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Managing Passenger Handling at Airport Terminal

Individual-based Model for Stochastic Passenger Behavior

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Abstract—**An efficient handling of passengers is essential for reliable terminal processes. Since the entire progress of terminal handling depends on the individual behavior of the passengers, a valid and calibrated agent-based model allows for a detailed evaluation of handling and for identifying system optimization capabilities. Our model is based on a stochastic approach for passenger movements including the capability of individual tactical decision making and route choice, and moreover, on a stochastic approach of the handling processes. Each component of the model was calibrated with a comprehensive, scientifically reliable empirical data set; a virtual terminal environment was developed and real airport conditions were evaluated. Our detailed stochastic modeling approach points out the need for a significant change of the common flow-oriented design methods to illuminate the still undiscovered terminal black box.**

Keywords-agent-based model; movement behavior; complex dynamics; stochastic process; simulation; validation

I. INTRODUCTION

Airports with their complex infrastructure represent a central component of today's traffic system and have to satisfy a variety of different tasks. From the passenger point of view, the building is primarily designed for providing handling processes for departure and arrival. These procedures possess different environmental demands, which result from safety/security and legal requirements. From the airport point of view, safety and security of the processes are a major issue, whereas the passenger expects adequate service and comfort levels. On the other hand, airport revenues are increasingly dependent on the non-aviation sector (retail revenues). The airline focuses on adequate terminal infrastructure and competitive product supply. To ensure an optimal combination of these frequently conflicting requirements, the airport operator has to balance all customer demands. Recent years have shown that, in particular, legal changes, growing security constraints and delays significantly consume system capacity.

To optimize processes and infrastructure, current models make use of aggregated approaches, where the behavior of single entities (agents) is represented by aggregated flows. Individual-based models allow for a scientifically reliable and detailed evaluation of the behavioral processes, considering agent demands, environmental perception and individual interactions. Therefore, appropriate agent models have to be developed and calibrated with empirical data. A calibration is mandatory to legitimate the application of the individual model characteristics and allows for developing efficient system design.

In turnaround procedures the behavior of the passenger is crucial for handling efficiency, since both deboarding and boarding are part of the critical path. Datasets from Airbus A380 ground handling at Emirates evidence a significant level of impact of passenger handling at hub structures, caused by a high transfer passenger volume [1]. The hub structure is a directly coupled transport system, which not only possess intermodal traffic change (landside arrivals) but as well as essential feeder flights (airside arrivals). Regarding to ref. [2] the most penalizing delay categories are technical/aircraft equipment (21%), weather (9%), restrictions at the departure airport (9%) and ATFM restrictions (9%) followed by passenger/baggage and aircraft/ramp handling (both 8%). A detailed analysis of landside terminal elements (table I) evidently shows their significant impact on airport delays [3].

TABLE I. FLIGHTS DELAYED DUE TO LANDSIDE TERMINAL ELEMENTS, TAKEN FROM REF. [3]

Category: terminal infrastructure and handling processes	**Delayed flights at top 5 airports per category**
Terminal building capacity	Not validated
Baggage handling	2 %
Check-in area / ticket desk	1-2 %
Security check	5-12 %
Departure gates and boarding	5-8 %

The proposed approach deals with agents describing passenger movement behavior at the airport terminal environment focusing the addressed delay categories. The individual-based movement model developed here is furthermore applicable for common economic issues (layout of service/retail areas or shopping malls), delay and process analysis, evaluation of person perception and design of appropriate signage, impact of an ageing society, efficient emergency and security planning, or scenario analyses, when introducing new safety/security technologies (e.g. recording of biometric features, full-body scanning techniques) [4]. The landside terminal infrastructure and the associated passenger handling processes are a black box for the airport operator. Thus, future and even current system states are hardly to predict/define, although they are a major driver for efficient airside operations. Regarding the claimed increase of passengers, the use of wide-body aircrafts (up to 550 passenger) and new safety/security demands for terminal processes, an adequate managing (monitoring and controlling) of the passenger handling processes is essential. An detached evaluation/optimization of landside and airside processes will fail to achieve the ambitious SESAR goals. Our agent-based terminal research provides an essential contribution for an efficient airport/ATM/ATC system.

II. MOTION MODEL FOR PASSENGER BEHAVIOR

The modeling of person behavior using mathematical approaches allows for a comprehensive understanding of complex situations. Depending on the field of applications a number of research areas and disciplines are involved (fluid mechanics, particle physics, sociology, economics, psychology, etc.). The different modeling approaches are based on particular discipline analogies, ranging from hydro-dynamic models to artificial intelligence and multi-agent systems [5]. Using the hydrodynamic model as an example, the behavior of persons is compared with that of a flowing fluid. This simplification is sufficient to describe common person behavior under certain conditions; however, specific motion patterns (e.g. upstream movements) and self-organization effects (e.g. oscillation or row formation – cf. figure 1) cannot be reproduced.

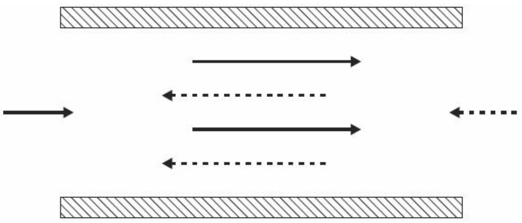

Figure 1. Global motion pattern arising from individual interactions between individuals (row formation due to self-organization) [6]

The complex dynamic human behavior is induced by individual decisions, which are classified to be short-range (operational) and long-range (strategic/tactical). The self-organization of persons is a further essential characteristic of human behavior [7]. Self-organization is an irreversible, non-deterministic process caused by the cooperative behavior of sub-systems and results in complex structures. The modeling of individuals (agents) and their specific interactions represents a major part of this research project. The developed mathematical model of human behavior is based on a stochastic approach to handle unpredictable behavior and individual path deviations.

