Analysis and evaluation of passenger flow at the Next Generation Station using microscopic simulations

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Abstract. The impact of mankind's change of climate system and ecosystem is evident. Nonetheless the society's need for mobility is still growing. Having these points in mind a transformation of mobility from fossil fuel based to renewable energy based is required. The German government is giving great hope on railways as a mode of transport implementing one aspect of this transformation. A growing number of passengers poses a tremendous challenge of the railway infrastructure, since nowadays train stations already reach their capacity limit at peak times. A train concept developed by the German Aerospace Center called Next Generation Train is one answer to this challenge. In this paper, we evaluate the performance regarding passenger flow of the corresponding station called Next Generation Station. To this end, we implemented a microscopic simulation of the Next Generation Station with input parameters such as expected number of passengers, walking speed distribution and dimension of passengers. The transfer time of passengers serves as key performance indicator during the simulation. We compare this transfer time with the reference value for train stations adopted by the German Rail. The methodology developed in this paper can be transferred to existing train stations.

Keywords: Next Generation Station, Next Generation Train, Passenger simulation, Passenger transfer time, Key performance indicator.

1 Introduction

The society's growing need for mobility and the associated burden on the environment and climate pose enormous challenges worldwide. The German government is giving great hope on railways as one mode of transport. It schedules a doubling of transport performance in passenger rail transport by 2030 [1]. This ambitious goal represents a huge challenge for the entire rail infrastructure. In addition to control and safety technology, track network and rolling stock, train stations need also to be able to handle the significant increase in passenger numbers [2].

However, some train stations are already reaching their capacity limit at peak times or their load limit as passenger numbers increase [3, 4]. In addition to enormous investments in station infrastructure, new concepts are necessary to ensure comfortable and efficient transfers in the future despite increasing passenger numbers.

The concept Next Generation Train (NGT) developed by the German Aerospace Center (DLR) is an answer to the challenge of increasing passenger capacity. This concept comes along with some paradigm changes, such as double-deck multiple-unit vehicles, missing stairs inside the wagon, simultaneous boarding and alighting of passengers, both on the lower and upper level, to reach the goal [5, 6]. Therefore, a new train station concept is necessary. Having this in mind, the DLR is researching the station concept Next Generation Station (NGS) which represents a multimodal hub station of a metropolis [6].

In this paper, the performance of the NGS concerning passenger flow is evaluated. To this end, a microscopic simulation is used making it possible to represent the complexity and the interaction of passengers. We use the transfer time as key performance indicator for the evaluation. The inputs consist of the geometric layout of the NGS, characteristics of passengers and an underlying timetable for train departure and arrival.

2 Simulation model

In this section, we describe the train station concept Next Generation Station (NGS), the input parameters for the simulation model and the basis for the evaluation of the performance of the NGS.

2.1 Next Generation Station

The NGT concept comes in two vehicle concepts, the high-speed train (NGT-HST) will operate mainly between metropoles and an intercity train (NGT-LINK) will carry passengers from the surrounding areas to the high-speed line´s hub stations [5]. The current design of the NGS has 14 platforms on four levels enabling the NGT HST to stop in double traction (approx. 1,600 seats) or the NGT LINK to stop in triple traction (approx. 1,425 seats). The lowest level is developed for regional traffic (NGT LINK). The intermediate level has an access and distribution function for passengers and the two upper levels are reserved for the 2nd and 1st class of the high-speed train NGT HST allowing simultaneous boarding and alighting on both levels (see Fig 1). Direct transfer between the comfort classes of the NGT HST is not provided, nor is direct transfer between the high-speed trains.

In the NGS concept analysed, a passenger on the LINK level intending to board the HST has to go to the intermediate level and then use the corresponding elevator or escalator.

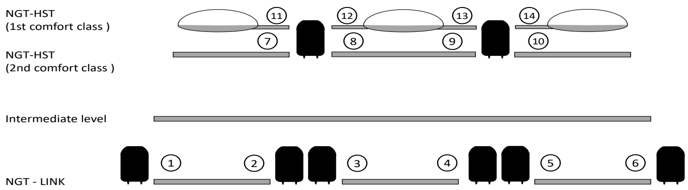

Fig. 1. Scheme of the NGS with corresponding levels and platforms

2.2 Input parameters

Building dimensions and data from literature were considered as input parameters for the simulations of the NGS model, namely

- geometric layout of the NGS,
- characteristics of passengers (e.g. walking speed distribution [7], body proportion [8]),
- properties of mechanical equipment (e.g. escalators [9, 10, 11], passenger elevators [12, 13]) and
- timetable distribution based on the peak load of the Berlin central station combined with the peak hour of London [14, 15].

We used a load factor of 100% for both vehicle concepts and a passenger change rate of 50% for the NGT HST and 100% for the NGT LINK.

