-defined threshold value T. When the crowding indicator of a given space in the station is equal to or greater than the threshold, this space is considered as crowded.

$$crowding_{station} = \frac{S}{P} \tag{1}$$

As cyclists are unlikely to change their route once they are en-route, incentives must be communicated to them before departure. This requires a level of crowding prediction for the moment a traveller arrives at the station. In general, algorithms can be tooled to achieve this effect based on smart combinations of historical data, automatic fare collection data, sensors and cameras (Hänseler, van den Heuvel, Cats, Daamen, & Hoogendoorn, 2020). Ideally, crowding is predicted based on data which is as close-to-real time as possible. Threshold values can be adjusted in accordance to operators objectives or business strategy. For conceptual purposes, two crowding indicators are proposed: first, a general one estimating the crowding level for a given time based on a preceding multi-day average. This is used for trips which are planned in advance (e.g. several hours or days). Second, a close to real-time crowd indicator permits for the assessment of current crowding levels and represents an active target for anti-crowding policies to address. The latter also helps to provide travel routes which are planned at most a few hours before departure. Note that the crowding measures allow for several 'levels' of crowding when using multiple threshold values.

4.3 Flow redistribution

Currently, the commissioner's route choice algorithm, like most, optimises towards the minimisation of travel time. Under the constraints of the designs this travel time minimisation remains preferable, albeit with the added clause that penalties are applied to routes which pass through crowded stations. When stations exceed the threshold value described earlier, the provided designs offer incentives to mitigate traveller flows via alternative non-crowded stations from which travellers will also be able to access their destination. The overall logic of the flow redistribution algorithm is presented in Figure 3.

In general, available alternative stations are selected based on their accessibility from the traveller's current position or final destination (i.e. a non-station location). These are determined based on the input in the operator's journey planner app. To be eligible, an alternative station must meet two requirements: First, it must be accessible within a predefined distance or time X by bike. Here, X can be adjusted to suit an individual traveller's willingness to walk or cycle. Second, the alternative station must offer a train itinerary (including transfers at non-crowded stations) to the traveller's intended destination. This latter requirement will in many cases limit the design's applicability to urban regions with multiple competing stations. In the Dutch railway network which is served by NS, major cities such as Amsterdam, Rotterdam and the Hague may offer such conditions.

4.4 Incentive specification

For access traffic, two complementary incentives are proposed: First, by indicating the (expected) available bike storage capacity, and lack thereof, per candidate access station in a