The movement model developed here is based on a stochastic approach, which is comparable to a common cellular automaton. It utilizes a regular grid structure. In contrast to the cellular automaton, a new model is developed on the basis of a fundamental paradigm shift: instead of changing the cell status depending on the status of its surrounding cells (neighbors), the agent is able to move over the regular lattice and to enter those cells, which are not occupied by other agents or obstacles (e.g. walls) [4].

A. Operational Behavior Level

To describe the movement behavior of an agent, the motion vector is separated into a desired motion direction and a transversal deviation [8]. Using a spatially discrete grid structure and defining three transition states (forward | stop | backward or left | on-track | right) the normalized transition probability (p) into these states is generally defined by the following equations:

$$\begin{aligned} p^{+} &= 0.5\,(\sigma^2 + \mu^2 + \mu) \\ p^{o} &= 1 - (\sigma^2 + \mu^2) \\ p^{-} &= 0.5\,(\sigma^2 + \mu^2 - \mu) \end{aligned} \qquad (1)$$

In the case of the desired motion direction, μ denotes the desired speed and σ^2 the corresponding variance. If the transversal deviation is considered, μ is the average and σ^2 is the range of the fluctuations. Considering a symmetric transversal deviation and an aim-oriented forward motion (no backward motion $p^{-} = 0$: σ^2 becomes a function of μ), the above equations are simplified to:

desired motion direction: $p^{forward} = \mu$ $p^{stop} = 1 - \mu$

transversal deviation: $p^{left,\, right} = 0.5\,\sigma^2$ $p^{stop} = 1 - \sigma^2$

Finally, the motion components are combined to a 3 x 3 transition matrix (M) as shown in figure 2. To create the transition matrices for the horizontal movement ($\hat{M}$) and for the diagonal movement ($\tilde{M}$) the motion direction (α) has to be integrated into the stochastic model by weighting the matrices:

$$M = \begin{cases} (1-\lambda)\,\hat{M} + \lambda\,\tilde{M}, & \lambda = \tan\alpha,\ 0 \le \alpha < \frac{\pi}{4} \\ \frac{1}{\sqrt{2}}\,(1-\lambda)\,\hat{M} + \sqrt{2}\,\lambda\,\tilde{M}, & \lambda = \tan\left(\frac{\pi}{2} - \alpha\right),\ \frac{\pi}{4} \le \alpha \le \frac{\pi}{2} \end{cases} \qquad (2)$$

The rotation of M (4-fold symmetry) allows for determining the entire spectrum of the motion direction. The underlying regular grid structure results in direction-dependent behavior (e.g. entering diagonal cells implies walking longer in comparison to horizontally located cells).

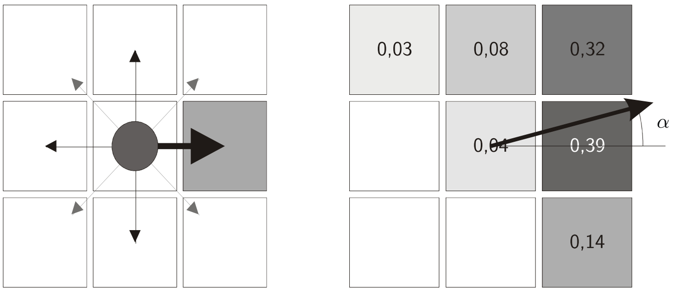

Figure 2. Grid-based transition probabilities (left) and corresponding generic transition matrix [9]

Model-specific parameter corrections ensure that the motion vector is equal to the expected value of the corresponding transition matrix [4]. This issue has in particular not been considered in previously published approaches. The description of the interactions between agents is a crucial element of individual-based (microscopic) motion models. The developed stochastic motion approach considers surrounding neighbors, which are in close vicinity of the local cell position. The fundamental diagram shown in figure 3 describes the empirical correlation of motion speed and agent density. The developed model is found to reproduce the characteristic shape of the fundamental diagram if the agent (i) does not wait for other agents, (ii) moves three/four steps at once inside the simulation environment and (iii) leaves a trace, which temporally blocks entered cells within the current time step of the simulation.

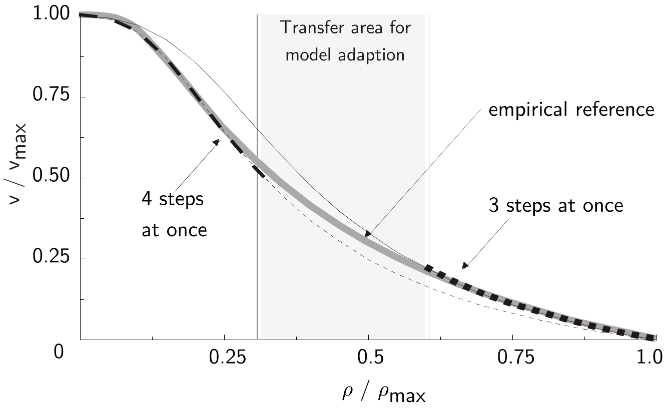

Figure 3. The stochastic movement model reproduces the empirical reference values (fundamental diagram) [4]

The dynamic group behavior is modeled by a weighted decision process considering the different speed profiles of the group members (e.g. faster agents wait, if they are too far away from the group center). The weighted decision process has various characteristics: from simple majority decisions (each member is entitled to vote) to leader concepts (leader chooses route, e.g. tour group leader or head of family).

The developed model of agent movements [4,9] is thus the first approach, which allows for a specific stochastic description without significant model restrictions (e.g. motion artifacts due to non-weighted diagonal movements).

B. *Tactical Behavior Level*

In addition to the above operational behavior, the tactical behavior component enables agents to act with environmental anticipation. This anticipation includes system knowledge about characteristics of handling processes, infrastructure knowledge (navigation, orientation) and perception/processing of provided information (signage). Using the model of visual human perception [10] and modeling the necessary properties of signage components allows for a valuable extension of the operational motion behavior approach. The evaluation of the signage concept at Dresden International Airport (DRS) offered the opportunity to test our model approaches (figure 4). Initially, we analyzed the overall signage planning concept and the real terminal environment.

