

Estimating Pedestrian flows at train stations using the Station Transfer Model

Jeroen van den Heuvel, MSc MA MBA
Department of Transport & Planning, Faculty of Civil Engineering and
Geosciences, Delft University of Technology
Stevinweg 1, PO Box 5048, 2600 GA Delft – The Netherlands
NS Stations, Netherlands Railways
Phone +31 6 29 59 81 19
E-mail j.p.a.vandenheuvel@tudelft.nl / jeroen.vandenheuvel@ns.nl

Koen Dekkers, MSc PDEng
Marktonderzoek & Advies
NS Reizigers, Netherlands Railways
Laan van Puntenburg 100, PO Box 2025, 3500 HA Utrecht – The Netherlands
Phone +31 6 55 74 31 46
E-mail koen.dekkers@ns.nl

Susan de Vos, MSc
Asset Development
NS Stations, Netherlands Railways
Stationshal 17, PO box 2534, 3500 GM Utrecht – The Netherlands
Phone +31 6 30 44 63 97
E-mail susan.devos@ns.nl

ABSTRACT

Train stations play a vital role in the door to door travel experience of train passengers. From the passengers' value of time perspective, the station is the weakest link in total time value of the journey. Within the station the transfer function – moving between the various transport modes and waiting at the next service - is the core function, because it connects all transport modes. Therefore, an optimal transfer process is a key requirement for a well performing station.

The basic requirement for optimization of the transfer process is to understand how many passengers use the transfer facilities, and at what time. This information is delivered by the Station Transfer Model, which taps into data already available at the train operating and station management divisions of Netherlands Railways (NS). With the model, the volumes of pedestrian flows at platforms, escalators and stairs can be estimated for various time frames.

The Station Transfer Model generates output that is useful for evaluation of the commercial performance of the station's retail. It can also be used to estimate the required capacity of stairs and escalators between the platforms and the station hall, tunnels or bridges. When renewed data is available, NS intends to further develop the model to increase the quality of the output.

INTRODUCTION

Netherlands Railways (NS) continuously searches for opportunities to increase passenger experience, commercial performance and contribution to society of its services. In The Netherlands, NS is both the largest passenger train operator in The Netherlands and the station manager of all railway stations. The latter is done in a shared responsibility with the railway infrastructure provider ProRail. Because the passenger train operating company (NS Reizigers) and the station management company (NS Stations) are part of the same company, the latest insights about customer trends are easily shared.

Customers (or passengers) are at the heart of the license to operate of any public transport company. One of NS' key challenges is to keep improving customer satisfaction. Existing research and experience point at the importance of stations in the passengers' trips from door to door. Within stations, the transfer function – the core function of the station – offers the connection between all transport modes which are connected to the station.

The first step in improving the transfer process in a train station is to understand where passengers come from and go to, in short to map pedestrian flows at a station. Because measuring pedestrian flows is extremely costly and several data sources already are available in the company, NS Stations and NS Reizigers decided to build a simple model which combines existing data. The model combines the passenger numbers of trains with the physical location of train stops in the station. This turned out to deliver a valuable tool which generates information to improve the transfer function of a station, and thereby the overall station experience. The "Station

Transfer Model” allows professionals of both divisions to estimate passengers flows at stations and to use it for understanding and optimizing their processes.

This paper is structured as follows: in the next section the importance of the transfer process for station experience is described. The data sources of the Station Transfer Model are presented in section three, including the way the data is combined. In sections four and five two cases are used to illustrate the working and results of the Station Transfer Model. Because the Model is still under construction, section six describes the future developments. The final (seventh) section concludes this article.

THE IMPORTANCE OF AN OPTIMAL TRANSFER PROCESS FOR STATION EXPERIENCE

In his research Van Hagen (2011) has listed the valuation of time of the individual links of a train trip, which is by definition a chain of modes. Van Hagen concludes that the value of time is different for each of these links. For example, waiting time at the station is valued up to three times lower than time spent in the train. The concept of different time values is shown in Figure 1. The figure shows that from the passengers’ value of time perspective, the station is the weakest link in total time value of the journey.

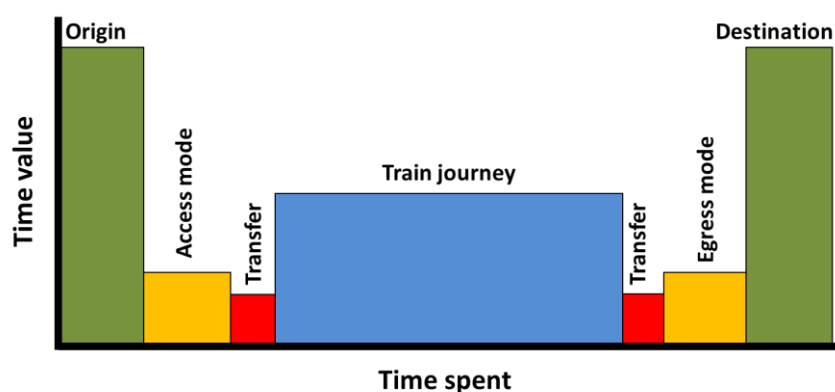


Figure 1 - Concept of different time valuation of train passengers (Van Hagen, 2011).

