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WIE WILT WEER NOAR HUUS

A STUDY INTO IMPROVING CROWD MANAGEMENT AT ENSCHEDE KENNISPARK

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Summary

In the east of the Netherlands, a small train station is located adjacent to a large football stadium. This station, Enschede Kennispark, is not designed to accommodate the large influx of train travellers following matches at the stadium. Crowd management measures are essential to ensure smooth operations, yet a disproportionately high number of stewards is required due to the misbehaviours that frequently arise during the outflow phase. Recognising these challenges, the social security manager of NS seeks to improve the situation at Enschede Kennispark.

The problem analysis identifies several challenges at the station after matches at the Grolsch Veste, with the most significant issues affecting travellers heading toward Hengelo. Consequently, this study focuses primarily on this flow. A mismatch between the safe platform capacity and train capacity results in waiting times of up to 30 minutes. Additionally, there are limited means to inform travellers about train delays or schedule changes. It is hypothesized that longer waiting times lead to an increase in misbehaviour. The objective is to reduce waiting times; however, this is complicated by varying match characteristics and end times, which affect the effectiveness of different measures. Furthermore, multiple stakeholders, each with their own responsibilities and objectives, may have conflicting interests, adding to the challenge.

A literature review provides insights into the effects and perception of waiting times. Waiting is generally perceived as a negative experience, with perception largely influenced by the availability and quality of information. Research indicates that standstill waiting times should be minimised, particularly those exceeding eight minutes, as they can significantly impact individuals' moods. Based on these insights, this thesis aims to *“reduce misbehaviours at Enschede Kennispark after football matches in the Grolsch Veste by providing recommendations to the social security manager of NS in order to decrease the actual and perceived waiting times.”*

To develop effective measures for reducing waiting times, this study applies the framework ‘selecting and assessing effective crowd management measures’ (Mensink, 2017). A microscopic pedestrian simulation model is used to accurately quantify the effects of various measures and to evaluate multiple interventions across different scenarios. The scenarios that are considered are 1) a regular FC Twente match on Sunday afternoon, 2) a match with a late ending when fewer trains are available, and 3) an FC Twente match with an increased number of visitors. The measures which are analysed are 1) a readjustment of the train stop position on the platform to better match the influx on the platform and increase the safe waiting capacity, 2) an expansion of the platform such that the safe waiting capacity can be further increased, 3) an extra shuttle train to decrease the headways, and 4) an alteration of the turnstile program to reduce the standstill wait time.

The impact of these measures is assessed based on key performance indicators, which follow out of the objectives of stakeholders, and include standstill waiting times, total pedestrian delays, walk-in and walk-out counts, average crowd density, and Level of Service. Among the proposed measures, introducing an extra train is the most effective at reducing standstill waiting times while maintaining a safe crowd density. This option is particularly beneficial in mitigating misalignment between match end times and train schedules. Platform expansion also significantly reduces standstill waiting times; however, it increases crowd densities on the platform to potentially dangerous levels. Readjusting the train stop position performs slightly worse than the other two measures, yet is still a large improvement to the baseline, and offers the advantage of being cost-effective. Lastly, the alternative turnstile programme alleviates queue densities at the turnstiles but results in slightly longer waiting times.

Future research could focus on intervention studies to assess the actual benefits of the measures, or on simulation of queues in the social forces model.

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1. INTRODUCTION

Enschede Kennispark is a train station located between Enschede and Hengelo. It is situated near the campus of the University of Twente and neighbours a business park. On a regular workday, about 2000 travellers arrive and depart combined[1]. The station is also used after (football) matches in the Grolsch Veste, a football stadium located right next to the station. On regular match days, typically once every two weeks during the football season, about 2300 fans arrive and an equivalent number depart by train, both phases within the timeframe of approximately an hour before and after the match, respectively. The station is not designed for such a large influx of travellers. To avoid overcrowding or other hazardous instances, crowd management is applied.

Crowd management is the set of measures taken in the normal process of facilitating the movement and enjoyment of people (Berlonghi, 1995). In practice, this involves predicting how, when, and why high-density crowd movements occur (Duives, Daamen, & Hoogendoorn, 2013) and implementing appropriate measures to prevent hazardous situations. These measures can be categorised into four strategic approaches: increasing throughput, preventing blockages, distributing traffic, and limiting inflow (Hoogendoorn, 2011). Stewards play a key role in executing these strategies, monitoring crowd conditions, and providing information to ensure safety and minimise misbehaviour (Martella, Li, Conrado, & Vermeeren, 2017).

Following football matches at Enschede Kennispark station, hazardous incidents frequently occur, including acts of vandalism, platform overcrowding, and cases of harassment (Borgerink, 2024; Schoon, 2024). These occurrences highlight the inadequacy of the current crowd management plan, as noted by the social security manager of the NS. One of the primary risks is platform overcrowding after matches, increasing the danger of people falling off the platform. To mitigate this, turnstiles have been installed to regulate inflow; however, this has resulted in long queues, with waiting times exceeding 30 minutes. Consequently, other significant issues have emerged, including traveller misconduct such as gate violations, aggression towards stewards, and even unauthorised access to the train tracks. A potential explanation for these behaviours is heightened frustration, as suggested by prior research (Larue, Blackman, & Freeman, 2020; van der Wal, Couwenberg, & Bosse, 2017). Van der Wal et al. specifically note that frustration increases with prolonged waiting times, leading to the hypothesis that a reduction in waiting times at Enschede Kennispark could decrease instances of misconduct and improve overall crowd behaviour.

In this thesis, we design and evaluate crowd management measures aimed at reducing waiting times and improving overall crowd behaviour. Measures are assessed *ex ante*, i.e., before implementation, using a pedestrian simulation model. This approach allows for evaluating their effectiveness and potential unintended consequences without the need for costly or unsafe real-life implementation. The remainder of this thesis is structured as follows. First, the current situation at Enschede Kennispark is examined, providing a detailed analysis of the associated problems and their interrelations (Chapter 2). Next, a literature review explores the relationship between waiting times, perceived waiting experiences, and their influence on traveller behaviour (Chapter 3). Based on this problem analysis and the insights gained from the literature, the research objective is defined, supported by four research questions (Chapter 4). The methodology for addressing these research questions is then outlined and the scope is demarcated (Chapter 5). Chapter 6 explains the different scenarios taken into account, the derivation and implementation of possible measures, and the different performance indicators that

[1] https://www.treinreiziger.nl/aantal-in-en-uitstappers-per-station-2013-2018/ There is no accurate data available to the researcher from later time periods due to the presence of another train service provider.

can be used for assessment. The setup of the pedestrian simulation model is then specified in detail in Chapter 7. In the results section (Chapter 8), the proposed measures are analysed, and their effectiveness is quantified using an assessment framework based on predicted pedestrian flows. This chapter ends with a sensitivity analysis to show the effects of the most important assumptions. Finally, the thesis concludes with a discussion of findings (Chapter 9) and provides recommendations for the social security manager of NS to enhance crowd management and improve the traveller experience at Enschede Kennispark station in the conclusion (Chapter 10).

2. PROBLEM DESCRIPTION

To fully understand the issues at hand, the chapter begins with a problem description. It first outlines the situation, followed by an overview of the crowd management operations for match visitors arriving and departing by train. Next, a problem analysis identifies the key challenges, their causes, and when they occur. A brief stakeholder identification then provides insight into the involved parties and their objectives. Finally, the chapter concludes with a summary of key findings.

2.1 SITUATION

As stated before, Enschede Kennispark is situated between Enschede and Hengelo. As can be seen in Figure 1, the stadium is situated right next to the station. The layout of the station is quite simple. There are two platforms which are 200m long and 3m wide in most places (see Appendix F for a schematic view), with one underpass facilitating all movement from one side of the tracks to the other. This underpass is also used by the bicycle freeway F35[2], connecting Enschede and Hengelo. The regular entries to the station are situated next to the underpass. There are no elevators available, but instead, gradual ascents provide access to the platforms for people not able to use the stairs. The station is further characterized by 'de puntmuts', a conical building meant to house a waiting area on the platform level and a refreshment room on the ground floor. However, the ground floor has been vacant for some time and will be in the future due to problems with drainage. The station is normally only serviced by Keolis (also called Blauwnet) sprinters on the route Enschede to Zwolle and vice-versa. During peak hours (on weekdays between 7:30-9:30 and 15:30-18:00), sprinters from NS also halt at Enschede Kennispark. These sprinters follow the route from Enschede to Apeldoorn and vice versa.

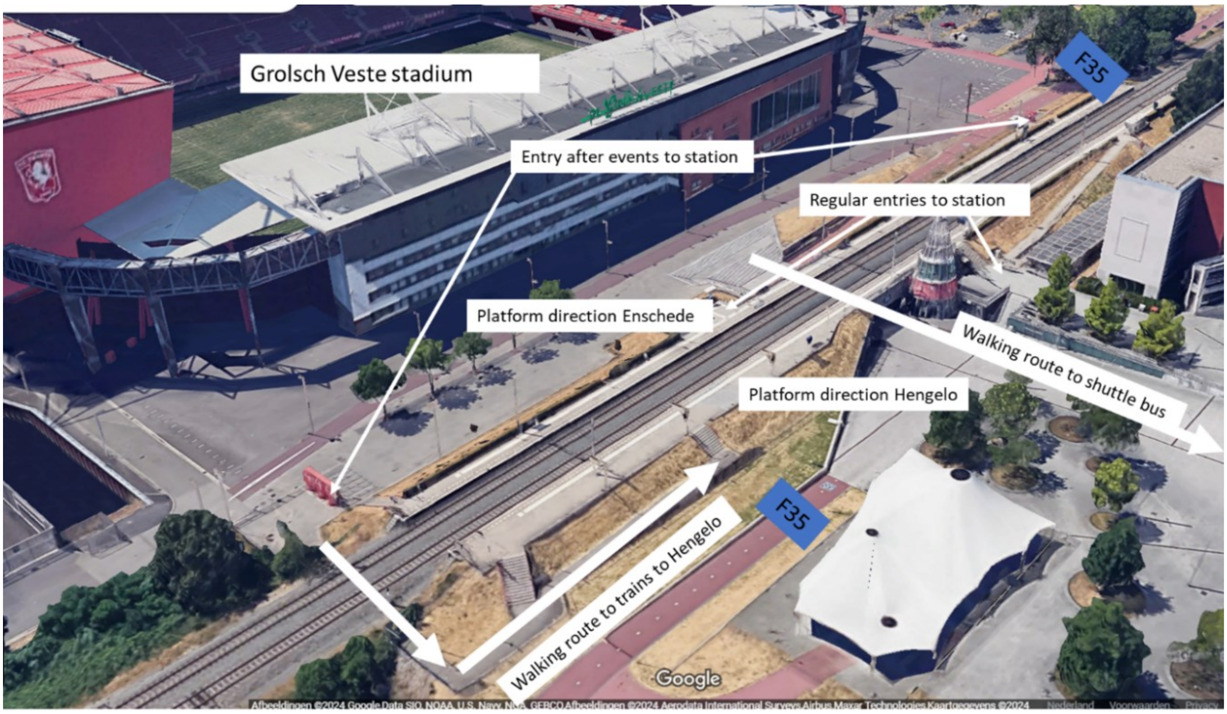

Figure 1 - Enschede Kennispark and Grolsch Veste, with travel routes and entrances to the platforms (Google Maps, 2024)

2.2 CROWD MANAGEMENT OPERATION

There are several crowd management measures on match days to facilitate the movement of that many people. Longer trains are deployed in the hour and a half before and after the match. During this period, the NS intercity service between Enschede and Den Haag or Rotterdam (and vice versa) also stops at

[2] Used by over 700 cyclists per weekday (Ndc, 2018)

Enschede Kennispark[3], resulting in a timetable with two trains per half hour (see Table 1). The different train types and their maximum capacity are also given. NS mostly uses the ICM-7 with a capacity of 728 people, while Keolis mostly uses the FLIRT-7 with a capacity of 810. This means that on average 1538 people per direction per half hour can be transported, assuming that the trains are empty upon arrival. During the pre-match phase, visitors arrive largely dispersed so that no additional crowd management measures are needed. During the post-match phase, however, all visitors try to leave at approximately the same time, resulting in a peak flow which demands extra measures. As such, hereinafter, we will focus only on pedestrian flows after the match.

Table 1 - Timetable at Enschede Kennispark when extra trains are deployed and their corresponding capacity (Ns, 2020; Wikipedia, 2024).

Direction Enschede			
Time	**Train**	**Type**	**Max Capacity**
XX:12	NS Intercity	ICM-6/7 or DDZ6	622 / 728 / 872
XX:22	Keolis Sprinter	FLIRT-6/7	700 / 810
XX:42	NS Intercity	ICM-6/7 or DDZ6	622 / 728 / 872
XX:51	Keolis sprinter	FLIRT-6/7	700 / 810
Direction Hengelo			
Time	**Train**	**Type**	**Max Capacity**
XX:08	Keolis Sprinter	FLIRT-6/7	700 / 810
XX:17	NS intercity (Schiphol)	ICM-6/7 or DDZ6	622 / 728 / 872
XX:38	Keolis Sprinter	FLIRT-6/7	700 / 810
XX:47	NS intercity (Utrecht)	ICM-6/7 or DDZ6	622 / 728 / 872

After an FC Twente match, thirty thousand people leave the stadium. A significant portion (53%) of the visiting crowd uses the underpass to return to their parked bikes, cars or shuttle buses (Goudappel, 2010) (see also Appendix E). Around 2300 travellers leave by train, approximately 70% in the direction of Hengelo, and 30% in the direction of Enschede. The stadium empties in around 20 minutes, and most travellers arrive at the station entrance within 30 minutes after the match ends. To prepare for the surge of travellers after the match, the standard entrances to the platforms are shut down. Instead, alternative entrances at the ends on the stadium side of the station are opened for use. This strategy aims to distribute people more evenly across the area between the stadium and the station and to prevent overcrowding in the underpass. Visitors who want to get a snack also have to go through the central underpass, as the snack bars are located on the other side. For travellers in the direction of Hengelo who want to access the platform, a whole separate underpass is opened (see Figure 2).

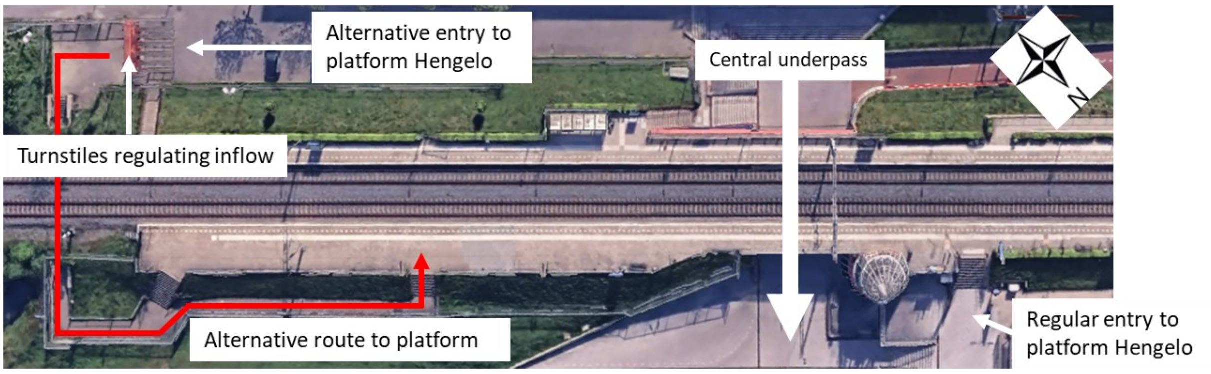

Figure 2 - Alternative route to platform in the direction of Hengelo (Google Maps, 2024)

[3] https://nl.wikipedia.org/wiki/Station_Enschede_Kennispark

The alternative entries are regulated by turnstiles to prevent overcrowding on the platform. The turnstiles automatically lock once 200 people have passed through. A pair of security personnel is required to reopen the turnstiles as long as the platform occupancy limit of 400 is not reached. If the platform limit is reached, the turnstiles will remain locked until passengers have boarded a train and the train has departed. Additionally, the personnel provide information to individuals (such as explaining why the turnstile has stopped) or allows people to leave the cordoned-off platforms. Additionally, eight pairs of stewards from NS and Keolis are stationed on the platform to monitor the crowd and oversee the closed gates at the main entrance, amounting to a total of 18 staff members on a standard match day. The stadium has also been used for the Nations League semi-final, for which a total of 13 teams (26 staff) were deployed. These additional teams were responsible for implementing extra crowd management measures, such as line-up gates in front of the turnstiles, which were necessary due to the increase in supporters travelling by train, and subsequently manage the crowd density in front of the turnstiles.

2.3 PROBLEM ANALYSIS

There are a multitude of problems at Enschede Kennispark, some resulting from solutions to others. The type of match also plays a role in the type of problems.

The primary risk is overcrowding in the central underpass. The high crowd density can lead to reduced mobility, and, in extreme cases, crowd crushes and suffocation. The risk is partly due to the sheer volume of travellers (estimated to be 16,000, see Appendix E), but also due to a narrowing from 12m to 10m width at the end of the underpass due to 'de puntmuts' (see Figure 3). To mitigate overcrowding, traveller flows are separated, and those heading towards Hengelo—who would typically use this underpass—are redirected to the alternative entry during the departure phase. However, the lack of information about this change contributes to inefficiencies in crowd movement, particularly during international matches with many visitors unfamiliar about the station layout.

While regular FC Twente attendees are accustomed to the setup, newcomers often struggle due to the absence of clear guidance. Many travellers instinctively move towards the non-stadium side of the station, following their arrival route, only to be redirected back to the stadium side to reach the platforms. This results in unnecessary and opposing crowd movements through the already congested central underpass, which, during the departure phase, remains open to cyclists using the F35 route, further exacerbating the issue.

Figure 3 - Narrowing of central underpass

The next risk is overcrowding on the platform. In the absence of a train, there is a risk of people falling off the platform or being involved in crowd crushes. Regulations are introduced to ensure sufficient waiting capacity, which is determined based on the length of the train stopping at the platform, as explained in Appendix F. At Enschede Kennispark, where trains of varying lengths halt, the shortest train length is used as the reference point. As a result, a static safe platform capacity of 400 people is established to account for the most constrained scenario. Even with this safe capacity in place, the occupancy on the platform is sometimes higher. This happens due to travellers bypassing the entry limits, malfunctioning turnstiles that do not automatically lock, or crowd managers who allow more people on the platform. This results in a higher occupancy, where people are standing close to the tracks, risking falling on the tracks and leading to an unsafe feeling by machinists[4].

The turnstiles regulate the flow onto the platform. The turnstiles lock after each 200 passages, and must be reset by a steward, until the maximum platform capacity is reached. After the turnstile stops, it remains inactive until the travellers on the platform board a train. The stadium empties in about 20 minutes. Most of the travellers arrive in the same period, with a small number arriving 10 minutes earlier or later to avoid the crowds. The bottleneck is most of the time not the transportation capacity of the train, but the maximum capacity of the platform, resulting in 400 boarding passengers per train. With 1600 people wanting to travel to Hengelo, arriving at roughly the same time, waiting times can extend up to 45 minutes. There is thus a large mismatch between demand and supply. It does not help that not everyone enters into the NS train, as this only stops at the main intercity stations. For travellers to stations other than these two intercity stations, it is not beneficial to enter the NS train, as they will have to change at Hengelo or Almelo into a busier train, and therefore choose to wait on the platform of Enschede Kennispark.

Due to the rigid operation of the turnstiles, the platform may become more crowded than its capacity. Consequently, situations may arise where the number of passengers wishing to board exceeds the train's capacity. This issue can also stem from a train being fuller than expected. In the worst case, such overcrowding could lead to a crowd crush; however, more commonly, it prevents the train from closing its doors and departing on time, causing delays that may disrupt subsequent train schedules and further increase waiting times. An uneven distribution of travellers across the platform may result in similar issues. While multiple entry points could help distribute passengers more evenly (Bosina, Britschgi, Meeder, & Weidmann, 2015), they would also make it more challenging to regulate the flow of people onto the platform. The absence of information provision on designated stopping points also hinders the efficient dispersion of travellers across the platform.

Often misbehaviours emerge. Individuals jump fences to get on the platform or cross tracks between platforms. The primary focus of steward deployment is to mitigate issues such as fence jumping. Stewards actively work to remove individuals who attempt to bypass the turnstiles by jumping fences. Those caught jumping fences are directed to join the back of the waiting line, ensuring fairness and order in the boarding process. This is in line with the national action perspective, where the starting point is to be reluctant to enforce and make arrests (Ministerie van Veiligheid en, 2011). Stewards do not only have to deal with physical misbehaviours but are also often confronted with social misbehaviours, such as aggression or threats, especially at the closed turnstiles.

The provision of information to travellers could further be improved. Directions to the alternative platform entries are not clearly indicated, leading to confusion among non-regular travellers regarding the correct entry points. Additionally, there is minimal information available for those waiting about potential delays or the expected duration of their wait. A single digital sign displaying train departure times is positioned inconveniently next to 'de puntmuts' on the non-stadium side of the station. Furthermore, no information is provided to travellers waiting in front of the turnstiles, making it impossible for them to anticipate whether they will catch the next train or be affected by delays.

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[4] Keolis wil na FC Twente-wedstrijd niet meer stoppen op station in late uurtjes https://nos.nl/l/2536873

Figure 4 illustrates the causal loop diagram detailing the interrelations among factors described earlier. It highlights how the number of visitors influences key variables such as waiting times, crowd density before turnstiles, and the density on the platform itself. Measures like entry limits via turnstiles and fencing monitored by stewards help regulate inflow but may also increase crowding at entry points, potentially leading to frustration and misbehaviour. Insufficient platform size and uneven dispersion exacerbate the risk of crowd crushes and individuals falling onto the tracks, while train capacity, frequency, and length influence the outflow, impacting the overall congestion. Additionally, issues such as unclear station layout and inadequate information provision contribute to circulation problems and further complicate crowd management efforts. This diagram underscores the importance of balancing inflow regulation, platform design, and train operations to mitigate safety risks and maintain passenger flow.

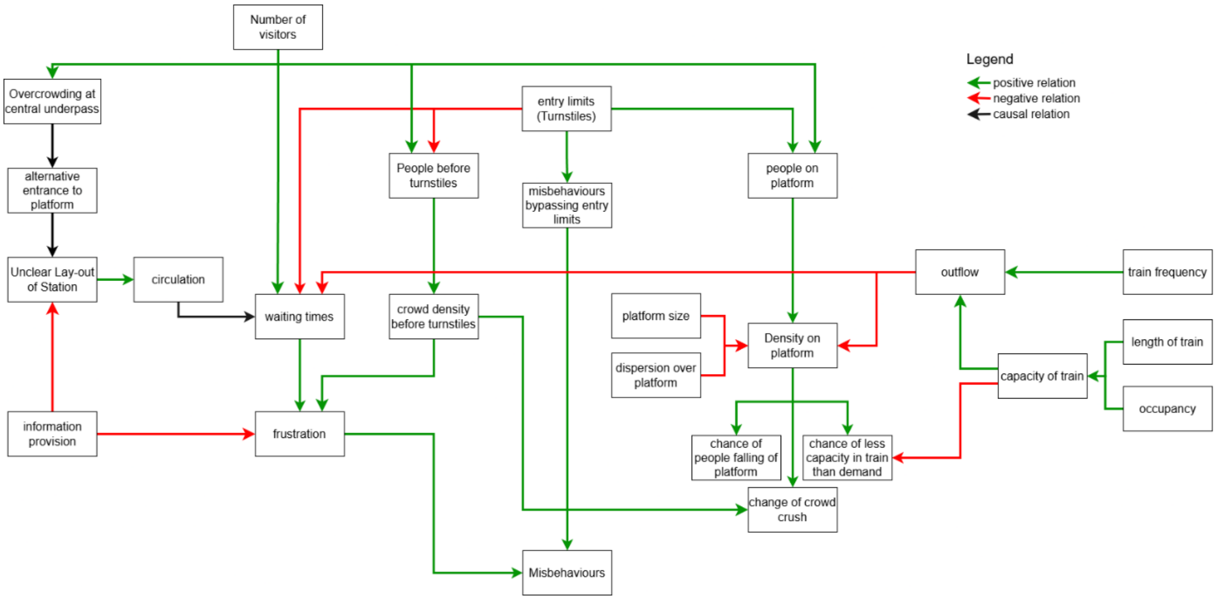

Figure 4 - Causal diagram of the problem analysis at Enschede Kennispark

Lastly, there are quite a lot of variables in play which are hard to account for. Match ends are for one hard to predict: extra time can largely influence the end time of matches, not to speak about matches which require a winner, leading to overtime and even penalties. A later end time than anticipated leads to inefficiencies in the crowd management plan, i.e., all stewards are positioned and trains make an extra stop yet there wont be any travellers as the match continues for at least another thirty minutes.

Late end times also put additional pressure on train services, which operate on a fixed schedule. After 23:20, NS no longer runs InterCity trains, eliminating extra stops toward Hengelo and effectively halving outflow capacity. Keolis ceases service after 00:40. As a result, when matches end at 23:00, only four trains are available for travellers heading to Hengelo. Given platform capacity constraints, this is insufficient to accommodate all passengers. To mitigate this, allowing more travellers onto the platform would be necessary, but this would increase crowd density, potentially compromising safety.

2.4 STAKEHOLDER IDENTIFICATION

The complexity of the potential solution to these challenges is enlarged by the large number of different (commercial) parties involved. There are two different train service providers, Keolis and NS, where Keolis is the main operator and NS halts their InterCitys as an additional service. The primary objective of these train operators is to generate revenue by transporting passengers while fulfilling contractual obligations and ensuring the safety of both their staff and passengers. This includes preventing dangerous situations such as excessive crowd densities inside trains, which could lead to passengers feeling unwell, vandalism by hooligans, or high platform densities that increase the risk of passengers falling onto the tracks – a situation that may also lead to unsafe feelings by train drivers[5].

In addition to operating train services, NS is responsible for developing and executing the crowd management plan. Their key objectives include ensuring the safety of both the crowd and personnel while minimising the duration of crowd management interventions. Crowd safety is maintained by preventing hazardous densities on the platform and in front of the turnstiles, whereas staff safety is ensured by minimising conflicts and frustration among travellers. Furthermore, NS aims to implement a crowd management plan with minimal adjustments to daily operations, seeking to limit the number of stewards required and reduce the need for significant infrastructure modifications.

ProRail owns the station and is responsible for its management and the maintenance of both the station and the rail tracks. As a result, any infrastructural improvements must be carried out by ProRail. Their primary objective is to maintain a consistent level of service while managing investment costs efficiently. The daily management of the station is outsourced to NS Stations, responsible for ensuring that the station remains clean, well-maintained, and safe for travellers. While ProRail focuses on infrastructure and long-term investments, NS aims to optimise operational efficiency and passenger experience, which can sometimes lead to conflicting priorities, particularly when infrastructure upgrades are needed to support service improvements.

The pedestrian flows primarily stem from matches at the Grolsch Veste, with FC Twente as owner and main team, though other events occasionally take place there. Such as the Nations League matches or the European Championships[6]. FC Twente sells (alcoholic) beverages and snacks, which contributes to an intoxicated crowd. After the match, FC Twente prioritizes clearing the stadium quickly to begin cleaning and preparation for future events. These objectives, however, conflict with those of transportation and crowd management authorities, who would prefer a more orderly and sober crowd that disperses gradually to prevent congestion and ensure safety.

Lastly, the municipality of Enschede is also involved. As owner of the public space between the stadium and station, they can act on public disorder through the efforts of the police. The mayor is responsible for setting the conditions allowed to play football matches (KNVB, 2022), and for the permit. The influence is thus high, but the interest sticks to avoiding public disorder.

Lastly, the passenger itself is of importance. It is of course the subject of crowd management, and aims to stay safe and comfortable. Also, it wants to minimize its own travel time. An overview of the different stakeholders, their interest and their objectives are given in Table 2. It can be noted that crowd and staff safety are common objectives. It is hypothesised that staff safety will improve as crowd waiting times decrease. While the other objectives are also important, they primarily serve to provide additional insight into the broader implications of the proposed measures.