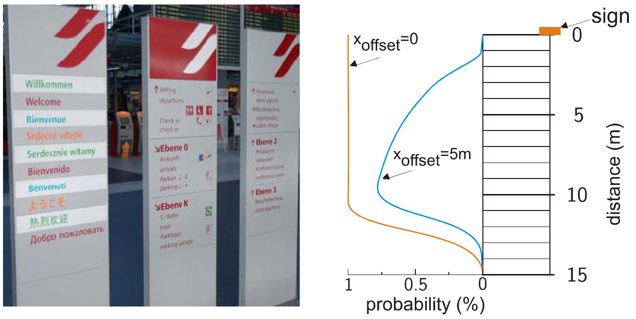

Figure 4. Evaluation of existing signage at DRS (left) and modeling of signage components for virtual terminal environment (right): The probability of sign recognition decreases with increasing offset of the walking path against the sign position [11]

At the next step we transferred the signage components in our virtual terminal environment (figure 5). Each component is characterized by font size, size of pictogram, contrast, position and offset regarding to commonly used walking areas/paths. Using the virtual terminal environment we could derive the coverage of signage information from both airport and passenger point of view. Due to the fact that the passenger perception directly depends on individual system experiences, specific requirements for business and touristic travel purpose could be identified.

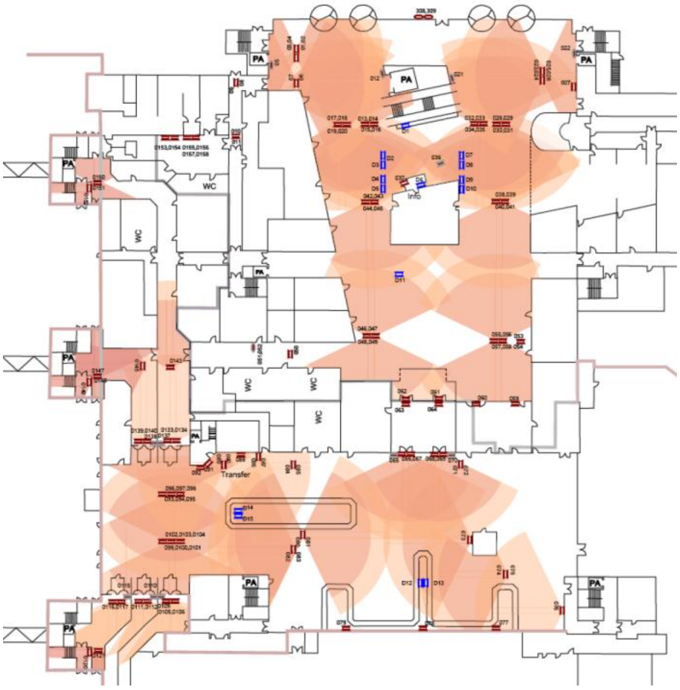

Figure 5. Overall signage model at terminal entry/exit area at Dresden airport considering aspects of font and pictogram size as well as contrast and positioning [11]

Using the provided navigation information combined with a passenger's specific airport knowledge enables tactical movement decisions. Therefore a common SPA (sense-plan-act) approach [12-16] is implemented, which evaluates the utility level regarding to available time to boarding, expected process queues, congested walking areas and individual preferences (e.g. usages of terminal service facilities) [4]. The navigation/orientation model is based on both static navigation network and free orientation (multi-level route choice behavior, figure 6). Optimized passenger signage, verification of specific guidance implementation and the development of standardized concepts (e.g. terminal area, parking, or public transport stations) are resulting from the developed tactical movement modeling concept.

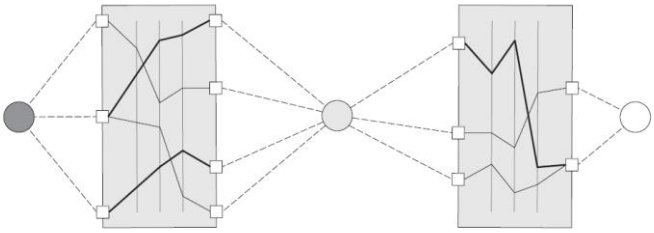

Figure 6. Agent (left) uses network (gray box) to navigate heading to an intermediate goal (e.g. sign or information point, center), orientates freely to gather information and use the network to finally reaches the nearest navigation point regarding to the destination (right) [4]

C. *Safety and Emergency Planning*

The critical reflection of terminal processes has to consider both regular handling and exceptional cases like security issues, emergency planning, delayed passenger handling, or common disturbances. In contrast to the standard terminal operations, the passenger generally has no experienced-based knowledge in these abnormal situations. Evacuation (rather egress) exercises points out the inefficient passenger behavior of going back to known terminal entries instead of searching/using the nearest emergency exit. This is enforced by infrastructural design, where emergency exits are only foreseen for emergency cases. According to ref. [17] unpredictable evacuation behavior can be categorized as follows:

- 10-15% act rational and are able to lead other persons out of the hazardous area,
- 70% are astonished and composed, they can be led by clear instructions,
- 10-15% act unpredictable, do freeze or start to stampede.

An emergency is modeled as areas of incident and consequence. The incident area directly influences near agents (they are unable to move), while the consequence area indirectly affects the motion behavior by setting speed and orientation limitations. The behavior parameters are primarily linked to the fractional effective dose model (FED, cf. [18]), describing the human response over a wide concentration range for both pure single and mixed toxic gases atmosphere. According to the FED, we proposed three behavioral levels: minor speed and direction deviations, serious limitations (additional route choice restrictions) and the urgent need of assistance (no independent motion). To provide FED-based agent feedback a connection to a numerical propagation model is needed. Simplified approaches have already been tested during research collaboration at Hamburg airport environment (grant-aided in the frame of LuFo III project “S3 – security from seat to seat”, figure 7).

