Delft University of Technology

Passenger Transfer Chain Analysis for Reallocation of Heritage Space at Amsterdam Central Station

Starmans, Marc ; Verhoeff, Lee; van den Heuvel, J.P.A.

DOI
10.1016/j.trpro.2014.09.108

Publication date
2014

Document Version
Final published version

Published in
Transportation Research Procedia

Citation (APA)
Starmans, M., Verhoeff, L., & van den Heuvel, J. P. A. (2014). Passenger Transfer Chain Analysis for Reallocation of Heritage Space at Amsterdam Central Station. In W. Daamen, D. C. Duives, & S. P. Hoogendoorn (Eds.), *Transportation Research Procedia: The Conference on Pedestrian and Evacuation Dynamics 2014 (PED 2014), 22-24 October 2014, Delft, The Netherlands* (2014 ed., Vol. 2, pp. 651-659) https://doi.org/10.1016/j.trpro.2014.09.108

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.
For technical reasons the number of authors shown on this cover page is limited to a maximum of 10.

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 2 (2014) 651 – 659

Transportation Research Procedia

www.elsevier.com/locate/procedia

The Conference on Pedestrian and Evacuation Dynamics 2014 (PED2014)

Passenger transfer chain analysis for reallocation of heritage space at Amsterdam Central station

Marc Starmans [a,*], Lee Verhoeff [b], Jeroen van den Heuvel [c,d]

[a]*Arcadis, Piet Mondriaanlaan 26, 3812 GV Amersfoort, the Netherlands*
[b]*ProRail, Moreelsepark 3, 3511 EP Utrecht, the Netherlands*
[c]*NS Stations, Stationshal 17, 3511 CE Utrecht, the Netherlands*
[d]*Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, the Netherlands*

Abstract

Amsterdam Central Station is the second busiest station in The Netherlands. Several bottlenecks in the 125 years old monumental station exist due to present train and pedestrian volumes. Further traffic growth is expected. To understand and quantify the options for redesign, a thorough understanding of the interaction between the core traffic functionalities is required.
The paper will demonstrate high-level evaluations of different train positions, train schedules and platform exits, using a tailor-made macroscopic passenger transfer chain model. This approach, the model and the outcomes helped the stakeholders involved to reach consensus regarding the choices to be made for the future.
© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of Department of Transport & Planning Faculty of Civil Engineering and Geosciences Delft University of Technology

Keywords: train station; heritage building; pedestrians; bottlenecks; macroscopic; modeling

1. Introduction

Amsterdam Central Station was opened 125 years ago in October 1889 and is now designated as a heritage building. In its original configuration it had one side platform, two island platforms and three passenger tunnels, each with a width of approximately 4.5 meters (Fig. 1). This station was designed to handle approximately 40 trains per day.

* Corresponding author. Tel.: +31-627061296 ; fax: +31-33-4772106 .
E-mail address: marc.starmans@arcadis.nl

2352-1465 © 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of Department of Transport & Planning Faculty of Civil Engineering and Geosciences Delft University of Technology
doi:10.1016/j.trpro.2014.09.108

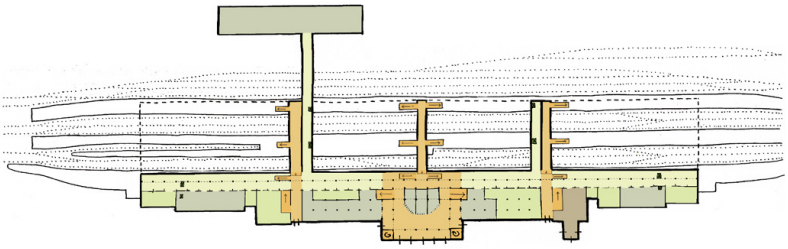

Fig. 1. Amsterdam Central Station layout in 1889.