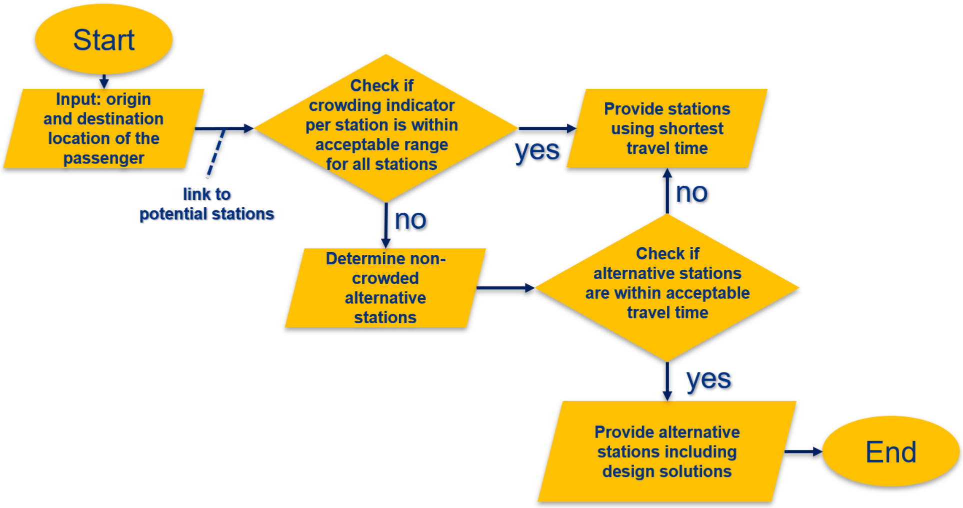


Fig. 3. Search algorithm for the route choice considering station crowding

prospective traveller's departure region. Considering full bike parking facilities as a proxy for station crowding, this incentive nudges travellers in two ways: on the one hand it discourages accessing the rail network via crowded stations. On the other it makes uncrowded stations appealing. Optionally, the design can include prospective bike parking times in the total journey time as provided by the journey planner. The idea builds on the finding by (Martens, 2007) that higher quality bike parking facilities attract cyclists, combined with research by van Mil et al. (2020) who find a willingness to pay €0.11 for every minute of reduced bike parking time. To contextualise this: this is found to be equal to the 'cost' of one additional minute of cycling, and more than a shorter train travel time or less transfer avoidance. This evens out the disutility to cycle to further-off stations having available bike storage capacity.

Second, by offering prospective travellers the option to reserve a first class upgrade if they make use of a less crowded station bike parking facility and check in for train services at that station. Once the bike parking facility at a station threatens to fill up to maximum capacity and crowding tracking systems in the station area indicate that the station has exceeded a threshold crowding level, travellers who opt for trips over an alternative, uncrowded, station are offered the chance to reserve an upgrade to a first class ticket by using the operator's journey planner application. As the total number of first class seats in the network are limited, and paying travellers should maintain priority, this incentive can only be deployed under severe circumstances, on particular routes and under meticulous prediction of average first class availability levels.

For egress traffic, the design incentivises travellers to egress the rail system at an alternative (uncrowded) station by offering them a shared bike from the operator's OV-fiets brand from such a station at a significantly reduced cost. In order to obtain such a bike, the traveller searches a route to a final (non-station) destination using the operator's journey planner application. If stations which offer the shortest travel time to the final destination are crowded, the traveller is presented with the option to egress by discounted shared bike from an alternative station which is within cycling range from the specified final destination. To determine crowding and alternative station availability, the route choice algorithm previously described is used. To guarantee that travellers who choose this option will have access to an OV-fiets, the traveller is able reserve a bike for the period around the traveller's arrival.

4.5 User interface specification

The aim of this design is to offer an instant gratification to the user. For this, usage should be intuitive and require relatively little up-front preparation. The ideas for this design are developed with NS in-house journey planner integration in mind, as is visible in Figure 4 and Figure 5. Both the access and egress designs are based around the digital journey planning environment of the app. For the egress design, information about bike parking availability is presented directly in the app's route overview screen. The reservation functionalities (first class upgrade and OV-fiets reservations) are available through a button on the route-specific level of the journey planner environment. Even though the underlying algorithms are adapted, trip travel times, prices, etc. remain displayed in their current locations. Reservation tickets can be retrieved as QR-codes by the user via the 'My tickets'-tab in the app.