The main function of a railway station is to facilitate passengers in their transfer: the changing between the modes in the chain, for example between trains, or between train and access/egress modes. As shown by Van Hagen (2001), waiting for the next mode is the main dissatisfier in the chain. This situation can be improved by decreasing the time spent at a railway station, for example by increasing public transport service frequencies. It can also be improved by increasing the value of the time spent at a railway station. In short: a better station experience results in a lower perceived waiting time and a higher total value of time.

To get a hold on what public transport users need, Peek and Van Hagen (2002) have adjusted the concept of Maslow’s Pyramid to the public transport environment (Figure 2). Each layer in the pyramid represents a set of requirements for public transport passengers. Safety and reliability are the

most important items for passengers. Safety is about physical and social security, reliability is all about basic functionality, like waiting facilities at the platforms. The next layer consists of speed and ease. Changing between public transport can be a process full of obstacles (ie. queues) and uncertainties (ie. “will I make it on time?”). Safety, reliability, speed and ease are categorized as dissatisfiers: if these items are not at a sufficient level from the passengers’ perspective, the service tends to be evaluated as unsatisfactory, no matter what other services are offered or measures are taken. Comfort and experience are the two satisfiers. They can be considered as additional quality aspects, on top of the required dissatisfiers. Comfort can be increased by providing extra services on top of the primary function of the station (transfer), like a heated waiting room, shops or a pub. Station experience can be increased by improving the atmosphere for example with colours, music and infotainment (Van Hagen, 2011).

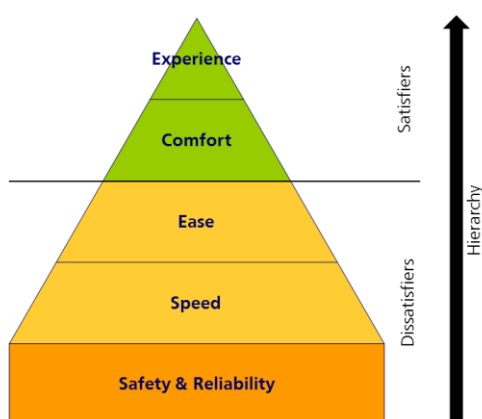


Figure 2 – Pyramid of Public Transport Customer Needs

To measure passenger station experience, NS has developed the Station Experience Monitor by applying the Pyramid of Public Transport Customer Needs to train stations (Van Hagen et al, 2009; Van Hagen & Heiligers, 2010). Since winter 2011, passengers are interviewed quarterly using a questionnaire which consists of questions about a large number of station facilities, services and experiences, the overall station experience and platform experience. Respondents are asked to give a rating between 0 and 10, where 0 refers to a very negative score, and 10 to a very positive score. All large stations (50 in total) are included in the monitor and also a sample of the small stations (over 300 in total). At every station, passengers are selected randomly when waiting at the stations platforms. Although this might introduce a selection bias - only passengers waiting at the platform are interviewed -, interviewing at other locations causes a non-response bias, since passengers prefer to get to the platform first, to make sure they are on time for their train. The interviews are taken from 6.30-20.30h at working days. The Station Experience Monitor has so far resulted in a dataset with feedback of approximately 112,000 unique customers on over 350 stations.

The existing dataset of the Station Experience Monitor allows a thorough analysis of similarities and differences between stations, categories and items, both cross sectional and longitudinal. Moreover, it allows the calculation of

correlations between individual categories and items and overall station experience, all from the passengers' perspective. Table 1 shows some statistics derived from the Station Experience Monitor data for Leiden Centraal, Duivendrecht and Gouda. These three stations represent the range of scores all Dutch stations are in. Relatively high correlations – larger than 0.6 – point at a very strong effect and are marked yellow. For all three stations, the table presents the average overall station experience scores and the correlations between the items, the overall station experience and the platform experience.

Table 1 - Station Experience Monitor of Leiden, Duivendrecht and Gouda

	Average score	Correlations					
Leiden		Overall station experience	Platform experience	Safety & reliability	Speed & Ease	Comfort	Experience
Overall station experience	7.22	1	.614	.582	.514	.677	.719
Platform experience	6.72	.614	1	.417	.363	.510	.639
Safety & reliability	7.17	.582	.417	1	.495	.468	.515
Speed & Ease	7.50	.514	.363	.495	1	.517	.370
Comfort	7.00	.677	.510	.468	.517	1	.652
Experience	6.43	.719	.639	.515	.370	.652	1
Duivendrecht		Overall station experience	Platform experience	Safety & reliability	Speed & Ease	Comfort	Experience
Overall station experience	6.35	1	.833	.574	.391	.683	.753
Platform experience	6.26	.833	1	.584	.408	.641	.754
Safety & reliability	6.73	.574	.584	1	.476	.488	.600
Speed & Ease	6.90	.391	.408	.476	1	.464	.357
Comfort	5.92	.683	.641	.488	.464	1	.660
Experience	5.60	.753	.754	.600	.357	.660	1
Gouda		Overall station experience	Platform experience	Safety & reliability	Speed & Ease	Comfort	Experience
Overall station experience	5.77	1	.697	.743	.659	.659	.693
Platform experience	5.62	.697	1	.655	.538	.605	.719
Safety & reliability	5.98	.743	.655	1	.706	.625	.707
Speed & Ease	6.09	.659	.538	.706	1	.589	.509
Comfort	5.45	.659	.605	.625	.589	1	.659
Experience	5.13	.693	.719	.707	.509	.659	1

All Pearson correlations are significant at the 0.01 level (2-tailed).

