The potential of modern mobile technologies to improve airport operations
A concept for controlling passengers flows

Nicolas Bontikous, Franziska Dieke-Meier and Hartmut Fricke
Chair of Air Transport Technology and Logistics
Technische Universität Dresden
Dresden, Germany
bontikous@gmail.com, {dieke-meier | fricke}@ifl.tu-dresden.de

Abstract — In this paper we present an innovative passenger flow handling concept inside airport terminals using state-of-the-art communication capabilities of mobile devices. It mainly relies on well adopted information presented to either all passengers or selected parties in time and space. The advantage of the newly designed processes as part of the concept are improved capacity utilization, on-time services to both passengers and airlines while maintaining typical service levels according to airport operator’s, passenger’s and airline’s expectations. Even temporary capacity bottlenecks decreased or did not show up while the infrastructure remains unchanged. The paper presents useful metrics to measure competing concepts for managing passengers. We finally applied these in a simulation with the setup of Berlin Brandenburg airport (BER). The results of the simulation suggest that already a passenger participation in concept of 25-30% provides remarkable improvements in the level of service (waiting times) and the utilization of capacity or rather resources.

Keywords— passenger handling, passenger flow, airport terminal, controlling concept, simulation, resource optimization, mobile technologies

I. INTRODUCTION

The passenger has to pass different handling processes within the airport terminal. Fig. 1 shows the passenger processes for departing from an airport (right flow) and arriving at an airport (left flow). For passengers the quality of handling processes is expressed by the provided service level (essentially waiting times) and the comfort level, e.g. available space in the queue [1]. Time pressure of passengers, caused or worsened by handling processes and a minimal remaining time to departure, is the main driver for stress and discontent. Among others a high space utilization, noise and/or the nature of handling process (e.g. personal space may be invaded at security check) may determine the stress level additionally [2]. According to Airport Council International (ACI) especially the handling processes, like check-in, security control, passport/border control and baggage claim area, are associated with a high or very high stress level for passengers [2]. For people, who are unknown with the circumstances because they visit the terminal for the first time or fly infrequently, the stress level may be higher as compared to others [3].

At present, a main problem of the passenger handling processes is not only the overall capacity itself, e.g. average throughput of the facilities; but also the unpredictable occurrence of passenger arrival peaks at the entry points of various handling processes, which exceed local capacity constraints and thus temporarily degrade passenger handling quality [4]. Current and future capacity utilization may be/become another problem. According to [5] and [6], a further growth of global passenger traffic at airports is expected in spite of global and regional financial and political crises. These favorable growth forecasts increase the airport operator’s serious challenges regarding available capacities of the terminal facilities. Although newly constructed or extended terminal capacities could counteract capacitive bottlenecks, these interventions in operative airport and terminal processes entail significant financial risks. Furthermore, construction work at existing facilities could negatively affect core business processes and also decrease passenger satisfaction.

Therefore, future customer-oriented handling processes require the monitoring of passengers to predict service and waiting times as well as controlling of passengers to avoid inefficient and uncomfortable waiting queues at the processes. Modern mobile technologies, like beacons (Bluetooth-low-energy-sender), near field communications (NFC), Wi-Fi and Bluetooth, provide the necessary technical requirements for

- Controlling of passengers via broadcast: all passengers get the same information. At present, the information output occurs typically via the airport signage system or voice announcements.
- Selective controlling of passengers: the passenger or group gets personalized information, for instance about the connecting status or waiting times at a handling process.
The receiving of boarding passes directly on mobile devices is already a popular procedure today, and further increasing [2]. Especially the flight booking and the check-in via mobile devices will become more important in the next few years [7]. Furthermore, mobile technologies are tested amongst others to guide visually impaired persons through the terminal [8] or to point to airline lounges. In the context of an often postulated low-stress and seamless journey (e.g. in [2], [9]), further concepts are currently in research, development and/or tested with the intentions to give guidance and/or to provide passengers with real-time information on predicted demand for airport services. References [10] and [11] and the project PASSME [12], in the framework of Horizon 2020, represent also the efforts to improve airport operations. In February 2016 the SITA (Société Internationale de Télécommunication Aéronautique) introduce a new application for passengers that uses the latest communication technologies to provide guidance and routing advices as well as flight (update) and travel information [13].