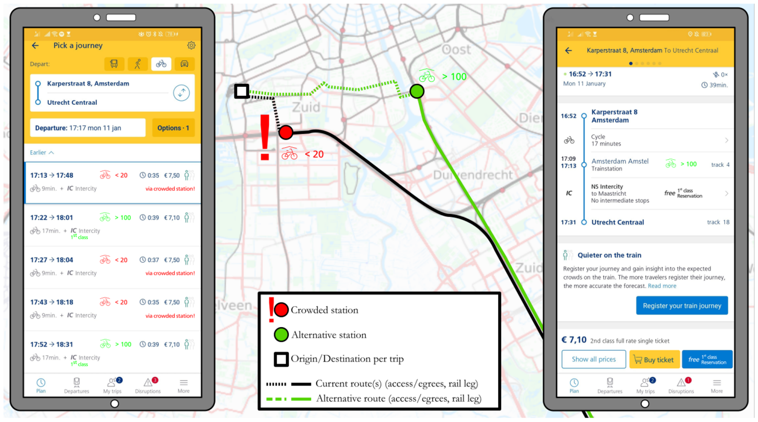


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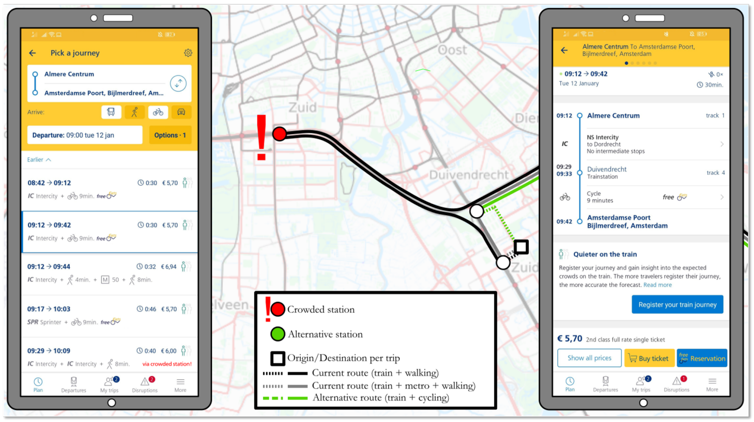
Fig. 4. Bike access design: application interface. The trip overview on the left-hand side shows the number of available bike stands at each station, colour coding these for remaining space. In the bottom-right of the itinerary overview the user can reserve a first class upgrade if and when all prerequisites for this are met. Note that parking availability numbers are entirely fictional and might also be expressed as e.g. percentages.

5 Impact Assessment

5.1 Approach

To come to a rough estimate the number of travellers which might use the proposed design, a case study is performed on the crowding-prone, yet nearby stations Amsterdam Centraal Station (CS) and Amsterdam Zuid. To assess the user potential, the average number of users of these stations for access and egress to/from the train network are estimated. Here, 'access' refers to the trips between a traveller's home and the station, both in the morning and in the evening, whereas 'egress' refers to the trips between a traveller's activity-end and a station. This total number of travellers is divided over the modes 'walk', 'bike', 'car', and 'BTM' (bus, tram and metro) to obtain the number of travellers per access/egress-leg and mode. To capture users' willingness and viability to enter/leave the network through to another station, tavel time isochrones are applied for all other intercity stations (which are more likely to have guarded bike sheds) in the Amsterdam area.



Register your journey and gain insight into the expected crowds on the train. The more travelers register their journey, the more accurate the forecast. Read more

Fig. 5. Bike egress design: application interface. For this design the trip overview shows whether an OV-fiets will be available for the final leg of each itinerary. The bottom-right of the itinerary overview offers a button through which the user may reserve an OV-fiets.

5.2 Theoretical user potential

The areas shown in Figure 6 represent the 'user potential areas' in which isochrones for a 15-minute access or egress bike trip to the crowded stations of CS and Zuid overlap with equivalent access/egress trips to non-crowded alternative stations.The 15-minute boundary was assumed as the proposed design solutions motivate travellers to walk or cycle, and the literature suggests that many people accept 15 minutes for a station access bike trip (assuming an average cycling speed of 15 km/h) (Shelat, Huisman, & van Oort, 2018). Although people's preference for egress trips is slightly shorter (approx. 11 minutes (Shelat et al., 2018)), this is disregarded for the sake of computational complexity and also set to 15 minutes.

When these 'user potential areas' are combined with postal code-specific mode shares per station, the number of travellers who have the possibilty to replace such trip with an active access/egress trip to an alternative non-crowded station can be estimated. This gives the total user potentials as shown in Figure 7. Overall, up to 150,000 and 41,000 travellers, fall within the likely catchment area of Amsterdam CS and Amsterdam Zuid stations, which respectively translates to 65% and 56% of all travellers using these stations. Here it is assumed that travellers who access or egress to/from the area have an equal probability of switching to a non-crowded station.Moreover, it is assumed that all non-Amsterdam-ends of trips can be reached via the available non-crowded stations, whereas in reality some destinations might be accessible via a crowded station only.The user potential indicated here is as such an overestimation.