2.3 Key performance indicators for evaluating the performance of a station

We use three performance indicators. The first is the transfer time, defined by the period that is necessary, according to the timetable, for passengers to change from an arriving to a departing train [10]. The Deutsche Bahn AG (DB) employs the guideline "Transfer times in the working timetable" [10] to determine a specific transfer time for each station in Germany. According to [10], the transfer time for the NGS is 10 minutes. That time represents a reference value for the evaluation.

Within the simulation, the beginning of the transfer time is represented by leaving the train or entering the intermediate level of the NGS via access from private transport or public transport. The time of taking a waiting position at the platform marks the end of the transfer time.

The traffic performance is assessed by comparing the simulated transfer time with the calculated transfer time (reference value).

The evaluation of the passengers’ perception of quality based on the so-called traffic quality split in quality walking area and waiting area are the second and third key indicator, respectively. It is also known as level-of-service (LoS) [11, 16]. Traffic load cases based on passenger density are assigned to six quality levels (A-F). Quality level A represents the largest comfort of movement and quality, and level F means a breakdown of the traffic flow.

3 Simulation results

The objective of this paper is to evaluate the performance of the NGS in terms of passenger flow. For this purpose, 12 operating hours were simulated and the key performance indicators were evaluated.

Table 1. Total number of transfers (italics) and proportion of transfers (bold) whose duration exceeds the reference time of 10 minutes, color coding of the proportion: below 2% green, between 2% and 5% orange, above 5% red.

from\to		LINK						HST 2st comfort class		HST 1st comfort class		Private transport	Public transport
		1	2	3	4	5	6	7	10	11	14		
LINK	1	**0.20%** *3421*	**0.29%** *3396*	**2.46%** *3461*	**3.44%** *3433*	**4.86%** *3479*	**4.31%** *3390*	**0.08%** *3992*	**0.43%** *3945*	**0.72%** *2625*	**0.69%** *2596*	**0.58%** *8999*	**0.54%** *8927*
	2	**0.43%** *2300*	**0.17%** *2317*	**5.18%** *2316*	**8.06%** *2319*	**3.91%** *2325*	**8.83%** *2322*	**0.26%** *2659*	**0.77%** *2605*	**1.30%** *1696*	**1.58%** *1708*	**0.97%** *6059*	**0.57%** *6008*
	3	**3.91%** *3400*	**2.97%** *3305*	**0.15%** *3366*	**0.81%** *3315*	**4.10%** *3265*	**2.97%** *3402*	**0.26%** *3798*	**0.22%** *3713*	**1.92%** *2243*	**0.89%** *2471*	**0.52%** *8637*	**0.44%** *8696*
	4	**5.09%** *2279*	**10.08%** *2342*	**0.40%** *2275*	**0.21%** *2346*	**2.00%** *2300*	**3.63%** *2317*	**0.36%** *2531*	**0.16%** *2561*	**1.19%** *1679*	**1.48%** *1753*	**0.49%** *6133*	**0.62%** *6082*
	5	**6.68%** *3413*	**6.69%** *3332*	**7.03%** *3430*	**5.00%** *3400*	**0.39%** *3356*	**0.85%** *3401*	**0.45%** *3770*	**0.10%** *3817*	**1.32%** *2652*	**1.15%** *2514*	**0.91%** *8800*	**0.44%** *9143*
	6	**4.23%** *2267*	**5.86%** *2302*	**4.98%** *2287*	**5.90%** *2442*	**0.34%** *2373*	**0.04%** *2312*	**0.53%** *2637*	**0.20%** *2508*	**0.77%** *1691*	**1.40%** *1787*	**0.61%** *6077*	**0.82%** *6076*
HST 2st comfort class	8	**2.27%** *3176*	**2.41%** *3814*	**2.08%** *3126*	**2.33%** *3129*	**1.64%** *3169*	**3.07%** *3061*					**0.09%** *7668*	**0.22%** *7655*
	9	**3.86%** *3292*	**3.58%** *3181*	**2.90%** *3167*	**1.77%** *3166*	**2.60%** *3110*	**1.37%** *3282*					**0.28%** *7543*	**0.10%** *7756*
HST 1st comfort class	12	**5.00%** *2079*	**4.97%** *2151*	**3.74%** *2086*	**4.19%** *2074*	**2.93%** *2082*	**4.76%** *2120*					**0.53%** *5115*	**0.30%** *5076*
	13	**6.45%** *2093*	**5.29%** *2172*	**4.23%** *2106*	**2.52%** *2144*	**3.27%** *2077*	**2.35%** *2087*					**0.34%** *5256*	**0.54%** *5017*
Private transport		**3.28%** *8681*	**4.74%** *6093*	**2.12%** *9153*	**7.06%** *5994*	**1.59%** *9106*	**4.77%** *5886*	**0.06%** *7950*	**0.00%** *7827*	**0.45%** *5287*	**0.41%** *5144*		
Public transport		**2.90%** *8862*	**4.82%** *6135*	**3.85%** *9212*	**10.18%** *6023*	**1.43%** *8911*	**5.51%** *6026*	**0.01%** *7015*	**0.06%** *7735*	**0.39%** *5176*	**0.33%** *5200*		

The arithmetic mean values of the simulated transfer times of all relations including the standard deviation range from 0.66 to 8.94 minutes. Thus, they are all below the reference value of 10 minutes.