The facts, that one third of travelers would permit being located or actively transmitting their position [14], more than 80% of smartphone users are interested in location-based services as advices for their orientation and more than 47% would use customer services, if schedules were provided [15], sound positively. Nevertheless, it is obvious that a hundred-percent acceptance quota is not achievable. Therefore, the questions have to be answered: how does the acceptance quota affect the handling processes in the framework of a concept for controlling of passengers and consequentially what is the best practice?

The paper deals with these key issues and estimates the changes of handling quality subject to acceptance quota of the passengers. For this, in a first step a metric to assess passenger-handling processes are described with appropriated performance indicators. Assuming the availability of modern mobile technologies, the following development of a concept of controlling departing passenger flows creates a reasoned procedure for monitoring and controlling of passengers, defines convenient thresholds to initiate control measures and identifies the needed notification to passengers. In a further step with the help of a simulation, which reproduces the handling processes check-in and security control, the variations of the developed performance indicators as a function of the acceptance quota are evaluated and discussed. Finally, the paper gives a conclusion and an outlook regarding further efforts of research.

II. METRICS TO ASSESS PASSENGER HANDLING PROCESSES

The stakeholders passenger, airport operator and airline have clearly its individual requirements towards quality of the passengers handling processes inside the airport terminal. A concept for controlling passengers should at best fulfill those expectations [11]. As such, at first metrics need to be fixed to enable measuring the achieved quality of these processes. Next, appropriate objective functions will be formulated based on these metrics.

A. Total time (TT) at check-in, security and passport control

All stakeholders try to minimize the waiting time at the mentioned processes. Passengers do not want to waste their time waiting in a queue. Consequently, airport operators and airlines try to offer low waiting times, but also demand a high passenger flow at check-in (CKI), security control (SC), inclusive fast lane (FL) and passport control (PC) because it indicates an efficient use of staff and facilities. The Total TIME (TT) of each relevant process is defined by the following equations:

For check-in: \( TT_{CKI} = WT_{CKI} + PT_{CKI} \)  
(1)

For security control: \( TT_{SC} = WT_{SC} + PT_{SC} \)  
(2)

For fast lane (at SC): \( TT_{FL} = WT_{FL} + PT_{FL} \)  
(3)

For passport control: \( TT_{PC} = WT_{PC} + PT_{PC} \)  
(4)

Figure 1. The passenger journey stress chart ([2], adapted)
with  \( TT \); ... total time of the process

\( WT \); ... waiting time of the process

\( PT \); ... process time.

**Process Time** (PT) depends on staff skills, technical equipment and object scope, such as printing boarding passes, checking passenger data or handling baggage drop off. Waiting Time (WT) is influenced by queueing theory, e.g. the number of available check-in and passport counters, security lanes and fast lanes as well as the number of arriving passengers.

**B. Variance (VAR) of total time at check-in, security control and passport control**

Another PI, which is closely linked to the metric TT, is the Variance (VAR). The variance is mathematically formulated as:

\[
VAR(TT) = E((TT - \mu)^2) \tag{5}
\]

with  \( VAR \); ... variance from Total Time (TT)

\( \mu \); ... mean value

\( E \); ... expected value.

A small variance is primarily in the interest of an airport operator, because a high variance of the TT results in inefficient use of the facilities and high peaks of waiting times. From this point of view, the handling process is optimal, if the waiting time is equally distributed over all passengers.