The high correlations of 60 to 85% between overall station experience and the platform indicate that a well performing transfer function is one of the basic needs in a railway station. In terms of the overall station experience Leiden Centraal (score: 7.2) is the best performing station of The Netherlands, Duivendrecht (score: 6.4) scores average for the portfolio of large (50) stations, and Gouda (score: 5.8) is one of the lowest performers.

The data from Gouda shows that when a station scores low on the overall station experience, the overall station experience correlates strongly with all other items. Moreover, safety & reliability correlates with all other items. This tells us that the basic function of the station needs improvement, which will probably result in a higher score on all other items and the overall station experience. The data from Duivendrecht shows that improving comfort on an average scoring station is a requirement to improve experience and overall station experience. A well performing station like Leiden Centraal only needs

experience measures to improve overall station experience. A good platform experience is a requirement for all types of stations.

The previous examples prove that passengers require the station operator to make sure that the transfer process in the station is always taken care of. Platforms, stairways, escalators and the station hall are the key ingredients for a well performing process. The first requirement for optimization is to understand how many passengers use these facilities, and at what time. This information is delivered by the Station Transfer Model.

USING TRAIN TRAVEL DATA TO GET THE STATION TRANSFER MODEL

Figure 3 presents an overview of the data which is combined in the Station Transfer Model. At the end of every year, NS makes an Origin-Destination (OD) matrix. This matrix contains for every OD pair in the Netherlands – approximately 120,000 in total, based on approximately 350 stations – the amount of journeys that have been made between these OD's. The matrix is constructed by combining four different data sources. The largest data source, with about 225,300,000 trips, is the number of day return tickets that were sold. These tickets contain an origin, a destination and have a timestamp. This source forms the basis for the OD matrix.

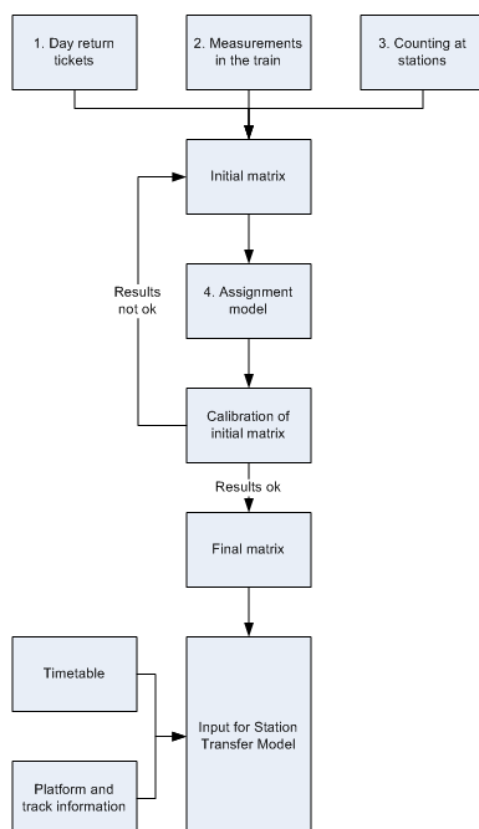


Figure 3 – Data combination in the Station Transfer Model

Passengers not only use single or return tickets, they also use e.g. a student card, a discount card or a company card. To measure the amount and distribution of these kinds of tickets, research is done at the train. Every train

service is measured at least once every four months. This is the second source of information that is used. Combining this data with the first data source leads to a first estimation of the OD matrix. This estimation is improved by adding available information from research that is done at stations. For around 40 stations the number of travelers boarding and exiting trains is counted each year. Comparing the outcomes of the first estimation with these figures leads to improvements of the matrix.

In the next step the matrix is used in combination with an assignment model. In this assignment model, the timetable of the corresponding year is combined with the OD matrix. The assignment result is compared with the fourth data source: passengers' kilometers obtained from measurements on the train. This data source is used for calibration of the matrix. The matrix is adjusted until the assignment result is consistent with the outcome of the measurements on the train.

The OD matrix is made for different periods. The most widely used is the average weekday matrix. This matrix contains all trips that are made on an average day of the week. Matrices for the two hours morning peak, two hours evening peak and the most busy hour of the day are also available. In the assignment model the final matrices for the specific time frames are combined with a timetable to determine for every OD pair the route that the traveler will follow. Following from these calculations are the number of departing and arriving passengers and the number of passengers that have to switch trains. Again, this information is available for different periods. In the model is assured that the timetable being used matches the matrix being used. In the Netherlands there are - next to NS - other railway operators. The information used in the assignment model does not contain information about stations that are not served by NS. For the model this is not an issue, because more than 95% of the passengers starts or ends their journey at an NS station.