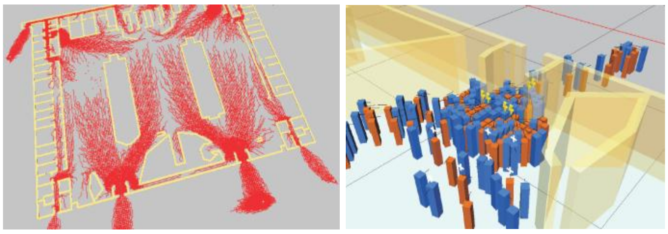

Figure 7. Evacuation scenario at Hamburg airport (left) and detail visualization off the congested entry/exit area

Another point of interest is the terminal separation into public and non-public area assured by the security control. A “safety first” rule will immediately imply, that the passengers have the possibility to move through the security control (without screening) heading to the next emergency exit. This situation touches significant security issues, because no further normal passenger handling is allowed until the entire non-public sector is cleared. Obviously, even minor incidences will entail an extensive economic impact. Considering to the economic pressure for an efficient infrastructure we are able to provide an appropriate scenario analysis and the development of airport specific safety concepts.

The stochastic model meets all criteria for a scientifically reliable movement model. It exhibits the absence of significant model-caused limitations and reproduces all common self-organizing effects (e.g. row formation or oscillation). Besides the operational movement definition by the stochastic transition matrix, strategic/tactical motion components, and emergency capabilities are taken into account as well. The stochastic model allows for the reaction of the agent to objects/agents in the immediate vicinity and it also provides the capability to consider the distant constellation of agents (jam) and potentially blocked bottlenecks.

III. HANDLING PROCESS CHARACTERISTICS

From the passenger point of view, the airport terminal building is primarily designed for dispatch (arrival/departure) procedures. These procedures possess different environmental demands, which result from safety/security and legal requirements. The calibrated stochastic movement model provides an appropriate method to determine the process performance by means of acceptable waiting times or efficient signage. A virtual passenger can move through the terminal environment and will use passenger handling facilities. The passenger has to fulfill several handling tasks at the airport depending on their travel status (departure, transfer, arrival) and their particular properties. The characteristics of handling procedures result from different operational demands, safety/security constraints as well as legal requirements.

Each process station at the airport terminal is modeled in detail (e.g. operational sequences, competence of personnel, and impact on potential disturbances). Using the security control as an example (figure 8), the passenger has to pass several sub-procedures. After depositing hand baggage and personal property the passenger has to wait at the walk-through metal detector. If the security personnel request the passenger to pass, they move through and are manually screened (gender specific) if the alarm is triggered. Furthermore, the accompanying baggage and personal property is X-rayed and additionally screened by the security personnel if required.

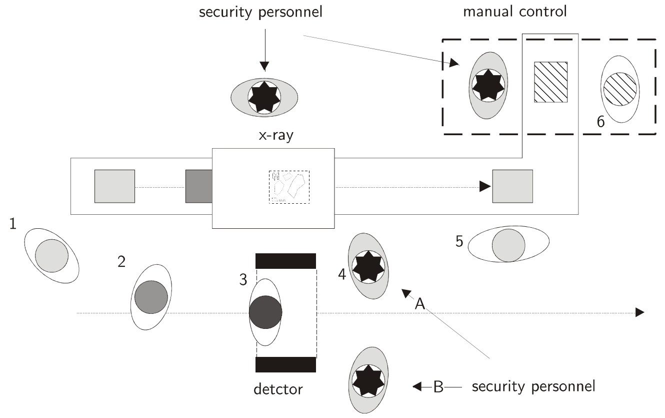

Figure 8. Detailed operational sequences at the security control [4]

For the statistical analysis of the specific process sequences, measurements at an airport terminal are required. Thus, all defined sub-processes are evaluated together with interdependencies between passenger characteristics (e.g. group size, baggage) and personnel qualifications. The investigation primarily focused on handling processes during passenger departure (check-in, security, passport control, and boarding). The recorded process characteristics are used for deriving statistical distributions for the stochastic model (figure 9).

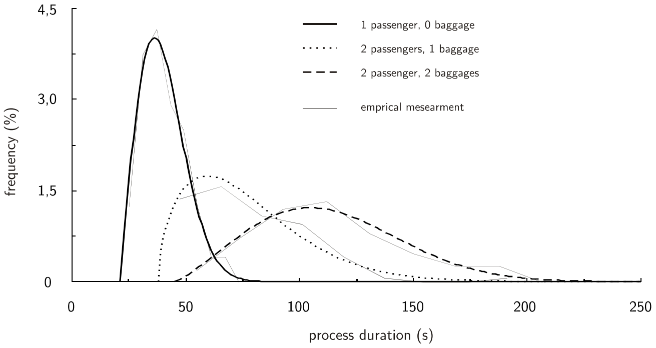

Figure 9. Statistical distributions for check-in process times with different amount and baggage constellation [4,19]

It is important to note that with respect to passenger departures, the arrival of passengers is essential for the handling processes (e.g. differentiation between business and tourist passengers, figure 10). Both individually available time budgets and the parallel handling of several flights at the process facilities are significantly influenced. Whereas a smaller time budget results in faster and direct passenger movements (no use of service facilities) the coincidence of flights yields to highly utilized handling processes. Due to the statistical analysis of passenger arrival times and the specific process duration at the handling facilities reliable stochastic distributions are available for scientifically reliable investigations.

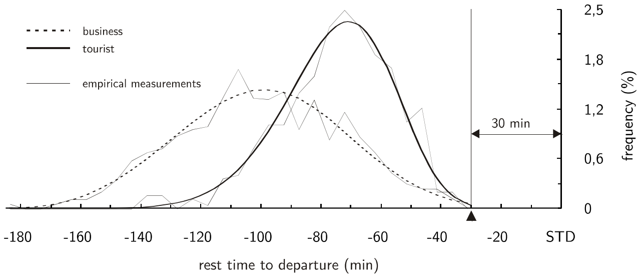

Figure 10. Specific distributions for landside passenger arrival at terminal for business and tourist passengers [4,19]

IV. CALIBRATION AND VALIDATION

The stochastic motion model defines the movement behavior of common agents and has to be adapted by specific parameters to determine passenger movements in the environment of an airport terminal. To validate the parameters of the passenger behavior model a test set-up in a real airport environment is needed. With respect to personal privacy and legal requirements the recognition of movement behavior is handled by a video tracking software (figure 11) developed for this purpose.