**C. Total transfer time (TTT)**

According to [2], [9], [16] an increasingly important indicator within the travel and transport chain is a “seamless” travel, a ‘free-from-disturbance’ journey with ideally direct routings through the terminal and minor or no waiting times. For airport operators, however, stressed passengers with no time available are ‘no source of income’. Therefore, a new trend is emerging in airport design: ‘airports of short distances’ balance seamless travel and airport income. The Total Transfer Time (TTT) comprises this trend as an appropriate metric. Equation (6) defines the TTT as the time from terminal entry (TE) to the successful passing of the security control (SC; or passport control (PC), if necessary):

\[
TTT = T_{SC} - T_{TE} \tag{6}
\]

TTT depends on walking distances and travel speed between terminal entry and security control, waiting and process time at necessary departure processes.

**D. Waiting time to remaining time ratio (WR)**

For passengers, the remaining time until departure or closing of related processes (check-in, boarding) is an important subjective figure. As the remaining time decreases, passengers typically react increasingly sensitive to disturbances in waiting and process times. For instance, a waiting time from about 12 minutes at check-in (economy) may be acceptable 40 min ahead of departure time whereas considered unacceptable 10 min ahead [17]. For the concept, the WAITING TIME TO REMAINING TIME RATIO (WR) referring to the security control (SC) is expressed by (7).

\[
WR_{SC} = \frac{WT_{SC}}{RT} \tag{7}
\]

From the perspective of the airport operator, the WR can be further associated with the propensity of the passenger to consume. According to [17] the following limits of WR are relevant and describe the propensity to consume and comfort of passengers:

- \(< 0.2\): high propensity to consume, high passenger comfort
- \(0.2 \leq 0.4\): fair compensation between waiting time and remaining time. Neutral propensity to consume, neutral passenger comfort
- \(> 0.4\): low propensity to consume, low passenger comfort.

**E. Punctual arrival of passenger at departure gate**

A survey of more than 2100 travelers from 2009 shows, that three fourths of the respondents (77%) consider punctuality as the most important aspect for a pleasant journey. Also for 43% of airlines, punctuality plays a major role for choosing an airport [18]. Hence, an on-time arrival of the passenger at the departure gate is not only an important PI for the passenger himself but also for the airline. Mathematically the PI can be written as:

\[
\Delta t = LP - BE \tag{8}
\]

with  \( LP \); ... last passenger’s time at departure gate

\( BE \); ... time of boarding completed.

When the condition \(\Delta t \leq 0\) is fulfilled, no passenger will come too late.

**F. Definition of objective functions**

Table 1 concludes the defined PIs and the related objective function for an optimization of relevant passenger handling processes for departure. In principle, the described PIs and objective functions are also applicable on the handling processes for arrival.
TABLE 1. DEFINITION OF PERFORMANCE INDICATORS (PI) AND OBJECTIVE FUNCTIONS

<table>
<thead>
<tr>
<th>No.</th>
<th>Performance Indicator</th>
<th>Objective function</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI 1</td>
<td>Total time at check-in process (including baggage drop off) [min.]</td>
<td>$TT_{ck} \rightarrow \min$</td>
</tr>
<tr>
<td>PI 2</td>
<td>Total time at security control [min.]</td>
<td>$TT_{sc} \rightarrow \min$</td>
</tr>
<tr>
<td>PI 3</td>
<td>Total time at fast lane [min.]</td>
<td>$TT_{fl} \rightarrow \min$</td>
</tr>
<tr>
<td>PI 4</td>
<td>Total time at passport control [min.]</td>
<td>$TT_{pc} \rightarrow \min$</td>
</tr>
<tr>
<td>PI 5</td>
<td>Variance of total time at check in, security control and passport control [sec$^2$]</td>
<td>$\text{VAR}(TT) \rightarrow \min$</td>
</tr>
<tr>
<td>PI 6</td>
<td>Total transfer time from terminal entry to security check [min.]</td>
<td>$TTT \rightarrow \min$</td>
</tr>
<tr>
<td>PI 7</td>
<td>Ratio of waiting and remaining time at security control [-]</td>
<td>$WR_{sc} \rightarrow \min$</td>
</tr>
<tr>
<td>PI 8</td>
<td>Punctual arrive at departure gate [-]</td>
<td>$\Delta \rightarrow \min$</td>
</tr>
</tbody>
</table>