When the timetable of 2012 is used, generally also the OD matrix for that specific year is used. However, this matrix can only be ready about half a year after the timetable has started. For the Station Transfer Model this has been solved by using a prognosis matrix. With a prognosis model, the matrix of the previous year is adjusted to make a prognosis matrix. The final matrix that is an outcome of the prognosis model can be used in the assignment model.

By combining the final matrix with the station's timetable and the platform/track information, the number of boarding, changing and exiting passengers for each platform can be estimated. Figure 4 shows an example for the Station Transfer Model at Leiden Centraal at an average working day in 2012. It shows clearly that the peaks in pedestrian flows in the station occur at minutes 7-11, 26, 37-41 and 56. The tracks 1 and 5 are used by the majority of the passengers who exit trains, either to exit the station or to change to another train.

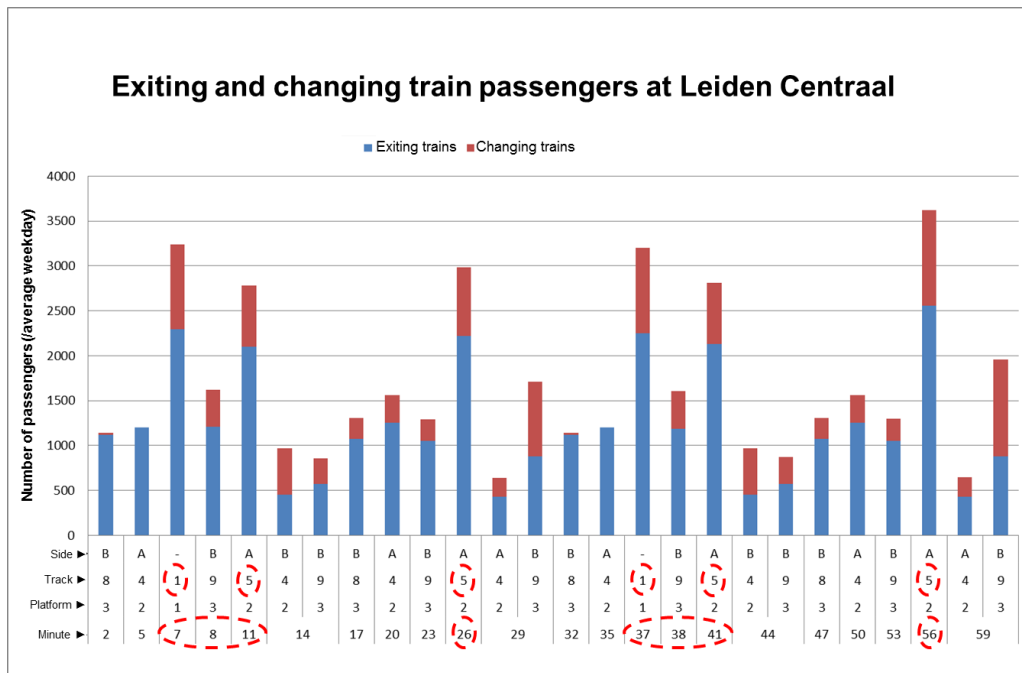


Figure 4 - Station Transfer Model output for Leiden Centraal

In the next two sections, the insights from the Stations Transfer Model are used in two different types of cases. The first is a commercial case, in which the performance of the Kiosk shops at Amersfoort Stations platforms is evaluated. The second case considers the capacity stairways and escalators at Utrecht Centraal station.

CASE 1: UNDERSTANDING THE PERFORMANCE OF KIOSKS AT PLATFORMS

In The Netherlands, many stations have Kiosks on the platforms. Kiosks are small stores (usually 25 m²), where passengers can buy last-minute beverages, food and readings before entering their train. Boarding passengers tend to have a higher demand for these products (especially coffee!) than passengers who exit the train to leave the station.

Because of its location and the nature of the retail outlet, a Kiosk is fully dependent on the pedestrian flow at the platform. Therefore, for evaluation of the Kiosk shops' performance, information is needed on the number of passengers using the platform during different moments of the day. The Station Transfer Model gives information about the number of boarding and exiting passengers and helps to determine the best location for the shop. This is illustrated by an existing situation at Amersfoort station.

Amersfoort is a medium-sized city in The Netherlands, with slightly under 150.000 residents (2011). Its main train station serves about 40.000 boarding and exiting passengers on an average weekday and 25.000 passengers who change trains, which makes it the 13th largest station in The Netherlands. Amersfoort station has three platforms, each with a Kiosk shop. Figure 5 shows the Station Transfer Model for Amersfoort on an average weekday. The graph clearly illustrates that the platforms 1 and 3 are much busier than

platform 2. The latter is mainly used by passengers boarding the .11 and .41 train services.