The station achieved its current six two side platforms and four island platforms in 1924 (Fig. 2). Since that time the west- en central tunnels have been widened. Most of the platforms are used in two phases, an A-phase on the west- (left) and a B-phase on the east-side (right). This track configuration allows four trains to halt simultaneously at one island platform. Between most of the platforms there are three tracks: the original use of the center tracks would have been to bring the locomotives of terminating trains to the other end of the train. While some platforms over the years have been extended to 650 meters in length, the distance between the outside staircases (200 meters) have only been marginally increased.

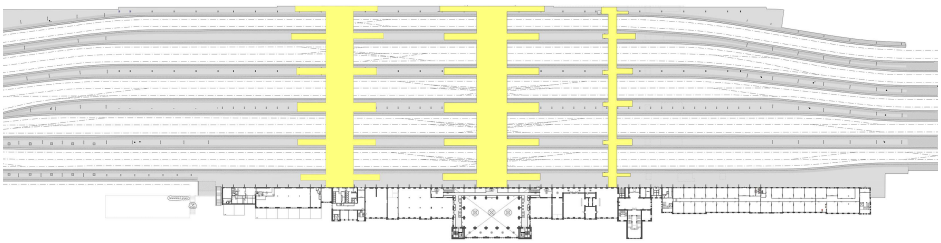

Fig. 2. Amsterdam Central Station layout in 2015 (when current reconstruction is finished).

Currently, Amsterdam Central Station is the second busiest station in The Netherlands: approximately 185,000 passengers per average workday arrive or depart at Amsterdam Central, and another 15,000 change trains. 34 passenger trains per hour use the 10 platform tracks. The centre (non-platform) tracks are used to allow the two platform phases to be used independently of each other, and to allow approximately 22 cargo trains per day to pass on non-platform tracks (ProRail (2014)).

2. Problem analysis

Being situated close to the historic city centre, Amsterdam Central station is accessed by many pedestrians. Exits are on the south (city center) and on the north (river side). The station offers a large number of connections to the metro, trams, busses and ferries. The main exits to the metro are in the central area, both on the north and south side of the station. Exits to trams are on the south side. The ferry docks and the new bus station are situated on the north side. Bicycle parking – approximately 10,000 places – is located around the station, but most are concentrated at the west entrances on both sides of the station. Recently, two new passages have been built in-between the transfer tunnels, which will soon provide a connection between both sides of the station for non-train passengers. See Fig. 3 for an aerial view of the station.

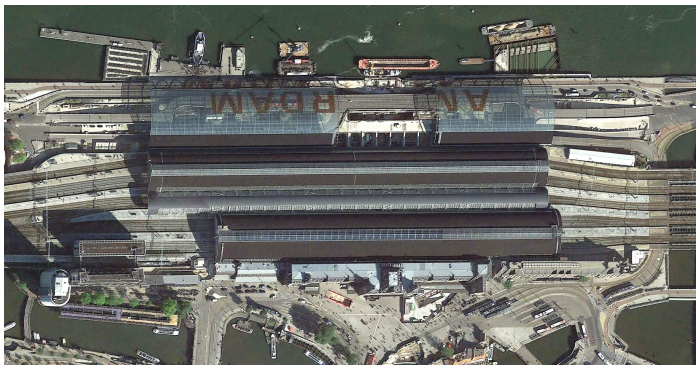

Fig. 3. Aerial view of Amsterdam Centraal station.

The current high passenger volumes and spatial limitations of the station have already created several bottlenecks at platforms, escalators and transfer tunnels (see Fig. 4). These main issues are (ProRail (2014)):

- At several points in the station the platforms are too narrow. The island platforms vary in width between the 8 and 10 meters at their widest point. This results in very narrow areas alongside the staircases, of about 1.8 meters. While the available width is greater on the two side platforms, the width next to half of the exits does not meet the minimum required width of 2.4 meters;
- Most platform exits consist of one upward and one downward escalator, or one approximately 3.5 m wide staircase. As one escalator can carry 70 to 90 passengers per minute and up to 650 passengers can exit from one train or over 1,000 from two trains arriving simultaneously at both sides of the platform, severe pedestrian congestion frequently occurs at the outer escalators. As the space next to the escalators is limited, passengers can only walk past the first escalator to another exit with great difficulty; most passengers simply wait to be able to use the first escalator;
- As the east tunnel still has its original width, it is currently operating during the morning peak at capacity;
- The west tunnel passes through the historic station building. Due to limited width at this section, the capacity of the entire tunnel is limited.