5.3 Adoption rates

Ultimately, the system's success in large part depends on the rate to which it is adopted. This is contingent on e.g. app usage levels, modal shifts and temporal dimensions such as rush hours. Due to this uncertainty, three fictional scenarios based on the values shown in Table 1 are estimatedfor the first two years of operation. The resulting daily number of expected users are visualised in Figure 8. The results provide first insight on the scale of potential changes in behaviour.

As the design presented in this paper targets a specific user group, this specific group is expected to witness a comparatively high adoption rate.A successful implementation of the 'Bike access' part of the design is expected to result in more available bike stands and less

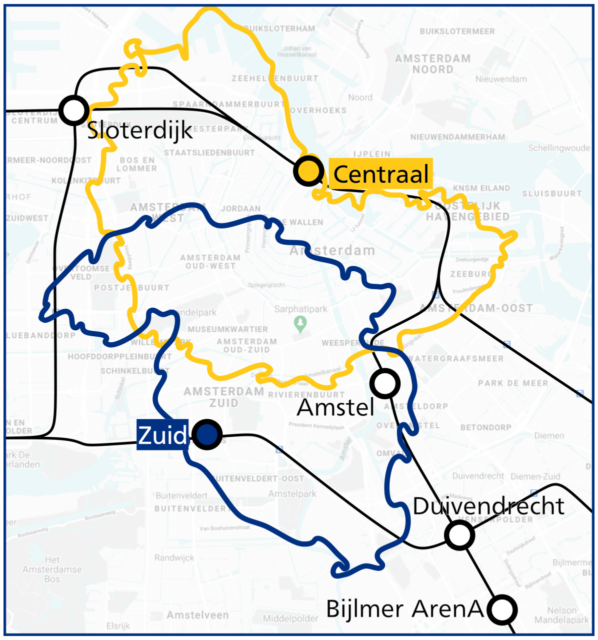


Fig. 6. Areas from which Amsterdam CS (yellow) and Amsterdam Zuid (blue) and competing other intercity-stations reachable within 15 minutes by bike (own visualisation based on Travel Time (2020))

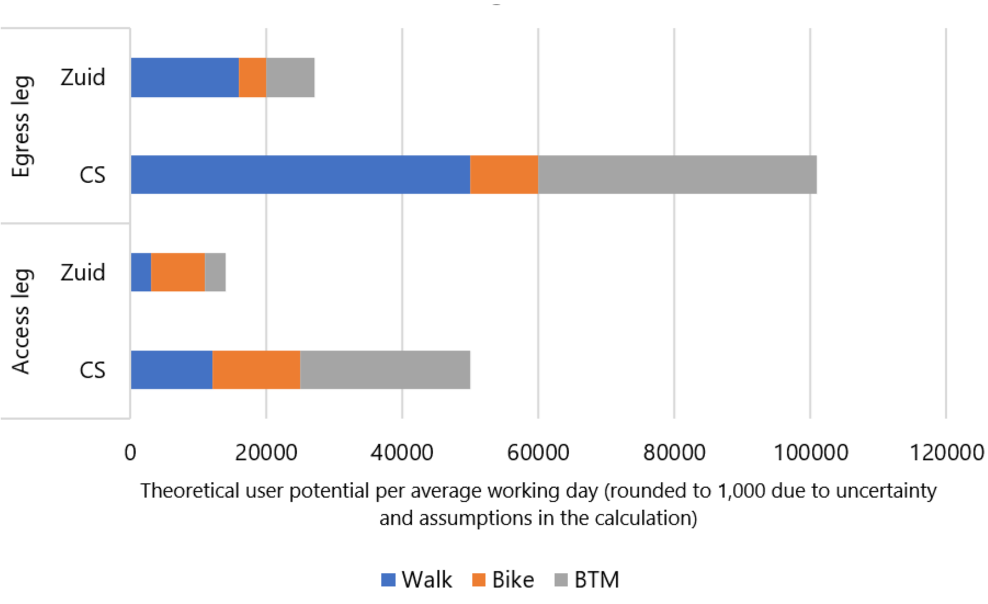


Fig. 7. Theoretical user potential per average working day (rounded to 1,000 due to uncertainty and assumptions in the calculation