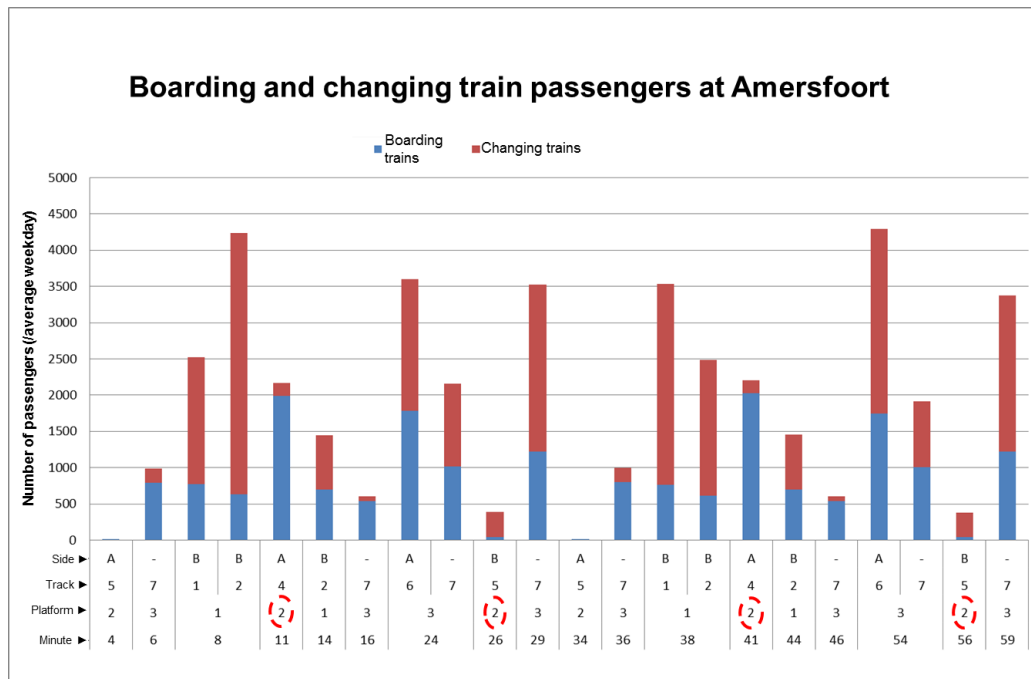


Figure 5 – Station Transfer Model out for Amersfoort

From sales data of NS Stations, the performance of the three Kiosks is known to be significantly different. The Kiosk on platform 3 performs very well with 50% of total Kiosk sales at Amersfoort. The one on platform 1 performs second best with 40% of total sales. The Kiosk on platform 2 performs poorly (10% of total sales). Figure 6 shows these differences graphically.

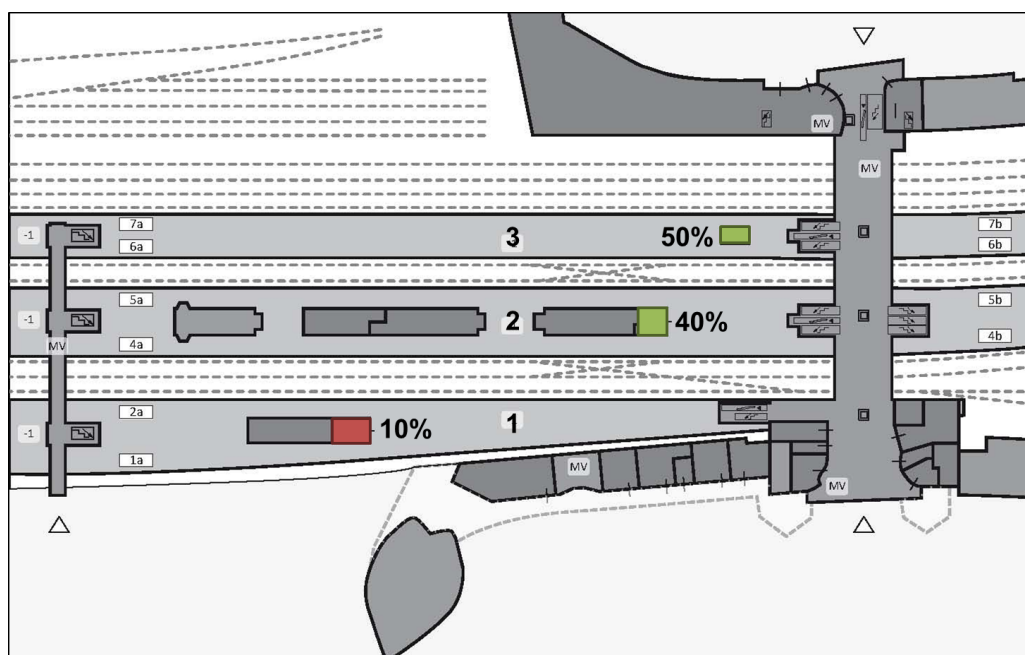


Figure 6 - Amersfoort Kiosk performance

From research is known that long distance travelers – typically by Intercity services - are more likely to buy at the station before boarding their train. When looking further into the Station Transfer Model data, we find that the majority of the long distance, high quality Intercity train services use platforms 1 and 3. Platform 2 is only used by one Intercity service and one regional train service. The platform use of all trains to and from Amersfoort is given by Figure 7. A closer examination using the Station Transfer Model for the type of train services on each platform also helps to understand whether or not to build retail services is worth the financial investment.