III. CONCEPT FOR CONTROLLING PASSENGERS

The concept, described below, focuses on departing passengers and covers the following processes chronologically: transport process to terminal – check-in – security and passport control – stay at the gate area and boarding. Each process was analyzed to identify the important monitoring parameters. If these parameters attain a certain threshold, measures of controlling the passengers will be initiated. For instance, the thresholds I – III of controlling are associated with the previous transport process to terminal. Controlling measures within this process should be initiated, if either

- The level of capacity utilization for access roads to the airport (threshold I) or
- The deviation between schedule and actual time of arrival for long-distance train, local train and public transport (threshold II) or
- The level of capacity utilization of the parking areas (threshold III)

attains a defined value. For this, a common management of passenger flows via broadcast or physical terminal infrastructure, like signs and loudspeaker, and a management of individual passengers via selected information mode are distinguished. The concept provides both guidance for passengers to find the best and shortest way to the departure gate and information amongst others about available parking slots, flight updates and/or about waiting time at handling processes or advices for the best-timed entry. Infrastructural conditions, passenger properties, like age and walking speed, passenger group size, status of handling processes and respective waiting times are considered. The concept assumes that the required technologies for positioning and information exchanges are available and installed to provide passenger information and guidance inside the airport terminal as well as before arriving the airport. The entire concept for controlling departing passengers (illustrated in Appendix) pursues the principle to involve the passenger as early as possible.

Fig. 2 shows exemplarily the developed conceptual controlling procedure for the handling process check-in. By entering the terminal, the passenger is being monitored. Within common passenger flow management the procedure identifies and reproduces general passenger walking behavior to avoid bottlenecks and counteract proactively. On the other side, the individual passenger management uses tracking information both for a geo-location of the passenger and for verifying the progress of the complete handling process until departure. Further, the total time of check-in ($TT_{ck}$) is monitored. If the value of $TT_{ck}$ exceeds the predefined threshold IV, the dynamic signage and guidance system change and if possible new counters will be opened to reduce waiting times and increase passenger satisfaction (common management).

A measure of the individual controlling concept is the transmission of a suggestion for check-in entry, illustrated in Fig. 3. After terminal entry (1), the procedure calculates the

![Conceptual controlling procedure of check-in](image-url)
suggestion for a last possible time for check-in (3) considering of departure time (5), boarding handling time (D), which depends on the boarding method, resulting boarding start (4) as well as forecasted waiting time at security and passport control (C). Furthermore, considering walking distances between terminal entrance and check-in (A) it is possible to calculate the first option for a time suggestion of check-in entry (2).

Figure 3. Approach to identify time slots as advice of check-in process entry

After calculation, the passenger receives a notification for a specific check-in counter and additionally a specific time, as a suggestion. Reaching the check-in at this suggested time, the passenger can expect a low utilization of the counter(s) and therefore a little waiting time. The time calculation bases on historical data, simulation and current passenger terminal arrival forecasts, waiting time forecasts at all passenger processes and the current check-in status and departure time of the passenger. With combination of individual and common passenger flow management and inclusion of forecast methods and interaction of passengers it is possible to reduce waiting time, increase the passenger experience and use resources efficiently (e.g. high capacity utilization of check-in counter).