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[5] https://www.oost.nl/nieuws/2577855/

[6] https://fctwente.nl/nieuws/uefa-nations-league-in-twente

Table 2 - Stakeholders and their objectives

Stakeholders	Responsibilities/interest/influence	Objective
Municipality of Enschede	Owner of the public space around the stadium and the station Granter of permits	Avoid public disorder
ProRail (rail infrastructure operator)	Owner of the station and the rail tracks Planner of the timetable	Avoid high investment costs
Station Operator (NS stations)	Daily management of the station Responsible for crowd management plan Ensure safe operation	Keep the crowds safe Keep the staff safe Minimize adjustments
Transport Operators (NS reizigers & Keolis)	Safe operation Low travel times Comfort Revenue (low operating cost)	Keep the crowds safe Keep the staff safe Avoid overcrowding in the train
FC Twente	Main owner and user of the Grolsch Veste Make profits (by selling beers) Attract visitors	Quick outflow from the stadium
Passenger	Comfort Low travel (and waiting) times Safety	Stay safe and comfortable Minimize travel time

2.5 CONCLUSION

As can be read in section 2.2 and 2.3, there are multiple challenges at Enschede Kennispark. The main challenge identified is the throughput of train travellers into the direction of Hengelo and further, which is inadequate due to the difference between the safe platform capacity and the capacity of the trains. This mismatch influences the waiting times, which influence misbehaviours. Thus, based on the causal diagram, waiting times seem to play a critical role. The main objective is then to decrease the waiting time, while at the same time taking the objectives of the stakeholders into account. The exact influence of waiting times on misbehaviours will further be studied in the literature review.

3. LITERATURE REVIEW

This literature review aims to explore the relationship between waiting times and misbehaviours. By substantiating this relationship, a clearer understanding can be gained of the potential direction for a viable solution. This chapter will provide a broad background knowledge on waiting, focusing on the different factors that influence the perception of waiting. Then, the relationship between waiting and misbehaviours is elaborated upon.

A large body of literature delves into waiting times for services, the perception of waiting and its impact on overall satisfaction with the service. To the best of our knowledge, Maister (1985) was the first to examine the psychological mechanisms of waiting. He hypothesized that the wait feels longer when one is unoccupied, anxious or uncertain, when the wait seems unfair, when the value of what one is waiting for is low, or when one does not understand why one has to wait at all. Additionally, pre-process waits tend to feel longer than in-process waits; for instance, receiving a menu at a restaurant gives customers a sense of being in the process. Moreover, waiting alone tends to feel longer than waiting in groups. All but this last proposition are confirmed by various scientists (van Hagen, 2011) as groups can have either a positive or negative effect. For instance, individuals' normal behavioural restraints may weaken when part of a crowd. In such situations, one is more susceptible to disorderly and uncivilized behaviour (Festinger, Pepitone, & Newcomb, 1952). This phenomenon highlights the tendency for individuals to mimic the behaviour of others in a group. In this context, if one person begins jumping fences, it increases the likelihood that others will follow, potentially escalating the situation

Notably, there hasn't been a distinction made between different groups of people, such as "lust" and "must" travellers. Lust (or hedonistic) travellers are occasional social and recreational travellers who prioritize convenience and comfort, while must (or utilitarian) travellers are regular task-oriented travellers who prioritize fast and reliable service (Kinkelder, 2013; van Hagen, 2011). van der Wal et al. (2017) redefined lust travellers as tourists who prioritize receiving adequate information and arriving at the stated times, while must travellers were categorized as commuters who prioritize punctual arrival. Match visitors comprise a mix of both lust and must travellers, though the exact division between them is unclear. Must travellers primarily attend to watch the match and return home as quickly as possible, while lust travellers treat the event as part of a broader leisure activity, often stopping for a snack before heading home. While this characterisation can vary between matches, it influences how travellers perceive waiting times and determines which measures will be most effective. Consequently, both fast and reliable service, as well as convenience, comfort, and access to accurate and up-to-date train information, are essential considerations.

Two equal waits can thus be perceived very differently by two different people, depending on their travel purpose. A 5-minute wait can be experienced quite differently depending on the location in which the wait occurs. A significant amount of research focuses on how waiting time is perceived and valued, as well as the factors influencing this perception. Taylor (1994) emphasized that waiting is inherently a negative experience, and when individuals cannot control the duration of the wait, efforts must be made to manage their perception of it. He sought to identify how delays affect mood, which in turn could influence overall service evaluations, and he explored situational variables that might impact affective reactions (in terms of uncertainty and anger) to delays. Taylor's conceptual model, depicted in Figure 5, captures four explaining variables influencing uncertainty and anger, influencing the overall service. The explaining variables at the left have a positive or negative influence on uncertainty and anger. For instance, the more common the delay, the lower the uncertainty, but the higher the anger. A higher uncertainty leads to higher anger; the higher the uncertainty and anger, the lower the overall service evaluation.

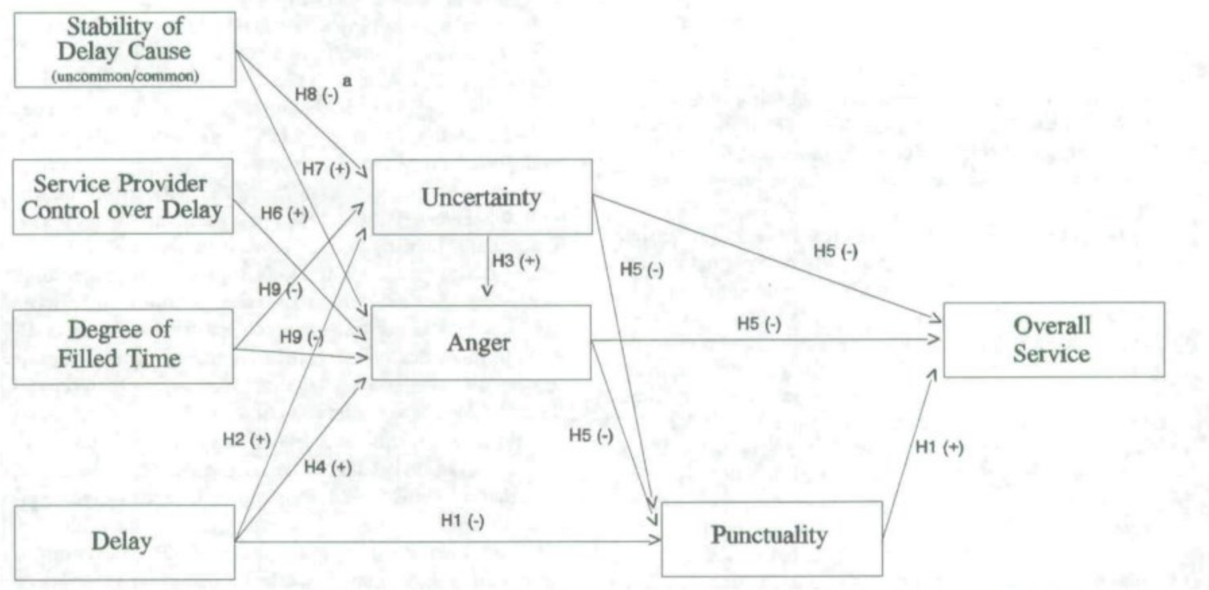


Figure 5 - The wait experience model (Taylor, 1994)

The location of the wait is also important, especially in the case of public transport, where the wait often occurs outside. Travellers prefer waiting in a comfortable area, out of the influence of weather conditions and comfortable lighting (van Hagen, 2011). Music and scent can also change the perception of waiting (McDonnell, 2007).

Anger and feelings of frustration have a negative influence on the overall perception and satisfaction of a service, but they might as well lead to aggressive behaviour. Frustration generally arises from the inability to achieve a certain goal, and people are more strongly instigated to attack their cause of frustration when they think they have been deliberately and wrongly kept from reaching their goal. An unanticipated failure to achieve an attractive goal is more frustrating than an expected failure (Berkowitz, 1989). Several characteristics have an influence on the translation from frustration to aggression. For instance, young men or intoxicated persons are more likely to behave in an aggressive manner than women or sober persons (Challenger, Clegg, & Robinson, 2010b; Mileti, 1995). This so-called frustration-aggression hypothesis plays a clear role in our case. As it is assumed that there are both must and lust travellers, there are two options for objectives. If the primary objective for individuals at Enschede Kennispark is to reach the platform to board a train, then the halting of turnstiles obstructs their goal, leading to frustration. And although the closing of the turnstiles happens every time and might be expected, the exact moment might still be unexpected. However, if the goal is to arrive at a specific destination, time becomes less critical, and people are less likely to be frustrated by delays.

The model developed by Taylor primarily focuses on how delays impact the overall evaluation of service. However, it has been observed that delays not only influence service evaluation but also individual behaviour. The question arises: at what point does a delay or wait become so long that people will misbehave? Feng, Wu, Sun, and Li (2016) found that a more anxious mood negatively affects satisfaction, and individuals perceive waiting time to be lower when they have something to occupy themselves. They present a linear model to capture perceived waiting time and establish that the threshold to distinguish satisfied from dissatisfied passengers is approximately 7.87 minutes. Their research focused on bus stops with headways ranging from 5 to 9 minutes. It is important to note that the threshold is set just above the average headway. The time threshold does align with Martella et al. (2017), who suggest that waiting in a queue for longer than 8 minutes can negatively impact an individual's mood, based on interviews with crowd managers of events in the Netherlands. Both cases consider waiting at a complete standstill. This is a far lower critical waiting time than the current waiting times at Enschede Kennispark, where standstill waiting times of over 15 minutes are common. Wijermans, Conrado, Van Steen, Martella, and Li (2016) further advise to keep the flow moving and keep the individuals informed of waiting times and causes for the block.

Predicting perceived waiting time is complex due to its reliance on psychological, social, and contextual factors. Unlike actual waiting time, which can be objectively measured, perceived waiting time is influenced by individual expectations, engagement levels, and emotional states. While it is closely related to objective wait time, it often differs significantly. Moreover, perceived waiting time cannot be directly measured but must be gathered through customer surveys, limiting its use to ex post evaluations (Worlitz, Linh, Hettling, & Woll, 2020).

In conclusion, managing waiting times is crucial, as they directly influence passenger satisfaction and behaviour. Ideally, waiting should be minimized or avoided, but when this is not feasible, the focus should be on improving the waiting experience. Research suggests that waiting is preferred in a comfortable area and that perceived wait time feels longer when passengers are unoccupied, anxious, uncertain, or perceive the wait as unfair or without purpose. Additionally, waiting in groups can have mixed effects—while social interaction may ease the experience for some, it can also increase frustration in crowded or tense situations.

Different passenger types respond differently to waiting: "must" travellers, who rely on trains for essential trips, may experience greater frustration than "lust" travellers, who travel for leisure. Furthermore, young men and intoxicated individuals are more likely to exhibit aggressive behaviour in response to long waits, highlighting the need for targeted crowd management strategies.

To mitigate negative emotions such as frustration, anxiety, or aggression, engagement is key. Keeping passengers informed and occupied—whether through clear communication about delays, structured movement, or entertainment—can help improve the overall waiting experience. Taylor’s conceptual model further emphasizes the psychological factors at play, reinforcing the importance of perception in crowd dynamics.

Since perceived waiting time cannot be measured directly, evaluating crowd management measures requires careful interpretation of results, taking into account these psychological and behavioural influences.

4. OBJECTIVE AND RESEARCH QUESTIONS

The observed misbehaviours at Enschede Kennispark station can be attributed to prolonged standstill waiting times and a lack of information. Reducing waiting times may be achieved by optimizing train capacity utilization and adjusting the operation of turnstiles to improve passenger flow. However, any proposed measures must not compromise passenger safety.

To systematically address this issue, the research is structured around an aim, objective, and set of research questions.

The aim of this research is to reduce misbehaviour at Enschede Kennispark station following football matches at the Grolsch Veste by providing recommendations to the social security manager of NS. These recommendations focus on reducing both actual and perceived waiting times. However, as highlighted in the literature review, perceived waiting time can only be assessed ex post. Therefore, while it cannot be used as a direct evaluation criterion, the recommendations will be developed with perception in mind.

The objective of this study is to develop recommendations for reducing waiting times at Enschede Kennispark station by analysing various solutions and scenarios using a pedestrian simulation model. Simulation models are a useful tool to predict the effects of measures, especially when experimentation in real-life is too complex, costly, or unsafe. Further considerations for using a simulation model are given in the methodology. By evaluating different scenarios, this research aims to identify effective strategies for minimizing waiting times, thereby mitigating misbehaviour, enhancing the overall passenger experience, and improving crowd management at the station. The proposed solution should be durable, meaning it must remain effective across multiple scenarios, including potential future developments.

To achieve this objective, the research is structured around the following research questions:

1. What are the key scenarios to consider when developing a solution for reducing actual and perceived waiting times at Enschede Kennispark station?
2. What measures can be implemented in these scenarios to reduce waiting times, and what are their operational implications and potential drawbacks?
3. What criteria and indicators should be used to assess the effectiveness of the proposed measures in reducing waiting times and improving crowd management?
4. How do the proposed measures perform across the identified scenarios based on the selected assessment criteria, and which measures are most effective for implementation?

Question 1 identifies relevant scenarios that influence waiting times at Enschede Kennispark station. Examples include late night matches, matches with international visitors, or scenarios with an increased visitor count. These scenarios define the broader context in which potential solutions will be applied. For instance, a future scenario with more train travellers may necessitate different interventions than a scenario involving a significant number of international visitors unfamiliar with the station layout.

Question 2 explores the crowd management measures applicable to each scenario and evaluates their feasibility, implementation challenges, and operational drawbacks. This comprehensive assessment provides a foundation for determining the most effective interventions for minimizing waiting times and improving crowd management.

Question 3 defines the methodological framework for evaluating the effectiveness of these measures. First, suitable analysis methods, such as pedestrian simulations and observational studies, will be identified. Next, key performance indicators—such as waiting times, level of service, and crowd density—will be established to systematically assess the impact of the proposed measures.

The last question synthesizes the findings by evaluating the performance of different measures within the identified scenarios using the selected assessment criteria. For instance, if a scenario involves international visitors, measures focused on information provision (e.g., multilingual signage and announcements) may be more effective than infrastructure-heavy solutions, such as increasing train frequency. Conversely, if train frequency can be increased, schedule optimizations may be prioritized over measures aimed at enhancing passenger comfort.

5. METHODOLOGY

To answer the research questions, both quantitative and qualitative methods are used. Before the methodology is explained, the scope of the solutions shall be defined.

5.1 SCOPE

As the discharge of people travelling by train towards Hengelo and further is the most problematic, this pedestrian flow is the focus of this study. Travellers by train in the direction of Enschede will be taken into account, but not assessed, as no problems are mentioned with this flow. Interventions are thus not (yet) needed, and if they are needed, the same type of solutions as to the flow towards Hengelo and further could be used. This research will not focus on the flow within the underpass, as no significant issues have been identified in this area. Furthermore, since the underpass is already operating at full capacity, any measures that would increase pedestrian flow through it will not be considered, as accommodating more people in this space is not desirable. Additionally, introducing more route options after the underpass could lead to increased congestion within it (Challenger, Clegg, & Robinson, 2010a), further straining its capacity. If the regular entrance were to be used more frequently, additional alterations to the platform would be necessary. Without these modifications, the platform's current layout would be too shallow to effectively distribute the pedestrian flow in both directions onto the platform, potentially creating new bottlenecks.

The study further focuses on the tactical decision level. This entails measures such as slight alterations to the layout of the station environment, or more/longer trains. Measures altering the stadium outflow, to reduce peak flow, shall not be considered (operational level). A whole redesign of the station environment will not be considered, although a result can be that with the current layout, the problems cannot be solved. Operational difficulties (such as availability of personnel or material) of the measures shall be mentioned but not fully analysed.

5.2 METHODS

To identify the scenarios, a qualitative method is used. The different scenarios which can occur are identified through observations and discussions with experts. Then, these identified scenarios are reduced to three main scenarios during a focus group meeting. The focus group consists of the supervisors of this study, namely a social security manager of NS, a crowd management expert of NS, and two researchers in the field of simulation and traffic management. This answers research question 1.

To answer question 2, crowd management measures are identified. For this, the long list of measures as developed by Mensink (2017) is used. Mensink sought to design a method to systematically select and assess effective crowd management measures to increase the safety and throughput at train and metro stations. The first step of the framework is an applicability check, which yields that the framework is applicable (see Appendix B). Other frameworks available limit themselves to the strategic level and do not go in depth towards the exact measures taken (Alafif et al., 2025; Almatuiri, 2024; Schubert, Ferrara, Hörling, & Walter, 2008). Mensink's framework is used to systematically select the measures.

To assess the different measures, and answer question 3, an assessment framework is required, consisting of criteria derived from the objectives and corresponding indicators. The stakeholder identification in Section 2.4 provided insights into these objectives. First, the objectives are translated into criteria for assessment. Then, a literature review is conducted to identify crowd management objectives and the indicators used to assess them. Based on this information, an assessment framework is proposed, outlining the criteria and relevant indicators.

Furthermore, a microscopic pedestrian simulation model will be used for the assessment. Simulation models are increasingly used in the process of creating a crowd management plan. Simulations support decision-makers in assessing the effects of certain choices before implementation (Bruijl, 2022; Mensink, 2017; Wijermans et al., 2016), utilising computational power to model complex interactions between – in our case – passengers and infrastructure. As such, various scenarios can be compared based on various criteria, particularly relevant in the case that real-life experimentation is deemed unsafe, complex, or costly, modelling software is employed to assess measures (Williams-Wood, 2024).

Duives et al. (2013) state that models can roughly be divided into slow but highly precise microscopic models, and very fast but inaccurate macroscopic models. The microscopic models focus on low-level behavioural details and individual features (Ijaz, Sohail, & Hashish, 2015), whereas macroscopic models describe pedestrian movement using potential fields or fluid dynamics (Yang, Li, Gong, Peng, & Hu, 2020). The choice of the most suitable model depends on the specific characteristics required to simulate a particular measure (Mensink, 2017). As individual waiting times have to be captured, only microscopic simulation models are usable. Yang et al. (2020) provide an overview of various crowd simulation models and their capabilities in representing crowd dynamics, identifying the Social Forces Model as the most comprehensive in capturing these behaviours, which will thus be used in this study.

The answer to research question four then follows out of this quantitative simulation approach. The model development shall be highlighted, with special attention to the assumptions within the model, as the results are dependent on these assumptions. As said by Simon Ancliffe: *"Simulations alone are not the means to an answer. They are visualisations of how the movement pattern you have assumed with the demand you have assumed through an environment that you have assumed represents reality."* (adapted from Challenger et al., 2010a, p. 69). The calibration, verification and validation are thus important parts of the construction of the model.

To ensure accuracy, several real-life observations of matches will be conducted to gather data for a predefined scenario. The model will then be calibrated based on the visual observations, the number of people on the platform and before the turnstiles, and the times the turnstiles are blocked and opened. This calibrated model will be verified and validated by the focus group and an expert by experience of the NS. The different identified measures shall further be specified, i.e. the adaptations in the model to simulate the measure are explained. The indicators will also be coupled to model variables, such that results can be presented. After presentation of the performance of the different measures, a conclusion can be formulated where recommendations will be presented.

6. SCENARIOS, MEASURES AND ASSESSMENT

This chapter aims to compile all relevant information to develop a solution. It will begin with the identification of key scenarios, followed by an exploration of potential measures, and conclude with an assessment framework to analyse these measures. Each section will first outline the methodology used to arrive at an answer, supported by relevant literature, before concluding. The conclusions serve as input for the model setup, where each scenario, measure and performance indicator will be further operationalized for the assessment.

6.1 SCENARIOS

Multiple scenarios can be thought of in the context of Enschede Kennispark. These scenarios are gathered by the researcher based on common knowledge of the area, and by taking note of the different scenarios experts talk about during on-site visits. The different scenarios which can be considered are first given. Then, three of those scenarios are selected based on practical considerations in accordance with the focus group. Finally, the resulting scenarios are further specified such that they are fit to implement into a model.

6.1.1 Possible scenarios

The Grolsch Veste is most regularly used by FC Twente playing against other Dutch clubs. This happens on average once every two weeks during an afternoon at the weekend. Furthermore, FC Twente also has a European campaign, where European clubs visit the Grolsch Veste, which often happens on weekdays in the evening. These matches end around 23:00 and even later in case of matches with extra time. Fewer trains are available to transport all travellers, thus heavily influencing the waiting times of passengers, with the risk that not everybody can catch a train. These two scenarios are mostly visited by regular visitors, as 29000 of the seats are for regulars, and only 1200 seats for away fans[7].

Then there are complete international matches, when the Grolsch Veste is used as a stadium for the Nations League[8] or potentially European or World Championships[9]. These types of matches attract a large crowd of unfamiliar visitors, with an expected increase in train passengers, as many attendees have limited access to alternative transportation options. Next, as the Grolsch Veste would like to expand their stadium capacity from 30 to 40 thousand, this is also a scenario to take into consideration. An increase in the available capacity is likely to also imply an increase in the number of visitors by train. Finally, one could also consider a scenario with delays. Delayed trains have an immediate impact on the waiting times, and are quite common. The aforementioned scenarios can further be combined to create almost any number of scenarios.

6.1.2 Selecting scenarios

The scenarios selected for analysis must be both applicable within the simulation model and non-redundant. Applicability means that any alterations in the scenario should be realistically implementable in the simulation. Non-redundancy ensures that each scenario introduces a distinct aspect for comparison rather than duplicating insights. Additionally, since the focus of this study is on tactical measures, the scenarios should present situations where such measures can be effectively applied.

The identified scenarios differ in terms of the number of visitors (and subsequently train travellers), match end time, visitor familiarity with the station, and potential train delays. This last scenario falls out of the scope of this study. Since train delays are typically unpredictable and only known when they

[7] https://voetbalstadion.net/grolsch-veste/
[8] https://fctwente.nl/nieuws/uefa-nations-league-in-twente
[9] https://www.twentefans.nl/de-grolsch-veste-een-wk-stadion-een-grote-voetbalhistorie/

occur, they are impossible to address with tactical measures in advance. Furthermore, a delay primarily results in extended standstill waiting times, which does not provide additional insights for the study's objectives.

The scenario involving a fully international match will also not be considered. These matches are relatively rare and present unique challenges due to the increased number of visitors unfamiliar with the station environment. Accurately estimating visitor numbers and predicting their behaviours or detours is difficult, introducing significant uncertainty into the analysis. Organizing such matches subsequently requires extra operational measures, which extend beyond the scope of tactical crowd management solutions. Any increase in visitor numbers can be effectively examined through other scenarios with high attendance, making a dedicated international match scenario unnecessary.

6.1.3 Resulting scenarios

Based on the discussion in the previous section, three scenarios remain for further consideration. These scenarios and the reasoning to discard the others have been presented in the focus group meeting, where all experts came to the same conclusions. The first scenario is a regular FC Twente match, the most recurring scenario. The scenario shall consider a match on Sunday afternoon, ending at 16:20, as those are regularly returning match times. The second scenario is an European match ending at 23:00. In this scenario, the discharge capacity of the trains becomes problematic, for which adequate solutions have to be found. The third scenario is a regular match on Sunday afternoon with an increased number of visitors. This scenario can be used to assess the future-proofness of the station environment, as well as the increased number of train travellers during an international match.

To further define the scenarios, a regular match refers to a match in the Eredivisie, which takes place approximately once every two weeks. The visiting crowd predominantly consists of men of various ages, with most travellers being under the influence of alcohol or drugs. The total number of attendees is 29500[10], the majority of whom are familiar with the stadium and its surroundings, as 76% are a season ticket holder[11]. Among these visitors, 2300 travel by train, with 700 heading towards Enschede and 1600 towards Hengelo. These numbers, of course, fluctuate; however, they will be used as the basis for the model.

The European match uses the same visitor characteristics and numbers. The only alteration is the later match end, with the fewer trains available due to the end of the train service.

The regular match with increased visitors is based on increasingly persistent rumours of development of the stadium. This is not surprising, seeing that already 22500 of the 30000 places are occupied by season ticket holders, and there is a waiting list of 5000 people for these season tickets. An idea is to complete the second ring of the stadium, which increases the capacity by 10000 places, or 33%, to 40000. If this increase also translates to the travellers by train, then 3060 people will travel by train, of which 2130 in the direction of Hengelo and 930 in the direction of Enschede. These travellers have the same characteristics as in the first alternative.

Table 3 provides an overview of the scenarios with the characteristics.

[10] https://www.transfermarkt.nl/fc-twente-enschede/spielplan/verein/317/saison_id/2023

[11] https://www.tubantia.nl/fc-twente/fc-twente-blijft-in-trek-grolsch-veste-komend-seizoen-alweer-nagenoeg-vol~ad5c859d/#:~:text=FC%20Twente%20blijft%20een%20publieksmagneet,komende%20seizoen%20opnieuw%20uitverkocht%20is

Table 3 - Overview of scenarios with the number of travellers and their characteristics

scenario	Characteristics	Visitors	Travellers Hengelo	Traveller Enschede
Regular match	Mostly men, likely intoxicated, well-acquainted with the area	29000 - 30000	1600	700
Regular match late ending	Mostly men, likely intoxicated, well-acquainted with the area	29000 - 30000	1600	700
Regular match with increased visitors	Mostly men, likely intoxicated, well-acquainted with the area	40000 ± 2000	2130	930

6.2 MEASURES

The second research question *"What measures can be implemented in these scenarios to reduce waiting times, and what are their operational implications and potential drawbacks?"* is answered by employing the framework of Mensink (2017). The framework comprises five sequential steps: applicability check, problem characteristics, measure selection, assessment and evaluation. The applicability has been proven in the methodology (Chapter 5), the next two steps will be further elaborated upon in this section within their subsection. The last two steps will follow in the assessment chapter. First, the goal of each step shall be explained, then the results of the prescribed methods are given, and the measures with promising applicability will be further

6.2.1 Problem Characteristics

The objective of this step is to gather case-specific data to better quantify the existing issues and refine the direction of potential measures. Mensink has devised six specific questions to assess the scale of the problems and provide guidance on appropriate solutions. These questions help classify measures based on their nature—static versus dynamic and proactive versus reactive. Additionally, Mensink distinguishes between measures targeting specific locations or broader system-wide challenges. By answering the questions, possible measures can be selected (see also Appendix D). For overview purposes, the answers to these questions are given in Table 4.

Table 4 - Guidance for selecting measures by specifying the problem characteristics

NR	Question	Explanation of use case	Answer
1	Are volatile and unpredictable passenger flows expected?	If not, more static measures can be suitable. If yes, both static and dynamic measures can be suitable.	The passenger flows can be anticipated, but are volatile.
2	Are problems expected incidentally because of, for example, events?	If not, more preventive measures can be suitable. If yes, both preventive and reactive measures can be suitable.	Yes, problems only occur after events.
3	Is there a specific location such as vertical infrastructure or the platform that is frequently operating at or above capacity?	If yes, look besides 'no specific location' measures at vertical infrastructure or platform measures. If not, look only at 'no specific location' measures.	Yes, the platform is often at capacity.
4	Are there intersections of flows?	If yes, look at bidirectional flow measures besides 'no specific problem' measures.	Yes, in the central underpass. But this is outside the scope of this study.

5	Are some exits used less than others?	If yes, look (also) at uneven distribution exits measures besides 'no specific problem' measures.	No, the exits are not the problem.
6	Does interference occur between passengers performing different activities?	If yes, look (also) at human blockades measures besides 'no specific problem' measures. If questions 4, 5 and 6 are answered with no, look at 'no specific problems' measures only.	Yes, waiting and walking occur at the same time on the same space on the platform. There is little space to walk around the other waiting passengers.
CONCLUSION Drawn by the researcher based on the answers		Look at static and both preventive and reactive measures at 'no specific location' and at the platform. And to 'no specific problem' and human blockades measures.	

6.2.2 Measure Selection

This step involves selecting a shortlist of viable measures from a comprehensive list, ensuring their applicability aligns with the problem characteristics identified earlier (see Appendix D). The selection process is informed by Mensink's framework, categorizing measures based on their field of application.

Each shortlisted measure is then elaborated upon in detail. First, its general purpose and function are explained, followed by a discussion on its potential implementation at Enschede Kennispark. Additionally, the operational implications and possible drawbacks are assessed. These evaluations are informed by literature reviews and discussions with stewards.

Create waiting areas

Platforms at train stations in the Netherlands are required to have respectively a safety zone, a walking zone and a stand-wait zone next to the track (ProRail Spoorontwikkeling, 2005) . Right now, at Enschede Kennispark, this stand-wait zone is too small to facilitate safe waiting for as many people as fit in a train (Appendix F). Moreover, people may wait in the walking zone, thus obstructing the flow over the platform, creating unsafe waiting conditions on parts of the platform (Bosina et al., 2015).

Increasing the waiting area is a promising alternative to reduce the waiting times, as the number of people on the platform then better matches the transportation capacity of the trains. The increase in waiting area is better done by widening the platform than by lengthening the platform. By widening the platform, no area surface is lost to the safety and walking zone. Furthermore, the area should ideally be widened at a place where the train halts, which should also be close to the platform entrance, as people tend to wait where the train will halt (if that is known to them) and near platform entrances (Bosina et al., 2015; Kupper & Seyfried, 2023).