Evaluating the performance of the concept of a Kiosk on every platform from a financial perspective, we conclude that the Kiosk at platform 2 is not contributing to the financial performance of the station operator. The Station Transfer Model tells us that both the number of boarding passenger on platform 2 and their travel distances are too small to operate a Kiosk profitably. This conclusion can be used in future investment decisions. Another insight is the train schedule dependency of Kiosks. A major change in the train schedule at Amersfoort can totally change the picture.

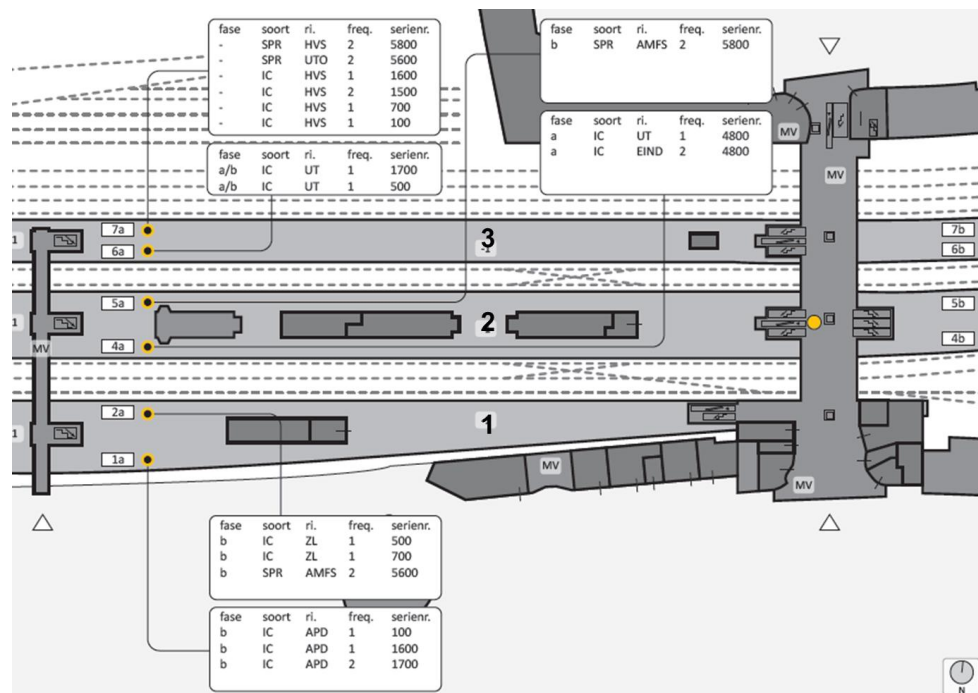


Figure 7 - Platform use by train services

CASE 2: THE USE OF STAIRS AND ESCALATORS

Stations in The Netherlands typically have tunnels and bridges to allow passengers to cross the tracks safely and comfortably. A connection with the platform is provided by height bridging infrastructure, like stairs, escalators, ramps and elevators. Stairs and escalators tend to be the transfer bottlenecks in many stations, primarily directly after train arrivals which instantly “drop” hundreds of passengers at the platform (Voskamp, 2012; Figure 8).



Figure 8 – Queuing at stairs at platform 7 at Utrecht Centraal station

To determine whether or not the capacity of stairs and escalators is sufficient, the Station Transfer Model provides the figures required. This is illustrated by an existing situation at Utrecht Centraal station, which is the 2nd largest station in The Netherlands with 170.000 boarding and exiting passengers on an average weekday and 60.000 passengers changing trains. For passengers transferring to connecting trains and busses, it is essential that the transfer function of the station is well performing. If not, these passengers might not make it to their connecting services on time, since they can leave within 5 minutes after train arrival.

