PEDESTRIAN DYNAMICS IN AIRPORT TERMINALS CONSIDERING EMERGENCY CASES

M. Schultz, S. Lehmann, H. Fricke*
***Chair of Air Traffic Technology and Logistic, Technische Universität Dresden**

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Abstract

Airport terminals aiming at providing smooth intermodal access to the air transport system and have to cope with constantly growing both safety and security requirements. A terminal is divided into public and non-public areas which shall guarantee different security levels and require several ways to control passengers (EU 2320/2002). The stochastic model presented here allows the validation of diverse terminal operations taking into account the mix of screened and non-trusted passengers, varying traffic volume to be handled within the capacity constraints of the system, the use of emerging technologies and procedures (managed alarms, guidance systems) as well as any changes of legal requirements. In the near future higher densities of human beings in public and non-public areas inside the airport terminal may be expected as well as the growing importance non aviation business is of to airport operation. Naturally, crowded areas have a hazardous potential even without considering cases of emergency. The developed model for pedestrian emergency dynamics may also be integrated into the ICAO Annex 14 safety management system (SMS) process to investigate emergency plans and evacuation procedures. Airport operators may so optimize emergency processes based on reliable simulation results and legitimize their modes of operation.

1 Safety and Security Research

Air traffic is characterized by requiring spot infrastructures at departure and destination which have the highest safety and security restrictions in the transportation sector. The Establishment of the European Aviation Safety Agency (EASA) end of 2003 has significant and sustainable influences on the responsibility of national public authorities. Change in the field of security due to the EU regulation 2320/2002 and, in Germany the Luftsicherheitsgesetz, e.g. enhanced security checks, authority responsibilities and new airport standards leads to new procedures and operational requirements. The future of the aviation sector will be characterized by the definition of European / international standards to ensure consistent safety [11] and security [2] appreciation.

To evaluate the safety and security status of an airport terminal these values have to be quantified. [6, 7] In the near future airports have to provide certifications for established safety and security levels. Significant legal developments are stated by the ICAO Annex 14 "Manual on Certification of Aerodromes"; airports have to establish a Safety Management System (SMS). „The intent of a SMS is to have in place an organized and orderly approach in the management of aerodrome safety by the aerodrome operator." [4]

2 Safety Management System

Due to the national acceptance of the ICAO recommendations since 24th November 2005 the SMS shall be realized on airports to ensure validated safety and security standards. The Implementation, functioning and realization of SMS on airports is assigned by civil aviation authority audits. To complete the implementation of the Safety Management System (§ 45/1/1

LuftVZO) the following points have to be fulfilled.

- Corporate safety policy
- Installation of a safety manager
- Assignment of responsibilities to processes
- Organization of safety committees
- Hazard analysis and risk management
- Reporting of safety/security relevant events
- Analysis of safety/security relevant events
- Documentation
- Auditing
- Change management
- Organization of security/safety training staff members
- Definition of safety objectives
- Control SMS efficiency
- Emergency planning

The SMS provide a consistent methodology to clarify responsibilities, to ensure transparency in processes and the quantification of safety and security enhancements. To analyse the planned procedures for emergency cases a methodology for the emergency management will be presented below.

2.1 Emergency Management

Legal requirements for the emergency management exist on several levels. The ICAO handles through Annex 14 / chapter 9 „Emergency and other services“. Starting with elementary statements about aerodrome emergency planning (chapter 9.1), requirements for rescue and fire fighting (chapter 9.2) are defined. Detailed informations are stated in the corresponding Airport Service Manuals (ASM) Part 1 and Part 7.

Recommendations stated by the ICAO cover few requirements with general character. The national authorities as well as the airports can complete and precise these guidelines.

Part 7 contains basic requirements for necessary emergency documents, from the definition of possible emergency cases, the description of involved services and their responsibilities up to the statements about emergency drills. [5] To verify the effectiveness of the emergency preparations operators shall use simulations to determine where potential improvements can lead to efficient airport emergency processes. Compared to simulations field test are extremely cost-intensive and the risk for all parties involved will sometimes be neglected.

3 Pedestrian Dynamics

To analyze the complex motion behavior of human beings during emergency and non-emergency situations surrounding conditions and human factors have to be analyzed. The multidisciplinary research on pedestrian dynamics combined safety experts and researchers with different profiles, e.g. civil engineering, computer science, psychology, physics and social research.

Models for pedestrian dynamics have to cope with psychological effects like attraction on repulsion as well as global social effect like herding and follow-the-leader concepts. [3] Complex global effects are not arising by defining rules for motion behavior. They are based on local interactions between very similar (uniform) entities. Effects of spontaneous structure forming, which can not be reduced to the single entity are known as self-organizing effects.