Widening the platform does involve investment costs for the station owner. Furthermore, the space needs to be there. This is somewhat problematic in the case of Enschede Kennispark. Widening the platform near the entrance entails building over the underpass and potentially even removing 'de puntmuts'. Widening the platform and the front of the platform, where the trains also halt, seems more promising. Currently there is an embankment sloping down to a bike storage, which could be altered to enlarge the platform. Passengers have to be made aware and directed towards this enlargement, as it is quite a distance from the platform entrance. By altering this layout, a platform enlargement is possible (see Appendix F.2).

Train stopping position adjustment

By adjusting the stopping position of the train to better suit the entrances and exits, dwell times of trains can be reduced. Alighting passengers can earlier find an exit to leave the platform, and boarding passengers sooner find a door to board the train. It is most effective at high passenger demands (van den Heuvel, 2016).

Currently, the entrance to the platform is located at the back of the platform, while the train stops at the front of the platform. A crowd management expert stated that passengers oftentimes only walk up to 100 meters once they enter the platform. Fox, Oliveira, Kirkwood, and Cain (2017) found that 25% of the passengers board less than 24 metres away from the platform entrance, but that higher crowding improves spreading over the platform. At Enschede Kennispark, regular visitors spread quite evenly over the platform. Next to that, the platform is also six meters wide at the back, and only three meters at the front. This influences the safe waiting capacity of the platform. If trains stop at the back of the platform, a higher safe waiting capacity can be adopted and travellers are naturally more dispersed over the platform.

Headway decrease

Decreasing the headways, by increasing the number of trains (and considering the same rolling stock) increases the discharge capacity and thus decreases the waiting times. Additionally, a decreased headway helps distribute passenger loads more evenly across vehicles, preventing overcrowding and improving safety and comfort. The overall throughput thus increases.

However, there are often practical constraints to decreasing headways. Sufficient rolling stock and personnel must be available, and the infrastructure must be capable of supporting increased train frequency. Additionally, extra train services need to be integrated into the existing rail network without causing disruptions or delays. Given that an additional Sprinter is already deployed between Enschede and Almelo during rush hours, implementing a similar measure after matches should be feasible. Careful coordination between train operators and infrastructure managers would be necessary to ensure smooth scheduling and operational efficiency.

Furthermore, decreasing headways is not a suitable solution if the resulting discharge capacity exceeds the inflow onto the platform. In such a case, trains would depart partially empty, leading to inefficient use of rolling stock and operational resources. This inefficiency is not in the best interest of train operators, as it increases costs without proportionally improving passenger transport.

Gating + Entry limits

Gating and entry limits are closely related crowd management strategies aimed at regulating passenger inflow to prevent overcrowding. Gating is a dynamic measure used to control access to the station, ensuring that queues form outside rather than within, thereby reducing congestion at bottlenecks (Mensink, 2017; Molyneaux, Scarinci, & Bierlaire, 2018; Seer, Bauer, Brändle, & Ray, 2008). This approach is particularly beneficial in situations where expanding infrastructure is not feasible (Hanseler & Hoogendoorn, 2018).

Entry limits, on the other hand, restrict the total number of passengers allowed into the station. Once the limit is reached, further access is denied, which avoids overcrowding on the platform, helps manage dwell times, maintain schedule regularity, and reserve capacity for downstream stations (Bueno-Cadena & Munoz, 2017). However, entry limits are only executable when used in conjunction with gating, as gates are necessary to enforce restrictions. Additionally, this measure can frustrate passengers, particularly if they are forced to wait long periods without a nearby train (Delgado, Munoz, & Giesen, 2012).

At Enschede Kennispark, only entry limits are currently in place, enforced by turnstiles that either fully open or close. With a flow rate of 15 persons per minute[12], the platform reaches maximum capacity in just five minutes, often resulting in waiting times of up to 15 minutes. This contradicts best practices in the literature, which suggest that entry limits are only effective if passengers do not have to wait excessively for the next train.

Introducing gating could provide a more gradual inflow, reducing the need for strict boarding limits and improving passenger experience. A comparable study by Bauer, Seer, and Brändle (2007) examined access restrictions at a metro station near a large football stadium in Austria. By dynamically adjusting access gates based on platform occupancy, the station successfully avoided overcrowding, though at the cost of a 20-minute increase in total clearance time. This suggests that while gating can improve safety and comfort, careful calibration is required to balance efficiency and passenger convenience.

Information provision on train stopping positions

Providing clear information about train stopping locations helps distribute passengers more evenly across the platform, reducing boarding and alighting times and increasing overall transfer capacity. In Den Bosch, an intelligent platform bar system indicates where trains will stop and where the doors will be, significantly improving passenger distribution (Prorail, 2023). Similarly, train stopping positions are displayed on platform signs when letterboards are available (NS, 2025). However, successful implementation of these measures depends on existing infrastructure and requires train drivers to consistently stop at the designated positions (Mensink, 2017).

At Enschede Kennispark, such systems are absent. The station has no letterboards and only a single platform sign in the middle, which is too small to be seen clearly from a distance and in crowded conditions. As a result, there is minimal real-time information on train arrivals and stopping positions. Regular travellers are familiar with train operations and naturally distribute themselves across the platform, but for unfamiliar passengers, the lack of guidance may lead to inefficient crowding and increased boarding times.

Despite the potential benefits, both interventions require significant infrastructure investments. Given the relatively low impact expected during regular matches at De Grolsch Veste, the cost-effectiveness of such upgrades remains questionable.

Light/music/scent

What lighting, music and scent can do is change the perception of waiting, and decrease the levels of discomfort (McDonnell, 2007). This measure is hypothesized to disperse people more evenly over the platform by strategically placing lights on the platform. It is based on the theory that travellers prefer waiting in a comfortable area. For instance, better lighting of the front of the platform might attract more people who would walk further. And the platform could further be lightened up when the platform fills up. Or lighting could be used to indicate where there is still some waiting space. However, the scientific effects of these hypotheses are difficult to make hard. Kinkelder (2013) identified no significant effects of lighting on the waiting location. And, as the effect of altered perception of the wait is hard to quantify in a model, this measure will further not be considered.

Only exiting/ entering the station

The rationale behind this measure is to eliminate bidirectional pedestrian flows, which are known to reduce capacity and complicate crowd movement (Buchmüller, 2006; Feliciani, Murakami, & Nishinari, 2018). By restricting station access to either entering or exiting passengers at a given time, operational efficiency can be improved. One possible implementation would be to prohibit alighting at Enschede

[12] https://www.geran-access.com/projecten/grolsch-veste-ombouw-tourniquets/

Kennispark during peak crowding periods, thereby minimising crossflows and simplifying crowd management. However, such a measure would require extensive communication to ensure that regular passengers are aware of the changes and can adjust their travel plans accordingly. Given its complexity, this approach is best suited for special events where large numbers of passengers travel in the same direction (Mensink, 2017).

At Enschede Kennispark, crossflows are minimal, with only a handful of passengers alighting per train. Although their presence does have a slight impact on boarding efficiency, the benefits of eliminating alighting would likely be marginal. Moreover, implementing such a measure would come with significant costs and inconvenience for other travellers. Due to the absence of reliable data on the exact number of alighting passengers and the expected limited impact on overall crowding, this measure will not be considered in the model.

Holding
Holding is a strategy commonly used in bus operations to regulate headways and improve service reliability. When the interval between two buses decreases to the point that passengers no longer need to board the second bus, holding the latter ensures a better alignment of supply and demand (UITP, 2024). This concept can also be applied to trains, particularly when headways become so short that passengers do not have sufficient time to reach the platform before the next train departs. While this situation is rare at Enschede Kennispark, it could potentially be beneficial in cases of delays.

However, implementing a holding strategy requires sufficient buffer space in the rail network, which is highly constrained in the Netherlands. The Dutch rail network is known for its cascading delay effects, where a single delay can propagate and disrupt schedules across the system. According to a ProRail train planning expert, a five-minute delay for the NS Intercity would only be recovered upon arrival in Amersfoort, while delays to the Keolis Sprinter could prevent passengers from making their connections at Hengelo. Given these significant network-wide consequences, holding will not be considered as a viable measure.

Manual intervention
Manual intervention, or crowd control, can be employed to enhance the safe waiting capacity of the platform. By deploying stewards, passengers can be guided toward the front of the platform, eliminating the need for designated walking areas and thereby increasing the effective waiting space by 0.9 meters along the entire train length. Additionally, stewards can manage boarding by temporarily blocking specific train doors, encouraging a more even distribution of passengers across the train.

However, the primary drawback of this approach is the significant staffing requirement. At Enschede Kennispark, ensuring optimal crowd control would necessitate one steward per train door, meaning that an ICM3+4 train would require 14 stewards. This would effectively double the required personnel for operations, making it an expensive and resource-intensive solution. Given that one of the key objectives is to reduce staffing needs, this measure will not be further considered.

6.2.3 Resulting Measures

As outlined above, certain measures will not be considered due to their limited expected benefits, challenges in accurately assessing their impact, or potential negative side effects. The four selected measures for further analysis are detailed below. It is important to note that entry limits are inherently applied in all measures, as platform overcrowding must always be prevented.

1. Readjustment of the train stopping position to make the platform fit for 530 pax

By changing the stopping position of the train on the platform, the widened part of the platform is used resulting in a higher capacity of the platform. Furthermore, the entrance to the platform is better located near the stop position of the train. This is illustrated in Figure 6 (based on the calculations provided in Appendix F). The current safe waiting capacity is set at 400 pax, but by halting at the back this increases to 534 pax for a Keolis Flirt 3+4.

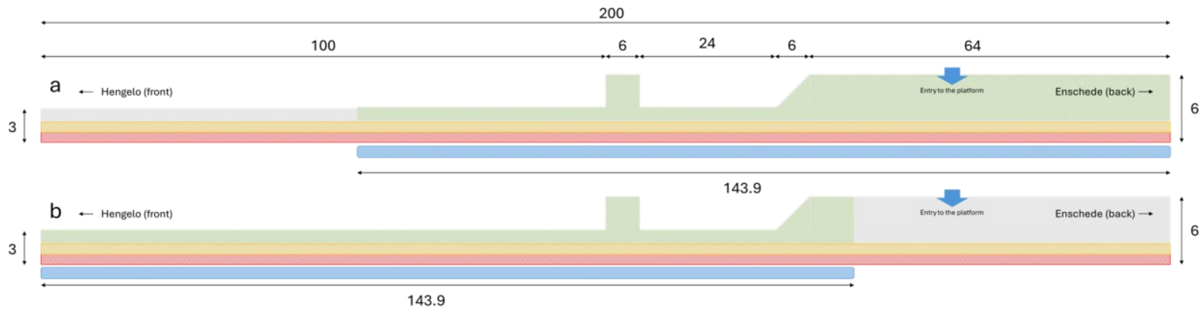


Figure 6 - Safe waiting area (green) for halting at the front (a) and halting at the back (b). Orange and red indicate respectively the walking zone and the safety zone. The blue rectangle represents a Keolis train.

This measure is the most cost-effective in the short term and easiest to implement. However, an implication of these altered stopping positions is that a steward must coordinate them, slightly increasing the overall workload. Additionally, passengers may begin waiting in front of the stairs leading to the platform, potentially creating a bottleneck and impeding the flow of people onto the platform. Moreover, travellers would need to be informed about or gradually adapt to the new stopping positions, which could initially cause confusion and inefficiencies when the measure is first implemented.

2. Expansion of the platform to make the platform fit for 900 pax.

As previously discussed in the explanation of the waiting area expansion measure, widening the front of the platform offers a solution to better accommodate the crowds. The detailed calculations and rationale for this measure are provided in appendix F.2, while an overview of the situation is illustrated in Figure 7. Implementing this measure increases the safe waiting area by 450 m², ensuring a total platform capacity of 900 passengers for a FLIRT-7 train and 1,199 passengers for an ICM-7 train.

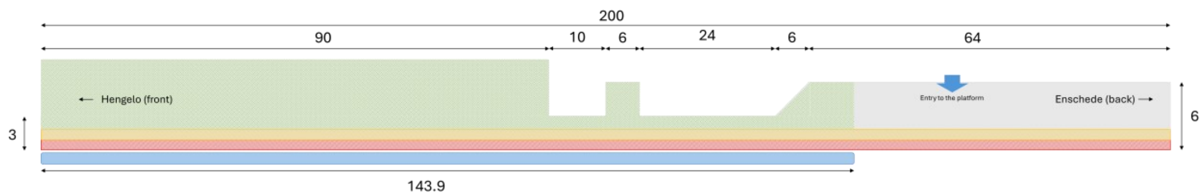


Figure 7 - Safe waiting area (green) for halting at the front in case of a platform expansion

As shown in the figure, a significant bottleneck exists over a 40-meter stretch between the platform entrance and the widened section. If a large number of passengers stop and wait in this area, overcrowding on the platform could still occur. To prevent this, guidance and manual intervention would be necessary to encourage travellers to move further along the platform. Additionally, the increased platform capacity may exceed the number of passengers that can fit into the trains. This could lead to either overcrowding inside the train or passengers being left on the platform due to insufficient space. However, it could also eliminate the need for queues in front of the turnstiles. Alternatively, entry limits could be adjusted to match train capacity rather than the platform's safe waiting capacity. While this measure effectively increases the station's handling capacity, it is a costly solution, as it requires a partial redesign of the platform infrastructure.

3. An extra train between Enschede and Almelo

The most straightforward way to decrease headways is by introducing an additional train. To evaluate the feasibility of adding a train between Hengelo and Enschede, an expert in train planning was consulted. Considering travel times, network constraints, and turnaround requirements, it was determined that a shuttle service between Hengelo and Enschede is not feasible. However, a shuttle between Enschede and Almelo is a viable option. This alternative also benefits passengers traveling to Borne and Almelo de Riet, as the train could make additional stops at these stations.

There are two possible ways to implement this shuttle service: either by introducing a completely new train or by extending the existing Apeldoorn–Almelo sprinter to Enschede, as is done during weekday rush hours. Both options require two additional trains to accommodate the expected passenger flow.

An independent extra train offers the advantage of being easily extendable and operable by either train operator. However, to fit within the existing timetable, some intermediate stops may need to be skipped. Conversely, extending the Apeldoorn–Almelo sprinter ensures a seamless fit into the timetable but restricts operations to NS. Additionally, the train would need to be lengthened to accommodate demand at Kennispark, yet this extended capacity would also be deployed throughout the entire network. A detailed comparison of these options, including timetable considerations, can be found in Appendix J. In the end, it was concluded that independent of the option, the timetable and capacity would be comparable.

4. Alteration of the turnstile program to implement gating

Currently, the turnstiles are either fully open or fully closed, leading to significant waiting times. To reduce these delays and facilitate a smoother flow of people, dynamic gating can be introduced. While the gates are already installed, the control system needs to be modified to allow for dynamic closure of the turnstiles. This will require investment in the turnstiles, as a new control program must be designed and implemented. A fully automated system may not be ideal, as it could present challenges in handling unforeseen issues. Furthermore, to set the system in place, the pre-sorting lanes in front of the turnstiles must be redesigned to prevent individuals from entering them only to face a closed turnstile, which could lead to frustration.

An alternative method for implementing gating is to station stewards in the pre-sorting lanes to manually close them, similar to the approach used at Rotterdam Stadion, adjacent to Feyenoord's stadium. This option avoids the need for costly turnstile upgrades, which are prone to malfunction. However, it would increase the number of stewards required for operation and place them in a potentially more hazardous position, as they would be managing crowds in a conflicting space.

6.3 ASSESSMENT

The objectives, scenarios, and measures have now been identified; the next step is to define an assessment framework. Typically, such an assessment framework includes a set of Key Performance Indicators (KPI's), which quantify performance and measure progress with respect to the objectives, and allows for an objective comparison of scenarios and measures. An overview of various objectives and indicators previously used in the literature will be provided, after which the assessment framework used in this study will be developed.

As previously outlined, the main objectives are to improve staff safety (by reducing waiting times) while ensuring crowd safety. Additionally, other key objectives include minimising investment costs, improving passenger comfort on the train, reducing the number of personnel required for operations, and minimising overall travel time.

Most researchers focus on the physical aspects of crowd safety, aiming to prevent high crowd densities and turbulence, as these are frequent causes of disasters (Haase, Kasper, Koch, & Müller, 2019; Helbing, Johansson, & Al-Abideen, 2007; Still, Papalexi, Fan, & Bamford, 2020). Crowd density is commonly used to assess this safety, but pressure within the crowd can also serve as a valuable indicator (Challenger et al., 2010b).

Rather than focusing on a single objective, Mensink (2017) executed a stakeholder analysis in an overcrowded train station environment and a literature review to come to five objectives of crowd management: improving safety, enhancing reliability, increasing comfort, reducing travel times, and boosting ticket and shop revenues. These objectives align closely with those identified in this study in section 2.4. However, this study excludes ticket and shop revenues, as there are no shops at Enschede Kennispark, and does not consider enhancing reliability, as it falls outside the scope of crowd management in this context.

For the other objectives, Mensink (2017) provides an overview of possible indicators. He mentions LOS, density and perceptions of stressfulness for improving safety and comfort. LOS means Level of Service, which combines the macroscopic flow properties of density, flow and velocity and is introduced by Fruin (1971). It defines six levels, where on levels A and B pedestrians can move freely, and LOS F is a completely crowded situation. LOS E can then for instance be accepted for short periods in bottlenecks. 'Perceptions of stressfulness' is a more subjective indicator only applicable in real life testing. Velocity, waiting time, walking time, platform clearance time and dwell times can be used as indicators for reducing travel times. A higher velocity means a lower walking time, and it is quite clear that by reducing the time factors, the travel times are also reduced.

Bruijl (2022) also conducted interviews and reviewed several studies analysing variables relevant for crowd monitoring dashboards or for crowd management decision-making for a comparable research area. The presented variables are crowd density, crowd flow, crowd speed, crowd count, direction/paths, travel times and crowd characteristics. Crowd characteristics are an umbrella term for age, social identity and mood. Crowd flow, speed, and count as well as paths/directions (or route choice) are all variables that influence and thus serve to predict the density. Bruijl (2022) concludes that crowd density, crowd flow and crowd characteristics are indicators relevant for analysing crowd safety. However, due to modelling limitations, crowd characteristics are dropped from the list. Eventually, travel time is added to his assessment framework to incorporate the objectives of passengers, next to the objective of safety.

What is interesting is that waiting times are generally only considered as part of the travel time (Van Oort, Wilson, & Van Nes, 2010) and often averaged out over all pedestrians (Hoogendoorn & Daamen, 2004). Whereas in this study, waiting times will be considered per individual, due to the relation with frustration and resulting misbehaviours.

An overview of the objectives and possible indicators is given in Table 5. The table only represents modellable indicators. Crowd characteristics, for instance, are not represented, just like the objectives 'minimising investment costs' and 'reducing the number of personnel required for operations'. The indicators will further be specified in section 7.4.

Table 5 - Suitability of indicators for objectives

	LOS	Density	Velocity	Waiting time	Walking time	Platform clearance time	Dwell times
Crowd Safety	X	X				X	
Steward Safety				X			
Travel times			X	X	X	X	X
Comfort	X	X					

7. MODEL SET-UP

For this study, the pedestrian simulation software VisWalk, which is part of PTV Vissim, is used. VisWalk employs the Social Forces Model to simulate interactions between agents, referred to as pedestrians. The pedestrians' strategic route choices are predefined through pedestrian routes, which determine their points of origin and destinations. However, their tactical and operational route choices, such as how they navigate around obstacles and other pedestrians, are dynamically computed based on model parameters. Thus, the modeller specifies a start, an end and eventual in-between areas to which the pedestrian should travel. The pedestrian decides over which areas it will travel, and how it will relate to other pedestrians in the vicinity. Furthermore, public transport can be modelled very detailed, with specific vehicle lengths and intervals; number, width and location of doors; dwell times based on the boarding passengers; and specific waiting areas.

This chapter describes the model set-up, starting with the area to be modelled and the input variables. Next, the implementation of the identified measures into the model is explained. Then, the performance indicators, the runtime, the warm-up period and the required number of simulation runs are highlighted. Subsequently, the model verification and validation are explained. Hereafter, the model is ready to be applied and the measures which should be applied are explored.

7.1 STATION ENVIRONMENT

An overview of the station environment that is modelled can be found in Figure 8. The pedestrians originate from both sides of the stadium (blue areas in Figure 6). The pedestrian flows (red arrows) towards the platforms and through the central underpass are modelled, with pedestrians exiting the simulation upon reaching their respective destinations (red dots). For those travelling towards Enschede, this occurs upon arrival at the platform. Pedestrians using the central underpass exit the model once they have passed through it. Meanwhile, travellers heading towards Hengelo are removed from the simulation only after boarding the train and once the train has departed from the system.

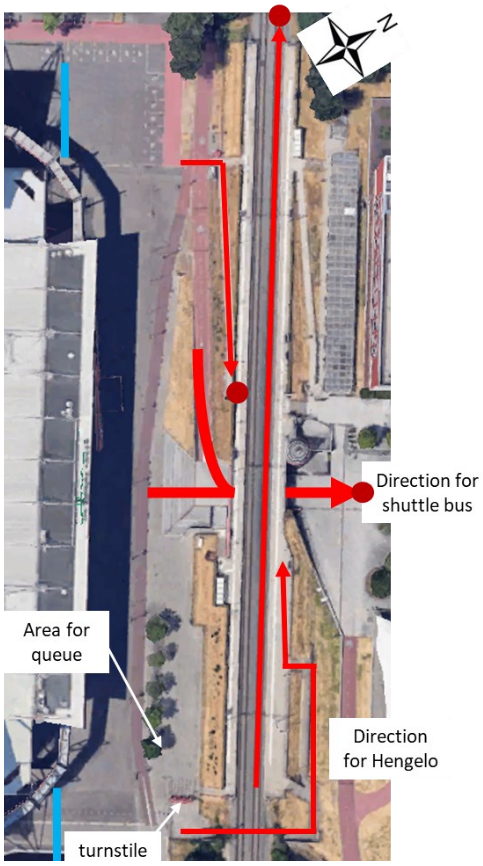


Figure 8 - Project location: pedestrian routes in red, origins in blue, destinations as red dot

Not the whole station environment is modellable with standard elements of Viswalk. Some adaptations have been applied to accurately model the stairs, turnstiles and waiting area in front of the turnstiles, which will be explained in Appendix G. An overview of the complete simulated area can also be found there.

There are a total of 6 turnstiles, for which queues of a length of 5 meters are created with the help of fences (Figure 9). In the model, this is achieved by creating six independent rectangular areas with a length of five meters. The turnstiles are modelled as signal heads, programmed with a Python script integrated with COM into Vissim (Figure 10). When the signal head turns red, it can be seen that pedestrians distribute themselves quite naturally over the area, thus no specific routing decision is added.

Figure 9 - Turnstiles in real-life, with fences creating lanes

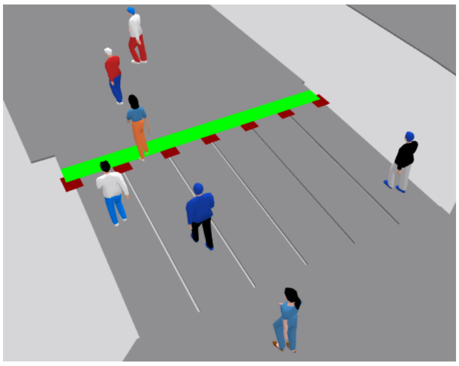


Figure 10 - Turnstiles in the simulation environment, with separate areas creating separate lanes

7.2 INPUTS

The model relies on three primary input variables: the total pedestrian demand per time interval, the distribution of route choices, and the arrival rate and capacity of trains. The pedestrian demand represents the number of pedestrians entering the model at the origins within a given time frame. Route choice is expressed as the percentage of pedestrians selecting one of three possible routes: the platform in the direction of Enschede, the platform in the direction of Hengelo, or the main underpass. Finally, the arrival rate and capacity of trains determine the number of passengers entering or leaving the system at specific intervals. While a demand profile can be predefined, accurately calculating the total pedestrian demand requires knowledge of the specific flow rates for each route.

The demand profile distinguishes four different time intervals: 1) A start-up phase in which the last minutes of the match are played, but supporters are already leaving the stadium to avoid the crowds. 2) A full outflow phase right after the match end, in which most people want to leave the stadium and the capacity of the exits of the stadium determines this outflow. 3) A trickle phase in which the last people leave the stadium and 4) the no outflow phase where everybody has left the stadium.

The exact pedestrian volume per time interval is hard to come by. The total number of visitors in the stadium and the number of pedestrians taking the train is approximately known, but the ones using the underpass are not counted. To come to a relevant number, a mobility plan of FC Twente is used, which was created for the enlargement of the stadium to its current capacity in 2010 (Goudappel, 2010). The total demand for the normative match is computed based on this mobility plan and found to be 18.200 pedestrians. The calculation can be found in Appendix E. Of these people, 15.900 (87.4%) people use the underpass, 1600 (9.8%) people travel by train to Hengelo and 700 (3.8%) to Enschede. Knowing this, the demand profile can further be specified with actual numbers, and is given in Table 6.

Table 6 - Input of pedestrians per time interval

Time interval name	In hours	Cum. in minutes	Cum. in seconds	Assumed distribution	Absolute distribution	Flow [peds/h]
Start-up phase	20:28	0	0	10%	1820	5460
Full outflow phase	20:38	10 (10)	600	85%	15470	24426
Trickle phase	20:57	29 (19)	1740	5%	910	5460
End of outflow	21:02	34 (5)	2040	0%	0	0
End of simulation	22:10	102 (68)	6120			

The arrival rate and capacity of the trains are already briefly discussed in the section 'Crowd Management Operation'. In Table 7, the modelled material, times and the maximum capacity are given. The maximum capacity for ICM-7 is higher than previously mentioned based on the experience of crowd management experts. It is assumed that trains have 100 occupants upon arrival at Enschede Kennispark. This number is based on analysed and counted traveller data from NS and is also mentioned by Keolis.

Table 7 - Time table, train types and used capacity and occupancy

Direction Hengelo					
Time	**Train**	**Type**	**Length (m)**	**Max Capacity**	**Occupancy upon arrival**
XX:08	Keolis Sprinter	FLIRT-7	143.9	810	100
XX:17	NS intercity	ICM-7	187.7	900	100
XX:38	Keolis Sprinter	FLIRT-7	143.9	810	100
XX:47	NS intercity	ICM-7	187.7	900	100

7.3 SPECIFICATION OF MEASURES

With the initial model set-up defined, this section specifies the four measures identified in section 0. They are made operational with specific attention to how they are implemented in the simulation environment.

7.3.1 Stop position readjustment

The readjustment of the train stopping position can increase the safe waiting capacity to 530 passengers (see appendix Appendix F). If the train halts at the start of the platform, the wider part of the platform is used, thus increasing the safe waiting capacity. In the model, this is simulated by increasing the maximum capacity. Also, the train halting positions are altered, such that the train stops in the right place.

7.3.2 Platform expansion

The expansion of the platform is a straightforward measure to implement. By widening the platform by 5 meters, the safe waiting capacity increases to 900 passengers (see appendix. Appendix F). Whereas normally in the model pedestrians get assigned a random space in the waiting area to wait, in this case, people will wait once they are held up. This serves to show the effects of people not willing to walk to the end of the platform.

7.3.3 Extra train

As mentioned in section 6.2.3, there are two ways to implement an extra train. It can be concluded that independent of the specific option, the timetable will look broadly the same at Enschede Kennispark (see Appendix J). This timetable is given in Table 8. These additional trains are incorporated into the model, with their maximum capacity set at 810 passengers, corresponding to a FLIRT-7 train. To optimize passenger flow, these trains arrive empty, ensuring maximum availability for departing crowds.

Table 8 - Timetable of shuttle train at Enschede Kennispark

Direction	Arrival time	Departure time
Enschede	XX:03	XX:05
Hengelo	XX:23	XX:25
Enschede	XX:36	XX:38
Hengelo	XX:52	XX:54

7.3.4 Alternative turnstile program

The alternative turnstile program serves to distribute the arrival rate of people onto the platform more evenly, such that there is a lower standstill waiting time on the platform while at the same time preventing long standstill waiting times in front of the turnstiles once the maximum capacity of the platform is reached.

A control program for the turnstiles is implemented with the help of Python. The control program dynamically adjusts the number of open turnstiles to ensure that the platform fills within the period of two consecutive trains. With a flow rate of 15 people per minute per turnstile[13], the program determines the required number of open turnstiles based on the time to the next train at the moment the previous train departs. For instance, if there are 9 minutes between trains, 3 turnstiles will be opened to allow the platform to fill in 8.9 minutes. If the interval is 21 minutes, only 2 turnstiles will be opened. Once the platform reaches its maximum capacity, all turnstiles will close to prevent overcrowding.