	'Access leg'			'Egress leg'		
	Walk	**Bike**	**BTM**	**Walk**	**Bike**	**BTM**
Scenarios Points collection						
Low	1%	1%	1%	1%	1%	1%
Medium	2%	2%	2%	2%	2%	2%
High	4%	4%	4%	4%	4%	4%
Scenarios Bike access & egress						
Low	1%	2%	1%	1%	4%	2%
Medium	2%	4%	2%	2%	8%	4%
High	4%	8%	4%	4%	16%	8%

Table 1. Fictional adoption rates based on the described assumptions per user group

crowding in CS and Zuid.For the'Bike egress' design, a high demand would lead to fewer travellers in the crowded stations as well, but at the same time might require an increase of the OV-fiets fleet at the non-crowded stations. In general, the designs seem quite likely to have a positive impact on crowding levels for both Amsterdam CS and Amsterdam Zuid. However, their success is highly contingent on the adoption rate which the designs manage to achieve. This may be achieved through adequate marketing efforts.

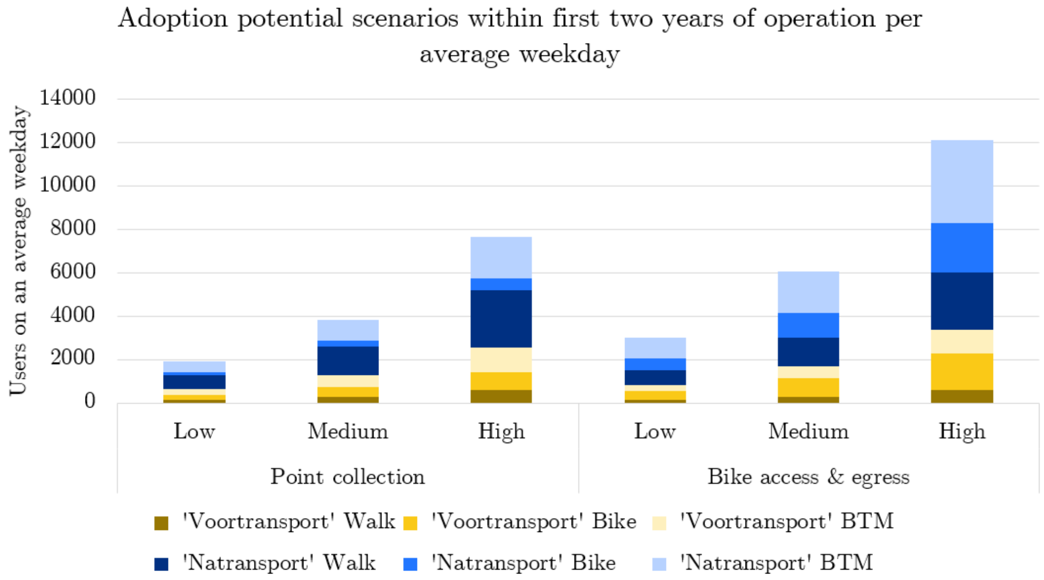


Fig. 8. Results of the fictional scenario calculation regarding the design adoption within the first two years

6 Discussion

This paper outlines a design and its prospective impacts. Although the design was conceived using an extensive methodology, a number of limitations and key assumptions must be noted. The contextual analysis is based on responses to a survey conducted within the established panel of NS. As such, non-panel members are not considered. Deeper analysis using e.g. smartcard data or stated choice experiments could help to get a better understanding of people's perception of and behavioural responses to crowding. Similarly, the stakeholder analysis was solely performed in-house among NS employees. External perspectives from relevant local stakeholders might help in identifying local preferences and/or barriers regarding potential design solutions which NS, TU Delft, and the project team are not aware of. Before implementation, a selection of these stakeholders should be consulted. The design development process was constrained by the need to be able to implement a solution based on digital technology only. Without this, or any other constraint, a significantly different design may have been proposed. With regards to the analysis, only city-level effects are considered. The provided method just allows for a first insight on the potential, without being able to conduct an overarching judgement on the feasibility or vehicle-level effects. Additional data and NS-internal and external information, could have permitted a more detailed investigation of potential solutions.