Fig. 4. (a): impression of current situation at platforms; (b): Vertical infrastructure; (c): East tunnel.

The most significant improvement is the widening of the platforms. As the station is fully hemmed in, this can only be achieved by removing tracks, which in turn will have consequences for train operations. Due to the physical limitations of the historic station building, compromises between its core functionalities must be made: train operations and the pedestrian transfer function.

Since 2013 the Ministry of Infrastructure, track/station operator ProRail and train/station operator Netherlands Railways have jointly searched for the optimal balance between both core functions of Amsterdam Central station. To quantify and assess current and future bottlenecks in the very interlinked pedestrian function of the station, a

passenger transfer chain analysis has been made. One of the tactical choices was the type of pedestrian model to use to support the many debates which were an essential part of the search.

3. Macroscopic versus microscopic model?

Existing research and practical experience has supported us in deciding on which pedestrian model to use. With his research, Fruin (1987) has provided the basis for many norms and guidelines for pedestrian functions. Similar situations exits in railway sectors in other countries and/or at other transportation facilities (i.e. airports). Fruin's concept of different levels of service for corridors, stairs, escalators are based on flow and density, both macroscopic indicators.

Following May (1990), many researchers classify pedestrian models in microscopic and macroscopic models. In the first category, pedestrians are modelled as individual units which have their own set of rules determining individual behaviour (i.e. behaviour in case of interactions). In the latter category, pedestrians are modelled as groups of units. Interactions are described by aggregated flow, speed and density indicators.

In her PhD-thesis Daamen (2004) concludes that specific train station processes in pedestrian models are hardly available, since most pedestrian models tend to be developed for other application areas or more generic applications. Therefore, she proposes a specific simulation tool for public transport facilities that has both microscopic and macroscopic characteristics. Since 2004, several other models have successfully been used in Dutch station studies (i.e. PTV's Viswalk, Pedestrian Dynamics of INCONTROL Simulation Solutions, Oasys' Mass Motion, STEPS of Mott Macdonald or NOMAD of Delft University of Technology) .

In their review of existing pedestrian models in the context of pedestrians crossing road traffic, Papadimitriou et al. (2009) show that macroscopic pedestrian models tend to be used for traffic flow problems, while microscopic model are developed for modelling complex situations with interactions (crowd/evacuations) and individual choices (route choice/wayfinding).

Based on their assessment of crowd motion modelling Duives et al. (2013) conclude that both microscopic and macroscopic models should be able to simulate crowd phenomena. The model choice is to be made on the modelling objective (i.e. the phenomena(s) of interest), but also context. Specifically the computational burden of microscopic models with many individual units and a complex pedestrian infrastructure can be significant. From a practical perspective, this results in both a costly and time-consuming study.

The train schedule is the dominant factor in pedestrian demand in train stations (Molyneaux et al. (2014)), but difficult to incorporate in pedestrian models as long as the number of arriving and departing passengers is unknown. Therefore the authors recently have developed an estimation framework which can be used to estimate pedestrian demand in train station using the train schedule. This framework has yet to find its way to pedestrian models which are used in the context of train stations.

From our literature survey we have concluded that any model – macroscopic, microscopic, station specific or generic – could potentially be helpful in our search, despite generic or specific limitations (i.e. lacking schedule-based pedestrian demand modelling). Dutch norms and guidelines for pedestrian facilities in train stations are set at a macroscopic level, which leaves open the choice for both microscopic and macroscopic models. As our study time was very limited and our focus was at pedestrian queues at the platform exits and the flows in the transfer tunnels, a macroscopic approach seemed to be preferred because of its speed.