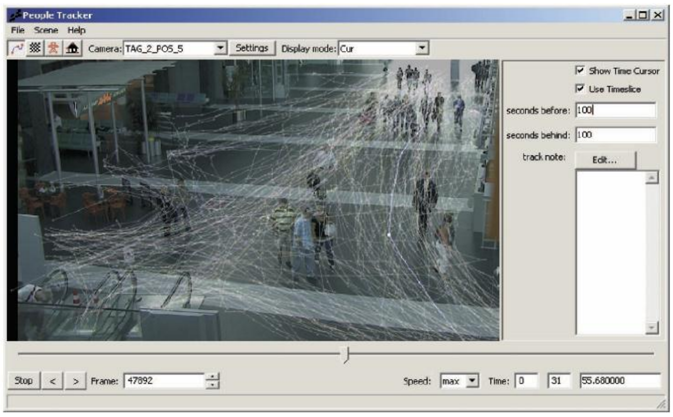

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Figure 11. Developed passenger tracking software for airport terminal environment [4,20]

Several capture techniques exist to track human movements. For the software development appropriate algorithms are implemented to segment the recorded image, to modify the lighting, to reconstruct the human silhouette (analysis of overlapping areas), and to determine the exact positions for a valid trajectory. Once calibrated, the tracking software performed without major difficulties even at slightly crowed areas. However, with increasing passenger density, the occlusion probability naturally increases and the tracking algorithm has to rely on statistical assumptions. Due to these assumptions (variations) the accuracy of the extracted trajectories decreases.

The trajectories are corrected afterwards manual intervention and finally linked to a consistent dataset. To determine the position of the passenger regarding to the terminal floor level (figure 12), intrinsic and extrinsic transformations must be performed. Intrinsic parameters are camera related, e.g. focal length and distortion, whereas extrinsic parameters define the transformation of the camera coordinate system into the terminal level related coordinate system (e.g. height above floor level or rotation of view).

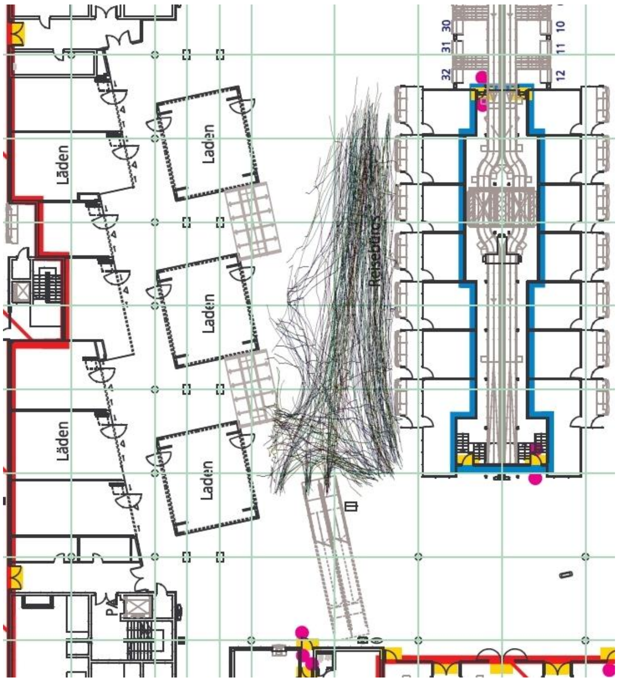

Figure 12. Transforming the identified passenger trajectories to terminal level (departure area at Dresden airport) [21]

A. Video-based Passenger Tracking at Airport Terminal

The analysis of the movements of 595 passengers at Dresden Airport (Germany) shows that the movement behavior mainly depends on parameters such as amount and characteristics of baggage (e.g. trolley, baggage cart, or rucksack), gender, group size and travel purpose (business or tourist). The tracking confirms existing results (e.g. that men are 10% faster than women) and, moreover, supports common assumptions about passenger behavior based on quantitative measurements. As an example, table II illustrates the dependence of passenger speed on group size and travel purpose.

TABLE II. MEASURED SPEED PROFILES FOR DIFFERENT PASSENGER CONFIGURATION INDICATED BY EXPECTED VALUE μ (M/S) AND STANDARD DEVIATION σ (M/S)

Group size	Business		Tourist		Average	
	μ	σ	μ	σ	μ	σ
1	1.38	0.21	1.19	0.25	1.36	0.23
2	1.17	0.17	0.97	0.20	1.06	0.21
3	1.04	0.23	0.93	0.17	0.96	0.19

A typical business passenger arrives at the airport terminal significantly later than a tourist and, consequently, possesses a smaller time budget. Thus, they walk faster than a tourist (approx. 10-20%), but with a similar standard deviation. The group size strongly affects the speed of passengers. An increase from one to three group members reduces average speed by 30% in the case of business passengers and 20% in the case of tourists. Previous data mostly consisted of qualitative measurements or provided unreliable scientific statements (e.g. no statistical background information, problematic test arrangements). To determine the influence of the carry-on baggage on passenger speed, the amount and type of carry-on baggage is counted (figure 13).