As discussed, the evaluation suggests a positive potential impact. Nevertheless, some risks regarding the design implementation need to be considered as individuals tend to not always behave the way one would expect. The following examples indicate some of the risks which are inherent to the designs as these are proposed in this report. Note that these are only examples and by no means an exhaustive list. There will always be other risks which cannot be foreseen at this point. Over-compensation: Before any of the designs can be implemented, it is imperative that a series of user acceptance studies are performed. Furthermore, incentive schemes must calibrated, so that they indeed encourage the forms of behaviour which are desired, but without providing people with greater incentives than required. Despite the efforts put in that calibration, there is always a risk that the designs overcompensate for some users. In different words, for some users, the incentive needed can be below the one found by calibration.As a consequence, it might be argued that some extra costs are incurred, which are actually not needed.

No changes in behaviour: For the implementation of either of the design, an incentive system has to be introduced. As explained before, such system aims to encourage people to behave in a certain way. However, it was not possible to find a strategy to only reward those people who do in fact change their behaviour. As a result, the design is generally applicable to all users, even those whose behaviour already matches what is desired. This creates the risk that some users are rewarded, even though they do not change their behaviour at all. The latter can be seen as an extreme case of the "over-compensation" risk described above. However, when considered at a network-wide scale, this could represent an even greater risk. It is possible that even though the design is used (i.e. users collect points, or get free first-class upgrades), no change in travel behaviour is actually achieved at an aggregated level. In such a case, the costs of the implementation would not deliver the expected benefits, causing an excessive burden on the operator. Cheating the system: Given the nature of both designs, it can be expected users will try to maximise their benefit at as little effort as possible. For most cases, it could be translated in them behaving as desired by the operator. However, there is the risk that in some cases users will try to "cheat the system". In other words, they could take advantage of small errors in the design (or implementation) of the incentive systems, to get rewarded without behaving as is actually required. Any implementation should actively monitor the way in which users interact with the system and adapt accordingly if malfeasance comes to exceed the system's benefits.

7 Conclusion

The COVID-19 pandemic has a substantial impact on the public transport sector. Countermeasures aim to reduce interactions among people, causing train ridership figures to plummet, with NS noting up to 90% reductions during lockdown periods. For passenger rail operators, these issues bring a new sense of urgency to an old problem: crowding. Whilst in the past just a phenomenon which reduced passenger satisfaction, this now constitutes a potential health hazard. Consequently, policies which try to reduce crowding across the railway network are receiving renewed attention. Simultaneously, the interruption of regular travel patterns may have created a window of opportunity through which operators may affect some measure of behavioural change.

Drawing on this context, this project has developed a design which sets out to reduce crowding in Dutch train stations by absorbing crowding at the logistical level by closer integration of active modes for travellers' access and egress mobility. As such, the design proposed in this paper solve a microscopic problem (crowding within train station facilities) at a macroscopic level (traveller route choice). If implemented, the design contributes to less crowded stations, which translated to fewer close interactions between travellers, a lower inherent infection risks throughout the traveller journey, and higher levels of passenger satisfaction. The potential impact of these designs was estimated by means of a case study of passenger flows in the Amsterdam region. It was found that by implementing the designs, up to 7% of all daily travellers per average working day can be nudged to travel via a non-crowded station instead of the crowded stations of Amsterdam Centraal and Amsterdam Zuid. The overall design impact will depend on the actual adoption rate and the scope of the system implementation. As such, the ideas presented here represent an initial foray into alternative solutions for station crowding. Ample space remains for both in-depth academic research, as well as operational-level implementation-oriented analysis.