7.4 PERFORMANCE INDICATORS

In Section 6.3 the different performance indicators that can be used are already defined. In this section, these indicators are further refined to ensure an accurate evaluation of the performance of different scenarios and measures. As waiting is of interest, data will be gathered for both the waiting area in front of the turnstiles, hereafter named turnstiles, and the platform. The data is gathered every minute with the help of section measurements, which are visualized as thin blue lines in Figure 11. The data represents the averages of the multiple runs.

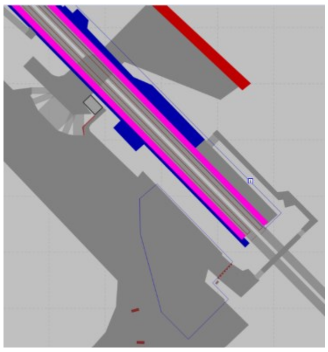


Figure 11 - Close-up on the section measurements

Occupancy data

The graph in Figure 12 shows the number of people present in a certain area at a certain time step. The number of people waiting in front of the turnstiles is presented by the blue line. The maximum capacity of the platform (orange line) can be derived from where this line becomes flat. The trains are presented as bars. The left side of the bar represents the arrival time, and the right side is the departure time (averaged over the multiple runs per scenario). The height of the bar represents the number of boarded passengers. Above the bar, the occupancy rate of the train is given. This is used to describe the density in the train and thus the comfort level.

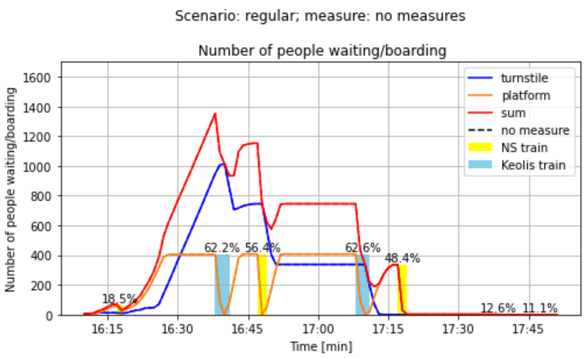


Figure 12 - Wait data for the regular scenario without measures

Experienced Density

The graph in Figure 13 shows the average experienced density of pedestrians in the respective areas to assess the crowd safety. The experienced density is calculated by dividing the number of pedestrians in the personal radius of the pedestrian by the area of the personal radius. The personal radius is measured as 2 meters around the pedestrian. This density metric is chosen over the regular density metric, which simply divides the number of pedestrians over the total walkable area in the section. At the platform, high peaks can be

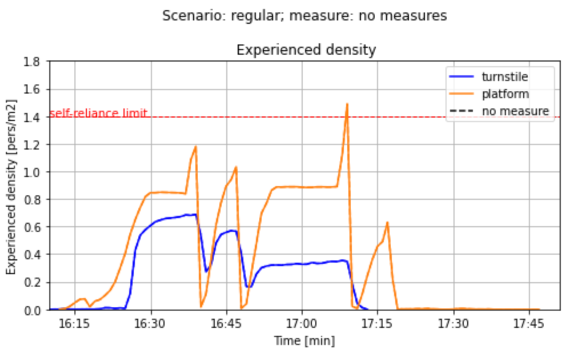


Figure 13 - Experienced density of the regular scenario without measures

[13] https://www.geran-access.com/projecten/grolsch-veste-ombouw-tourniquets/

seen: these are the result of crowding to board a train. When a train opens its doors, all pedestrians walk towards the nearest door, resulting in a high experienced density. The self-reliance limit as used by ProRail and NS is represented by the red dotted line. This line should not be crossed when a train is not present. LOS F for walking and waiting are defined by Fruin (1971) at respectively 2.1 peds/m^2 and 5.4 peds/m^2. These limits are not given in the graphs.

Level of Service (LOS)

Figure 14 presents a spatial experienced density plot for the worst time interval per pedestrian grid cell. This grid gives insight into the crowd safety and comfort. The grid cells measure 0.8 by 0.8 metres, and the time intervals are 180 seconds in duration, approximately matching the time a train remains at the platform. The values displayed in each cell represent the highest experienced density recorded within any single time interval across all simulation runs. In other words, the plot shows the maximum density observed in any run for each grid cell. This serves to illustrate the Level of Service (LOS) while waiting. Each figure has the same scale, based on the LOS for queueing of Fruin (1971). Note that the self-reliance density limit for the platform used by Prorail and NS is 0.7 m^2/person or 1.4 persons/m^2.

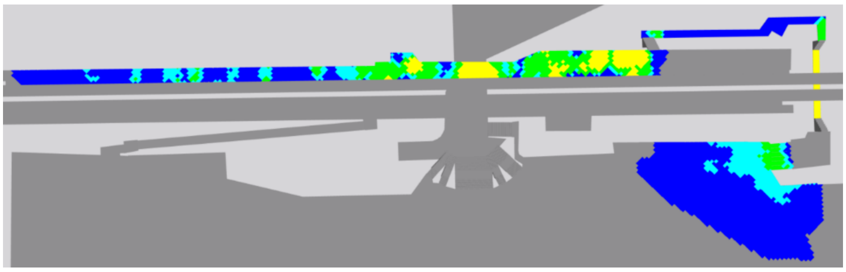


Figure 14 - Spatial density plot for the regular scenario without measures

Table 9 - Legend for spatial density plots

LOS	Density (peds/m^2)	Colour
A	> 0.000	
B	> 0.828	
C	> 1.076	
D	> 1.538	
E	> 3.588	
F	> 5.382	

Individual wait data

The individual wait data represents the standstill waiting times of individuals, and can serve as proxy for the steward safety. The standstill waiting times are computed by gathering the simulation seconds when the speed of the pedestrian is below the threshold of 0.4 m/s. This threshold is taken from the medical field and considered to be the minimum speed considered walking (Mansfield, Inness, & McIlroy, 2018). This data is gathered for pedestrians in front of the turnstiles and on the platform.

As pedestrians tend to exhibit slight movements while waiting in front of the turnstiles rather than remaining completely still, an algorithm was required to interpret this data accurately. In the simulation, this phenomenon—referred to as *jittering*—occurs when pedestrians attempt to overtake those ahead of them due to a random behavioural factor. However, in reality, this behaviour is rarely observed. Even when an individual does push ahead in a queue, it is generally perceived as part of the overall standstill waiting time.

To address this, waiting time data was processed as follows: if two consecutive entries in the dataset fell within a defined threshold of six seconds, the waiting period was considered continuous. If the threshold was exceeded, the wait was split into separate standstill waiting sessions. The duration of each session was then calculated, summed for each individual, and categorised into two-minute intervals: [X, X+2). Each count group was subsequently divided by the total number of pedestrians travelling to the platform to derive relative counts, allowing for scenario comparisons.

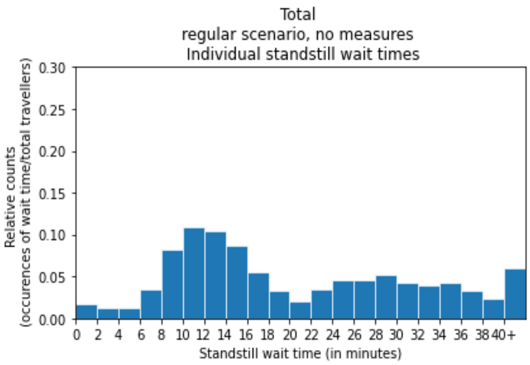


Figure 15 - Standstill wait times for the regular scenario without measures

For waits exceeding 40 minutes—frequently observed in scenarios with increased visitor numbers—the data was grouped into a single category of *over 40 minutes*. While this threshold was somewhat arbitrarily chosen, it is high enough to represent undesirable waiting times while preventing an excessive concentration of counts in the final bin. This approach ensures that the visual representation remains both insightful and manageable.

The resulting individual wait time charts display the average values across multiple simulation runs and can be seen in Figure 15. A statistical analysis was conducted to determine the number of runs required to achieve significant results, which will be explained in section 7.5.3.

Delay

To represent the total performance of measures for visitors, also travel times should be taken into account. However, as total travel time (walking + waiting time) does not sufficiently capture waiting times on the platform, it was decided to report on delay instead. This metric still offers valuable insights into the effectiveness of the measures across different scenarios for the average pedestrian, while standstill waiting time already provides sufficient detail on individual pedestrian experiences.

Delay is calculated for each pedestrian by analysing the deviation between their desired speed (which is predetermined when the pedestrian is generated in the model) and their actual speed, resulting in a delay. Delay data is collected once pedestrians enter a section and recorded by Vissim when they exit. Vissim then provides the average delay for all pedestrians who have left the section.

The total delay is determined by multiplying the average delay by the average number of pedestrians for each time interval. This delay is then converted from seconds to hours and reported separately for the turnstile section, platform section, and overall. Additionally, the delay is averaged across the total number of pedestrians to provide insight into the average delay per person in minutes.

7.5 RUNTIME, WARM-UP PERIOD AND REPLICATIONS

7.5.1 Runtime

The runtime is already briefly mentioned in the model inputs. Here it will further be explained. The simulation is run from 10 minutes before the match end until one and a half hours after the match end. This start time was chosen because it was observed that people would leave the stadium from this moment to catch a train. The end time for the simulation was chosen because the platform in the direction of Hengelo is serviced by 6 trains within 90 minutes of the match end. In the increased visitor scenario, 2130 people are using the platform. Considering the maximum platform capacity of 400 people, these 6 trains are enough to transport everybody in all scenarios.

7.5.2 Warm-up period

Warm-up periods are typically used for models to achieve a state which corresponds to the initial state in real-life (Grassmann, 2009). Since the station is completely empty until ten minutes before the match ends, a warm-up period is not needed.

7.5.3 Replications

Given the stochastic nature of the simulation models and their results, multiple runs with different seeds are needed to come to significant results. In this model, the demand and route choice are stochastic. The influence is most clear in the standstill wait times, where small differences can make large impacts due to the grouping of the data into bins. The number of replications needed is computed based on the maximum allowed relative error of the standstill wait times using a confidence interval. It was found that with 7 replications the model yields statistically significant results. The computation can be found in Appendix I.

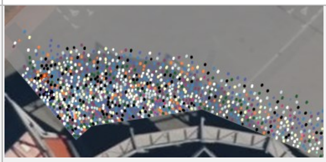
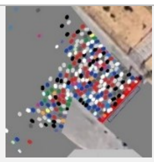
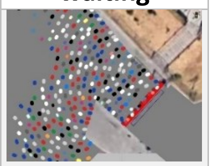
7.6 CALIBRATION, VERIFICATION AND VALIDATION

Calibration, verification and validation are important steps in the modelling process, as they guarantee that the model is reliable and credible. Calibration reduces the uncertainties in the model, while verification of the model ensures that it is implemented correctly and operates as intended (Haar, 2021).

The model is calibrated based on a normative match played between FC Twente and Almere City on Wednesday, 24th of April. Around 30.000 supporters were present in the stadium. The match ended at 20:38, after which an estimated 2300 people took the train, 1600 in the direction of Hengelo, and 700 in the direction of Enschede. To give some information about the crowd characteristics: The weather was dry, but cold (2°C). FC Twente won, which was expected, three against one. It was the third to last match in the competition, in which FC Twente was still fighting for a position granting access to the Champions League.

The main pedestrian flows were calibrated based on these numbers. In addition to adjusting the flows within the model, the pedestrian behaviour parameters also required calibration. This process is thoroughly detailed in Appendix H. Given the default values, some unforeseen bottlenecks emerged, with pedestrians clustering near the stadium and extremely high densities forming in front of the closed turnstiles. To better align the model with observed behaviour, the parameters were adjusted accordingly. However, a single uniform parameter set could not resolve both issues simultaneously, as pedestrian behaviour differs significantly when walking versus when standing still. As a result, two distinct parameter sets were introduced. These sets differ considerably due to the nature of the social forces model, where most parameters lack a direct interpretation, and individual parameters often influence multiple aspects of walking behaviour (Kretz, Lohmiller, & Sukennik, 2018). The final parameter values are presented in Table 10.

Table 10 - Calibrated parameters for walking and waiting behaviour

	Default parameter set	**Calibrated for walking**	**Calibrated for waiting**
Figures for cornering and queue at turnstiles	 		
Tau	0.4	0.4	0.2
ReactToN	8	1	20
ASocIso	2.72	5	4
BSocIso	0.2	0.3	0.8
Lambda	0.2	0.8	0.1
ASocMean	0.4	0.8	0.4
BSocMean	2.8	2.8	5
VD	3	3	3
Noise	1.2	1.2	0

The model verification process involved checking input-output consistency and conducting a visual analysis to ensure the accuracy of the boarding process and the operation of turnstiles. Additionally, individual components that had already been calibrated, such as the turnstile queue and the area surrounding the stadium, were re-examined to confirm their correctness. Furthermore, a test was conducted using an empty model to verify that travel times remained within an acceptable range, ensuring that the fundamental mechanics of pedestrian movement were functioning as expected.

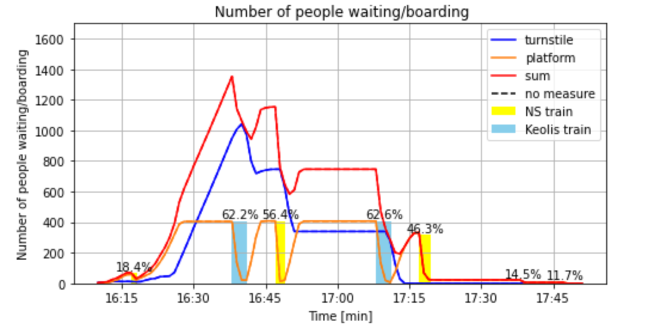
Given the lack of adequate in and outflow data, it was not possible to validate the model using statistical tests. However, some other validation methods have been applied. Cross validation has been carried out for a different match which yielded similar results. Also, several experts by experience have been consulted to validate whether the model's structure and behaviour are reasonable. Based on this validation, the parameters for turnstile queueing received some additional attention (see also Appendix H.2).

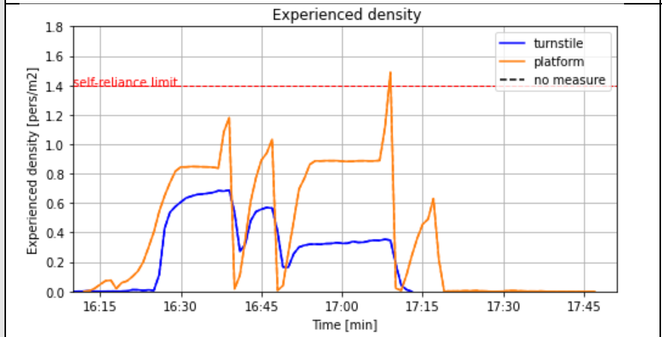
8. RESULTS

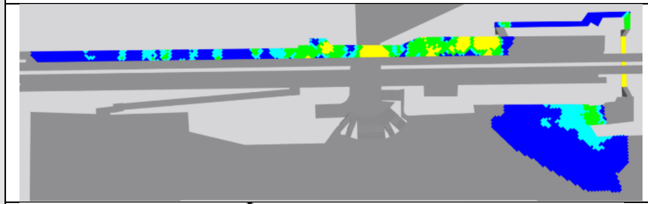
The results will be presented in a structured manner to facilitate clear comparisons. First, all scenarios without measures will be highlighted to establish baselines. These baselines provide a reference point for assessing the effectiveness of different interventions. Next, each measure will be introduced and evaluated against its corresponding baseline, offering insight into how well it performs on the different performance indicators. In some scenario-measure combination, there are stranded passengers. These passengers are not able to catch the last train. These passengers are not accounted for in the total delay measurement, but are taken into account in the standstill waiting time. Thereafter, to enable cross-comparison, the standstill wait times across all scenarios and measures will be presented together, ensuring that the impact of each intervention can be directly compared. The results will be displayed using page-wide tables accompanied by visual figures, as illustrated in paragraph 7.4. These tables will follow a standardized format, with the scenarios in the columns and the performance indicators presented per row. Which measure is presented, is indicated on the left of the table. Additionally, a description will be provided before or after each results table to explain the figures and facilitate interpretation.

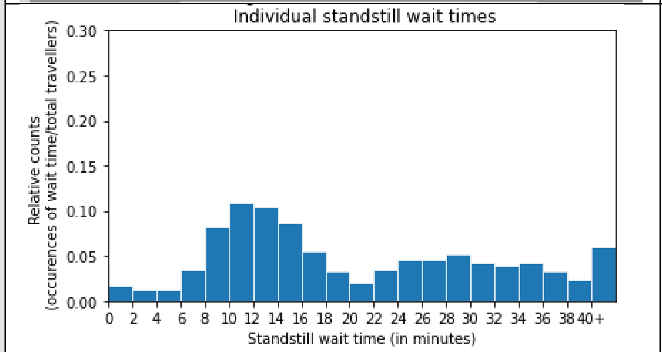
No measure (Baseline)

Regular scenario

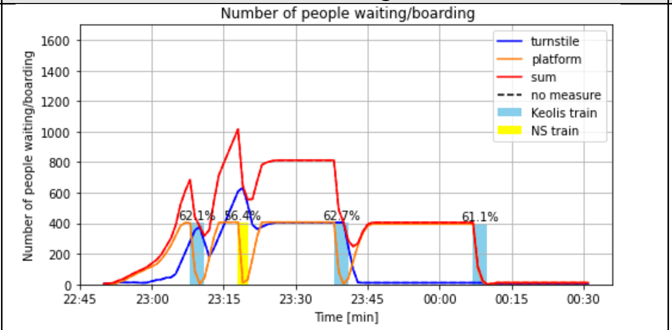


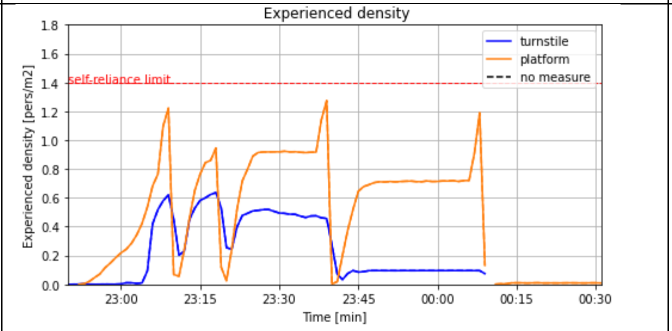


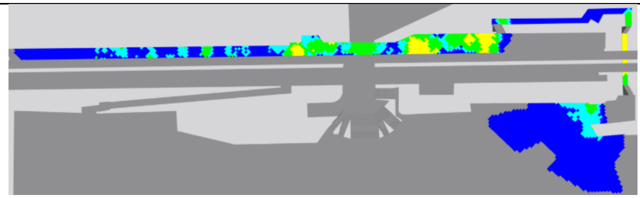


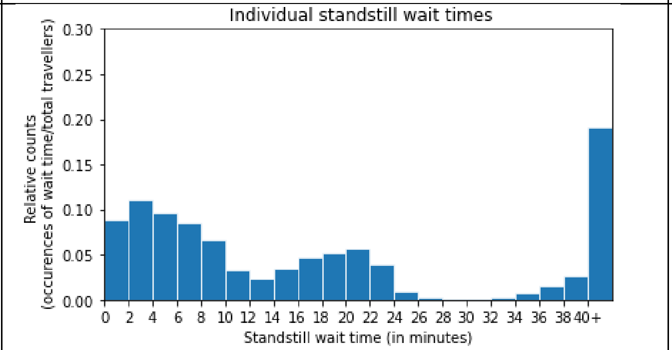


Late ending

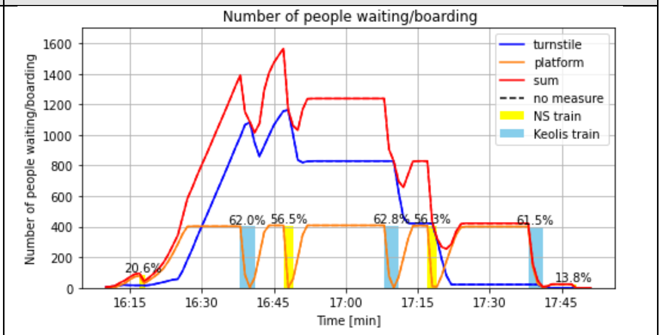


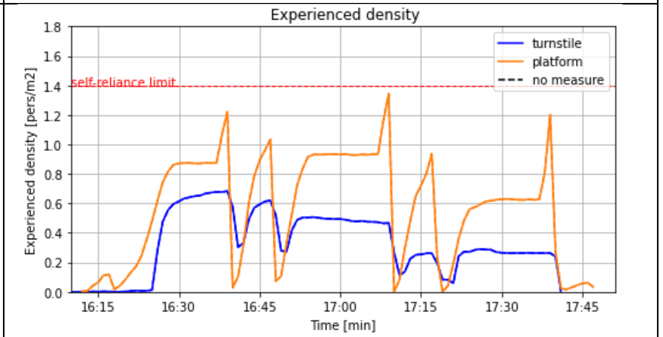


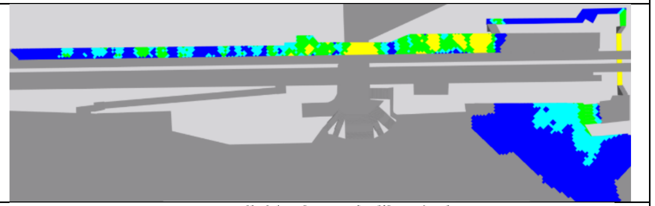


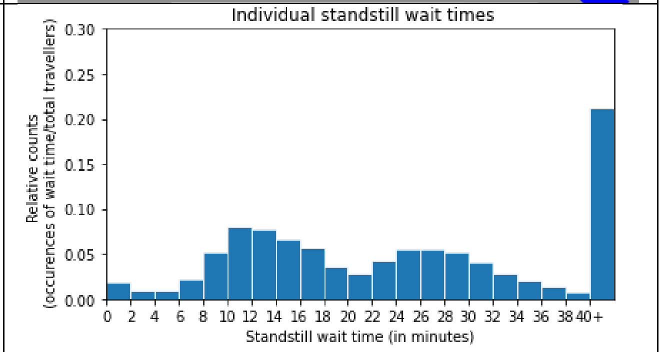


Increased visitors









		Regular scenario		Late ending		Increased visitors	
		Stranded passengers	0	Stranded passengers	10.4	Stranded passengers	0
Delay	Turnstile	352.2 hours	13.2 min/pers	209.6 hours	7.9 min/pers	647.4 hours	18.2 min/pers
	Platform	80.8 hours	3 min/pers	110.7 hours	4.2 min/pers	118.7 hours	3.3 min/pers
	Total	433 hours	16.2 min/pers	320.3 hours	12 min/pers	766.1 hours	21.5 min/pers

8.1 BASELINES

The trends are broadly comparable in the figures. One bigger difference that catches the eye is in the standstill waiting time and the delay. For the late ending scenario, this delay is the lowest, for the increased number of visitors scenario, this delay is high. An explanation that the late-ending scenario performs better is due to a better connection of the match end to the train table. The trains arrive almost 10 minutes earlier relative to the match end than in the regular scenario. Due to this difference in the train table, the individual wait times in the late-ending scenario are also more skewed to the left. This is because the first train arrives just when the platform is full. Even though the time between trains is larger in the late ending scenario compared to the regular scenario, the delay is lower. This illustrates the effect and importance of a good connection between the match end and the train table. Yet it also illustrates the naivety of the model. This good match is more or less a lucky strike, making the late end scenario look better than it actually is.

The late ending scenario still has a relatively large group which needs to wait more than 40 minutes. This is explained by the fact that on average 10.4 travellers are left at the platform after the last train. Luckily, this does not happen in real life, but the rigid programming of the model and the stochasticity in the number of people travelling by train in the direction of Hengelo has this as a result.

When comparing the standstill wait times of the regular and increased visitors scenario, similar histograms can be seen, the bins are the same for the minutes 0 to 40. The difference lies in the 40+ bin, which is higher in the increased visitor scenario. The arrival rate of passengers is namely increased for the start-up and end-of-outflow phases, only the full-outflow phase is a bit lengthened in the increased visitor scenario. The arrival period is 11 minutes longer, but there are also 533 people more to transport. There are 2 trains extra needed to transport these people, obviously leading to much longer waiting times. Combined with the bad connection between the match end and the train table, this results in an extremely high average waiting time of 21.5 minutes per person. These figures illustrate clearly that the station is currently not suitable for increased visitor flows

In the regular scenario, approximately 1000 people wait in front of the turnstiles at a given time, leading to higher maximum experienced densities in the plots compared to the late ending scenario. A similar pattern is observed in the increased visitors scenario, where 1200 people wait in front of the turnstiles. However, in the late-ending scenario, the peak number of waiting passengers is significantly lower, with only 600 people in front of the turnstiles, also reflecting a lower spatial density.

Despite the higher number of people waiting in front of the turnstiles, the density there remains lower than on the platform. This can be explained by the fact that the platform feels more crowded because passengers must navigate through others who are already waiting, leading to a higher perceived density. Additionally, it can be attributed to the different walking behaviour assigned to the turnstile queue, which results in a more evenly distributed crowd. Furthermore, no density is observed on the right side of the platform, as the train does not stop there. Observations indicate that passengers do not wait in this area, so it is not designated as a waiting area in the model, and people do not move there.

Looking at the density at the platform, the same trend can be seen, namely yellow grids between the entrance and halfway on the platform and dark and light blue spots at the front of the platform. These plots clearly illustrate the different densities on the platform, and the reluctance of people to spread over the platform. The hotspots near the platform edge on the track side can be explained by the boarding people. Moreover, it is interesting to see the density in the side underpass. This is already yellow, meaning a density of over 1.538 peds/m^2, where people are walking, translating to an LOS level E.

The small differences in the experienced density plots with regard to the platform are harder to explain. Given that the platforms all have a maximum capacity of 400 people, it would appear that the density plots would also be similar. Especially when looking at the experienced density graphs for the platforms, where all graphs follow the pattern of an experienced density of 0.9 people/m^2 when the platform is full, and a peak when a train arrives. The difference might be explained by the time interval aggregate this data is saved to. To speed up the simulation runtime, it was chosen to gather the grid cell data per 180 seconds. This is also on average the time a train halts at the station. It might be that due to the different start times of the simulation, the train halting is inadequately captured by the grid-based experienced density data.

8.2 STOP POSITION READJUSTMENT

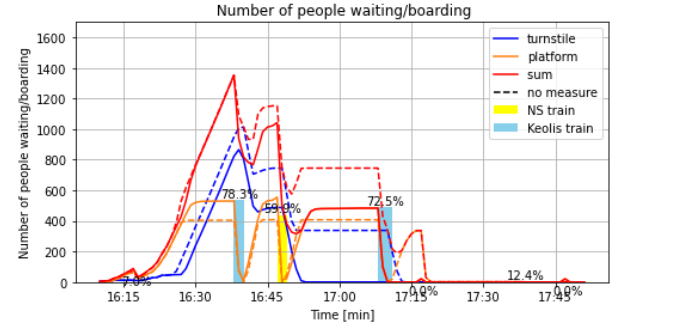
When looking at the stop position readjustment, the first thing that becomes clear is the decrease of the total delay and the drastic decrease in high standstill waiting times. This is solely because the platform capacity is increased. The platform capacity has increased to 530, as can be seen in the graph of people waiting/boarding. A direct result is that the queue in front of the turnstile starts its buildup later, and becomes less high. In all scenarios, this queue disappears one train earlier, thus also directly translating to one train fewer to discharge all pedestrians. Even with this positive effect, it is not enough to avoid stranded passengers in the late end scenario. The occupancy of the trains furthermore increases slightly to around 78% for Keolis trains and 59% for NS trains.

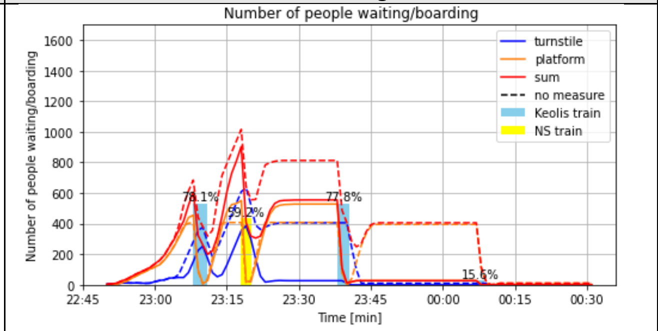
The experienced density is comparable at the turnstiles while the queue is building up, but slightly lower over longer standstill waiting times. This is easily explainable by the lower number of people in the queue. Peaks in the experienced density on the platform are in neither scenario as high as in the baseline. This can be explained by the better distribution of passengers over the platform and the train length.