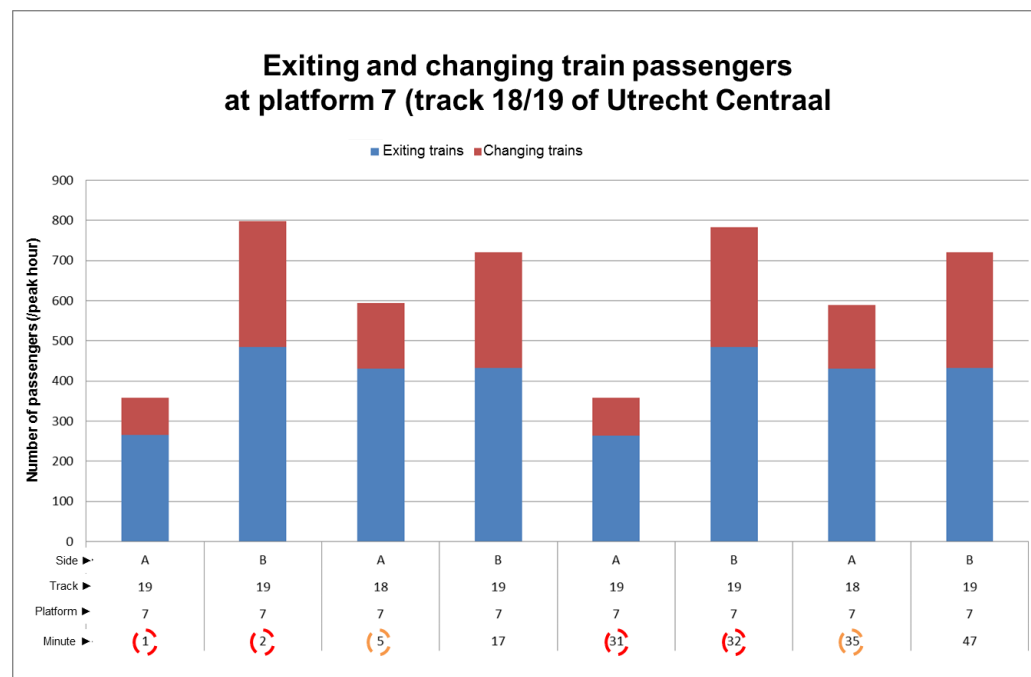


Figure 9 - Station Transfer Model output for platform 7 at Utrecht Centraal

Looking at Station Transfer Clock data for the 7th platform at Utrecht Centraal (Figure 9) for the peak hour, it is clearly visible that the stairs and escalators are heaviest used during the time intervals .1-.2 and .31-.32. In these two blocks of two minutes each, approximately 1,150 passengers exit the trains and walk either to the station exit (e.g. to continue their trip by bus or bike) or to other trains, which in this case all leave at other platforms. This is 50% of the total hourly pedestrian flow.

From measurements it is known that 80% of all passengers use the escalators and stairs which offer access to the station hall. In case of platform 7 with three stairs and one escalator to the station hall, the peak load of these transfer facilities is over 900 passengers in two minutes.¹ The escalator and three stairs combined offer a transfer capacity of approximately 500 pedestrians per minute. So the minimum platform clearance time – the time required until the last passenger has left the platform - is just under 2 minutes.

The platform clearance time increases when the passengers are not using the stairs and escalators efficiently. Voskamp (2012) has shown that passengers that arrive at platform 7 have an escalator preference. This results in a higher demand for this specific transfer facility, and a lower demand for the stairs. The average waiting time for passengers increases because of queuing at the platform. Interpreting data presented by Voskamp (2012), this could add an additional time of half a minute, resulting in a platform clearance time of approximately 2.5 minutes.

Figure 9 also shows that delays can cause an increase in the platform clearance time. When the train services which are scheduled to arrive at minutes .1/.31 and .2/.32, are delayed by a couple of minutes, their arrival coincides with the arrival of the train services which are scheduled at minute .5/.35. In this situation, the peak load at platform 7 increases to 1,750 exiting passengers of which 1,400 use the transfer facilities to the station hall. Thereby, the platform clearance time increases to over 3.5 minutes assuming an efficient use of the escalator and stairs. The real clearance time is estimated at least 4 minutes.

Another cause of a longer platform clearance time is the bidirectional use of stairs. This occurs when peak flows of arriving and leaving passengers arrive at the transfer facilities at the same time. At platform 7 this usually does not occur, because arrivals and departures of trains do not coincide here (see Figure 10).

¹ The escalator has an effective capacity of 70 pedestrians per minute. The stairs of 3,5 meters width each, have an effective capacity of 40 pedestrians per meter width per minute, assuming the target occupancy.