8 Contact

This paper is an edited version of the final report for the 'Design Project'-course for the master's programme in Transport, Infrastructure and Logistics at TU Delft. The original report was written as a commissioned assignment for Nederlandse Spoorwegen (NS), completed in January 2021. The authors would like to thank their supervisors at both Ns and TU Delft for making this project possible. For remarks and further information please reach out to the authors at:

R.U. Bhatt: r.u.bhatt@student.tudelft.nl,
J.K. Krom: j.k.krom@student.tudelft.nl,
A. Montes Rojas: a.montesrojas@student.tudelft.nl,
F. Wilkesmann: f.l.wilkesmann@student.tudelft.nl, and
Z. Zhang: z.zhang-29@student.tudelft.nl

References

Arendsen, J. (2019). Shared mobility for the first and last mile: Exploring the willingness to share. , 1–148. Retrieved from `https://repository.tudelft.nl/islandora/object/uuid{%}3A9976ea22-07be-4674-b984-1a8f6563f0ee`

Bhatt, R., Krom, J. K., Montes Rojas, A., Wilkesmann, F., & Zhang, Z. (2021). *Modelling transport.* TU Delft, TIl5050-20 Design Project.

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

Chakour, V., & Eluru, N. (2014). Analyzing commuter train user behavior: A decision framework for access mode and station choice. *Transportation*, *41*(1), 211–228. doi: 10.1007/s11116-013-9509-y

Das, S., Boruah, A., Banerjee, A., Raoniar, R., Nama, S., & Kumar, A. (2021). Impact of COVID-19 : A radical modal shift from public to private transport mode. *Transport Policy*, *109*(April), 1–11. Retrieved from `https://doi.org/10.1016/j.tranpol.2021.05.005` doi: 10.1016/j.tranpol.2021.05.005

Fruin, J. J. (1971). *Designing for pedestrians: A level-of-service concept* (No. HS-011 999).

Givoni, M., & Rietveld, P. (2007). The access journey to the railway station and its role in passengers' satisfaction with rail travel. *Transport Policy*, *14*(5), 357–365. doi: 10.1016/j.tranpol.2007.04.004

Hänseler, F. S., van den Heuvel, J. P., Cats, O., Daamen, W., & Hoogendoorn, S. P. (2020). A passenger-pedestrian model to assess platform and train usage from automated data. *Transportation Research Part A: Policy and Practice*, *132*(January), 948–968. doi: 10.1016/j.tra.2019.12.032

Jonkeren, O., Kager, R., Harms, L., & te Brömmelstroet, M. (2019). The bicycle-train travellers in the netherlands: personal profiles and travel choices. *Transportation*, 1–22.

Kager, R., Bertolini, L., & Te Brömmelstroet, M. (2016). Characterisation of and reflections on the synergy of bicycles and public transport. *Transportation Research Part A: Policy and Practice*, *85*, 208–219. doi: 10.1016/j.tra.2016.01.015

La Paix, L., & Geurs, K. T. (2016). Train station access and train use: A joint stated and revealed preference choice modelling study. *Accessibility, Equity and Efficiency: Challenges for Transport and Public Services*(August), 144–166. doi: 10.4337/9781784717896.00017

Laverty, A. A., Millett, C., & Majeed, A. (2020). COVID-19 presents opportunities and threats to transport and health. , *113*(7), 251–254. doi: 10.1177/0141076820938997

Margozzini, P., Ryan, A. C.-o., & Mu, J. C. (2020). Nutritional and metabolic benefits associated with active and public transport : Results from the Chilean National Health Survey ,. , *17*(April 2019). doi: 10.1016/j.jth.2019.100819

Martens, K. (2007). Promoting bike-and-ride: The dutch experience. *Transportation Research Part A: Policy and Practice*, *41*(4), 326–338.

Martin, A., Panter, J., Suhrcke, M., & Ogilvie, D. (2015, 05). Impact of changes in mode of travel to work on changes in body mass index: Evidence from the british household panel survey. *Journal of epidemiology and community health*, *69*. doi: 10.1136/jech-2014-205211

McCutcheon, A. L. (1987). *Latent class analysis* (No. 64). Sage.