Similar to check-in process the controlling procedure monitors the service and waiting times at security and passport control (threshold V: total processing time at security control/fast lane and threshold VI: total processing time at passport control). If there is an exceedance of a predefined value the procedure adjusts the guidance and signage routing to optimize resources and, if possible, opens additional security and passport lanes. Within the individual passenger flow management it is possible to get a “ticket” to access the fast lane permission. The algorithm to define and calculate time suggestions is similar to the check-in process, see Fig. 3. Of course, the concept considers the prioritized requirement for minor waiting time at the fast lane and does not disadvantage primary passengers, who already got a fast lane permission. The “ticket” allows participating passengers to access/use a specific fast lane for a specific time in case of sufficient capacity and respective level of service of the fast lane. By controlling individual passengers, it is possible to relieve security lanes and optimize the utilization of fast lanes and avoid not used resources. Within the passport control process, only waiting times are monitored. If necessary, more passport control lanes open. The threshold of total processing time is composed of the monitored waiting time and the service time at passport control.

After successfully passing security and passport control, the general passenger flow management does not intervene on the guidance and control of passengers. Only general information, such as remaining walking duration to departure gate or gate changes may be displayed. Within the individual passenger flow management, the concept sends individual and personalized notes and warnings to guide passengers to their departure gate. By tracking individual passengers, it should be provided to send warnings, if they are far away from the associated gate shortly before the departure time.

IV. SIMULATION

The success of the described controlling concept depends essentially on the quota of passengers, who accept the given advices for handling process entry. To estimate the impacts of the passengers’ acceptance quota on the handling processes and respective performance indicators a simulation is used. The simulation platform consists of a JAVA application and an EXCEL-file output for various data series. The infrastructure and simulation setup is based on the German airport Berlin Brandenburg (IATA code: BER), which is currently under construction. The simulation uses a forecasted flight plan including more than 55,000 passengers and 120 departures. Fig. 4 shows the distribution of the passengers for a representative day at BER with significant peaks of demand.

Figure 4. Daily load curve of passengers (number of departing people)

The assumed distribution of passengers arriving at the handling process is based on a WEIBULL distribution with the following scale and shape parameters: \( \alpha = 6.2, \beta = 120 \text{ min} \) and \( \Delta t = -150 \text{ min} \) according to [16]. For the process handling time at check-in, also a WEIBULL distribution with \( \alpha = 1.5, \beta = 45 \text{ sec} \) and \( \Delta t = -20 \text{ sec} \) is applied [17]. The average process handling time at security control (including fast lanes) is predicted on [19] with 22.5 seconds per passenger.

Initially, for each passenger and flight the JAVA application generates WEIBULL-distributed arrival times at the necessary handling processes (check-in and security control). For check-in a constant check-in @ home quota of 59% is assumed. The check-in @ home quota includes all passengers, which do not check-in at the airport in relation to the total number of departing passengers. Based on the check-in passenger demand, the determined process handling time
and the number of available check-in counters, the waiting time for the handling process is calculated. Depending on a defined acceptable level of service and the calculated waiting time, the simulation delays participating passengers and assigns check-in arrival times for these passengers. The calculations for the security control process follow the same procedure. If the number of restrained passengers is too large in the context of the acceptable level of service (maximum admissible area utilization), the simulation sends passengers to the respective handling process. Furthermore, the number of passengers with fast lane access is limited according to the level of service. The calculated walking times depend on the infrastructure specification of the departure hall of the application airport BER. Table 2 shows the main steps of the simulation.

### TABLE 2. SCHEME OF THE SIMULATION SEQUENCE

<table>
<thead>
<tr>
<th>Step</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stochastic generating of passengers based on input data</td>
</tr>
<tr>
<td>2</td>
<td>Stochastic calculation of check-in arrival times</td>
</tr>
<tr>
<td>3</td>
<td>Calculation of waiting and service time at check-in</td>
</tr>
<tr>
<td>4</td>
<td>Calculation of arrival time at security control based on step 3 output and walking durations</td>
</tr>
<tr>
<td>5</td>
<td>Calculation of waiting and service time at security control</td>
</tr>
<tr>
<td>6</td>
<td>Output of EXCEL-file for subsequent analysis</td>
</tr>
</tbody>
</table>

The simulation includes variable and fixed input parameters. Fixed input parameters are the arrival distributions, process service time distributions, the walking speed (according to [17]) and the flight plan, including the number of passengers and departures. Furthermore, to guarantee a required level of service for primary passengers a fast lane permission of non-primary passengers is fixed to 6%. The level of service is defined as “excellent” (category A) according to the definitions of IATA [20]. Four sensitive, variable input parameters are present:

- Number of check-in counters [-]
- Number of security control lanes [-]
- Number of security control fast lanes [-]
- Participation quota [%].