Transparency is another key factor in a joint search of several stakeholders with different interests, which is not mentioned in the literature of pedestrian modelling we have reviewed. When we started our search for the best solution, the parties involved were not in agreement with regard to the magnitude of the pedestrian challenge inside the station. Moreover, some stakeholders already had their own vision of what was the best solution for specific problems. Some of these visions were inconsistent, sometimes even contradictory, and in most cases just partially covering the complex problem at hand. An essential requirement for acceptance of the study results was the ability of all stakeholders to understand the calculations made to support the discussion. From the stakeholder perspective, microscopic models tend to be black boxes with respect to input and assumptions regarding individual pedestrian behaviour and the modelling of interactions between pedestrians and the physical environment. We expected this disadvantage to outweigh the common advantage of microscopic models to be able to show simulation results more intuitively because of their powerful graphical presentation capabilities.

Modelling speed and transparency of input, throughput and output were our decisive factors for our decision to create a relatively simple macroscopic model specifically designed for our challenge at Amsterdam Central station. With this approach, quick changes to the configuration could be made to show the effect of design choices. It became easy to 'play' with the configuration of bottlenecks in the station pedestrian infrastructure (i.e. adding an escalator or widening a tunnel) and see the effects of the changes for the level of service in the entire chain from train door to station front door.

4. Passenger transfer chain model

A root-cause-analyse of the current bottlenecks has shown that the transfer tunnel capacity at the busiest cross sections at the outer tunnels (west tunnel and east tunnel), the exact stopping position of trains and the vertical infrastructure configuration (staircase/escalators) are decisive factors for the level of service of the pedestrian system of the station. Moreover, train arrivals are determinants of bottlenecks in most situations due to the bulky nature of arriving pedestrians they cause.

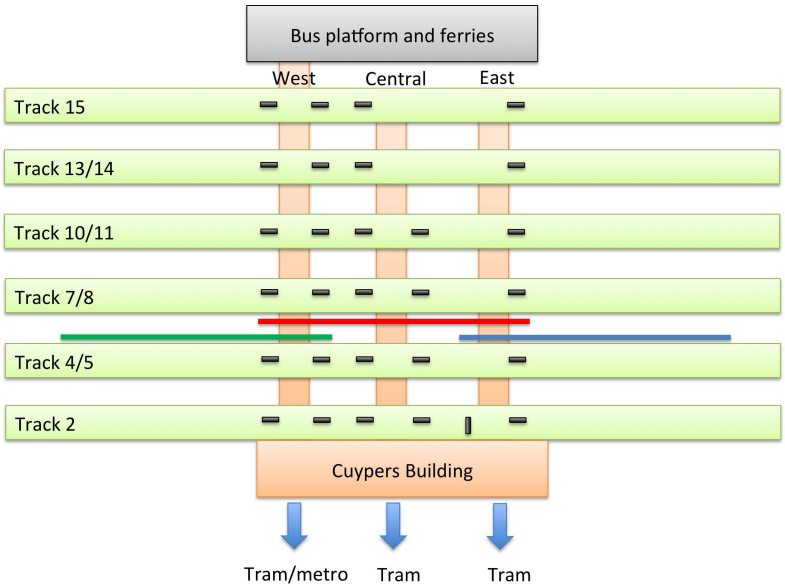

Fig. 5. Schematic representation of the pedestrian network layout with possible stopping locations for trains.