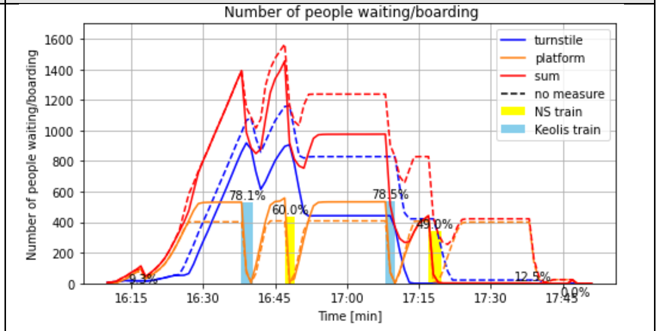
Due to the alteration of the stop position and the subsequent change in the waiting area, the entrance now lies in the middle. In the spatial density plots, it can be observed that this creates a small bottleneck, as not only is the level of service (LOS) on the platform yellow (Level D), but the area before the stairs also exhibits congestion.

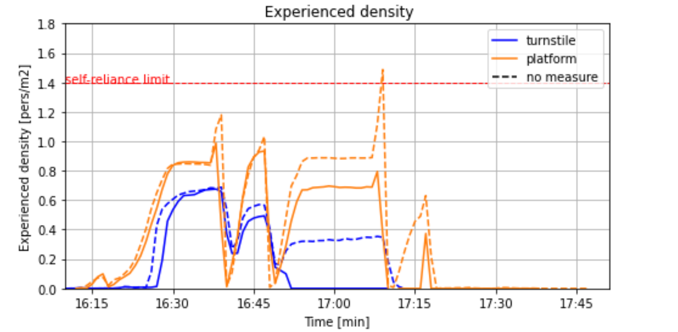
Stop position readjustment

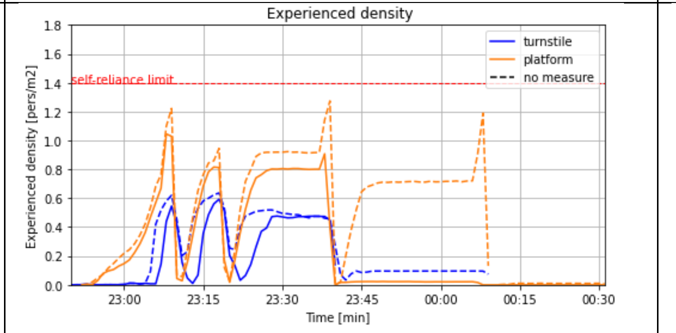
Regular scenario	Late ending	Increased visitors

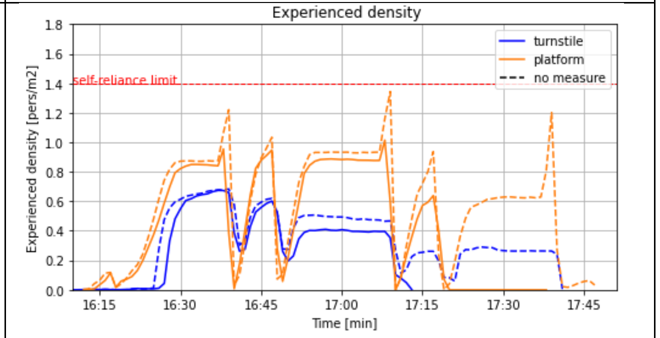


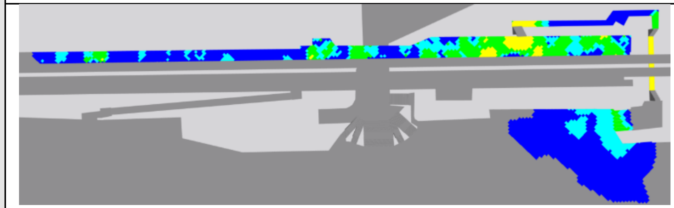


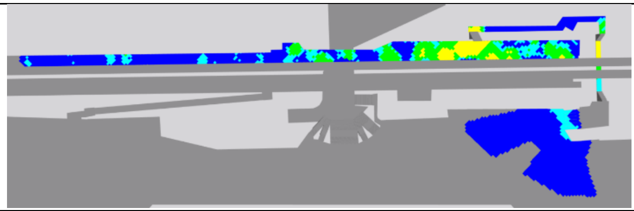


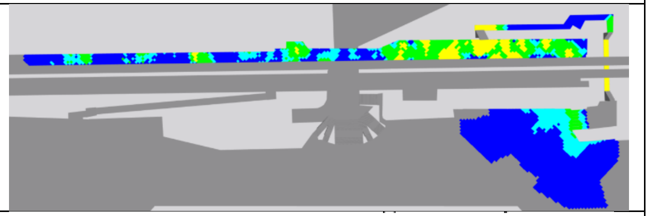


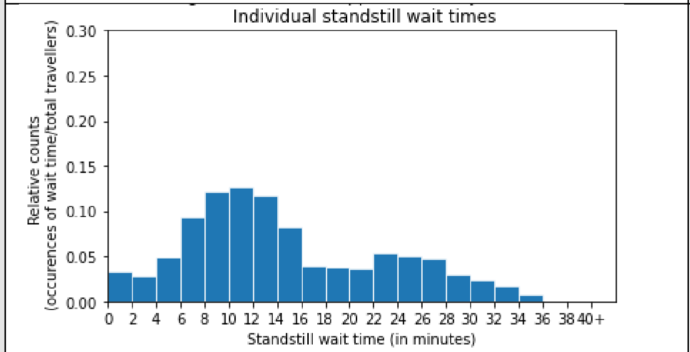


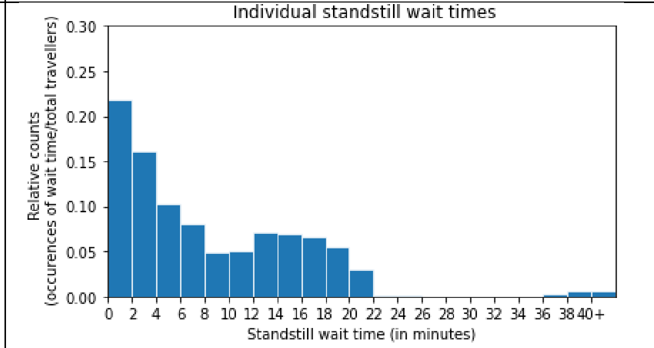


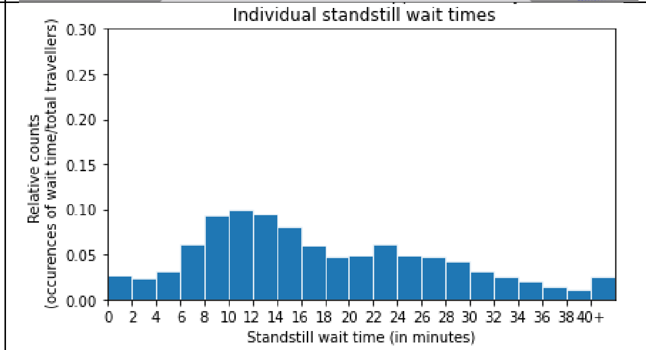












		Regular scenario		Late ending		Increased visitors	
		Stranded passengers	0	Stranded passengers	1	Stranded passengers	0
Total delay	Turnstile	174.4 hours	6.5 min/pers	35 hours	1.3 min/pers	362.2 hours	10.2 min/pers
	Platform	88 hours	3.3 min/pers	61.7 hours	2.3 min/pers	101.8 hours	2.9 min/pers
	Total	262.3 hours	9.8 min/pers	96.7 hours	3.6 min/pers	464 hours	13.1 min/pers

8.3 PLATFORM EXPANSION

What immediately meets the eye when looking at the results of the platform expansion is the mostly dark blue spatial density plot and complete reduction of the turnstile queue in the late-ending scenario. Due to the large increase of the platform capacity to 900, and the good connection between the match end and the train table, everybody can simply walk towards the platform and the turnstiles never have to be closed. Thus creating no standstill waits and delays there. Instead, everybody simply walks almost straight into the train waiting at the platform. The maximum capacity of 900 people on the platform is even never reached.

There are some downsides to this, for which the model does not account. First of all, the model takes each train as one entity with a maximum capacity. It does not account for the fact that pedestrians do not uniformly distribute over the train and that thus only a limited number of pedestrians can enter a certain door. For the earlier scenarios, this was not a problem, as the number of people on the platform did not exceed the capacity of the train. It can also be seen that the dwell time of the trains is significantly longer. This is because the trains wait since people are boarding the train. This leads to delayed departures, with delays in the whole network as a result. The crowding around the train doors is also well represented by the appearance of hotspots at the platform edge in the spatial density plots.

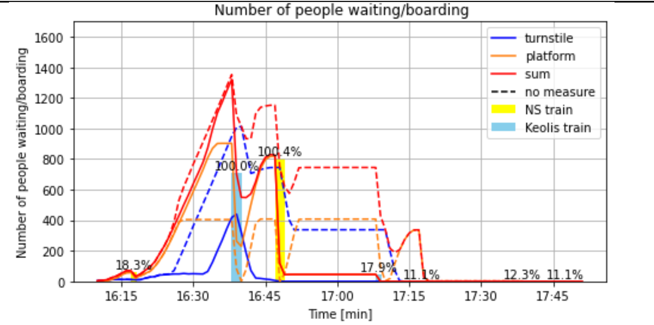
In the regular and increased visitor scenarios, the capacity of 900 people on the platform is reached. However, the boarding limits for the trains lie below this capacity. This means that not everybody on the platform can catch the train. This can also be seen in the experienced density charts, where the spikes on the platform reach values above the self-reliance limit. This is not necessarily a problem for the crowd density when a train is present, as the risk of falling off the platform is then no more and the LOS F for walking lies at 2.1 peds/m^2. Yet, pedestrians in the model do not try to enter the train once the capacity is reached. In real life, however, people would push themselves into the train, increasing the density further and possibly creating even more hazardous situations than this study wants to prevent.

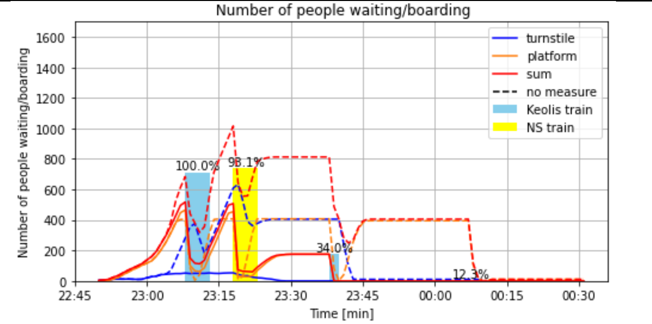
Apart from the downsides of such a full platform leading to such full trains, the improvements in front of the turnstiles are remarkable. As discussed the queue disappears in the late ending scenario, and this is in a lesser amount visible in the other two scenarios, where the peak in number of people before the turnstiles is reduced with respectively 500 and 700 people, and the queue resolves 30 minutes earlier in the regular scenario and even around 50 minutes for the increased visitor scenario.

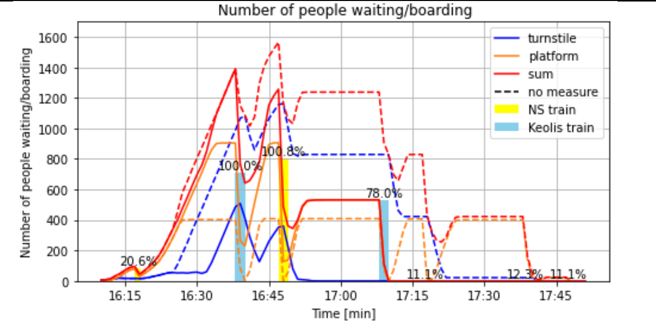
A last point of interest is the spatial density plot. In the late-ending scenario, it appears that two perpendicular queues form. This is however not the case, as there is no queue and simply the two walking lanes of pedestrians are shown. In conclusion, although the delay and standstill waiting times are low, safety on the platform is not necessarily improved with this measure.

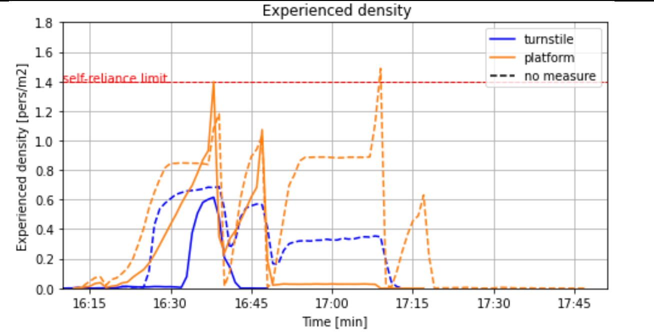
Platform Expansion

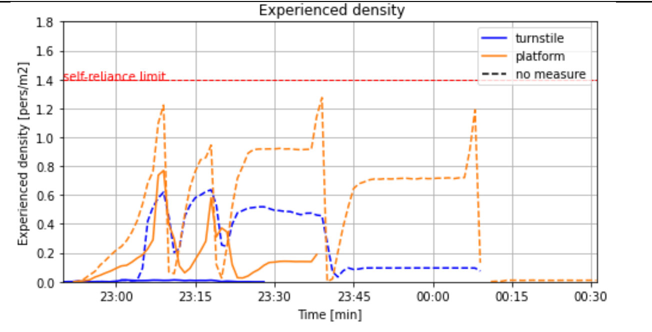
Regular scenario	Late ending	Increased visitors

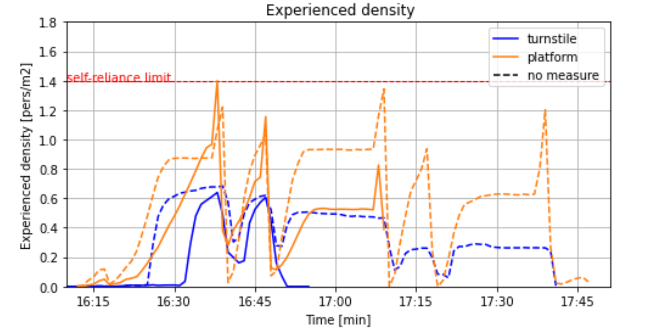


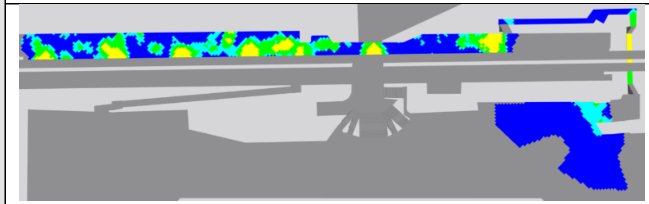


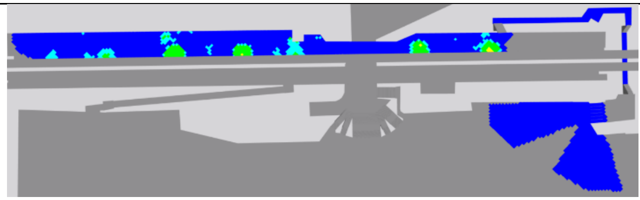


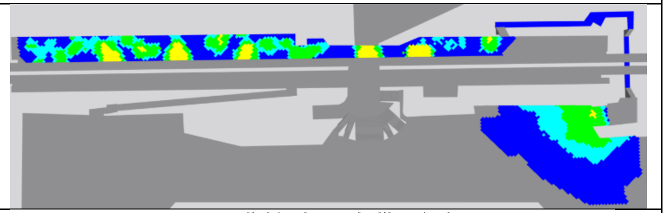


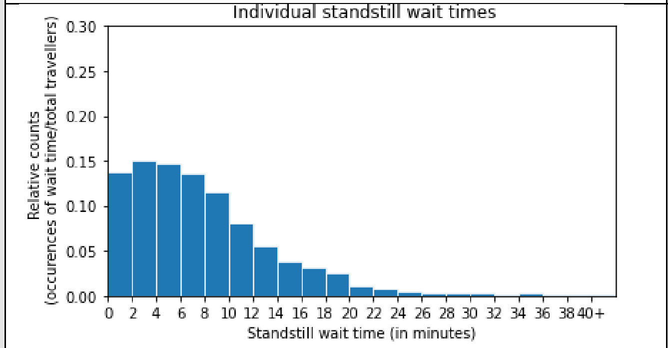


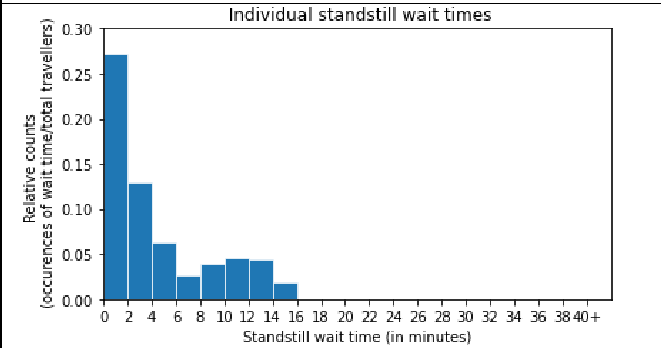


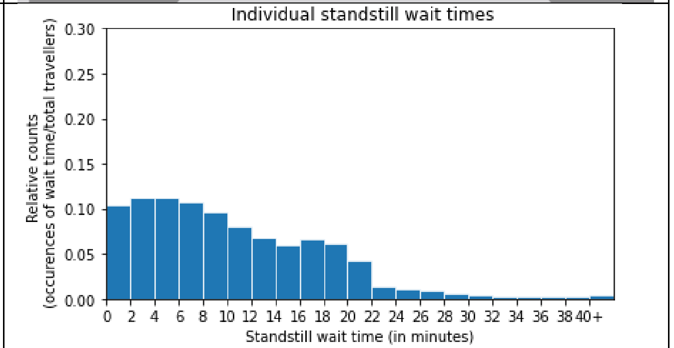








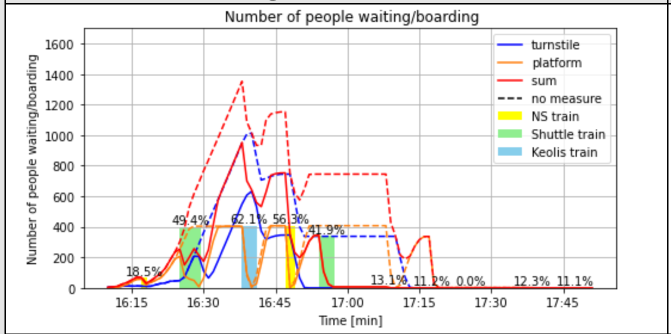


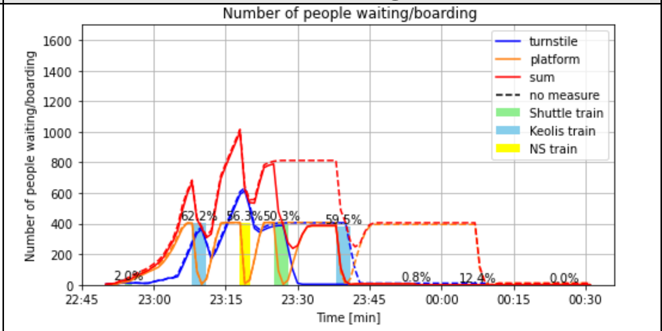


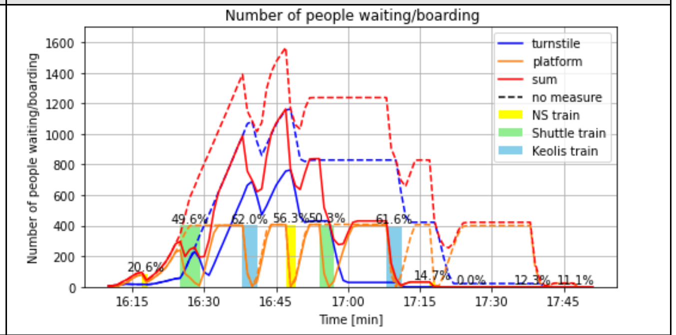
		Regular scenario		Late ending		Increased visitors	
Stranded passengers			0		0		0
Total delay	Turnstile	32.4 hours	1.2 min/pers	1.2 hours	0 min/pers	62.3 hours	1.8 min/pers
	Platform	37.8 hours	1.4 min/pers	11.7 hours	0.4 min/pers	64.8 hours	1.8 min/pers
	Total	70.2 hours	2.6 min/pers	12.9 hours	0.5 min/pers	127.1 hours	3.6 min/pers

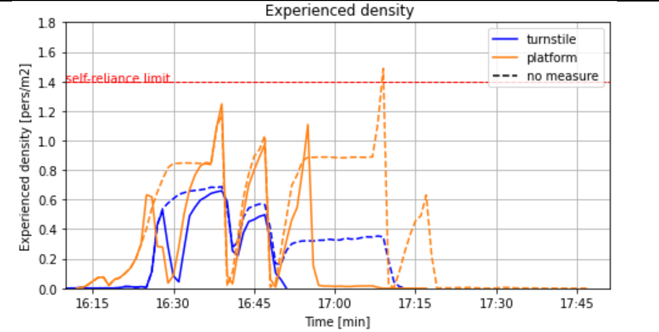
Extra train

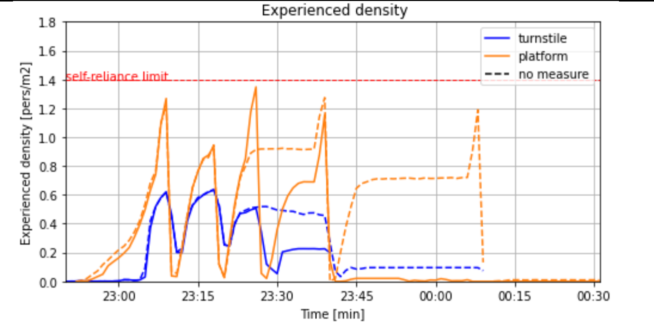
Regular scenario	Late ending	Increased visitors

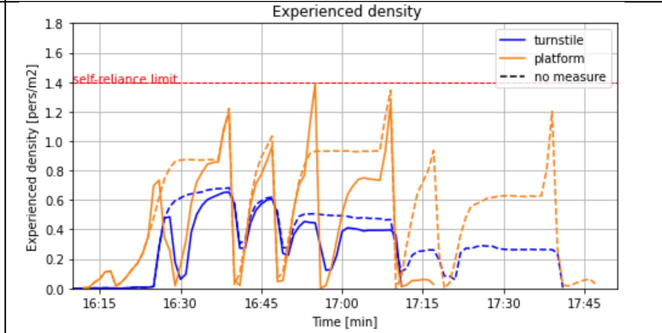


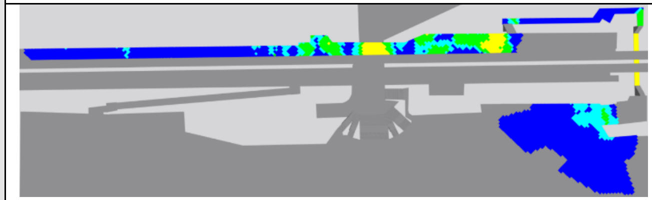


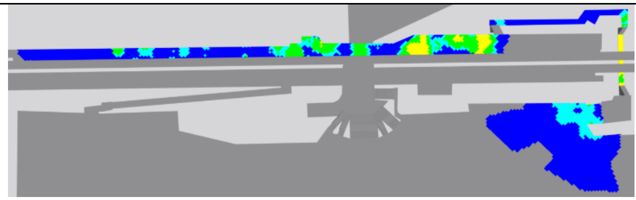


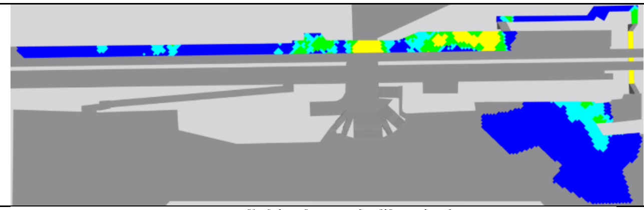


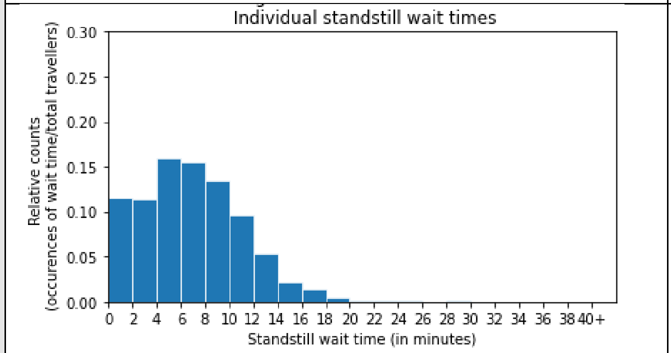


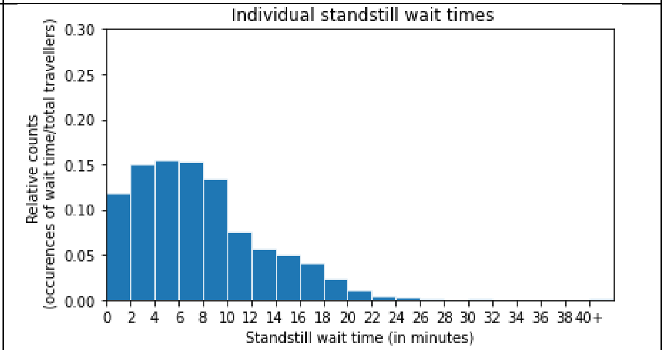


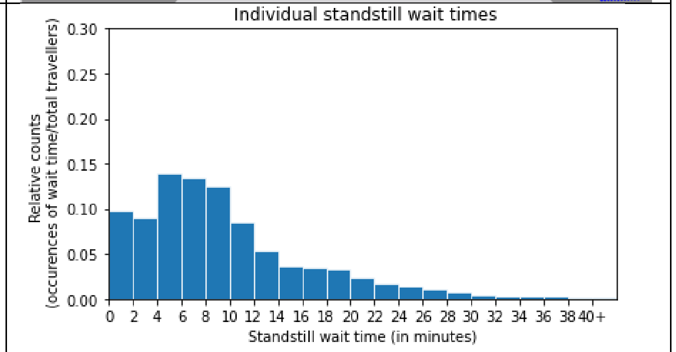












		Regular scenario		Late ending		Increased visitors	
		Stranded passengers	0	Stranded passengers	0	Stranded passengers	0
Total delay	Turnstile	110.1 hours	4.1 min/pers	112.2 hours	4.2 min/pers	215.8 hours	6.1 min/pers
	Platform	33.6 hours	1.3 min/pers	43.6 hours	1.6 min/pers	54.4 hours	1.5 min/pers
	Total	143.7 hours	5.4 min/pers	155.7 hours	5.8 min/pers	270.2 hours	7.6 min/pers

8.4 EXTRA TRAIN

With this measure, it is interesting to see the resemblance in the results between the regular scenario and the late ending scenario. By adding an extra train, the time between two trains is always around 10 minutes, thus reducing the effect of having different match end times. The first shuttle train in the late-ending scenario departs just before the first people arrive at the platform, resulting in graphs very similar to the no-measure late-ending scenario for the first half hour. The regular and increased visitor scenario however benefits highly from the extra shuttle train, effectively reducing the number of people waiting.

The effects in the density graph, plot and delays are quite straightforward. Interestingly, less hotspots are visible on the platform. A possible explanation is that people are simply waiting less long on the platform. Furthermore, the density in front of the turnstiles is also reduced compared to the baseline.

It is noteworthy that pedestrians can make it to the platform in time. By reducing the headways of trains there is always a possibility that simply not enough people can make their way to the platform. Furthermore, the average delays are reduced to below 10 minutes per person. And standstill times are also drastically reduced, to a maximum of 38 minutes in the increased visitors scenario.