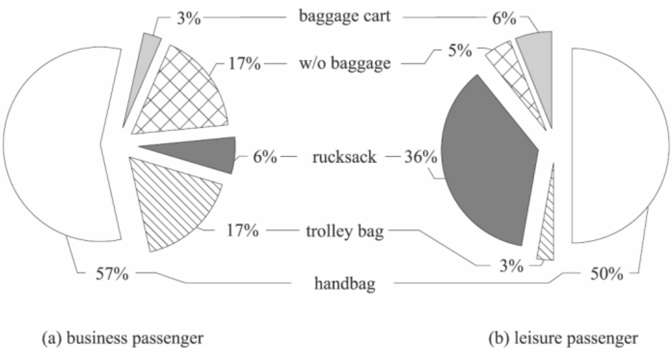

Figure 13. Baggage distribution after check-in process as essential input for security control progress

Due to the fact that many business passengers do not check in their baggage, the amount of trolley bags is significantly higher within this group. In contrast, most of the tourists prefer to carry a rucksack or have no observable baggage. Investigations on the speed influences due to different baggage types point out, that the usage of a trolley bag does not decrease the passenger speed. The performed measurements present a valid data base, which legitimate the application of individual-based models. Due to the comprehensive measurements and analysis of passenger movements in the airport environment the stochastic movement model is calibrated with reliable data sets. The investigation of various group behaviors provides substantial information, which is not considered in existing approaches (e.g. groups with more than three members tend to split up into smaller groups to efficiently manage crowed situations). Hence, further research activities are planned to evaluate this specific behavior in detail.

B. Behavioral Investigations

After entering the terminal area passengers are going directly to the check-in facilities, if they not already have their boarding pass (e.g. off airport check-in or web check-in). The followed selection between a handling and service process depends on passenger's preferences [4,19]. Gathered airport survey data suggest, that the process choice is associated with both the remaining time until boarding and the passenger profiles: business, tourist, and attendees (figure 14, next page).

C. Process Validation

The validation of the modeled passenger handling processes is realized by the comparison of empirical data, which are provided by Stuttgart airport. Stuttgart airport arranged two different process scenarios for both the check-in and the security control. For the check-in validation the number of open counters is reduced from three to two and for the security control validation the opened lanes are reduced from two to one.

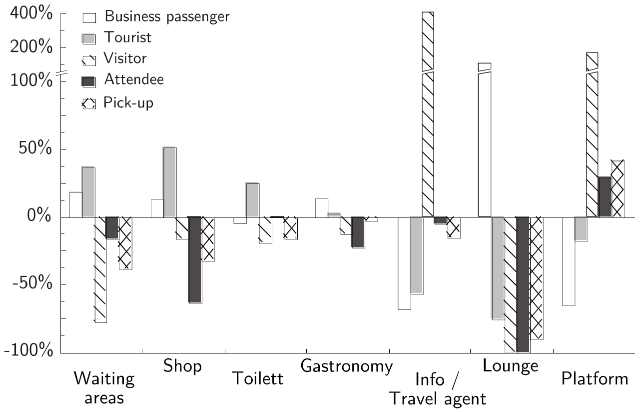

Figure 14. Use of terminal facilities by different passenger categories in relation to an average passenger [4,22]

The virtual terminal environment (see following application section) is initialized with the terminal floor plan, the identified passenger and process characteristics. For each scenario 100 simulation are calculated, statistically analyzed and compared with the empirical data. First, the arrival distribution, amount of baggage and group size were compared, to ensure that the calculation results are not significantly influenced by this boundary condition. It could be shown that minor deviations are covered by the statistical assumptions (see check-in example at table III [4,19]).

TABLE III. COMPARISON OF EMPIRICAL CHECK-IN DATA (DAY 1 & 2) AGAINST SIMULATED EXPECTED VALUE μ AND STANDARD DEVIATION σ

Quantity	unit	Day 1	Day 2	μ	σ
Duration	s/passenger	62.40	62.30	62.37	2.30
Handling rate	passenger/ counter/min	1.25	1.27	1.26	0.05
Group size	passenger/ group	1.26	1.28	1.27	0.04
Amount of bags	baggage/ passenger	0.76	0.75	0.76	0.03

Due to the substantial data sets for the check-in process and the intense level of modeled details (see figure 8) at the security control the simulation points out a high reliability. In figure 15 the characteristic shape of the length of the passenger queue at the security control is shown. While the empirical data are represented by only one bar per time frame, the simulation provides a statistical result, consisting of the expected value (black line) and an area which covers a range of 80% of the calculated results (gray area, limited by 10% quantile and 90% quantile). The empirical scenario could appropriately be reproduced by the modeled and calibrated virtual terminal environment. The comprehensive collection of movement data at the Dresden airport terminal and the evaluation of the handling processes at Stuttgart airport provide a scientifically reliable database. Further on, the calibrated stochastic movement model allows for determining specific passenger characteristics, while the calibrated handling process model ensures a reliable determination of all terminal processes (handling and service facilities).

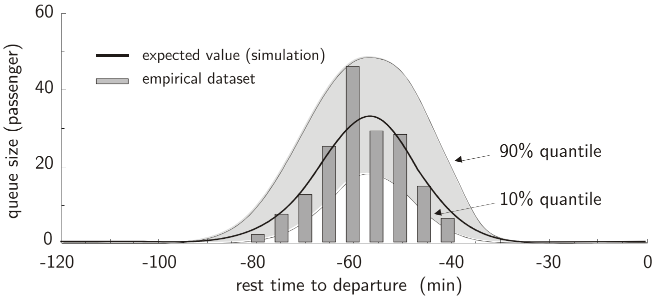

Figure 15. Validation of security control process [4,19]

V. APPLICATION

The theoretical and methodological requirements for the generation of an application environment is provided by the development of a reliable stochastic movement approach and the modeling of the passenger handling processes as shown above. To use the scientific models representing a virtual terminal environment an appropriate application environment has to be realized.

A. Virtual Terminal Environment

An application environment with a graphical user interface was developed such that it allows for the initialization of the scientific model, for integrating the terminal infrastructure and process boundary conditions (e.g. disposition of counters, staff assignment) [4,23,24]. The terminal infrastructure is based on the terminal floor plan, including the positions of all necessary entry/exit points (e.g. terminal entries, emergency exits) and the positions and dimension of passenger handling and service facilities. Although the realized application environment (figure 16) is primarily developed to provide a scientifically-focused implementation of the virtual airport terminal.