In order to verify the objective functions, several scenarios were developed and simulated. A participation quota of 0% represents the current situation without an implemented concept (baseline scenario). Comparative to the concept development, the application focuses exclusively on the handling processes check-in and security control (without an evaluation of the fast lanes). However, the simulation covers the essential handling processes from the focused point of view of the expressed key issues. Due to the limitation at check-in and security control an evaluation of the PI 3, 4 and 8 is not possible. Table 3 lists the input parameters of the defined scenario 1 – 3. For PI 1 and 2 it has to be noted, that the evaluation only covers the waiting time and not the TOTAL TIME of the certain process, which is defined as a performance indicator. Because the process time is not a variable input parameter in the framework of the simulation, the time is not evaluated. The consideration of the process time is more relevant under real-life circumstances.

### TABLE 3. INPUT PARAMETERS OF THE SCENARIOS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>scenario 1</th>
<th>scenario 2</th>
<th>scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of check-in counters</td>
<td>118</td>
<td>variable</td>
<td>30</td>
</tr>
<tr>
<td>No. of security control lanes</td>
<td>34</td>
<td>34</td>
<td>variable</td>
</tr>
<tr>
<td>No. of security ctr, fast lanes</td>
<td>2</td>
<td>2</td>
<td>variable</td>
</tr>
<tr>
<td>Participation quota [%]</td>
<td>Variable</td>
<td>variable</td>
<td>variable</td>
</tr>
</tbody>
</table>

V. EVALUATION

The results of the simulation are shown as heat maps, with numeric values also indicated.

A. Waiting time as part of the total time at check-in (PI 1)

Fig. 5 shows various waiting times at check-in in relation of the number of check-in counters and different participation quotas for scenario 2. With an increasing number of participants (total PAX times participation quota), the waiting time at check-is reduced by up to 16 %. However, the influence of the passenger participation quota upon waiting times is marginal. In order to achieve the desired level of service of 6 min per passenger, a total of at least 30 check-in counters is needed. These results show the obvious sensitivity of the number of open check-in counters to waiting times.

B. Waiting time as part of the total time at security control (PI 2)

With the first scenario, it is possible to evaluate the waiting time at security control ($WT_{SC}$) in relation to the participation quota. As Fig. 6 shows, a participation quota of around ten percent is sufficient to achieve an acceptable level of service of about 6 min mean waiting time at the security control. This improvement would not require additional resources. Without
a controlling concept and the necessary participation of passengers, the waiting time is more than 13 min. Furthermore, with a higher participation quota of more than 25 – 30 % there will be no further improvement. The utilization of resources is near-optimal from a participation quota of about 30 % up.

C. Variance of total time at check-in (PI 5)

The simulation output is combined with PI 1 (Fig. 5) and scenario 2. Fig. 7 shows the various variances for the check-in process. Despite the minor improvements in average waiting time (see Fig. 5) the variance is significantly affected in a positive way (lower variance, higher improvement). Observable peaks of passenger demand are flattened. Similar to evaluation of PI 2 a higher participation quota of more than 25 – 30 % does not result in further significant improvements. Even a small improvement of waiting time leads to a large improvement of variance. A sufficient participation of passenger assumed, a concept implementation could reduce waiting times and high peaks of demand.