In addition to the motion behavior the simulation models have to consider that heterogeneous groups of people are addressed with different personal profiles. These profiles are fundamentally categorized by citizenship, language, knowledge of the environment, cultural attitudes, assertiveness and the general physics of each person. In airport terminals one my find employees, passengers, well wishers, and visitors.

The used stochastic approach for modeling individual motion behavior and primary components will be described in the next paragraphs.

3.1 Stochastic Approach

The discrete microscopic simulation model for passenger motion behavior used here is based on an enhanced cellular automaton model, in consideration of repulsion potentials, friction and clogging effects, as well as path finding/guidance algorithms.

The cellular automaton model is discrete in both space and time. The simulation environment is split in squares with a dimension of 0.4 m, therefore reflecting the typical minimum space needed of a single person [13]. A cell may possess two different states - the ground state "free" and the state "occupied" in case a person or an obstacle is located on it. A person can move to all adjacent cells (Moore-Neighborhood). The movement to other cells depends upon the transition probability stored in the preference matrix $\boldsymbol{M}_{q,p}$.

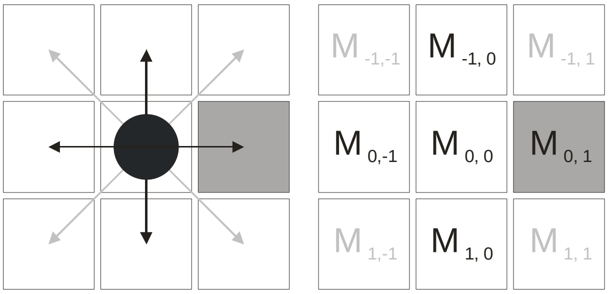

Fig 1. Probability Matrix

The preference matrix will be generated by superpositioning of the probability (1-3) moving to an adjacent cell in motion direction and transversal deviation. The transversal deviation is defined by an expected value of μ_T=0 and variance of σ_T^2, whereas the longitudinal motion component is described by μ_L und σ_L^2.

$$p_{-1} = \frac{1}{2}(\sigma^2 + \mu^2 - \mu) \qquad (1)$$

$$p_0 = 1 - (\sigma^2 + \mu^2) \qquad (2)$$

$$p_{+1} = \frac{1}{2}(\sigma^2 + \mu^2 + \mu) \qquad (3)$$

Using the quantifiable parameters (μ_L, σ_T^2, σ_T^2) together with the desired motion direction α for the stochastically modeling of human behavior allows developing a reliable simulation model and the calibration of the parameter set due to experiments. [1, 8-10]

To ensure trustworthy safety enhancements the simulation model shall describe the typical behavior of persons. Due to the statistically approach the model can cope with unpredictable behavior of human beings and ensure reliable evacuation simulation.

3.2 Interactions

By using the cellular automaton approach for modeling human motion behavior only direct / local interactions can be considered. To implement any interactions between human beings [3], the model has been extended by a repulsion field *Φ (x, y)* approach, where *x* represents the longitudinal component and *y* represents the transverse component of the person's velocity [10].

$$\Phi(x,y) = a\, e^{\frac{w_{x1}}{w_{x2}}\left(1-e^{-\frac{x}{w_{x1}}}\right) - \frac{x}{w_{x2}} - \frac{y^2}{w_y}} \qquad (4)$$

In the equation (4) *a* represents the amplitude and *w* the set of shape parameters for the repulsion field.

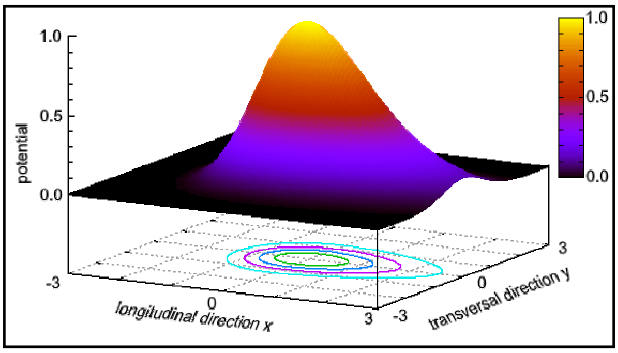

Fig 2. Repulsion Field

The shape of the repulsion field (Fig. 2) is defined by the repulsion based on the relative velocity and on the distance between the corresponding persons. If two persons move directly to each to other the relative velocity reaches the highest value. In the opposite case, which means that the two persons move in the same direction with the same speed the velocity induced repulsion component will be zero. Additional to the velocity induced repulsion force the distance between persons is an important factor. These repulsion component will increase if the corresponding persons getting closer. [9]

3.3 Emergency Cases

An emergency case can be defined as an auto-dynamic, damaging process, caused by a specific incident. The effects of the emergency case can lead to disturbances of terminal processes or in the worst case to the destruction of the affected area. It may take only a small incident to initiate a chain of subsequent events leading to an emergency situation in complex buildings, like airport terminals. [12] To simulate emergency cases, areas being affected by the incident and the arising consequences have to be explored.