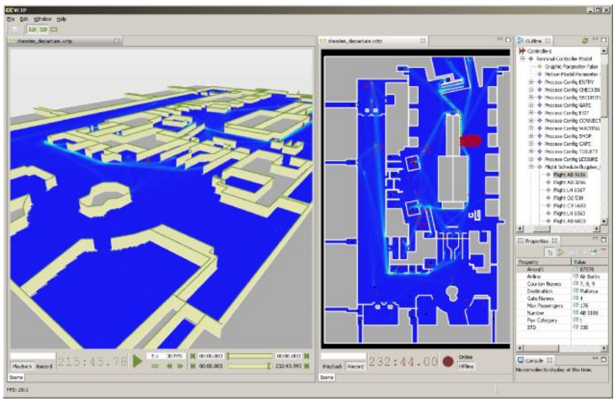

Figure 16. Overview of virtual terminal environment [4]

The software design and implementation consequently meets high–quality development standards (e.g. absence of proprietary components, meta-modeling, use of industry modeling and implementation standards). The modular software architecture ensures a suitable reusability of all components and allows for an appropriate, problem-oriented extension. Existing modules are assigned for scenario generation (e.g. evaluation of different process designs or staff assignment, impact of signage), statistical result analysis of terminal processes and individual passenger progress, graphical result presentation to identify congested areas and optimization potential, animation of passenger motion for terminal overview, visual system checking and situational awareness, and a test bed for model enhancements (e.g. passengers visual perception) and for system extension (e.g. parallel computing, direct human interaction interface).

To evaluate individual passenger progress inside the airport terminal existing standards for the level of service (available space, tolerable passenger density or average waiting times) are not sufficient. The application of the individual-based stochastic movement model allows for perceiving the airport terminal and the handling processes from the passengers point of view. For this purpose existing standards are extended by individual passenger evaluation criteria. Using the process waiting times as an example, an average waiting time of 15 minutes at the check-in appears to be appropriate; however, if only 25 minutes are left to the scheduled time of departure this time is obviously unacceptable. The implementation of several airport layouts (Dresden airport, Hamburg airport, and Stuttgart airport) is used for a problem-oriented scenario evaluation. Based on the floor plan and the flight schedule of Dresden Airport, the developed passenger process evaluation is tested. To support the improvement of passenger evacuation behavior and the investigation of the impact of infrastructure on evacuation progress the layout of Hamburg Airport is used. Finally, Stuttgart Airport terminal is transformed in the virtual terminal environment for processes validation, evaluation of existing handling processes, and the analysis of different staff assignments.

B. Boarding and Turnaround

The stochastic passenger motion model was slightly simplified for efficient calculation of the boarding process. Since the deboarding and boarding are always located at the critical path of the aircraft turnaround reliable statistical investigations are needed. Three different aircraft seating layouts are analyzed in detail: A320-200 (single aisle), B777-200 (twin aisle) and A380 (double deck layout). Whereas the A320 single aisle layout will significantly benefits from a 2 door usage and a procedure change with reduce boarding time μ and variance σ (table IV [25]), the B777-200 twin aisle layout points out a slightly different result [26].

TABLE IV. A320: ONE DOOR AGAINST TWO DOOR CONFIGURATION

Config.	Boarding procedure	μ (s)	σ (s)	%
1 door	Random	1191.0	83.8	0.0
	Block	1151.7	80.8	3.3
2 doors	Random	886.8	55.6	25.5
	Block	1018.8	69.2	14.5

Instead of proper efficiency enhancements of boarding time and variance, only a range of 1.7-8.2 % of boarding time efficiency is achieved (figure 17). Nevertheless, this benefit is even remarkable because it comes with an important reduction of variance (random, 1 door: σ = 44.7 s against random, 2 doors: 33.1 s [25]) and finally allows for a more reliable turnaround calculation.

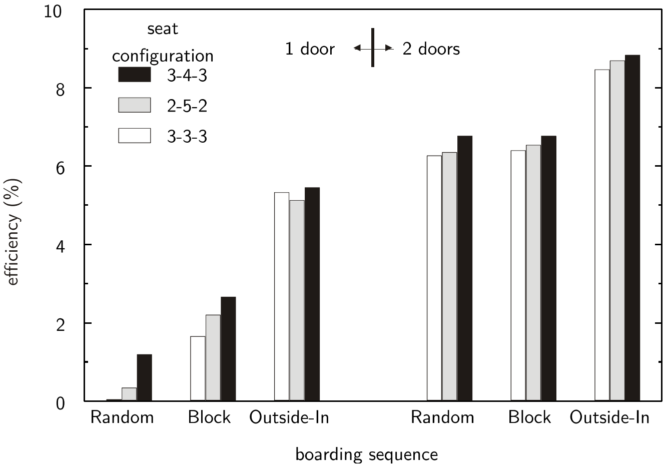

Figure 17. Boarding efficiency using Boeing B777-200 with 3 boarding strategies, 3 seat configurations (3-4-3 means 3 seats left and right, 4 center seats) as well as 1 and 2 door configuration [25])

Due to the introduction of the A380 at Emirates and the analysis of the A380 turnaround first measurement for the boarding are available and could be used to validate the results of the turnaround simulation. For this reason the current Emirates A380 seat layout and the applied boarding sequence (block sequence) is considered. For the analysis of the A380 boarding time a dataset of 145 values is available [1], but unfortunately these values are not assigned to a specific seat load factor. So the empirical boarding time is more a first indicator than a reference time. A deeper analysis of the A380 boarding points out, that two different turnaround procedures are used at Emirates. The first procedure follows the common turnaround progress definition with parallel catering and cleaning (fast turnaround), whereas at the sequential turnaround procedure cleaning only starts if the catering is finished. Considering these limitations and the priority boarding the expected boarding time is 30.75 min with a standard deviation of 9 min for the fast turnaround (sequential: 35.25 min and 9.75 min). The high deviation values are caused by several disturbances during the passenger boarding (e.g. passenger handling problems will induce approx. 40 min delay at average). The boarding simulation results in an average boarding time of 26.8 min and a significantly decreased deviation of 0.6 min.