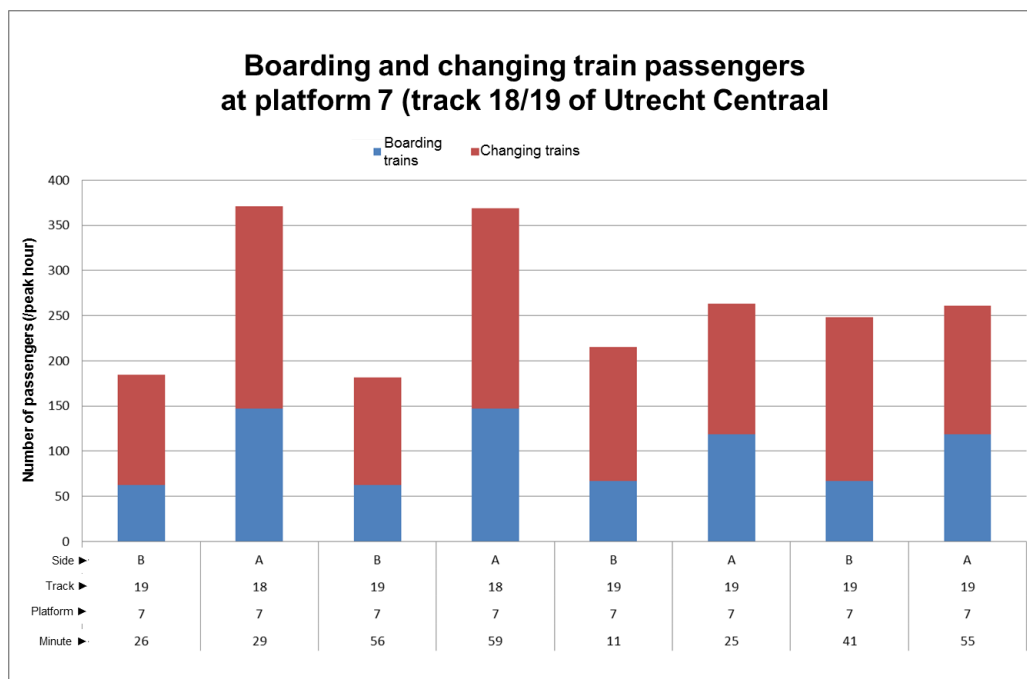


Figure 10 - Station Transfer Model output for platform 7 at Utrecht Centraal

Evaluating the transfer performance of the stairs and escalators of platform 7 of Utrecht Centraal using the Station Transfer Model data, we concluded that in the current situation the escalators and stairs are used at capacity. Under normal circumstances, the last passengers leaving an arriving train can just make it on time to connecting services that leave within 5 minutes after arrival. However, in case of slight delays several trains could arrive at the same time. This results in an increase in the platform clearance time, which causes passengers to miss their connecting train (or bus) service.

FUTURE DEVELOPMENTS

The first future development is the extension of the Station Transfer Model with future timetables. The railway sector in The Netherlands spends a significant amount of effort on the design of future timetables. These studies provide estimates for the expected amount of passengers, the required number of trains and average travel times. Although this data gives an estimate of total (daily) transfer flows in the stations, it is not possible to give a more detailed estimation of the transfer flows at the station. To solve this data gap two issues need to be addressed.

Firstly, the current input for the Station Transfer Model from the assignment procedure is based on the hourly cyclic timetable which is the basis of the train schedule in The Netherlands. In reality, there are differences in train use within hours of the day on a specific line and the addition of peak hour services in the schedule. The passenger estimates per train that are used for the Station Transfer Model do not take into account these differences. Currently, NS Reizigers is planning to work with a new model that is able to perform dynamic assignments. This allows the model to include a complete day timetable and to assign passengers to individual trains. This additional

feature will only be beneficial when the OD-matrix is also on a more detailed level. This situation will be reached when the public transport chipcard, which is currently being implemented in the whole network, delivers the required detailed data. Note that this data is encrypted, aggregated and safely stored to ensure the privacy of NS customers.

Secondly, it is required to find a way to include the track numbers for arriving and departing trains for future timetables. Currently, the train scheduling process delivers this data just a couple of months before the start of the new schedule. The cases have shown that this is essential for valuable output of the Station Transfer Model, since transfer bottlenecks are all about minutes and specific locations. When the required data is available, NS Reizigers and NS Stations intent to extend the current Stations Transfer Model with a prediction function.

A second future development is to add information about the choice of escalators and stairs to the Station Transfer Model data. The second case has shown the sensitivity of transfer bottlenecks for this issue. A third future development is the calibration of the Station Transfer Model with measurement data. Currently, there is hardly any detailed data available about pedestrian flows within stations, neither in the station hall, nor at platforms. NS Stations, NPC (a subsidiary of Royal Haskoning DHV) and Delft University of Technology are jointly performing studies at Utrecht Centraal station to map pedestrian behaviour in this station. For measurements, SMART Station is being used, which is a pedestrian flow measurement system using multiple technologies. This system is currently under development by NS Stations and NPC.

CONCLUSIONS

The transfer function is at the heart of every station. Station Experience Monitor data has confirmed that the transfer function needs to perform well in order to let passengers have a good experience at the station.

Platforms, stairways, escalators and the station hall are the key ingredients for a well performing transfer process. A basic requirement for optimization is to understand how many passengers use these facilities, and at what time. This information is delivered by the Station Transfer Model.

The Station Transfer Model combines existing data from NS' train operating division (NS Reizigers) and its station management division (NS Stations). For all large stations in The Netherlands – approximately 50 – the model can generate graphs which give an hourly picture of the platform use by passengers boarding, exiting and changing trains. This is done for several time frames, ie. average working days and peak hours.

The first case has shown that with the Station Transfer Model, the station manager can evaluate the commercial performance of station stores. The model can support decisions to change or expand the retail portfolio at the stations.

The second case has shown that with the Station Transfer Model, the station manager can easily evaluate or estimate the capacity of stairs and escalators in a station. A station designer can evaluate which combinations of escalators and stairs offer the required capacity.

When the required data is available, NS intends to further develop the Station Transfer Model. Improvements are the use of data about future train schedules, the addition of data about passengers' choice for escalators and stairs, and the calibration of the model using data from large scale pedestrian flow measurements at Utrecht Centraal.

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