To model emergency cases methods from the external risk analysis will be used. The emergency area is divided into two emergency zones (see Fig. 3):

- Consequence area (pink) and
- Incident area (red).

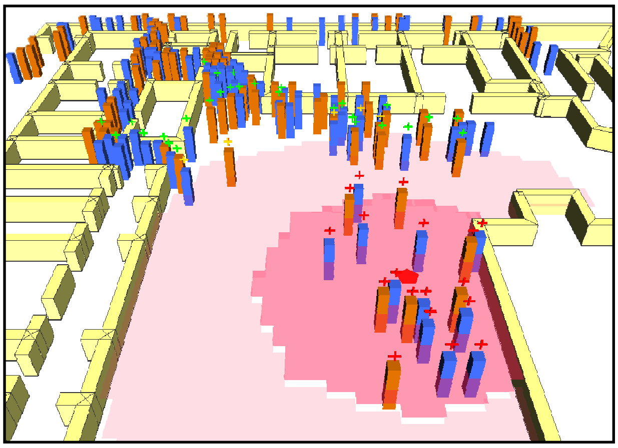

Fig. 3. Emergency Zones

In the simulation environment, emergency cases are determined in three different ways: the lack of orientation information, the modification of the motion parameters, and the changing of the person's surrounding area (e.g. blocked exits).

Persons located inside the consequence area are primarily constricted in terms of route choice and motion behavior. These constrictions will lead to immobility if the persons are inside the incident area. A self-contained motion will not be possible so recovering can be provided only by rescuers.

The temporal expansion of the so called consequence area depends on the character and the dimension of the emergency and on the conditions of the surrounding environment. To ensure reliable simulation results for potential threat scenarios an additional emergency module describes the broadening of the emergency zones by considering the environment conditions.

3.4 Route Choice / Guidance System

Even in crowded situations the modeled emergency guidance system has to provide typically both optical and acoustic lead information (aware of international differences) at an early stage, to alert and advice people about possible dangers. These situations highlight the limits of a static guidance system, as the system cannot ensure that the using of pre-defined routes is safe for the escaping persons.

With a managed guidance system, airport operators are able to analyze the current situation and may start a successive evacuation (re-routing) regarding the character of the emergency and the terminal area classifications, e.g. security/safety zones, operational/public zones and international/domestic zones.

4 Application

The presented stochastically approach for modeling individual motion behavior offers the ability to react fast to changed surrounding conditions and provides multiple simulation runs with altering parameter sets in a short time.

To ensure a reliable result a multi-level diagnostic of the evacuation process is necessary by considering the overall evacuation time as well as the identification of potential bottlenecks (Fig. 4), the analysis of the critical path through the airport terminal, guidance system influences on pedestrian dynamics and the effects of adjusted structural measures. For the analysis of the evacuation process data from real conditions and from the simulation of the terminal procedures are taken, respectively.

The developed model is integrated in a software environment that automatically imports these records together with prepared architectural data (e.g. ground plan).