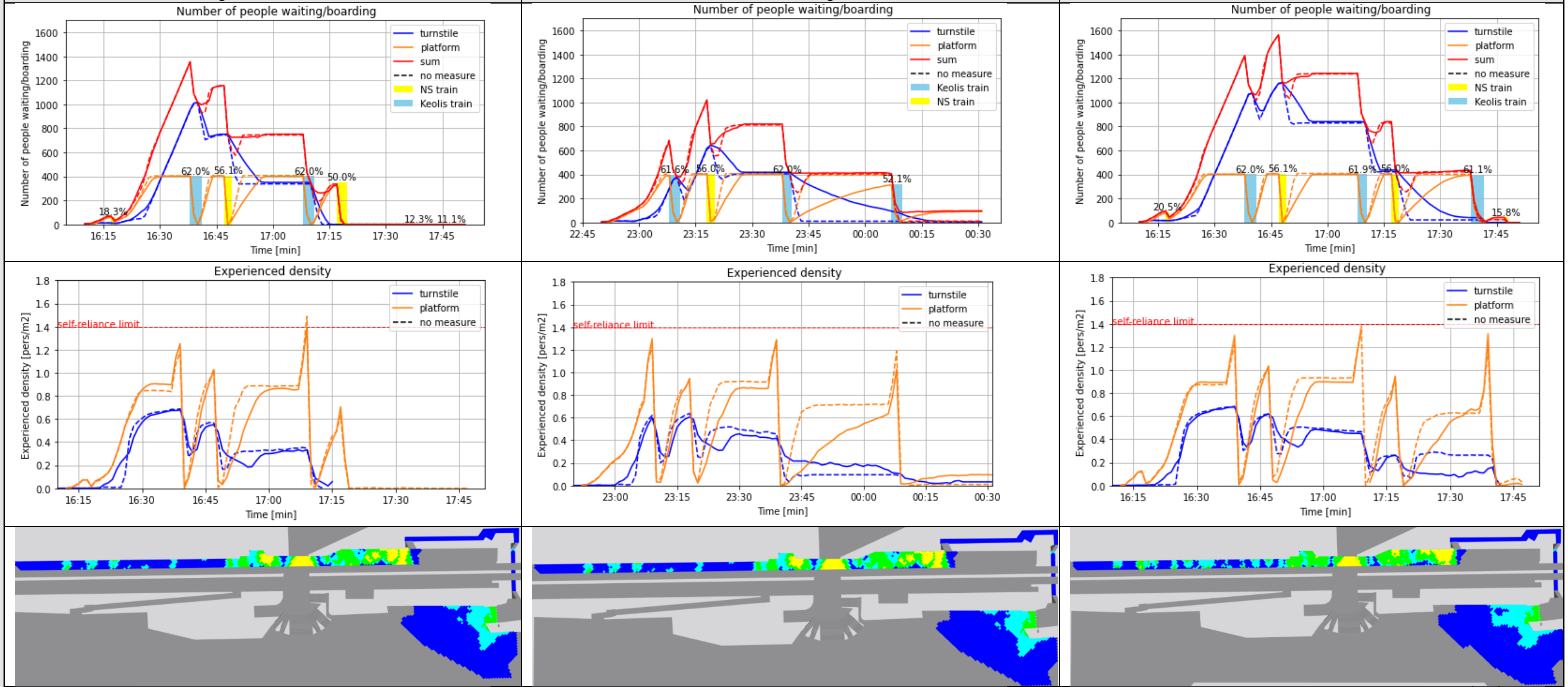
8.5 ALTERNATIVE TURNSTILE PROGRAM

When comparing the results of the alternative turnstile program with the scenarios without measures, the effects are not so straightforward. The alternative turnstile program performs a bit worse in terms of total delay, and also results in more stranded passengers in the late ending scenario. What is interesting to see is the change in number of people on the platform and before the turnstiles in the late-ending scenario between 23:20 and 23:40 and between 23:45 and 00:10. In the first interval two turnstiles are opened, slowing the flow only marginally. While in the second interval only one turnstile is opened, slowing the flow substantially. The maximum platform capacity is not even reached when the last train arrives. This shows that modelling adequate flowrates of turnstiles is more easily said than done.

Where this measure performs well is that the experienced density at the turnstiles is lower while there is outflow from the area. Also, the spatial density plot shows a reduced LOS in the side underpass and route towards the platform. This measure is thus applicable to create a so-called ‘happy flow’, but does need more calibration with respect to flow rates.

Alternative turnstile program

Regular scenario	Late ending	Increased visitors



		Regular scenario		Late ending		Increased visitors	
Stranded passengers			0	Stranded passengers	96.6	Stranded passengers	0
Total delay	Turnstile	181.5 hours	6.8 min/pers	373.7 hours	14 min/pers	709.7 hours	20 min/pers
	Platform	98.8 hours	3.7 min/pers	70.3 hours	2.6 min/pers	98.5 hours	2.8 min/pers
	Total	280.2 hours	10.5 min/pers	444 hours	16.6 min/pers	808.2 hours	22.7 min/pers

8.6 MEASURE COMPARISON

To compare the results of the different measures with each other, the standstill waiting times of each measure will be compared to the baseline scenario as a relative change. The significance of the results is assessed using the Student's t-test, with a 95% confidence interval. Red numbers indicate that the change is not significant. The results are presented as occurring frequencies (in percentages) of a certain waiting time bin. The baseline represents its frequencies, and the measures are compared to the baseline with an absolute change in the frequencies. Cells with high plusses are marked in dark blue, cells with high minuses are marked in red. It should be noted that large plusses are desired at the low waiting time bins, and large minuses are desired at the high waiting times.

8.6.1 Regular scenario

Table 11 – Absolute percentual change of standstill waiting times in the regular scenario. Red numbers indicate non-significance

bin	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22
counts	1.8%	1.2%	1.3%	3.4%	8.1%	10.9%	10.4%	8.6%	5.6%	3.3%	2.0%
stop position readjustment	+1.5%	+1.7%	+3.6%	+5.9%	+4.0%	+1.8%	+1.4%	-0.4%	-1.6%	+0.4%	+1.7%
platform expansion	+12.0%	+13.8%	+13.4%	+10.1%	+3.4%	-2.9%	-4.9%	-4.8%	-2.4%	-0.9%	-1.0%
extra train	+9.7%	+10.2%	+14.7%	+12.1%	+5.3%	-1.4%	-5.1%	-6.4%	-4.1%	-3.0%	-1.9%
alternative turnstiles	+0.0%	+0.1%	+0.1%	+0.5%	+0.8%	-0.5%	-0.1%	-0.8%	-0.7%	-0.7%	+0.1%
bin	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38-40	40+	
counts	3.5%	4.5%	4.6%	5.2%	4.3%	3.9%	4.3%	3.3%	2.4%	6.0%	
stop position readjustment	+1.9%	+0.6%	+0.2%	-2.2%	-2.0%	-2.1%	-3.5%	-3.2%	-2.4%	-6.0%	
platform expansion	-2.8%	-4.0%	-4.3%	-5.0%	-4.1%	-3.7%	-4.1%	-3.1%	-2.3%	-5.8%	
extra train	-3.5%	-4.4%	-4.6%	-5.1%	-4.3%	-3.9%	-4.3%	-3.3%	-2.4%	-6.0%	
alternative turnstiles	-0.6%	-0.3%	+0.1%	-0.6%	-0.1%	+0.1%	+0.2%	+0.6%	+0.2%	+1.7%	

What becomes clear from this table is that platform expansion, an extra train and stop position readjustment perform well in reducing the waiting times. The extra train measure does this the best, reducing all waits to under 20 minutes. The platform expansion measure shows this shift as well, increasing the number of waits between 0 and 4 minutes, but performs slightly worse in reducing waits above 10 minutes. The stopping readjustment performs well in time ranges between 2 and 14 minutes, but also features an increase in waits around 20-24 minutes. There is more or less a shift from waits between 12-18 minutes and 22+ to shorter waits. This is a logical effect of the slight increase in platform capacity in this scenario. The alternative turnstile programme now shows only minor alterations compared to the baseline scenario, with almost half of the changes in frequencies being non-significant. Furthermore, the changes in frequencies do not exceed 1%.

8.6.2 Late ending scenario

Table 12 - Absolute percentual change of standstill waiting times in the late-ending scenario. Red numbers indicate non-significance

bin	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22
counts	8.9%	11.1%	9.7%	8.4%	6.5%	3.2%	2.4%	3.4%	4.7%	5.2%	5.6%
stop position readjustment	+12.9%	+5.0%	+0.6%	-0.5%	-1.7%	+1.9%	+4.6%	+3.5%	+2.0%	+0.3%	-2.7%
platform expansion	+18.4%	+1.9%	-3.4%	-5.8%	-2.7%	+1.3%	+2.0%	-1.5%	-4.7%	-5.2%	-5.6%
extra train	+3.0%	+4.0%	+5.8%	+6.9%	+6.9%	+4.3%	+3.3%	+1.7%	-0.6%	-2.9%	-4.5%
alternative turnstiles	+1.0%	-0.5%	-0.6%	+0.6%	-0.0%	-0.4%	+0.6%	+0.2%	-0.4%	+0.5%	-0.0%
bin	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38-40	40+	
counts	4.0%	0.9%	0.3%	0.2%	0.2%	0.3%	0.8%	1.5%	2.7%	19.1%	
stop position readjustment	-3.9%	-0.7%	-0.3%	-0.2%	-0.1%	-0.3%	-0.8%	-1.3%	-2.1%	-18.5%	
platform expansion	-4.0%	-0.9%	-0.3%	-0.2%	-0.2%	-0.3%	-0.8%	-1.5%	-2.7%	-19.1%	
extra train	-3.5%	-0.6%	-0.2%	-0.2%	-0.1%	-0.3%	-0.8%	-1.5%	-2.7%	-18.9%	
alternative turnstiles	-1.4%	+0.1%	-0.1%	-0.1%	-0.0%	-0.1%	-0.3%	-0.7%	-1.0%	+3.2%	

In this scenario, it can be seen that the platform expansion measure performs best by almost eliminating waits of over 18 minutes. The extra train measure is mostly effective in reducing waits over 22 minutes, but does not negate them, only reduce them with several minutes, as the highest improvement can be seen in the range between 8 to 14 minutes. This can easily be explained by the fact that the extra train in this scenario only arrives after the station is already serviced by the Keolis and NS trains, thus having a smaller effect on the standstill wait times. The stop position readjustment shows the same trend as in the regular scenario, improving shorter waits, and reducing longer waits, but not negating them. The alternative turnstile program shows similar results compared to the regular scenario, only slightly altering the wait durations, but without showing a clear trend. Comparing these results to the results of the regular scenario, it can be concluded that when the match end connects well with the train table, an increase in the platform capacity is more effective.

8.6.3 Increased visitors scenario

Table 13 - Absolute percentual change of standstill waiting times in the increased visitor scenario. Red numbers indicate non-significance

bin	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22
counts	1.9%	1.0%	1.0%	2.2%	5.1%	8.1%	7.8%	6.6%	5.7%	3.7%	2.8%
stop position readjustment	+0.9%	+1.4%	+2.1%	+4.0%	+4.2%	+1.8%	+1.7%	+1.4%	+0.2%	+1.1%	+2.1%
platform expansion	+8.6%	+10.3%	+10.3%	+8.5%	+4.5%	-0.1%	-1.0%	-0.5%	+0.8%	+2.4%	+1.4%
extra train	+7.9%	+8.0%	+12.9%	+11.3%	+7.3%	+0.4%	-2.5%	-3.0%	-2.2%	-0.3%	-0.5%
alternative turnstiles	+0.0%	+0.2%	+0.1%	+0.2%	+0.4%	-0.2%	+0.1%	+0.1%	-0.6%	-0.4%	+0.2%

bin	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38-40	40+
counts	4.3%	5.4%	5.6%	5.2%	4.1%	2.8%	2.1%	1.4%	0.8%	21.2%
stop position readjustment	+1.9%	-0.5%	-0.8%	-0.9%	-1.0%	-0.4%	-0.0%	+0.0%	+0.3%	-18.7%
platform expansion	-2.9%	-4.4%	-4.6%	-4.6%	-3.6%	-2.5%	-1.7%	-1.0%	-0.6%	-20.8%
extra train	-2.5%	-4.0%	-4.5%	-4.4%	-3.6%	-2.6%	-1.8%	-1.2%	-0.6%	-21.0%
alternative turnstiles	-0.3%	-0.9%	-0.5%	-0.3%	-0.5%	-0.2%	+0.3%	+0.3%	+0.3%	+1.7%

When examining the increased visitor scenario, the same trends as those previously discussed are observed, particularly when compared to the regular scenario. The extra train measure once again performs the best, reducing all waiting times longer than 12 minutes. The platform expansion measure is also quite effective at reducing waiting times exceeding 22 minutes, but it slightly increases the number of waits between 16 and 22 minutes. The stop position readjustment is particularly effective in reducing waiting times longer than 40 minutes, though it shows only slight improvements for the other waiting times. The alternative turnstile programme again has only a marginal impact on the standstill waiting times compared to the baseline.

8.7 SENSITIVITY ANALYSIS

To better understand the effects of the measures, the uncertainty in the output of the model has to be quantified. The model is based on some assumptions, and here the effects of these assumptions are to be quantified. Currently, the outflow rate of travellers from the stadium is assumed, and the number of people in the train is fixed at 100 people. Also, it is assumed that there are no alighting passengers in the train. Moreover, the sensitivity of the model to the social force parameters shall be analysed.

8.7.1 Altered outflow rate

The duration of the different phases in the outflow is fixed based on observations during matches. However, the exact number of people leaving the stadium in each phase is estimated using sample counts. Therefore, analysing the impact of alternative outflow rates is crucial.

In the model, the current outflow distribution is assumed to be 10/85/5% for the start-up, full-outflow, and end-of-outflow phases, respectively. To assess the effects of a different distribution, we consider a scenario where the number of people in the start-up and end-of-outflow phases doubles while maintaining the same time intervals. This adjustment results in a new distribution of 20/70/10%, reducing the outflow rate of people leaving during the peak full-outflow phase.

As shown in Figure 16, this adjustment leads to an earlier start of the outflow, allowing more people to board the first available train. Consequently, the peak number of people waiting in front of the turnstiles decreases by approximately 100. This reduction in congestion carries through the entire outflow period. Additionally, as illustrated in Figure 17, this change significantly decreases standstill waiting times over 24 minutes with a couple of percentages.

Seeing the relative small changes in standstill waiting times, the model is not that sensitive to an alternative outflow rate. It does affect the number of people in the queue, yet has no effect on the experienced density there.

Figure 16 - Number of people waiting on platform and at turnstiles compared to baseline

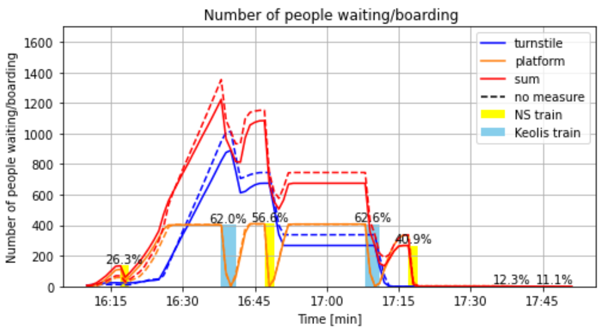


Figure 17 - Absolute change in percentage of people waiting with a certain waiting time

bin	no measure	altered arrival rate	bin	no measure	altered arrival rate
0-2	1.8%	+1.7%	22-24	3.5%	+0.5%
2-4	1.2%	+1.0%	24-26	4.5%	-0.3%
4-6	1.3%	+0.3%	26-28	4.6%	-0.5%
6-8	3.4%	-0.2%	28-30	5.2%	-1.1%
8-10	8.1%	-2.2%	30-32	4.3%	-0.5%
10-12	10.9%	-1.3%	32-34	3.9%	-0.9%
12-14	10.4%	-0.6%	34-36	4.3%	-1.1%
14-16	8.6%	+0.3%	36-38	3.3%	-0.7%
16-18	5.6%	+2.7%	38-40	2.4%	-0.8%
18-20	3.3%	+2.4%	40+	2.2%	-1.4%
20-22	2.0%	+0.8%			

8.7.2 Alighting passengers

Due to a lack of available data, alighting passengers have not been explicitly accounted for in the initial model. However, they can significantly impact train dwell times (Seriani, Fernandez, Luangboriboon, & Fujiyama, 2019) and influence platform density during the boarding and alighting process. To assess these potential effects, it is assumed that 10% of passengers arriving at Enschede Kennispark will alight from the train. This assumption allows for an evaluation of how alighting passengers contribute to platform crowding and affect the overall boarding process. Additionally, it is important to note that the presence of alighting passengers reduces the train's occupancy rate, which may, in turn, influence the capacity available for departing passengers.

Figure 18 - Number of people waiting on platform and at turnstiles

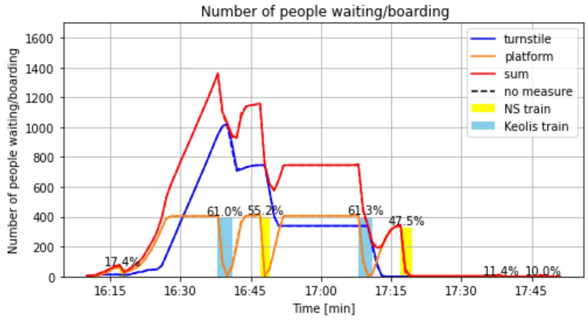
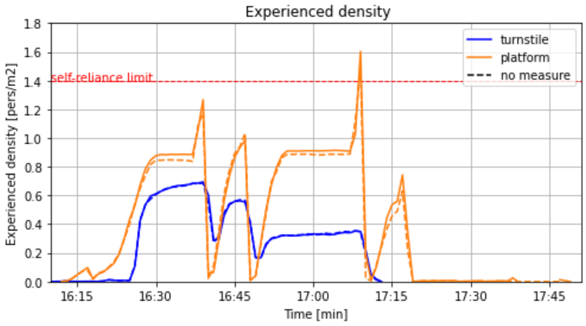


Figure 19 - Experienced density with alighting passengers scenario



When examining Figure 18, no noticeable difference is observed in the number of people on the platform or in front of the turnstiles when comparing the baseline scenario to the scenario with alighting passengers. However, the peaks in experienced density are approximately 0.1 persons per m^2 higher. This becomes particularly evident when comparing Figure 19 with the figures presented in section 8.1. Although the impact on dwell times is not visible, there is a measurable increase in platform density due to the presence of alighting passengers. However, given the relatively small proportion of alighting passengers, this effect remains marginal. There is no significant change in the standstill waiting times.

8.7.3 Higher number of people in the train

This assumption is of non-significance in most scenarios, as the number of people on the platform is always far below the occupancy of the trains. For instance, the occupancy of arriving trains should increase fourfold to over 410 people before there are problems with people boarding the train, given that a maximum of 400 passengers are waiting on the platform. However, an increase in the number of people in the train does have significant effects on the platform expansion measure. This measure is namely most affected by an alternative occupancy rate, as the trains are filled to the brim in this measure. Therefore, this scenario will be analysed with an increase of passengers from 100 to 200 people in the train.

Table 14 - Absolute change in relative waiting time counts comparing the widened platform scenario with 100 people in the train to 200 people in the train

bin	no measure	increased passengers in train	bin	no measure	increased passenger s in train
0-2	13.7%	-2.3%	22-24	0.7%	+1.2%
2-4	15.0%	-1.9%	24-26	0.5%	+0.8%
4-6	14.7%	-1.8%	26-28	0.3%	+1.1%
6-8	13.5%	-1.6%	28-30	0.2%	+0.9%
8-10	11.6%	-1.6%	30-32	0.2%	+1.0%
10-12	8.1%	-0.7%	32-34	0.2%	+0.9%
12-14	5.5%	-0.4%	34-36	0.2%	+0.7%
14-16	3.8%	-0.0%	36-38	0.1%	+0.6%
16-18	3.2%	+0.4%	38-40	0.1%	+0.5%
18-20	2.4%	+1.5%	40+	0.1%	+0.6%
20-22	1.0%	+1.7%			

The primary effect is an increase of 200 people on the platform after the departure of the first three trains. This leads to a rise in experienced density from 0.05 to 0.3 persons per square meter over a 20-

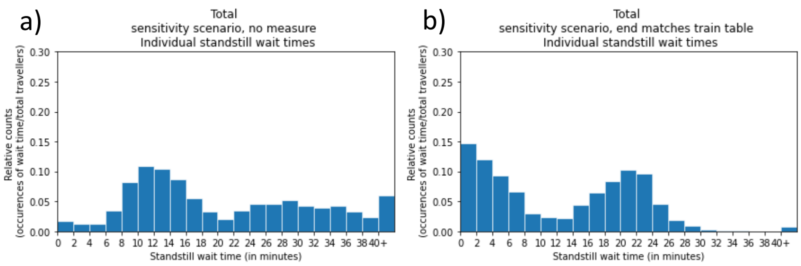
minute period. Whereas this density remains well below critical levels, the more significant impact is on waiting times. On average, waiting times increase by 0.7 minutes per person (Table 15), but the effect is particularly pronounced for those experiencing longer waits. Specifically, wait times exceeding 30 minutes are multiplied by a factor of five (Table 14), highlighting the disproportionate impact on those at the higher end of the waiting spectrum.

Table 15 - Delays due to different train occupancies in the regular scenario with widened platform

	Train occupancy of 100		Train occupancy of 200	
delay turnstile	28.6 hours	1.1 min/pers	28.8 hours	1.1 min/pers
delay platform	58.9 hours	2.2 min/pers	77.3 hours	2.9 min/pers
total delay	87.5 hours	3.3 min/pers	106.1 hours	4 min/pers

8.7.4 Good connection between match end and train table

As observed in the results, the timing of the match end significantly impacts standstill waiting times. To further illustrate this effect, an analysis was conducted comparing the no-measure scenario with two different simulation start times: 16:10 and 16:21. By delaying the match end by 11 minutes, exactly 400 people are present on the platform when the first Keolis train arrives. Additionally, the next NS train follows just 9 minutes later, ensuring a more continuous passenger flow. The impact of this adjustment on waiting times is presented in Figure 20.



bin	no measure	end matches train table	bin	no measure	end matches train table
0-2	1.8%	+12.9%	22-24	3.5%	+6.1%
2-4	1.2%	+10.8%	24-26	4.5%	+0.1%
4-6	1.3%	+8.1%	26-28	4.6%	-2.8%
6-8	3.4%	+3.1%	28-30	5.2%	-4.3%
8-10	8.1%	-5.1%	30-32	4.3%	-4.0%
10-12	10.9%	-8.6%	32-34	3.9%	-3.7%
12-14	10.4%	-8.1%	34-36	4.3%	-4.2%
14-16	8.6%	-4.2%	36-38	3.3%	-3.2%
16-18	5.6%	0.9%	38-40	2.4%	-2.4%
18-20	3.3%	5.0%	40+	6.0%	-5.3%
20-22	2.0%	+8.3%			

Figure 20 - Histograms of the regular scenario with simulation start at 16:10 (a) and 16:21 (b) and absolute relative change between those scenarios

Aligning the match end time with the train schedule reduces the total operation time by 11 minutes. This is expected, as the same trains are used for transporting all passengers, and the process begins 11 minutes later. The impact on standstill waiting times is particularly notable, with the histograms shifting significantly to the left, indicating a reduction in waiting times comparable to the effects of an expanded platform. This improvement is also reflected in the delay data (Table 16), where the average delay per person decreases by nearly 7 minutes. However, no significant differences in density are observed.

Table 16 - Delay data

	No measure		End matches with train table	
delay turnstile	343.7 hours	12.9 min/pers	179.3 hours	6.7 min/pers
delay platform	81.3 hours	3 min/pers	61.9 hours	2.3 min/pers
total delay	424.9 hours	15.9 min/pers	241.2 hours	9 min/pers

8.7.5 Altered behavioural parameters

The social forces model relies on numerous parameters, each influencing the simulation results. One key parameter that has not been thoroughly discussed is the desired speed. Delays are calculated based on the discrepancy between this desired speed and the actual speed. However, the desired speed is also a crucial factor in the social forces model itself, as it significantly impacts pedestrian movement, including flow rates (Helbing, Farkas, & Vicsek, 2000; Ma et al., 2019).

Currently, the desired speed is assigned to each pedestrian based on a distribution derived from Fruin (1971) (PTV, 2022). Since multiple distributions are available, an alternative distribution is tested to evaluate its impact. Specifically, the IMO<30 distribution is used, which represents walking speeds for individuals under 30 years old. This distribution is defined by the International Maritime Organization for modelling pedestrian movement in ship evacuations. The differences between the two distributions are illustrated in Figure 21. Notably, the distributions differentiate between male and female pedestrians, as studies have shown that males tend to walk significantly faster.

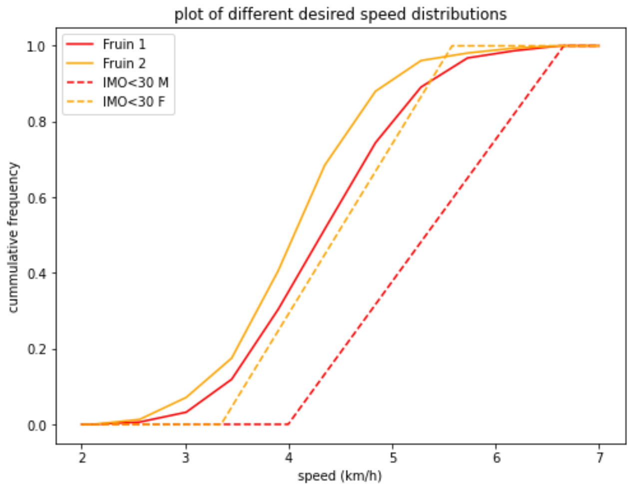


Figure 21 - Difference between speed distributions in Vissim

The result of this alternative desired speed distribution has a large effect on the density while waiting, but surprisingly lowers the peaks when boarding a train (Figure 23). The passengers are also a bit quicker to pass through the turnstiles (Figure 22), this only does not have a significant effect on the standstill waiting times. To get better insight into the experienced density, it would thus be important to further analyse the speed distribution used in the model. For instance, with strategies proposed by Ma et al. (2019).

Figure 22 - Number of people waiting/boarding considering an alternative speed distribution

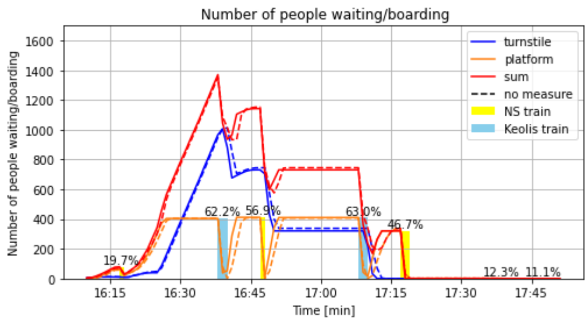
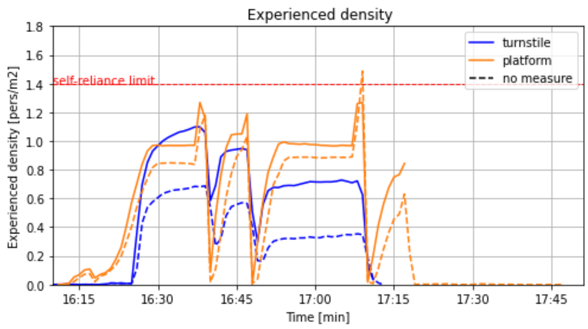


Figure 23 - Density in a scenario with an alternative speed distribution



9. DISCUSSION

With regards to the measures, there are still some points left for discussion, which will be handled in this chapter. Next, a modelling study inherently makes some assumptions, and although the effects of the main assumptions are tried to be quantified, there are still some other effects on the results which will be explained here. Finally, the research approach shall be discussed upon and recommendations will follow out of this.

9.1 MEASURES

Concerning the measures, no strategies involving direct communication with pedestrians were studied. These were excluded due to the need for a different type of modelling approach to accurately simulate their effects. In the microscopic simulation model based on the Social Force Model (SFM), implementing such measures would first require defining their—currently unknown—impact on pedestrian behaviour. This would result in findings based on assumed effects rather than empirical data, making it difficult to draw reliable conclusions. However, communication and information provision should not be overlooked as potential measures to mitigate misbehaviour.

For instance, clearer indications of the routes travellers should take to access the platforms could reduce unnecessary circulation and alleviate congestion in the central underpass. This could be achieved through temporary signage during a match or by providing travel information alongside FC Twente tickets. Additionally, frustrations caused by encountering closed gates and being redirected could be minimised. This aligns with Berkowitz (1989), who argues that frustration often stems from an inability to achieve a goal. Furthermore, when turnstiles are closed, real-time information should be provided on the reason for closure and the expected waiting time, as suggested by Martella et al. (2017). Even better, travellers could be engaged during their wait—for instance, by installing flatscreens showing match highlights—to enhance the perception of occupied time and reduce frustration (van Hagen, 2011).

A measure that was not considered is flattening the peak outflow by reducing the outflow from the stadium. This was excluded as it involves managing flows within the stadium, which falls outside the scope of this research conducted for the rail operator NS. Peak spreading could be facilitated by organizing a post-match event, but this comes with significant uncertainties. If the event is too attractive, the peak outflow is merely delayed, whereas if it is not appealing enough, it has no effect. Moreover, for late-ending matches this measure would not be feasible, as train availability is already stretched to its limits and delaying the outflow could further compromise the ability to transport all visitors.

Regarding the analysed measures, there are still opportunities for improvement. For instance, the platform capacity in the widened platform scenario is currently set too high compared to the train's capacity. Adjusting this capacity to ensure that all waiting passengers can board the train would help reduce overcrowding issues during boarding. However, to set this capacity more accurately, a detailed analysis of train occupancy rates is required. This would allow for tailored platform capacity limits based on the type of match and the expected number of passengers at different times. To facilitate this, NS and Keolis would need to share their ridership data, enabling a more precise calibration of platform use.