The proportion of transfers with a duration greater than the reference value is listed for each transfer relation in Table 1. It is used to determine the transfer relations for which there is an increased risk of the transfer time exceeding the reference value. To provide a clearer overview, the values have been color-coded: Green <2%, Orange ≥2% - <5%, and Red ≥5%.

In 0.08% to 1.92% of all transfers with long-distance transport or private transport and public transport as destination have a transfer time greater than the reference value. In contrast, passengers having a platform served by the NGT LINK as their destination take longer than 10 minutes, i. e. longer than the reference value, for their transfer in at least 5% of a total of 15 transfer connections.

To find the reason for these high values, we examined several transfer relations with a high percentage of passengers needing longer than 10 minutes for their transfer. First, we evaluated the residence times of the passengers on different levels. It is notable that the passengers on the destination platform LINK level have a higher residence time than the reference time for the way from the escalator or elevator to the waiting area. Consequently, we investigated the passenger density on the LINK level. The results correspond to Level D of the LoS for walking areas during 40% of the simulation time. Such a quality level leads to high obstruction and temporary standstill of the passenger flow. High passenger density on the destination platform leads to low walking speeds and an uncomfortable stay for the passengers. Also, it encourages safety-critical situations such as passenger standing in the marked danger zone at the edge of the platform.

The high passenger density on the destination platform is caused by the use of the nearest escalator/elevator in this simulation model. Consequently, the randomly selected waiting area on the destination platform may be far away from the escalator or elevator and blocked by passengers.

To prevent a long residence on the destination platform, we designed and examined a new scenario. We evaluated the effect of passenger paths shifting from the destination platforms to the intermediate level. Therefore, each passenger is assigned to the escalator or elevator closest to his or her waiting position, which is also close to the boarding door of the booked train at the destination platform. Thus, a minimum distance on the destination platform can be guaranteed. The input parameters for the simulation of this scenario are not changed to obtain a comparable result.

The results of the simulations show a slight improvement in the mean values of the transfer times: they now range between 0.67 and 7.49 minutes including standard deviation. This measure significantly reduces the proportion of transfer relations exceeding the reference value. It is less than 2% for all relations. In contrast to the first scenario, passengers have a shorter path and consequently spend less time on the destination platform. For this reason, the traffic quality on the regional platforms is evaluated by the criteria LoS for waiting areas. Thus, the passenger density on all platforms can be assigned the traffic quality LoS A in more than 99% of the simulation time. In the intermediate level, the passenger density in both scenarios corresponded to LoS A for walking surfaces during the whole simulation time.

4 Conclusion and outlook

The DLR is researching a new type of rail transport concept for the future to meet the growing mobility needs of the population and the increasing demands in terms of comfort and travel time. An important aim of this project is to connect major cities by high-speed rail connections as an alternative to short haul flights. This involves the use of a high-speed train (NGT HST), which has special demands on the station infrastructure due to simultaneous boarding and alighting of passengers, both on the lower and upper levels. To fulfill these demands, a new type of station concept was developed with the NGS. Some train stations are already reaching their capacity limits during periods of high passenger volume. Therefore, it is important to investigate the performance of the NGS in terms of passenger flows. This procedure involved the development of a simulative method to illustrate complex passenger movement behavior at a train station. Also, it contains the identification of appropriate key performance indicators for evaluating the passenger flow within a train station and the development of recommendations for improvements by using simulations.

The results of this simulation provide approaches for improving traffic quality for NGS passengers. These need to be further investigated and evaluated in future work.

Due to a complex system, we made simplifications and assumptions for the simulation structure. An example for a future research topic could be the extent to which a specific operating concept for the NGS, assuming a doubling of passenger numbers, affects the simulation results. Other factors that should be considered include baggage drop-off and pick-up on long-distance travel, retail stores, food and service facilities. Also, changes in passenger decision-making behavior regarding escalators and elevators should be considered.

The method developed in this study allows not only the evaluation of the NGS, but also the performance of existing stations in terms of passenger flow. The method can also be used to assess the impact of future structural and operational changes of existing stations.

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