Based on this passenger chain analysis, the macroscopic model has been built for the critical cross sections of the transfer tunnels. Model inputs are the number and arrival time of trains, number of arriving, departing and transferring passengers, the stopping position of trains in the station and the accompanying distribution of passengers over the staircases, vertical infrastructure widths and configurations and the walking distances and speeds. The model was developed in such way that the effect of simultaneous flows from trains arriving on different platforms could be taken into account. One of the important questions to be answered was the difference in the transfer process if trains arrived on a single phase centred around the staircases (red line in Fig. 5) or on one of the two-phases of the platform (green and blue lines in Fig. 5). In the model, provisions have been made to adjust critical parameters such as the configuration and capacity of vertical infrastructure, tunnel width and north-south (city centre – river side) distribution of flows. In short, the model allows to analyse the critical sections of the transfer tunnels and compare levels of service of flows with norms and guidelines. It provides insight into the trains and vertical infrastructure configuration that effectively determine the pedestrian flows at the critical sections and to queue lengths and waiting times at the platforms.

5. Calibration by current situation data

To calibrate the model for the current situation, data from multiple sources were combined. The number of arriving, departing and transferring passengers are based on actual figures of train occupation data from the train operating company of NS. In general the distribution of arriving, departing and transferring passengers over the various transfer tunnels is a key factor which generally only can derived by manual counts. For this study, we have used a different approach by inferring transfer tunnel usage from check-in and check-out distributions from smartcard data (see Van den Heuvel and Hoogenraad (2014) for details). Table 1 shows the distribution of arriving passengers over the tunnels when a train arrives on the western A-phase or the eastern B-phase.

Table 1. Share of arriving passengers per tunnel).

Train stopping position	West Tunnel	Central Tunnel	East Tunnel
A-phase (west side, green line in Fig. 5)	87%	8%	5%
B-phase (east side, blue line in Fig. 5)	24%	26%	50%
Centered around staircases, red line in Fig. 5)	45%	21%	33%

The smartcard data point at an interesting situation. When trains stop on a particular phase, one may expect that arriving passengers will use the vertical infrastructure closest to the point where the train stops. However, the smartcard data shows a tendency for all passengers to favour the west tunnel. This suggests that the western tunnel has a higher attraction level for pedestrians. See Verhoeff (2014) for a discussion about this topic.

Next, pedestrian flows in the current physical configuration of the station were modelled on the basis of the schematic of the transfer system as shown in Fig. 6. This figure shows the flow for a train stopping at the B-phase (blue line in Fig. 5).

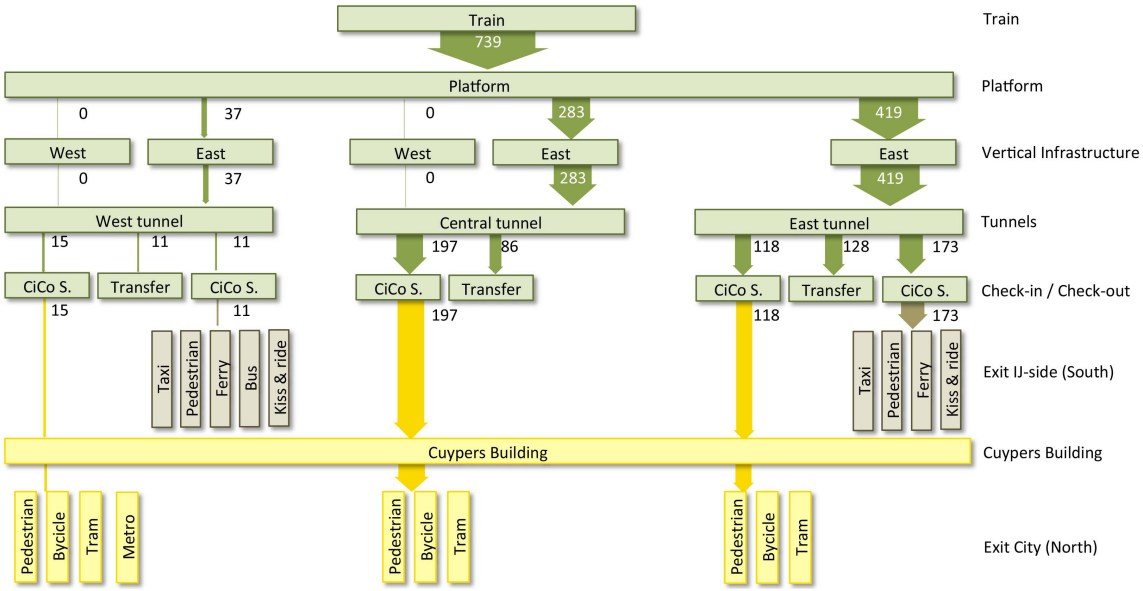

Fig. 6. Example of train stopping at the B-phase in the current situation.