Additionally, combining multiple measures could further enhance efficiency. For example, introducing an additional train alongside train stop readjustment to better distribute passengers along the platform could significantly increase discharge capacity. Without requiring major infrastructure modifications, this strategy could allow up to three trains to transport 530 passengers per half hour, effectively increasing the hourly capacity to 3,180 people—nearly doubling the current limit of 1,600. Such an increase would drastically reduce the time needed to clear the station, cutting overall operation time in the regular scenario to just half an hour.

9.2 ASSUMPTIONS AND SIMPLIFICATIONS

First of all, the outflow from the stadium is assumed and highly dependent on the type of match that is played. Despite efforts to validate these assumptions with the Grolsch Veste / FC Twente, no response was received. As a result, the outflow data remains an estimate derived from project visits and varies according to match characteristics. For instance, if a match is uneventful, more spectators may leave early to catch a train, whereas a tense match decided in the final moments may either prompt a rapid mass departure or delay the peak significantly. The results and sensitivity analysis indicate that the match end time and to a lesser extent arrival rate of passengers significantly impacts standstill waiting times and delays. Further research could focus on gathering more quantitative outflow data with a field study.

Several other simplifications have been made regarding pedestrian movement. Firstly, it is assumed that no passengers alight from the trains. Observations indicate that only a small number of passengers disembark, and due to the lack of reliable data, they have been entirely excluded from the model. While their impact is minimal, it is important to acknowledge this limitation. Additionally, some peak flow spreading occurs due to the presence of snack bars located on the opposite side of the central underpass. These have also been disregarded for similar reasons, although their effect is likely more significant. This is not only due to their role in dispersing peak flows but also because they increase the usage of the underpass. Moreover, the model only simulates individual pedestrians, whereas match attendees typically travel in groups. The model thus likely overestimates the pedestrian throughput, as individuals move freely in available space, whereas groups tend to wait for each other (Challenger et al., 2010a).

Another assumption is the distribution of passengers over the platform. In the simulation model pedestrians got assigned a random place to wait on the waiting area representing the platform. Where the platform was wider, more pedestrians would thus wait. To simulate the reluctance of passengers to walk to the end of the platform, a smaller waiting area is modelled (PTV, 2022). Visual inspections by the researcher and a crowd manager comparing the simulation model with the real-life situation yielded that this approach was applicable. However, more experts could have been contacted to validate the model.

The absence of flow data also affects the calibration of parameters within the social forces model. Currently, these parameters have been calibrated based on walking times and observed densities. However, multiple parameter sets can produce the same walking times and densities, as illustrated in Appendix H.2 (Kretz et al., 2018). If more accurate data were available—such as the exact times when the turnstiles opened and closed, along with the number of people passing through—this calibration could be further refined. The desired speed of pedestrians, assigned by a speed distribution, could also be further analysed. It has been shown that this desired speed significantly impacts density, suggesting that more accurate distributions for pedestrians in this specific use case could be developed. In this simulation study, the Fruin distribution is used, which is suitable for passengers in public spaces. However, the IMO<30 distribution yields higher densities in the simulation results but is less appropriate for this study, as it represents the walking speeds of individuals under 30 years old on ships, who are likely healthier and walk faster than the average football match attendee.

A last point of discussion with regards to the pedestrian behaviour is the different sets of social forces parameters needed to adequately capture the behaviour of the pedestrians waiting in front of the turnstiles. By altering the parameter set, there is also less creep in this area. Creep is the motion where people gradually move forward in a queue even though the service point has not advanced (Challenger et al., 2010a). This effect is assumed to be marginal, but does influence the effects on the density in front of the turnstiles. It also might explain why in some results the density in front of the turnstiles is less than on the platform, even though there are more people waiting in front of the turnstiles. However, to further improve the model in this regard, far more research is needed into simulation of queues in social forces models. Especially the associated behavioural parameters could further be calibrated, yet more accurate data should be gathered to do that.

9.3 RESEARCH IMPLICATIONS AND IMPROVEMENTS

A recurring challenge in this study is the limited availability of data, which has constrained model calibration. Key details, such as actual train arrival times and precise platform crowd numbers, were unavailable. Consequently, the model relies on assumptions based on current practices, raising questions about its realism in capturing pedestrian movement. However, as far as could be studied, the pedestrian movements in the model align with observed behaviour. While efforts were made to match available data, further refinements in pedestrian behaviour, numbers, and arrival rates are needed for greater accuracy and precision. This does not render the model ineffective but rather positions it as a valuable tool for comparing the relative effectiveness of different measures across scenarios.

Even though communication and information provision measures could not be modelled with the Social Forces Model, this model was still chosen as most suitable for the research approach. This approach made it possible to analyse the standstill waiting times of pedestrians, which was identified as one of the main impactors on the mood of individuals. Further research could focus on how to adequately capture such measures in a Social Forces Model.

With more time for this research, the problem analysis could have been expanded with semi-structured stakeholder interviews. Currently, stakeholder perspectives are based on informal discussions, literature reviews, and general knowledge of stakeholder types. Conducting interviews specific to this use case would have provided a deeper understanding of the issues and revealed diverse perspectives on potential solutions. Additionally, the focus group validating the scenarios and model could be expanded with the interviewees, enhancing the robustness of the findings.

While increasing transportation capacity is crucial for reducing waiting times and has the greatest impact on visitors, alternative measures, such as improving crowd management strategies or enhancing visitor communication, could also be effective. In fact, these measures might better serve other stakeholders, such as crowd managers, who benefit from minimal preparation and reliable systems. For instance, during one event last year, the turnstiles failed to unlock, forcing a last-minute crowd management adjustment. As a result, people had to enter through a side gate, eliminating controlled entry limits and raising safety concerns.

As mentioned above, stakeholder interviews could shine a light on these issues. Another method that could be applied is the use of a questionnaire to get a better understanding of the experience of visitors. By using such survey, the effects of measures focussing on information provision and waiting engagement could be quantified. This is a direction for further research. Additionally, further research could carry out an observational study to assess the effects of the stop position readjustment measure and the extra train measure, to provide better insight into the actual effects of these measures.

10. CONCLUSION

This research aimed to reduce misbehaviours at Enschede Kennispark following football matches at the Grolsch Veste by providing recommendations to the social security manager of NS to decrease the actual and perceived waiting times. The problem analysis showed that especially the waiting times for travellers in the direction of Hengelo and further were problematic. Therefore, this study focused on this direction of the outflow.

Reducing both actual and perceived waiting times can lead to a decrease in passenger misbehaviour. Perceived waiting times, in particular, can be minimized through various strategies, such as enhancing the waiting environment, providing clear information on the causes of delays, altering the perception of the wait, or preventing complete standstills. However, perceived waiting times cannot directly be measured. At Enschede Kennispark, standstill waiting times range from 15 to 45 minutes, suggesting that the greatest improvements in passenger behaviour can be achieved by addressing this issue.

The objective of this study was then to provide recommendations for reducing actual waiting times at Enschede Kennispark station by analysing various scenarios using a microscopic pedestrian simulation model. Three representative scenarios were identified: 1) a regular match on Sunday afternoon, which is an often recurring match and representative for any match at the weekend. 2) A match with a late ending at 23:00. Due to the late ending, there are only a few trains in the train table, resulting in longer waiting times. And 3) a match with increased travellers, which might well be possible if the Grolsch Veste continues with its expansion plans.

Four suitable measures are identified to reduce the waiting times: 1) stop position readjustment, 2) platform expansion, 3) an extra shuttle train, and 4) an alternative turnstile programme. Other measures either had limited expected benefits, potential negative side effects, or the impact could not be accurately assessed with a microscopic pedestrian simulation. Measures addressing passenger information for instance would rely on assumptions about input variables.

The measures have been assessed on standstill waiting times, as these should be avoided. But standstill waiting times alone were not sufficient, as reducing them could compromise the physical safety of the crowd. Therefore, additional performance indicators were considered, including experienced density, train occupancy, and delay. These aspects provided insights into physical crowd safety, crowd comfort, and the average travel times of the measures.

It can be concluded that the extra train scenario performs best in terms of reducing standstill waiting times and has a positive benefit in that the waiting times and discharge of travellers are less affected by the match end time. Moreover, a shuttle train could also stop at stations between Hengelo and Almelo, making it more attractive for people travelling in these directions. A downside is that an extra train is quite an expensive measure, which also fills up the train network even more, making it more susceptible to delays. The platform expansion scenario performs almost as well in reducing the standstill waiting times for pedestrians, but quite definitely results in delays for trains and dangerously high crowd densities at the platform entrance and the whole platform once a train arrives.

The stop position readjustment performed a bit worse in terms of delay compared to the other two measures but is still a huge improvement when compared to the baseline scenario. This measure also has very few drawbacks, as there are no extra costs involved, except for the need to implement a system for machinists to know where to stop. It would take some time for travellers to get accustomed to this new practice, or investments may be needed in informing the public of this practice. The alternative turnstile programme has a slight negative effect on standstill waiting times, but shows a positive effect in alleviating crowd density before and after the turnstiles. However, implementing this would require investment in the turnstile system. Moreover, passengers waiting in front of the turnstiles may fail to understand the rationale and could become frustrated if only one or two turnstiles are open, despite there being additional turnstile options.

This report recommends that the social security manager of NS prioritise the readjustment of train stopping positions. This would reduce overall crowd management time by 10 to 20 minutes, depending on the match's end time. It also reduces the standstill waiting times. If further improvements are desired, consideration should be given to arranging a shuttle train or expanding the platform, taking into account train occupancy rates. Implementing an alternative turnstile program would only be effective if the density before and/or after the turnstiles is problematic and when flow rates through the turnstiles can be adjusted dynamically.

Further research could focus on improving the social forces model to better capture the effects of information provision or lights/music and scent, such that these types of measures could also be employed and quantitatively analysed. Another improvement can be made in the simulation of queues and the respective behaviours in the social forces model. Social Force parameters and desired speed could be analysed and calibrated by setting up experiments or carrying out observational studies to present standard combinations of parameters for different types of crowds. Lastly, an intervention study could be carried out in which the proposed measures will be applied to assess whether the predicted and actual effects are in line.

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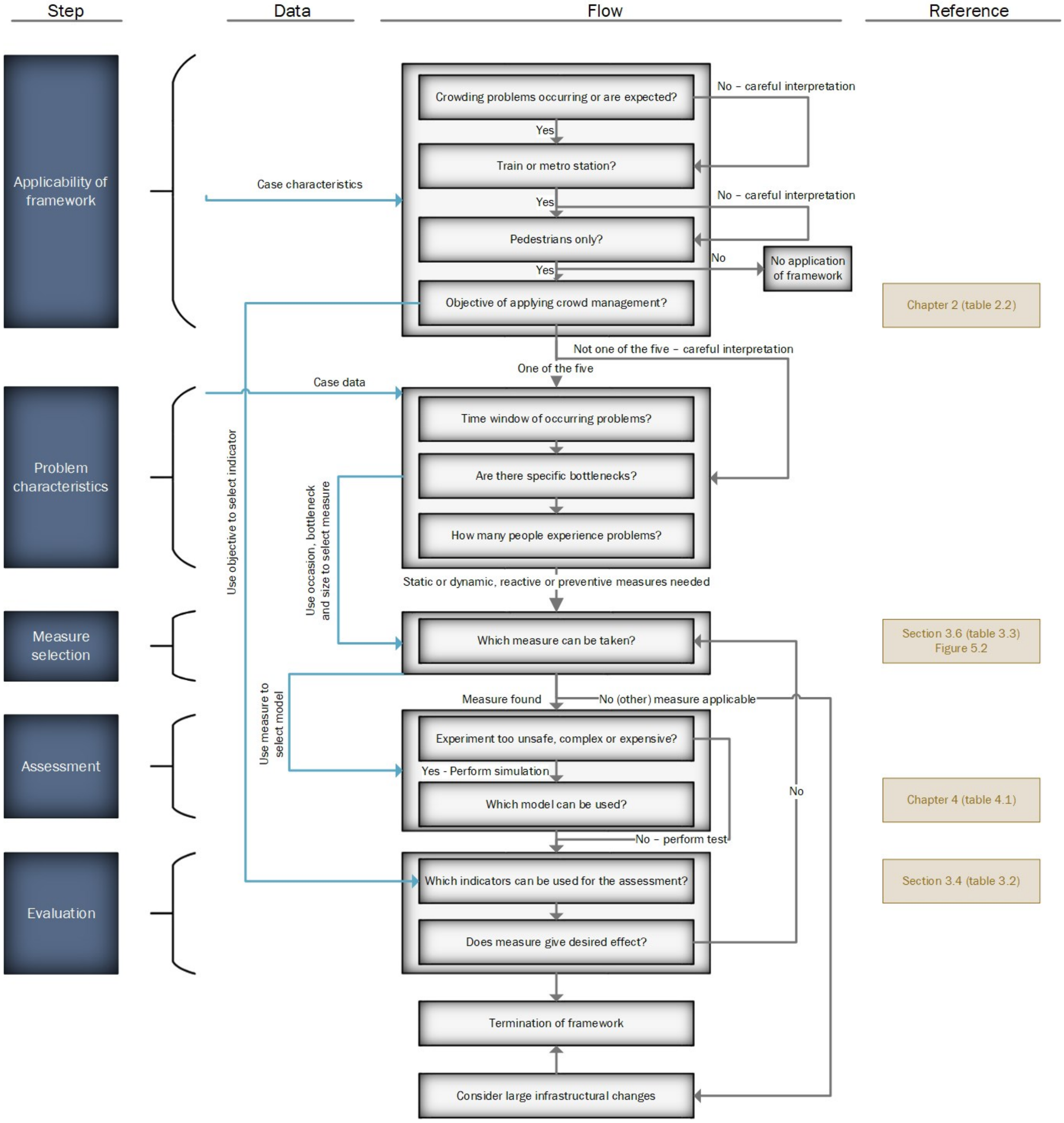
APPENDIX

APPENDIX A. LIST OF USED TOOLS

During the preparation of this work, the author used ChatGPT in order to improve the quality of writing such that the text conveys the message better. No sensitive information is given to ChatGPT. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the work.

APPENDIX B. FRAMEWORK OF MENSINK



APPENDIX C. MEASURES IDENTIFIED BY MENSINK

↑ Static — Dynamic ↓

		Increase throughput	Prevention of blockades	Distribution of traffic	Limitation of inflow	Effects off-peak	Punctuality	In-vehicle comfort	Self-organization	Surface area	Effects on minority travelers	Complicated (multiple stakeholders)	Communication required	For specific group only		
Measure	**Field of application**	**Strategy**				**Characteristics**									**Cost**	**Ref**
Creation of doors for each direction	Stations with 1 large door	x				-			+						€€€	
Funnel shaped corridors	Large angle corners	x							+	-					€€	
Separating bi-directional flows on path	Wide platform with bidirectional flow	x				-			+	-					€€	
Handrail on stairs	Stairs wider than 6 meters	x							+	-					€	[61]
Gates/kiosks/vending machines relocation	Queue interference		x							+		-			€€	
Increase attractiveness of route	Predetermined locations of less used exits			x										+/-	€-€€	[60]
Markings on floor	Crossings	x	x			-			+						€	[61]
Arrival tracks separation	Simultaneous arrival of trains			x			+					-	-		€€	
Fast and slow walking lanes	Longer stretches with more lanes in same direction	x							+				-		€	
Boarding/alighting procedure change	Counterflows and pressure when boarding	x	x				+		+				-		€-€€	[3]
Arrival pattern offset	Simultaneous arrival of trains			x			+					-	-		€€	[37]
Direction gate placement	Large crossing flows towards exits	x	x								-		-		€€	[45]
Headway decrease - #pax constant	Large flows after arrival			x								-	-		€€€	
Object in front of bottleneck	Bottlenecks with arch-forming	x	x			-			+	-					€€	[61]
Clear indication of less used exits	On predetermined locations of less used exits			x		-								+/-	€	
Information provision on train stopping position	Inefficient use of platform length and train doors (first and last wagons)			x			+	+							€-€€€	[46] [75]
Light/music/scent	Inefficient use of platform length and train doors			x			+	+						+/-	€€	[49] [71]
Waiting areas	Inefficient waiting or preparation for activity locations		x	x										+/-	€	
Only exiting/entering from station	Many travelers temporarily in same direction	x			x						-	-	-		€	[17]
Walking time information provision	Inefficient distribution over routes			x							+				€€	
Headway increase	Platforms structurally occupied			x	x		+	-			-	-	-		€	
Crowdedness indicator	Inefficient use of train doors			x			+	+				-	-		€€€	
Train stopping position adjustment	Inefficient use of exits			x		-	+								€	[69]
Escalator direction change	Heavy temporary loads	x			x						-				€	
Holding	Delay of vehicle			x			+				-				€	[74]
Boarding limits	Next vehicle nearby				x		+	+			-				€	[19]
Gating	Demands exceeding capacity				x		+	+			-				€-€€	[5]
Delayed arrival	Platform occupied with passengers from previous train			x			+				-				€	
Manual intervention to disperse	Stations where problems are expected frequently	x	x	x					+						€-€€	

APPENDIX D. ASSESSMENT OF LONG LIST OF MEASURES

The assessment of the long list of measures is based on the problem characteristics. As concluded there (in section 6.2.1), the measures should be static, preventive and reactive in nature. The location should be at no specific location or at the platform. And the measures should focus on no specific problem or at human blockades. Figure 24 shows the classification of measures in a diagram, where the applicable measures quickly show up. These are further assayed in Table 17, where a good or possible applicability is given based on the situation.

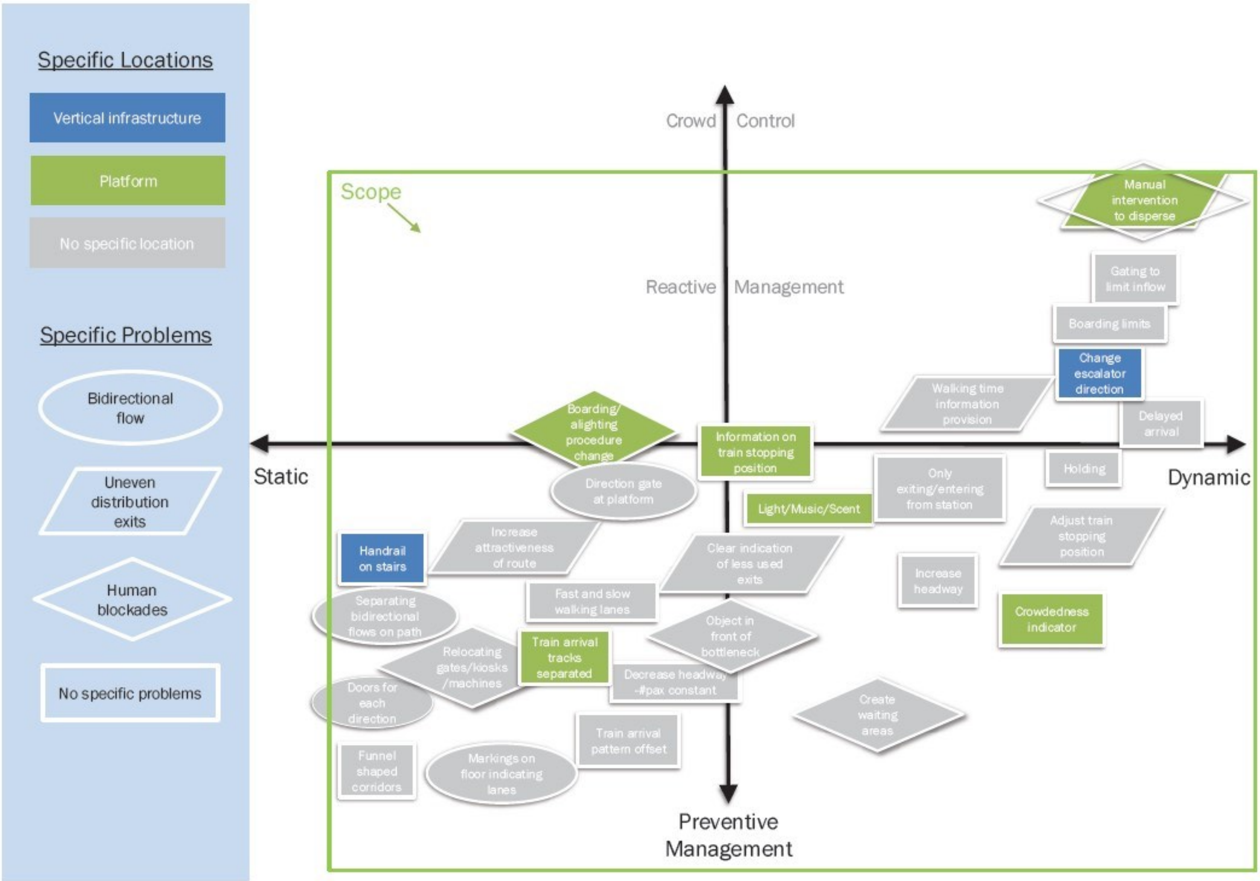


Figure 24 - Classification of measures by Mensink (2017)

Table 17 - Assessment table. FoA means there is no Field of Application for the measure.

Measure	Applicability
Creation of doors for each direction	FoA: no doors
Funnel shaped corridors	FoA: the problem is not in corners
Separating bidirectional flows on path	FoA: the bidirectional flows are not a problem
Handrail on stairs	FoA: stairs are not the problem
Gates/kisosk/vending machine relocation	FoA: not hindering the flow
Increase attractiveness of route	FoA: there are no other routes to take
Markings on floor	FoA: no problems at flows
Arrival tracks separation	FoA: trains do not arrive or leave from the same platform

Fast and slow walking lanes	FoA: not the problem at walking lanes
Boarding/alighting procedure change	Procedure is already good enough. First people alight, then board. Just a small amount of people alights altogether. To optimize this procedure, too large investments are needed.
Arrival pattern offset	FoA: not the problem that trains arrive at the same time
Direction gate placement	Possible applicability: Might serve to pre-sort between travellers taking the intercity and stoptrain, to avoid waiting on the platform.
Headway decrease - #pax constant	Good applicability
Object in front of bottleneck	FoA: efficient in panic situations, not the case.
Clear indication of less used exits	FoA: there is only one entrance and exit
Information provision on train stopping position	Good applicability, although the train already stops on approximately the whole platform
Light/music/scent	Possible applicability: strategically placed lights might distribute people more evenly over the platform. More research is needed.
Waiting areas	Possible applicability: More space for waiting allows for less crowding on the platform, and more room for movement, thus reducing the changes of people falling in the spoorbak.
Only exiting/entering from station	Possible applicability: There are no real bidirectional flows to split, because there are already separate entrances and exits to the platform.
Walking time information provision	No applicability: There is no choice between routes
Crowdedness indicator	FoA: Tries to optimize the distribution over platform and train, but after an event both will be totally full.
Train stopping position adjustment	Possible Applicability If trains stop closer to the stairs, people will likely board quicker.
Escalator direction change	FoA: there are no escalators
Holding	Possible applicability Mostly used to maintain a certain headway. It might be fruitful when a train arrives so close on its predecessor that there are not yet enough people on the platform to assure the full capacity of the train while it might be needed. Due to the cascading effects of delays, this option is not the most wanted one.
Headway increase	See holding.
Boarding limits	Good applicability Already applied. Might need some review.
Gating	Good applicability Is off course already used to avoid overcrowding. But might be used in different/other ways.
Delayed arrival	Not applicable. Serves to clear the platform from alighting passengers, which is not the problem in this case.
Manual intervention to disperse	Possible applicability Is also sometimes already done. But measure is quite costly.

APPENDIX E. PEDESTRIAN VOLUME PER TIME INTERVAL

The volume of travellers by train can be estimated well, the travellers using the underpass are still quite uncertain. To determine how many people use this underpass, the mobility plan of FC Twente Goudappel (2010) is used, with the modal split in Table 18. This mobility plan considers the future scenario of FC Twente, after the enlargement of 2011.

Table 18 - Modal split visitors FC Twente

Visitors	Absolute	Relative
Train	6,000	19%
Bike	1,900	6%
Bus (opponent)	1,000	3%
Regulated bus transportation	1,100	4%
Foot	500	1%
Car	21,500	67%
Total	32,000	100%

Figure 25 - Bicycle parking spots

By knowing the location of the parking spaces for cyclists, busses and cars, the number of people using the underpass can be computed. This will be done per mobility.

E.1. Cyclists

The bicycle parking can be seen in Figure 25 are given in red. The squares are regular parking for the station, and more closely located to Enschede. It is assumed that 50% of cyclists park their bike north of the station.

E.2. Bus

Transportation for the opponents is completely separated from transportation of the home fans. The opponent arrives by bus in a secluded section after which they can enter the stadium. They do not have to cross the station.

The regulated bus transportation is organized by the supporters associations from the neighbouring villages to get together to the stadium. The busses park north of the station, thus everybody using this transport mode has

E.3. By foot

All people arriving on foot come from the neighbourhoods in the direct vicinity of the station. These neighbourhoods are located on the north side of the station, and they thus have to walk through the underpass.

E.4. Car

The mobility plan of Twente is based on a study from 2009 in which the present parking spots are counted. These spots can be seen in Figure 26. To compute the actual number of parking spots, the observed capacity is used and where not specified the occupied spots are used. After this mobility plan, extra parking spots are realised, these are added to the computation. The parking spot capacity of the current and extra areas can be seen in Table 19. An occupation grade of 3.1 people per car is assumed in the study, which will also be used here. Differentiating the areas into ones for which the underpass is used to get access, a total capacity of 4647 is counted, translating to approximately 14400 pedestrians using the underpass to access their car.

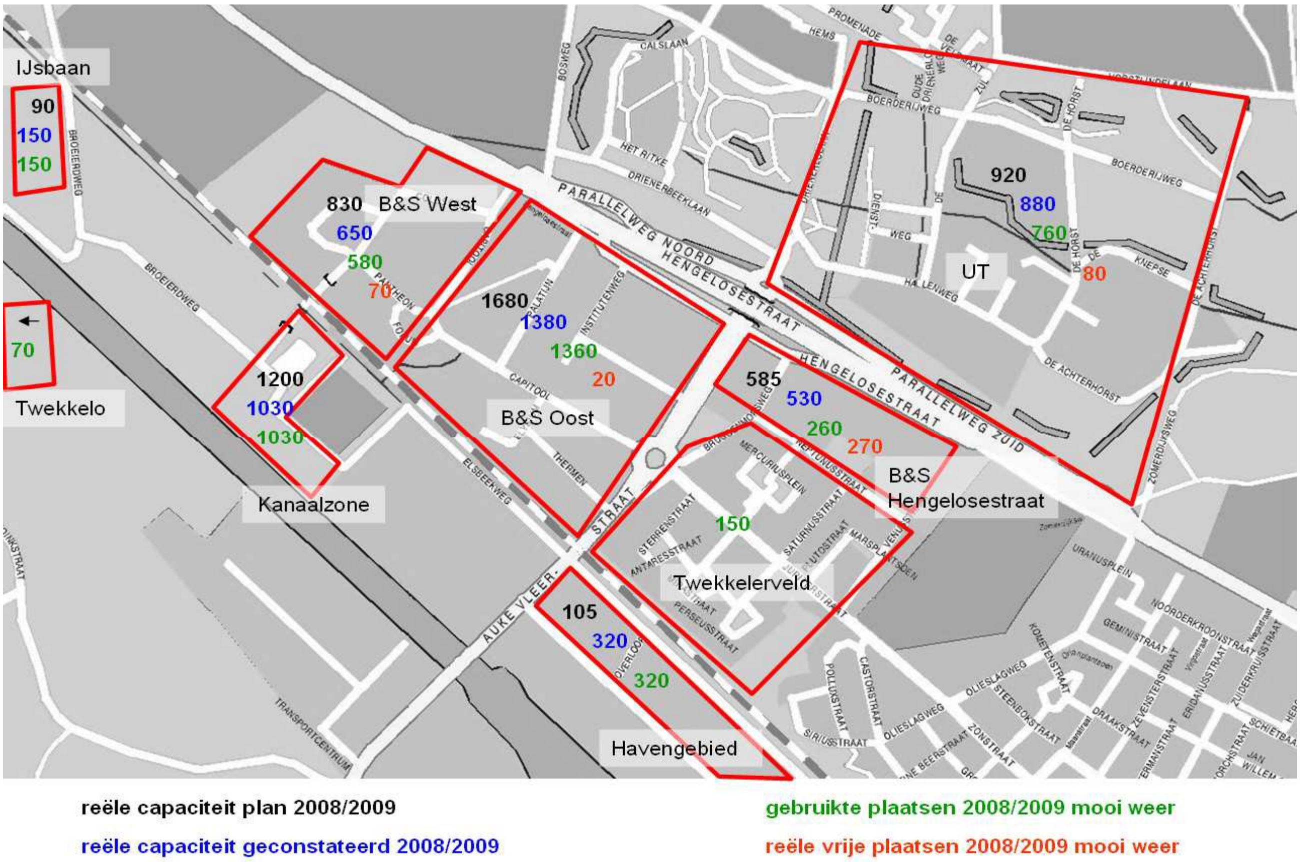


Figure 26 - Parking spots for the Grolsch Veste

Table 19 - Current and extra parking spots

Current parking areas			**Extra parking areas**		
Area	**Real capacity**	**Use of underpass?**	**Area**	**Real capacity**	**Use of underpass?**
UT	874	Yes	Intensifying current areas	380	Yes
Stadion	1031	No	Havengebied walking distance	80	No
B&S west	644	Yes	Havengebied shuttleservice	350	No
B&S oost	1378	Yes	Area municipality	250	No
B&S Hengelosestraat	531	Yes	Intensify P1	200	No
Havengebied	320	No	Area Vitens	600	Yes
IJsbaan	150	No	UT swimming pool	90	Yes
Twekkelo	70	No			
Twekkelerveld	150	Yes			
Total Current	**5148**		**Total Extra**	**1950**	

Table 20 - Maximum number of people using the underpass to access their parked car

Use of underpass?	**Parking spots**	**Number of pedestrians**	**Percentage**
Yes	4647	14400	65.5%
No	2451	7600	34.5%
Total	7098	22000	100%

E.5. Conclusion

To conclude, the maximum number of passengers arriving at the station, with the relative number of passengers using the underpass is given in Table 21. This relative number is needed to compute the number of passengers when a less crowded match is visited.