Using the empirical boarding time as a quality indicator and considering the disturbance naturally occurs when introducing new aircrafts at airport, the proposed boarding simulation seemed to be an appropriate tool for stochastic boarding time estimation. Furthermore, the delay code analysis of Emirates A380's confirms the need for an efficient passenger handling management due to stochastic terminal simulation by means of reporting reliable minimum connecting times and developing economic adequate process designs.

C. Level of Serivce

Following the Level of Service concept (LOS) [27] six categories (Level A-F) are defined by measurements of available area per passenger, capacity utilization and (acceptable) waiting times. Tracking the evaluation of LOS concepts [28,29] it could be noticed, that the individual passenger perception and status is not considered [4]. So, the LOS is not more than recommended design criteria for terminal construction. To develop system indicators for evaluation of handling process performance specific KPI's (key performance indicator) have to be established. Passenger surveys regarding to quality of service point out the significance of efficient signage, comfort, and short process connections [30,31]. The developed virtual terminal environment allows for the examination of comprehensive, specific passenger status (e.g. position, passed handling stations, waiting and process times) and his individual interaction with the environment (information demand for decision support).

To design an appropriate KPI the waiting time at the check-in can be used as an example. As shown in figure 18 the simulated waiting time per passenger decrease over the time depending on passenger arrival (per flight check-in). Using [ADRM] as reference the individual waiting for the check-in should not exceed 30 minutes for long waiting time and 12 min for an acceptable waiting time (qualitative rating).

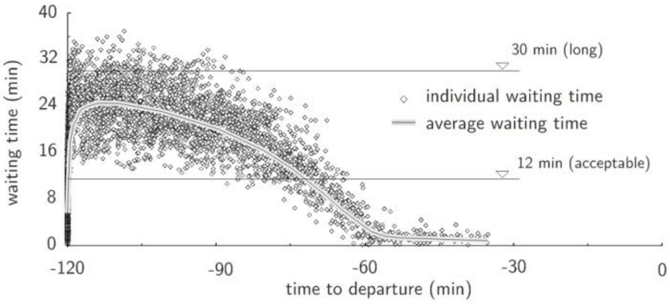

Figure 18. Simulated waiting times of tourists at check-in (150 passenger per flight, 2 counter, 60 simulation runs) [4]

Obviously, the waiting time is a quantitative measurement, but the specific implication additionally depends on the available amount of time until boarding. With the decreasing residual time budget a waiting time of 20 minutes could be crucial. If the check-in closes 30 minutes before scheduled time of departure, the associated relation of waiting time against residual time to check-in closing time possesses the shown characteristics at figure 19.

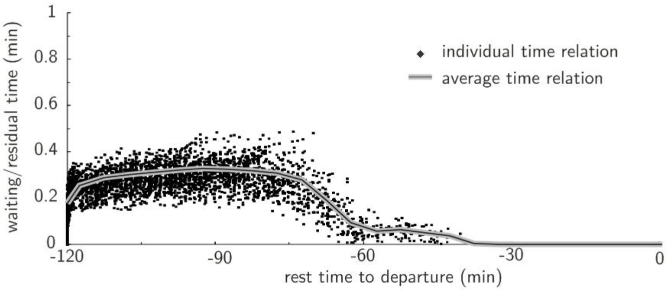

Figure 19. Relation of waiting times against residual time until check-in closing [4]

In contrast to figure 18 the time relation exhibits two levels, upper level is about 0.3 and the lower level is about the ratio 0.07. Further investigations at Dresden airport terminal design and flight schedule points out two economic reasonable and from a passenger point a view acceptable relation level: 0.4 as a upper limit for economic forced process design (but the risk of missing flights increases) and a lower limit of 0.2 which comes with a comparative good comfort (20% of residual time have to be used for waiting). These levels values will naturally increase for the security control because of the decreasing amount of time until boarding. The waiting time against residual time relation allows for adaption of check-in and security personal disposition.

The identification, validation and implementations of KPIs for the airport management are one important application of the virtual terminal environment. Efficient management of the complex passenger behavior at airport terminals will be the basis for reliable planning and following efficient ATM/ATC operations.

VI. OUTLOOK

Innovative concepts for sensitive infrastructures such as terminal buildings require sophisticated simulation capabilities prior to any physical tests in the operational airport environment. The presented movement model and the application environment based on it have been shown to achieve this goal. A field of application is the investigation of the influence of adaptive airport signage on passenger flows. The efficient use of concessionary areas may increase airport revenues, while an appropriate service level regarding passenger perception is expected to enhance the efficiency of the facility. The time-dependent guidance of passenger flows may significantly contribute to safe, secure and reliable planning airport procedures. Thus, the airport is able to cope with the demanding SESAR requirements for 2020 regarding capacity, security and business orientation.

The passenger-related evaluation and simulation of handling processes show that the developed stochastic movement model is able to reproduce the behavior of passengers in an appropriate way. The application-oriented implementation offers a variety of convenient solutions to face future scientific and practice-oriented challenges of passenger dynamics as well as airport planning, management and optimization. Besides the reproduction of existing processes the application of a virtual terminal enables the investigation and optimization of altered process structures, particularly in the face of the introduction of new safety/security technologies (e.g. recording of biometric features, full-body scanning techniques). Future research projects will focus on the following fields of modeling and application:

- coupling passenger simulation and airside (gate) management tools to minimize passenger transfer costs,
- transferring stochastic agent model to airside operations and allow for decentralized organization and optimization,
- improvement of the non-aviation area layout regarding passenger flow and signage optimization,

- dynamic route planning in the airport terminal regarding normal operation, security issues, emergency cases,
- investigation of enhanced group-dynamic behavior,
- optimization of handling-driven processes chain.

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