MyOV. (2019, 11). *Welkom op de website van myov.* Retrieved from `http://www.myov.nl`

MyOV. (2021). *Bahnbonus: Fahren. punkten. freuen.* Retrieved from `https://www.bahn.de/p/view/bahncard/bahnbonus/bahnbonus.shtml`

Nederlandse Spoorwegen. (2018). *Vervoerplan 2018.* Retrieved from `https://www.ns.nl/binaries/_ht_1533726799171/content/assets/ns-nl/over-ons/vervoerplan-2018.pdf`

NS. (2016, 8). *Myov:punten sparen buiten spits nu ook bij ns.* Retrieved from `https://nieuws.ns.nl/myovpunten-sparen-buiten-spits-nu-ook-bij-ns/`

Olafsson, A. S., Nielsen, T. S., & Carstensen, T. A. (2016). Cycling in multimodal transport behaviours: Exploring modality styles in the Danish population. *Journal of Transport Geography*, *52*, 123–130. doi: 10.1016/j.jtrangeo.2016.03.010

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, *53*, 49–57.

Sener, I. N., Lee, R. J., & Elgart, Z. (2016). Potential health implications and health cost reductions of transit-induced physical activity. *Journal of Transport & Health*, *3*(2), 133–140. doi: 10.1016/j.jth.2016.02.002

Shelat, S., Huisman, R., & van Oort, N. (2018). Analysing the trip and user characteristics of the combined bicycle and transit mode. *Research in transportation economics*, *69*, 68–76.

Smith, G. (2007). Morphological charts: a systematic exploration of qualitative design space.

Tan, L., & Ma, C. (2020). Choice behavior of commuters' rail transit mode during the COVID-19 pandemic based on logistic model. *Journal of Traffic and Transportation Engineering (English Edition)*(xxx). doi: 10.1016/j.jtte.2020.07.002

Tirachini, A., & Cats, O. (2020). Covid-19 and public transportation: Current assessment, prospects, and research needs. *Journal of Public Transportation*, *22*(1), 1.

Ton, D., Shelat, S., Nijënstein, S., Rijsman, L., van Oort, N., & Hoogendoorn, S. (2020). Understanding the role of cycling to urban transit stations through a simultaneous access mode and station choice model. *Transportation research record*, *2674*(8), 823–835.

Ton, D., Shelat, S., Nijënstein, S., Rijsman, L., van Oort, N., & Hoogendoorn, S. (2020). Understanding the Role of Cycling to Urban Transit Stations through a Simultaneous Access Mode and Station Choice Model. *Transportation Research Record*, *2674*(8), 823–835. doi: 10.1177/0361198120925076

Travel Time, G. (2020). *How far could i live from - i amsterdam mapitout.* Retrieved from `https://mapitout.iamsterdam.com/`

Van Kampen, J., Jayaraj, M. A., Pauwels, E., Van Der Mei, R., & Dugundji, E. R. (2020). Understanding the relation between distance and train station choice behavior of cyclists in the western region of the Netherlands. *Procedia Computer Science*, *170*, 98–106. Retrieved from `https://doi.org/10.1016/j.procs.2020.03.013` doi: 10.1016/j.procs.2020.03.013

van Mil, J. F., Leferink, T. S., Annema, J. A., & van Oort, N. (2020). Insights into factors affecting the combined bicycle-transit mode. *Public Transport*, 1–25.

van Oort, N. (2020). *Fiets en ov - corona impacts.* Retrieved from `nielsvanoort.weblog.tudelft.nl/files/2020/10/Covid-en-FietsOV-Van-Oort-2020PDF.pdf`

Yang, M., Zhao, J., Wang, W., Liu, Z., & Li, Z. (2015). Metro commuters' satisfaction in multi-type access and egress transferring groups. *Transportation Research Part D: Transport and Environment*, *34*, 179–194. Retrieved from `http://dx.doi.org/10.1016/j.trd.2014.11.004` doi: 10.1016/j.trd.2014.11.004

Young, M., Blainey, S., Young, M., & Blainey, S. (2018). Railway station choice modelling : a review of methods and evidence evidence. *Transport Reviews*, *38*(2), 232–251. Retrieved from `https://doi.org/10.1080/01441647.2017.1326537` doi: 10.1080/01441647.2017.1326537