Based on the distribution of the passengers of per train the pedestrian flows in each tunnel and it's level of service could be determined. This resulted in the flow during a morning rush hour for the east tunnel as shown in Fig. 7. The figure clearly confirms that the east tunnel currently used at capacity at some moments (red dashed line),

and that the comfort norm is frequently reached (yellow line). This has been recently confirmed by measurements in the tunnel.

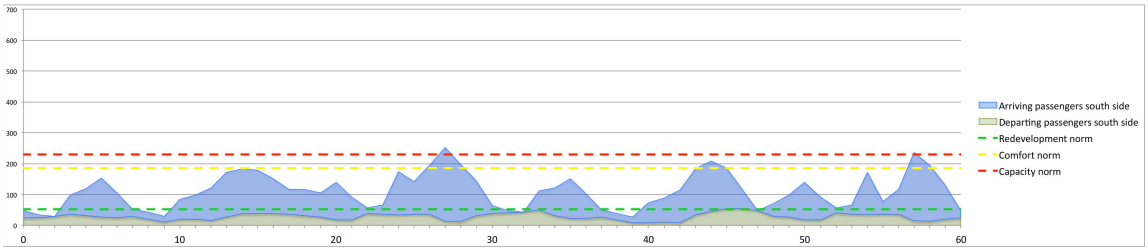

Fig. 7. East tunnel flow during a morning rush hour in the current situation.

6. Exploring the future situation with 2030-scenarios

During the study, all stakeholders could swiftly agree on the necessity to widen the platforms to create more space for passengers waiting for or exiting from trains. Therefore, the removal of the four non-platform through tracks soon became a starting point, despite the further pressure it caused on the already scarce track capacity inside the station.

A critical and more controversial issue in our joint search was the choice between single phase or two phase operation of the platforms. For train operations, two phase operations offer more track capacity and more flexibility in train scheduling. For pedestrian flows, single phase operations makes better use of all platform exits, resulting in significantly shorter transfer times and better distribution of passengers over the three tunnels. A balance was needed between both issues, which were intrinsically in conflict with each other: at one hand passengers do not like long walking distances at the platforms, queuing at platform exits and overcrowded transfer tunnels. On the other hand, passengers also do not appreciate trains that cannot be run and crowded trains due to the impossibility to increase train service frequencies while the number of passengers is growing.

With our macroscopic passenger transfer chain model we could analyse the level of service of pedestrian flows in the transfer tunnels for various future scenarios with different train positions and vertical infrastructure configurations. For one scenario it was assumed that the east tunnel had been widened to 18 meters and that the number of arriving and departing trains has increased by 30% to approximately 240,000 per average work day. Fig. 8 shows the flow through the station transfer network for a future train stopping at the B-phase (blue line in Fig. 5). As the new east tunnel will be similar in design and accessibility to the west tunnel, it is expected that there will be no difference in attraction levels. The distribution of the passengers over the tunnels is therefore based on the distribution in the current situation of a train arriving on the A-phase.