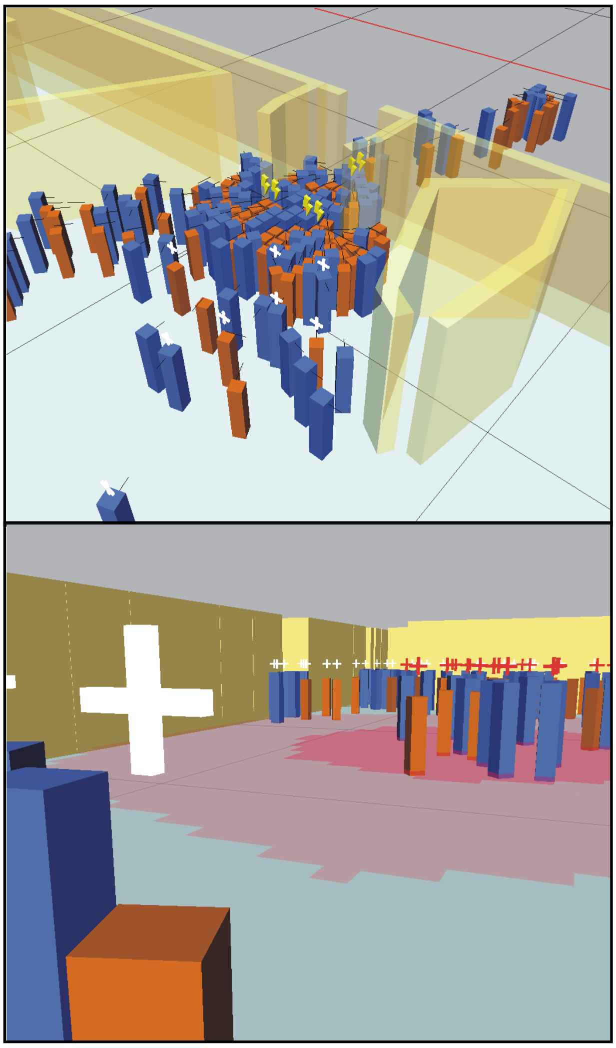

Fig. 4. Emergency Simulation

To start the emergency simulation the user can choose both a pre-defined, categorized emergency case with selection of time and location and a user-specific determination of the emergency properties (an interface will be provided by the software environment). The developed software can be integrated in the safety management system to investigate emergency plans and evacuation procedures. Airport operators can optimize emergency processes based on reliable simulation results and legitimize their actions.

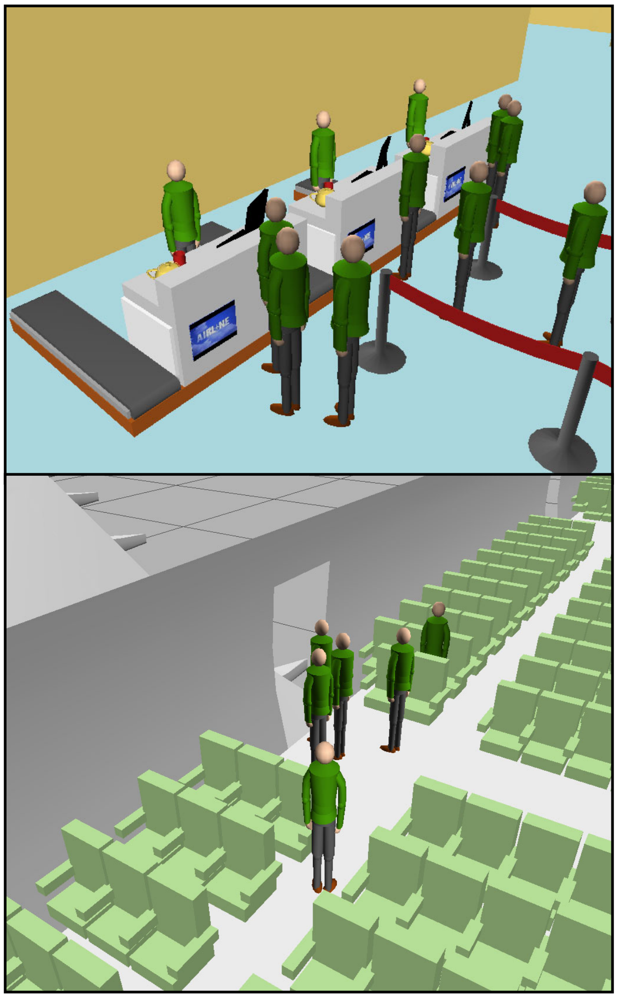

Fig. 5. Process Simulation

In addition to the simulation of emergency cases the individual behavior model can be used for the simulation of airport terminal processes (Fig. 5) like dispatch procedures, security checks and boarding / deboarding of aircrafts.

5 Conclusion

Passengers expect a fast access to the terminal, reliable dispatch and due to the increasing feeling of harassment, objective and reliable security and safety guidance in the airport terminal. The requirements to the future air traffic will have to cope with these enhanced expectations in terms of safety, security and facilitation. Thus, airports must aim at high system reliability in conjunction with efficient and safe evacuation procedures. The proposed discrete microscopic model allows a fast identification of potential weaknesses in the emergency planning by simulating a significant amount of airport specific emergency scenarios.

In consideration of the exceptional position of an airport terminal as a location of intermodal interchange, these critical points can be eliminated beforehand by means of technical, operational and architectural instruments. Together with the emergency requirements described in the Safety Management System the model allows to quantify emergency procedures.

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