Table 21 - Computation of relative number of people using the underpass

Visitors	**Absolute**	**Relative**	**percentage using underpass**	**Absolute using underpass**	**Relative using underpass**
Train	6,000	19%	0%	0	0%
Bike	1,900	6%	50%	950	3%
Bus (opponent)	1,000	3%	0%	0	0%
Regulated bus transportation	1,100	4%	100%	1,100	4%
Foot	500	1%	100%	500	1%
Car	21,500	67%	65.5%	14,400	45%
Total	**32,000**	**100%**		**16,950**	**53%**

APPENDIX F. CAPACITY CALCULATION OF PLATFORM

F.1. Current safe waiting capacity

The safe waiting capacity threshold is set at 0.7m² per traveller. While this indicates crowding, it ensures that travellers can still find a safe waiting space on their own. The first 1.8 meters of the platform are excluded from this calculation. This includes a 0.9m danger zone, which must remain clear at all times to prevent people from falling onto the tracks, and a 0.9m walking zone, which should be kept free for people to move along the platform. In situations where crowd control is enforced, the walking zone can also be used as a waiting area. Crowd control efforts should focus on evenly distributing the crowd across the platform. Additionally, only the sections of the platform where the train halts are considered in capacity calculations. This means platform capacity is dependent on the length of the train, as people are unlikely to wait far ahead of or beyond the train's stopping point.

Figure 27 - Real life view of platform 1

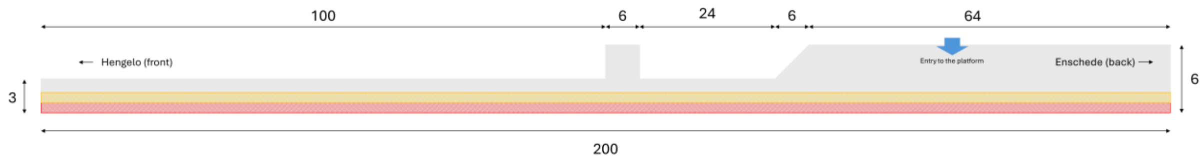


Figure 28 - Schematic view of platform 1, distance given in meters. The length is not to scale, the width is.

Platform 1, where trains to Hengelo are halting, is partly widened at the end of the platform, this creates a larger waiting area. But, since trains normally halt at the front of the platform, this area is not optimally used. Table 22 provides inside into the safe waiting capacity of the platform per train type, halting location, and whether crowd control is applied. It is decided that the safe waiting capacity is 400 pax, but it can be seen that with alterations, this capacity can be increased or decreased.

Table 22 - Safe waiting capacity per train type, halting location, and whether crowd control is applied.

			Stopping at the front				Stopping at the end			
Treinen	length	volnorm	effectief wachtgebied		wachtgebied met crowd control		effectief wachtgebied		wachtgebied met crowd control	
	[m]	[pax]	[m2]	[pax]	[m2]	[pax]	[m2]	[pax]	[m2]	[pax]
ICM-3 + ICM-4	187.7	728	389	556	558	798	426	609	595	850
DDZ-6	153.9	872	247	353	386	551	386	551	524	749
FLIRT Keolis 3+4	143.9	810	205	293	335	478	374	534	503	719

F.2. Safe waiting capacity when widening the platform

There are two options when widening the platform: (1) connecting the two current widened parts, or (2) widening the front of the platform. However there are some spatial difficulties. First of all, to connect the two widened parts, one should build a bridge over the central underpass, a costly operation. For the other option a bicycle parking is standing in the way. Due to the heightened tracks, there is some space required for the ground to slope down.

Option 1 will increase the safe waiting capacity with 141 people. This is because this part of the platform is always used by a train, and an widening linearly increases the safe waiting capacity.

The effect of option 2 depends on where the train halts. But the platform can be widened with 5 meters and still facilitate space for a gradual ascent and stairs as entrance to the platform. When halting at the front, the safe waiting capacity is increased with 643 people. When halting at the back, the capacity increase ranges from 242 to 555, depending on the train length. A sidenote which should be made is that when creating this extra waiting area at the front, people have to walk over the whole platform to arrive there. However, people tend not to do that, possibly creating bottlenecks and overcrowding on the back of the platform.

Table 23 - Capacity calculations for widened front of the platform

			Stopping at the front				Stopping at the end			
Treinen	length	volnorm	effectief wachtgebied		wachtgebied met crowd control		effectief wachtgebied		wachtgebied met crowd control	
	[m]	[pax]	[m2]	[pax]	[m2]	[pax]	[m2]	[pax]	[m2]	[pax]
ICM-3 + ICM-4	187.7	728	839	1199	1008	1440	815	1164	984	1405
DDZ-6	153.9	872	697	996	836	1194	605	865	744	1062
FLIRT Keolis 3+4	143.9	810	655	936	785	1121	543	776	673	961

APPENDIX G. OVERVIEW OF SIMULATED AREA

A complete overview of the simulated area can be found in Figure 29. Some adaptations to accurately model the stairs, turnstiles and waiting area in front of the turnstiles are further explained.

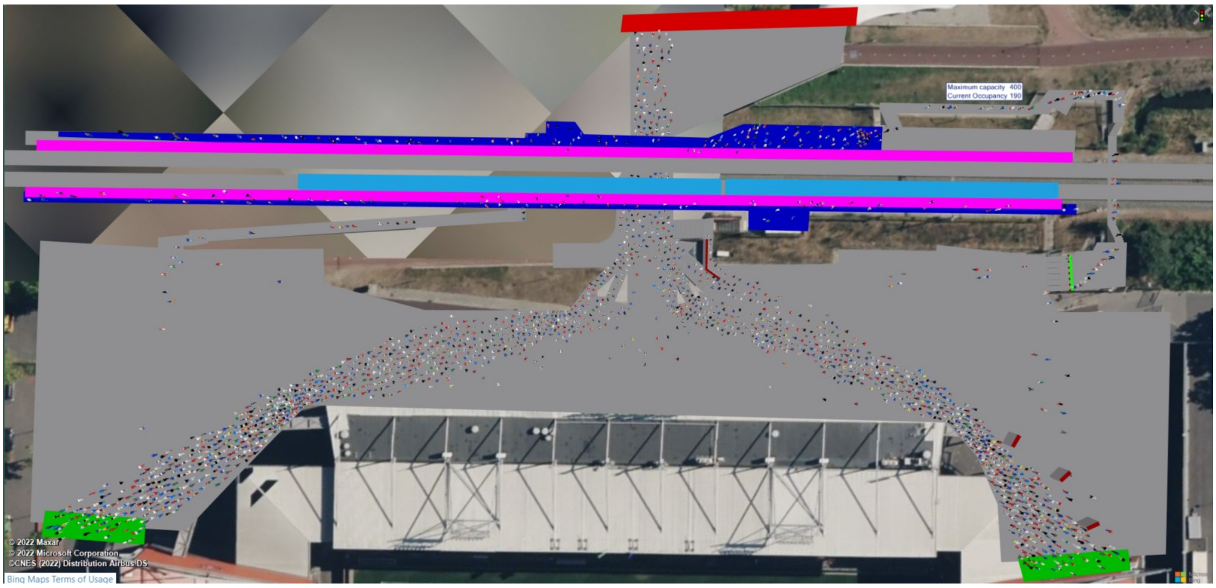


Figure 29 - Complete overview of simulated area (after 12:12 minutes)

The pedestrians originate from the green areas next to the station and walk towards the red and dark blue areas. The dark blue areas correspond to the waiting areas for the trains. Pedestrians will wait there until a train arrives, which they will board and then leave the simulation. The red area corresponds to all other directions pedestrians might walk to. They will leave the simulation once they arrive at this area. The light blue block is an Keolis train in the direction of Enschede.

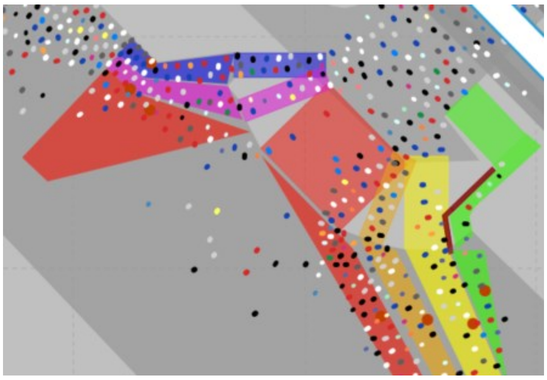


Figure 30 - Division of pedestrians over central staircase

In Viswalk, only straight staircases can be modelled. Therefore, the large staircase leading to the central underpass cannot be easily represented in Viswalk. Instead, five different staircases were partially overlapped to approximate the shape of the large staircase in the actual situation. Viswalk, however, recognizes the staircases as five separate entities. The choice of a staircase is made based on a partial pedestrian routing decision, where pedestrians choose the closest staircase. This is illustrated in Figure 30. Once a pedestrian walks onto an area with a specific colour, he will walk to the staircase with the corresponding colour.

The turnstiles are programmed with a Python script integrated with COM into Vissim. The turnstiles are shown as a signal head located on a short pedestrian link. The turnstiles close by turning the signal head red if the occupancy exceeds the capacity. The capacity can be set by a user-defined attribute in the signal heads attribute list. The occupancy is computed by adding the walk-in count of the area after the turnstiles and subtracting the boarded passenger count of leaving trains. Once a train has left the station, the signal head will turn green again.

APPENDIX H. PARAMETER CALIBRATION

The walking behaviour in Viswalk is based on the social forces model expanded by prof Dr. Dirk Helbing (1995). The pedestrians move freely in two directions. How they interact with each other and their environment is based on several parameters, which is further explained below.

The social force is the sum of two terms, the social isotropic and the social mean force. Both forces have an A and a B factor, where A defines the strength and B is the range of the social force between two pedestrians. These four parameters are defined as **ASocIso**, **BSocIso**, **ASocMean** and **BSocMean**. The difference between the isotropic and mean force is that the isotropic force is reduced by a factor **Lambda**, which takes into account how one is affected by events in the back versus events ahead. It is assumed that crowds are quite social and take people in their back into account when walking, which implies a higher lambda. Next, **VD** is used by the computation of the mean force, where VD represents a look ahead time. Furthermore, **Tau** represents the relaxation time or inertia that can be related to response time. **React_to_n** defines the number of closest pedestrians which are taken into account when calculating the total force for a pedestrian. The **noise** parameter adds a random force to the systematically calculated forces.

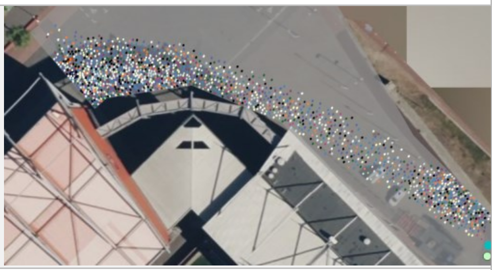
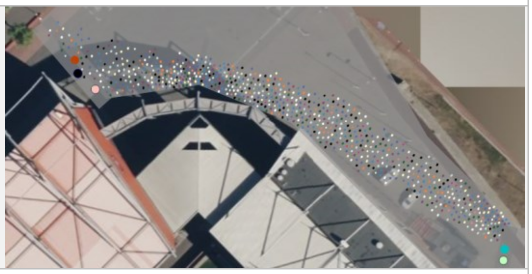
By using the default values for these parameters, two issues arose. First, a bottleneck occurred when pedestrians walked around the corner of the stadium. Since this bottleneck would not arise in a real-life situation, adjustments to the parameters were necessary. Second, the waiting area in front of the turnstiles resulted in unreasonably high crowd densities, far exceeding observed levels. Therefore, different parameter values were required to accurately capture this.

However, a single uniform parameter set could not resolve both issues simultaneously, as pedestrian behaviour differs significantly when walking versus when standing still. As a result, two distinct parameter sets were introduced. For both situations, criteria were defined to ensure that crowd movement aligned with realistic behaviour. This resulted in quite different parameter sets, which is logical due to the formulation of the social forces model. Most of the parameters do not have an immediate interpretation, and often one single parameter has an impact on many aspects of the walking behaviour (Kretz et al., 2018), resulting in two different parameter sets for walking and waiting.

H.1. Calibration of cornering the stadium

To come to adequate walking values when cornering the stadium, the following criteria are defined: First of all, the travel time of a single pedestrian from the pink dot to the green dot is approximately 100 seconds. This travel time should not be substantially higher in the modelled situation. Next, visual inspection of the situation should yield a crowd moving in unison, without people jittering (haphazardly moving one or another way), hugging the corner, or forming swift lanes. The final configuration used is presented in Table 24.

Table 24 - Results of walking behaviour calibration

	Default situation	Calibrated situation
situation after 650 seconds		
Avg travel time	271 s	108
# of stops (x1000)	931,8	1,2
	Parameters	
Tau	0.4	0.4
ReactToN	8	1
ASocIso	2.72	5
BSocIso	0.2	0.3
Lambda	0.2	0.8
ASocMean	0.4	0.8
BSocMean	2.8	2.8
VD	3	3
Noise	1.2	1.2

In the original configuration, it can be seen that pedestrians are hugging the corner. Furthermore, separate lanes are formed, where pedestrians following each other move more quickly, while other pedestrians have to wait. In a crowd with enough space to move, this behaviour is not expected, as people will keep more distance from each other (Corbetta, Meeusen, Lee, Benzi, & Toschi, 2018). A smaller tau (=0.1) results in people cramming together unrealistically, whereas a higher tau (=0.8) results in jittering behaviour and a larger bottleneck. Tau is thus kept the same. When ReactToN is set to 0, pedestrians no longer take each other into account. Each and every one of them takes the shortest route, resulting in a single row of pedestrians walking over each other. When set to 1, pedestrians do cram together but form more orderly lines in the crowd. The higher the value gets, the worse the pedestrians perform when moving around the corner, with outer pedestrians hugging the corner and cutting it for pedestrians on the inner side. A decrease in ASocIso (=1) means a drastic decrease in the distance between pedestrians, really cramming together (and being simulated into each other) in the corner. A higher ASocIso (=5) means a small increase in the distance between the pedestrians. The parameter BSocIso has an even larger correlation with the distance between the pedestrians. When set to 0.01, the pedestrians walk shoulder to shoulder, whereas a higher BSocIso translates immediately to a larger distance between pedestrians. A low lambda creates more jittering behaviour in the pedestrians, whereas a high lambda improves the flow through the corner. The same can be said from the ASocMean, where a high value creates more jittering behaviour. But since the ASocIso is almost doubled from the default value, the value for ASocMean is also doubled from the default value. When changing the values of BSocMean and VD no significant differences could be found. This could be explained by the fact that these terms are more relevant with opposing traffic, which is not present in this specific scenario.

H.2. Calibration of turnstile queue

Various alternatives were tested to develop a suitable solution that would allow the queue in front of the turnstiles to function effectively with the previously calibrated parameter set. For instance, by creating waiting queues, resulting in unreal queues as can be seen in Figure 31.

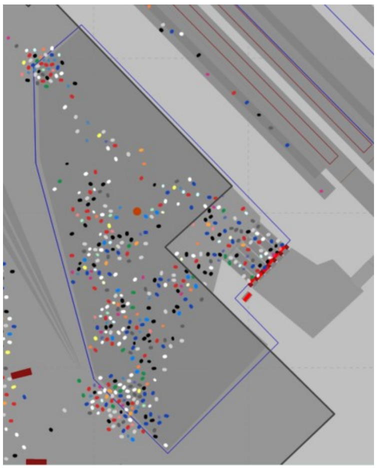


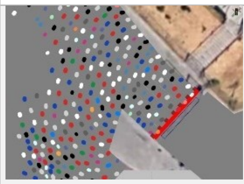
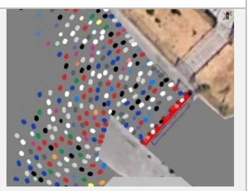
Figure 31 - Waiting for turnstiles when using waiting queues

However, none of these alternatives proved successful, necessitating the use of an alternative parameter set. The calibration of this parameter set is based on two key criteria: the density of people in front of the turnstiles and the time required for 400 people to pass through them.

With the default parameters or earlier calibrated parameters the densities before the turnstiles became unrealistic high, reaching almost 4 people per square meter. During visual inspections an average of 8 people per queue was found, resulting in a density of 1.6 people per square meter. Next to that, the parameter set should guarantee that once the turnstiles open, the people move timely through the turnstiles. Depending on the parameters, this time had still a quite large range. The results are given in Table 25 below.

Due to the time it takes for 400 people to pass the turnstiles, the parameter set of option B is preferred over option A.

Table 25 - Results of turnstile queue calibration

	Default values	**Football Supporters**	**Option A**	**Option B**
situation with full queue [after 100s]				
Density [people/m^2]	3.8	5.8	1.6	1.8
Seconds it takes for 400 people to pass	88	54	201	114
		Parameters		
Tau	0.4	0.4	1.2	0.2
ReactToN	8	1	4	20
ASocIso	2.72	5	2.7	4
BSocIso	0.2	0.3	0.4	0.8
Lambda	0.2	0.8	0.176	0.1
ASocMean	0.4	0.8	0.4	0.4
BSocMean	2.8	2.8	2.8	5
VD	3	3	3	3
Noise	1.2	1.2	0	0

APPENDIX I. NUMBER OF REPLICATIONS

Since the model is stochastic, multiple replications with different random seeds are needed to make sure the outcomes have statistical relevance. The number of runs needed can be computed by determining when the maximum allowed relative error of a Performance Indicator falls within a certain confidence interval. The method and equation to compute this is adapted from Bruijl (2022).

$$n^* = \min_n \left(\frac{t_{i-1,1-\frac{\alpha}{2}} * \sqrt{S_i^2/i}}{|\bar{X}_i|} \leq \frac{\gamma}{1+\gamma} \right)$$

Where
n^* is the determined number of replications
t is the t-value based on i replications and a confidence level α
S_i^2 is the variance at the current analysed number of replications
$\bar{X}_i$ is the mean at the current analysed number of replications
γ is the maximum desired relative error

The number of replications needed is to determine how many runs are needed for statistically significant results, such that one more extra run does not contribute to the significance. To determine this value, multiple runs with different seeds are run and afterwards evaluated when the average values fall within a confidence interval. The individual wait time per person is used to determine the minimum number of runs, because this is the indicator that is most dependent on the stochasticity.
In Table 26 the minimum number of runs required to come to statistical significant results is given. An analysis is done for two different confidence intervals and three different relative errors. For the most bins, only a small number of replications is needed. Interesting to see is that at minute four, no minimum required number of runs can be found. This can be explained by the fact that there is a very low number of counts in this bin. This fact is observable at each bin: where the average is lower, the required number of runs is also higher.

Table 26 - Number of runs needed to achieve a certain confidence interval given a relative error. Based on a total of 30 runs. None values mean that more than 30 runs are needed for significant results.

		95% confidence, different relative errors			90% confidence, different relative errors			count after 30 runs	
		20%	10%	5%	20%	10%	5%	average	stdev
Minutes	0	3	3	3	2	3	3	181.2	19.1
	2	3	4	7	3	3	5	96.9	24.5
	4	None	None	None	None	None	None	1.3	1.2
	6	9	19	None	7	15	None	8.4	2.9
	8	4	7	24	4	6	17	18.2	4.2
	10	4	5	11	3	4	8	39.9	8.0
	12	2	3	5	2	2	4	74.3	9.9
	14	3	3	5	2	3	4	100.3	9.2
	16	2	3	3	2	2	2	118.0	13.7
	18	3	4	7	3	3	5	100.6	32.5
	20	2	5	10	2	2	7	38.0	8.5
	22	3	4	10	3	3	8	43.6	9.7
	24	4	6	10	2	4	8	38.9	10.2
	26	6	20	None	5	10	None	14.5	9.4
	28	None	None	None	None	None	None	0.2	0.6

Based on this data, it is chosen to go with seven replications. This is a number where, looking at the 95% confidence interval, most bins are covered, while at the same time not much improvement can be made by increasing the number of runs.

APPENDIX J.SHUTTLE TRAIN

To check whether a shuttle train fits in the network, it is essential to have an overview of all trains. Prorail and all rail operators use Donna for this. Donna is a software package in which all trains are being planned. Time-space diagrams show which train is at what timestep at what place. For a Sunday this results in the diagram in Figure 32.

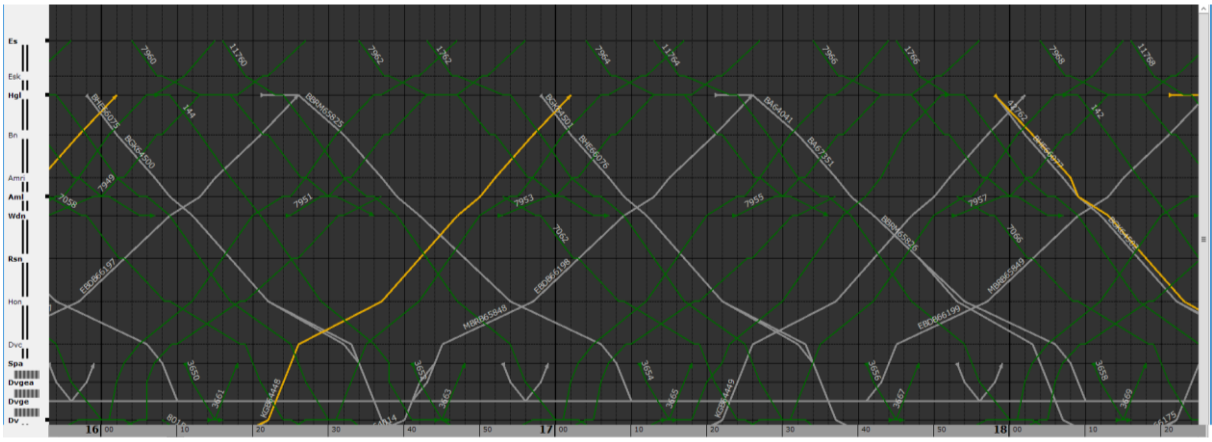


Figure 32 - Space-Time diagram of all trains between Enschede and Deventer

On the x-axis the time is given, on the y-axis the place. Hengelo is abbreviated to Hgl, Enschede to Es and Enschede Kennispark to Esk. Each dark green line is a passenger train. Each grey and golden line is a freight train. In this diagram, the shuttle train can be planned, which can be seen in Figure 33. The single trajectories of the shuttle train are given in blue. Due to other trains at Almelo, it is impossible for the train to stay put for 24 minutes before it should travel back, so an other solution has to be found.

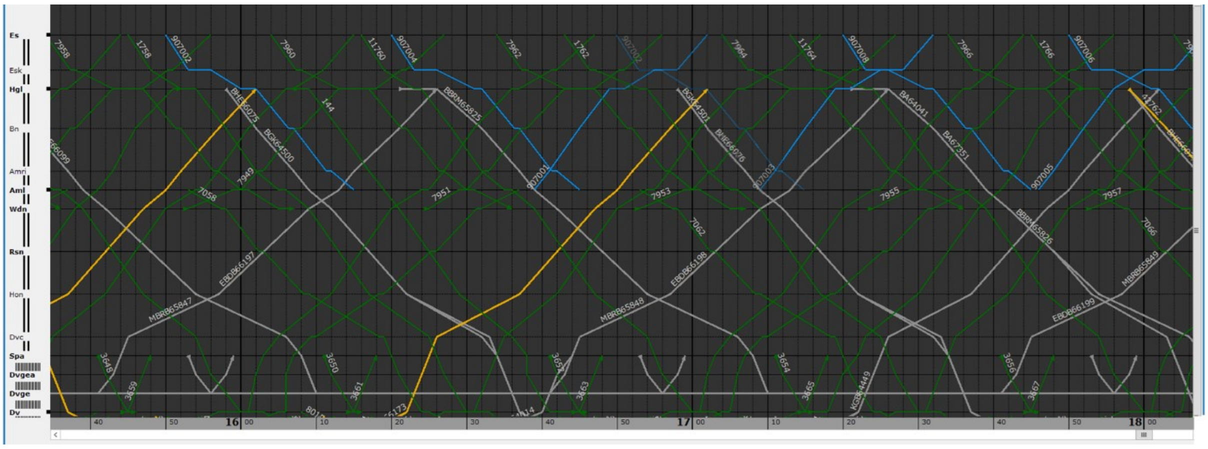


Figure 33 - Space-Time diagram with shuttle train in Blue

The shuttle train could either connect to the 7000 series (which is also done on weekdays), or the timetable has to be altered just a bit such that the shuttle can return within 6 minutes without hindering other trains in the timetable. Connecting to the 7062 is difficult in weekdays, as this train is only travelling once per hour. This would mean that the shuttle train could only be added once per hour. The benefit is that this would only take one extra trainset.

The timetable could also be altered a bit, such that the shuttle train departs from Enschede a bit earlier than illustrated in Figure 33, and departs a bit later from Almelo (Aml). It is then not possible for the shuttle train to stop on stations between Almelo and Enschede Kennispark, which is not deemed a problem since the traveller peak flow is not there.

For weekdays the same two options apply. Only then, the 7000 series travels every half hour, thus connecting the shuttle train to this series can also be done every half hour, resulting in a Space-Time diagram as can be seen in Figure 34. This diagram repeats itself every two hours.

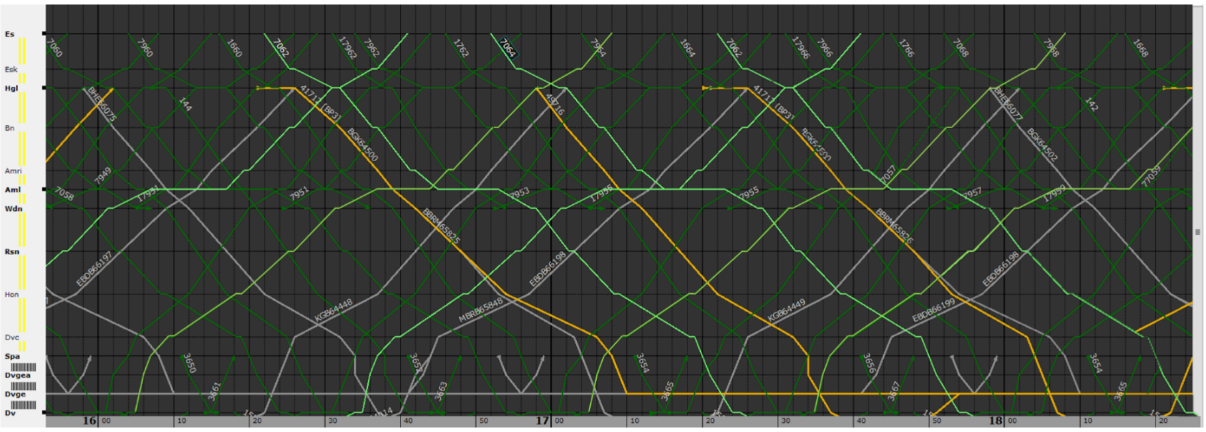


Figure 34 - Space-Time diagram of a rush hour in a week day. The 7000 series is marked in light green

Independent of the different options, the shuttle train will have roughly the same departure times at Enschede Kennispark which can be seen in Table 27

Table 27 - Resulting time table of shuttle train at Enschede Kennispark

Direction	Arrival time	Departure time
Enschede	XX:03	XX:05
Hengelo	XX:23	XX:25
Enschede	XX:36	XX:38
Hengelo	XX:52	XX:54