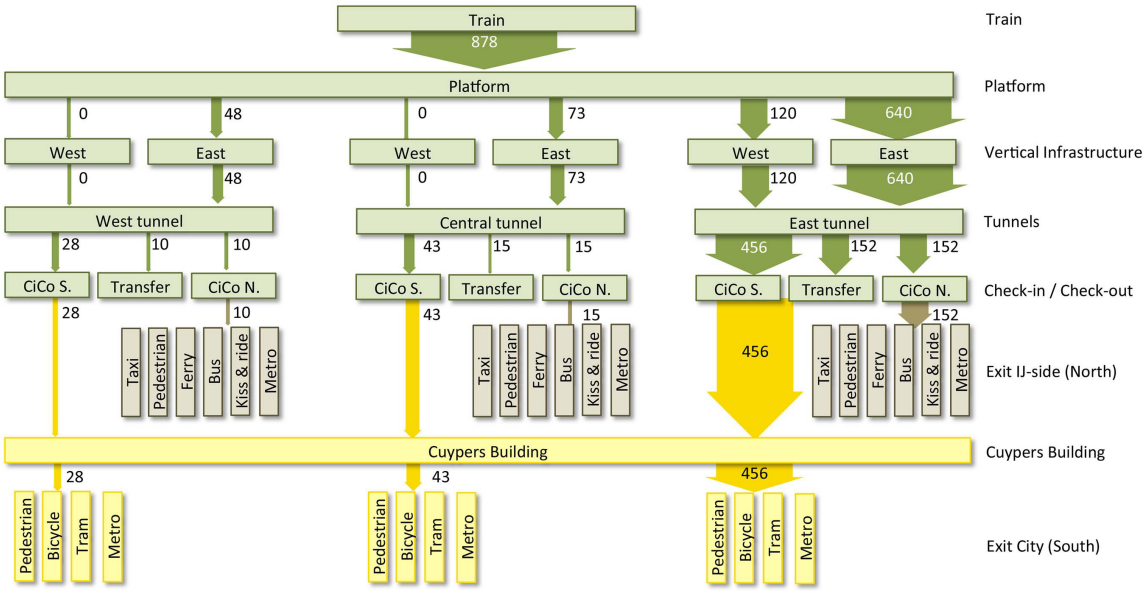

Fig. 8. Example of train stopping at the B-phase in the future situation.

One of the most important parameters to determine the level of service in the transfer tunnels is the capacity of the vertical infrastructure which connects the transfer tunnels to the platforms. Fig. 9 shows the model results for the east tunnel when the staircase capacity is increased to a level that waiting times at the platform are minimal. The blue graph shows the flow in the tunnel in case of a single-phase train operation. The green graph shows the two-phase operation. According to our calculations we can conclude that a single-phase train operation results in short and high flow peaks in the tunnel, while a two-phase operation results long lasting "plateaus". This is due to longer inflow of pedestrians due to the buffering of arriving passengers at the platforms at the outer vertical infrastructure caused by limited escalator capacity.

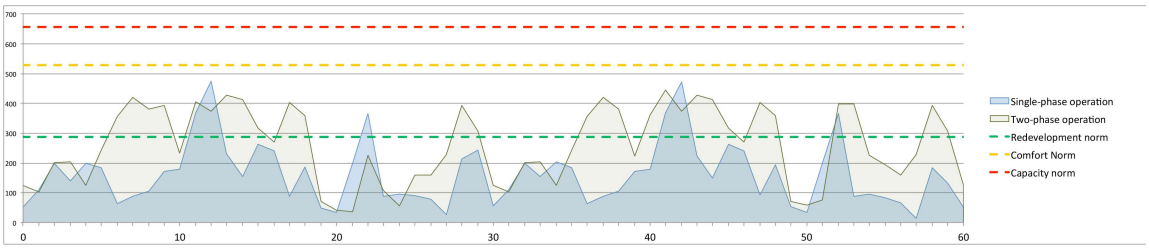

Fig. 9. East tunnel flow during a morning rush hour in the 2030-scenario.

Decreasing the capacity of the vertical infrastructure results in most cases even in lower peaks for two phase operation. However, it results in longer waiting times at the platform. Even in that case, some of the peaks remain high due to the fact of 'overlapping' arriving trains. The effect on one phase operation is less as the available staircase capacity is used more effectively.