E. Ratio waiting time to remaining time (PI 7)

The probability, that a passenger visit the non-aviation area after a successfully passing of the security control, depends on the WRSC. A high WRSC indicates a low potential for consumption in the non-aviation area, because of stressed passengers. Fig. 9 shows that the WRSC varies between 0.090 and 0.097. As described before, a WR under 0.2 is an indicator of passenger comfort and the propensity of the passenger to consume. Despite of an unfavorably increasing WR with increasing participation quota, the calculated WR is well acceptable in all cases. Due to an implementation of the developed concept and a necessary participation of passengers assumed, it is feasible to reduce the waiting time and variance and to obtain/maintain a good passenger satisfaction as well as to avoid negative influence on propensity of passengers to consume and thus on non-aviation revenue.
F. Summary of the evaluation

In summary, the following findings concluded the investigation:

- From a minimum required participation of passengers to the newly developed controlling concept, waiting times at check-in and security control can be significantly reduced. At a participation quota of 25-30%, remarkable savings in waiting time up to 50% are achievable, whereas a participation quota above 55% did not show significant additional reductions.

- Aside those partly significant savings in waiting time at check-in or security control, we also found a remarkable reduction of variance in all cases and therefore more balanced passenger demand.

- The concept implementation however will negatively impact the total transfer time which may increase.

- The specific PI waiting vs. remaining time will only increase below 10% caused by controlling activities of certain passengers. Nevertheless, the absolute values remain rather low, to have a significant influence on the propensity of passengers to consume.

In summary, Fig. 10 shows the qualitative change of the considered PIs with a passenger flow control scheme using personalized messaging in place.

Figure 10. Qualitative changes of the PIs

<table>
<thead>
<tr>
<th>PI</th>
<th>change</th>
<th>PI</th>
<th>change</th>
<th>PI</th>
<th>change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI 1</td>
<td>→</td>
<td>PI 5</td>
<td>→</td>
<td>PI 6</td>
<td>→</td>
</tr>
<tr>
<td>PI 2</td>
<td>→</td>
<td>PI 7</td>
<td>→</td>
<td>PI 8</td>
<td>n/a</td>
</tr>
<tr>
<td>PI 3</td>
<td>n/a</td>
<td>PI 4</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

positive
none
negative

VI. CONCLUSION AND OUTLOOK

The results of the evaluation indicate that the developed concept as well as other concepts for controlling passenger flows, which are currently subject to research and development, hold considerable potential to improve airport operations. Applying the presented individual passenger flow concept while assuming an appropriate passengers’ participation, passenger satisfaction may increase while minimizing the utilization and usage of resources.

Furthermore, it is estimated that further potentials exists to implement efficient terminal operations. The presented concept provides exclusively an approach for the controlling of departing passengers. The arriving passengers are outside of the consideration of this study. In addition, the simulation does not cover all defined PIs. Hence, further improvements regarding the PIs are expected. All these aspects are subjects of future enhanced researches.

ACKNOWLEDGMENT

The authors would like to thank the colleagues C. Spaak, M. Weigt and D. Nündel of Berlin Brandenburg Airport for their information, data and useful comments. Furthermore, we thank Thomas Kunze for his support and hints regarding the development and implementation of the concept/simulation, and Markus Vogel for his useful editorial comments.

REFERENCES

APPENDIX: CONCEPT FOR CONTROLLING DEPARTING PASSENGERS

![Flowchart diagram showing the concept for controlling departing passengers. The diagram outlines the process from arrival to departure, including various decision points and actions such as passenger guidance, notification transmission, and security checks.]

- **Terminal Entry**
  - Start passenger tracking
  - Check-in process
  - Dynamic signage
  - Security control
  - Passport control

- **Boarding Pass Check**
  - Fast lane authorization
  - Waiting time at security lines
  - Passport control

- **RGN Public Area**
  - Notification about boarding start
  - Waiting time to departure gate
  - Boarding time

- **Depature**
  - Individual guidance
  - Notification of departure time

The diagram details the steps involved in controlling departing passengers, from arrival at the terminal to departure, highlighting key processes such as passenger handling, notifications, and security checks.