Besides the possibility to 'play' with the staircase configuration, the model has also been used to explore the impact of a different spreads in the arrivals of passengers, the impact of tunnel width, the critical cross section within the tunnel and the balance between north and south side.

7. Conclusion

At 16 June Dutch Secretary of Infrastructure has decided to invest €431 million in the enlargement of the track and station capacity of Amsterdam Central station (Ministerie van Infrastructuur en Milieu, 2014). The reconstruction works will take place after all adjustments at and around the station have been designed and engineered in detail, probably in the period between 2018 and 2023. The unanimity of all stakeholders involved stakeholders has contributed to a very smooth decision making process with an outcome where everybody agrees with.

With respect to the most controversial issue, the choice is made to mostly preserve the current two-phase infrastructure concept, but to use the station as a one-phase concept when track capacity allows this. In practice, this will results in some platforms to be used by two trains at the same time, while others will be used by four, and schedule changes which are less constrained than in a rigid application of either the one-phase or the two-phase concept.

With respect to vertical infrastructure capacity the choice is made to prepare for a capacity increase of the outer escalators and stairs. A capacity increase will decrease the queues and waiting times at the platforms significantly, but at the same time will not cause overcrowding in the critical sections of the outer transfer tunnels of which the effective width is limited due to the monumental station building at the south side (city centre).

Our macroscopic passenger transfer chain model has proven to be a valuable tool in our joint effort to get a hold on the station challenge at hand. It allowed us to explore the space for solutions which needed to be in accordance with the spatial constraints posed by the monumental station, the track capacity required for increased train traffic to approximately 57 trains per hour and the pedestrian capacity required for an even larger number of train passengers than is currently using the station.

As important as the usability of the model and quality of the results is the transparency of input, throughput and output. Moreover its flexibility allowed us to quickly respond to development in the dialogue between all stakeholders involved.

For similar studies we recommend to always critically assess the usability of multiple pedestrian models using criteria, which are directly linked to the case at hand. Although the outcomes of microscopic simulation models are very tempting because of their graphical presentation capabilities, in some cases it can be more effective to build a simple, transparent tailor-made macroscopic model as we did. It all depends on the objective, object and context of the study for which the model is to be used.

References

Daamen, W., 2004. Modelling passenger flows in public transport facilities. PhD dissertation. Delft University of Technology.

Duives, D.C., Daamen, W., Hoogendoorn, S.P., 2013. State-of-the-art crowd motion simulation models, Transportation Research Part C: Emerging Technologies 37, 193-209.

Fruin, J.J., 1987. Pedestrian planning and design. Elevator World, Inc..

May, A. D., 1990. Traffic flow fundamentals. University of California, Berkeley, Prentice Hall.

Ministerie van Infrastructuur en Milieu, 2014. Kamerbrief besluiten PHS, 17 June 2014 (in Dutch). Available at http://www.rijksoverheid.nl/documenten-en-publicaties/kamerstukken/2014/06/17/besluiten-programma-hoogfrequent-spoorvervoer-phs.html [Last accessed at 9 July 2014]

Molyneaux, N., Hänseler, F., Bierlaire, M., 2014. Modeling of train-induced pedestrian flows in railway stations. STRC Proceedings.

Papadimitriou, E., Yannis, G., Golias, J., 2009. A critical assessment of pedestrian behaviour models, Transportation Research Part F: traffic psychology and behaviour 12(3), 242-255.

ProRail, 2014. Informatiedocument Programma Hoogfrequent Spoorvervoer Amsterdam Centraal. ProRail, Utrecht (in Dutch). .

Van den Heuvel, J.P.A., Hoogenraad, J.H., 2014. Monitoring the performance of the pedestrian function of train stations using automatic fare collection data. Pedestrian and Evacuation Dynamics 2014, in press.

Verhoeff, L., 2014. Choice and experience of the movement route. Pedestrian and Evacuation Dynamics 2014 , in press.