Managing Passenger Handling at Airport Terminals

individual-based model for stochastic passenger behavior

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Structure

- motivation

- stochastic movement model
  - development and adaptation of model
  - validation using the fundamental diagram (speed-density correlation)
  - navigation inside virtual environments

- airport terminal
  - passenger and handling processes
  - data collection at Dresden and Stuttgart airport

- implementation
  - development of an application environment
  - proof of concept

- summary and outlook
Motivation

- modeling of individual movements to ensure
  - reliable optimization of traffic and handling infrastructures
  - sustainable configuration of guidance systems

- high variety of scenarios of model application, supported by high performance of current computer architectures

- demand for adequate approaches to model individual passenger behavior
  - delay caused by terminal processes significantly influences performance
  - e.g. security check (5-12%), baggage (2%), dep. gates and boarding (5-8%)

- application area: airport terminals
  - optimization often based on staff experience
  - scientific models of passenger behavior barely used
Dynamic Movement Behavior

- dynamic effects caused by
  - individual characteristics
  - decentralized decisions and control

→ self driven agents with capability to
  independent problem solving

- self organization
  - spontaneous pattern
  - non-standard physics
  - no external rules given, only local
    interactions defined
  - higher order of system leads to
    efficient use of infrastructure
Self-Organization - Formation of Bi-Directional Lanes
Microscopic Model

- **social force model**
  - bi-directional attraction and repulsion forces, depending on distance, direction, relative speed and group constellation
  - additional contact forces within highly congested areas
  - continuously in time and space

- **cellular automat**
  - discrete, grid-based model (cell size equals to minimum space requirement)
  - transition probability to adjacent cells
  - *simple exclusion* - only free cells could be used by agents

- convergence of approaches: discretization to speed up model implementation vs. use of conceptual analogies

- reliable passenger model demands for stochastic model (fast performing) approach
Development of Stochastic Model - Cellular Automat

- stochastic model defined by specific transition matrix $M = p \cdot q$
  - 3 transition states for both horizontal and vertical \{-1, 0, +1\}

$$
\begin{align*}
  h^{+1} &= \frac{1}{2} (\sigma^2 + \mu^2 + \mu) \\
  h^0 &= 1 - (\sigma^2 + \mu^2) \\
  h^{-1} &= \frac{1}{2} (\sigma^2 + \mu^2 - \mu)
\end{align*}
$$

- simplistic approach for $p$ and $q$
  - no backward movements
    $$
p^{+1} \text{(vorwärts)} = \mu, \quad p^0 \text{(stop)} = 1 - \mu
\$$
  - symmetric variance
    $$
    q^{\pm1} \text{(rechts,links)} = \frac{1}{2} \sigma^2, \quad q^0 \text{(stop)} = 1 - \sigma^2
    $$
Development of Stochastic Model (2)

- horizontal and vertical probability is only 1,5-dimensional (variance ≠ movement)

- turning the transition matrix (re-indexing) to cope with diagonal movements

- superposition of horizontal and diagonal matrix for 2D movements

\[ M = \begin{cases} 
(1 - \lambda) \bar{M} + \lambda \bar{M}, & \lambda = \tan \alpha, \quad 0 \leq \alpha < \frac{\pi}{4} \\
\frac{1}{\sqrt{2}} (1 - \lambda) \bar{M} + \sqrt{2} \lambda \bar{M}, & \lambda = \tan \left(\frac{\pi}{2} - \alpha\right), \quad \frac{\pi}{4} \leq \alpha \leq \frac{\pi}{2}
\end{cases} \]
Model Adaptation

- sample configuration

\[\begin{align*}
\alpha &= 15^\circ \\
\mu &= 0,8 \\
\sigma^2 &= 0,2 \\
\end{align*}\]

\[\begin{align*}
\alpha' &= 15,39^\circ \\
\mu' &= 0,78 \\
\sigma'^2 &= 0,072 \\
\end{align*}\]

- investigation of the model points out
  - expected value of transition matrix deviate form movement vector
  - additional dependence of movement angle regarding to
    - variance and
    - speed

- demand for efficient compensation: correction functions
Interactions Between Agents

- stochastic model defines the movement of one agent

- consideration of collisions
  - random shuffled update
  - crossings not allowed

- additional set of parameter
  - movement strategy
    - stochastic choice of occupied cell: wait vs. move
  - amount of movements per simulation round
    - investigated band width: 1-5 steps
  - movement trace
    - all temporally used cells are occupied during current simulation round
Validation - Fundamental Diagram (I)
Validation - Fundamental Diagram (II)

- stochastic transition model fulfill standard criterion for valid movement approach
Navigation - Continuous Movement Direction

- navigation in complex environment demands for efficient algorithms

- automatically created navigation points as a basis for a network structure
Navigation - Grid-Based Movement Direction (I)

- primary approach for navigation to one specific goal
  - *flood fill*, mark the target area (cell) and step wise fill all adjacent cells of the grid
  - corresponding distance metric consists of artifacts

- resulting metric: $|\Delta x - \Delta y| + \sqrt{2} \min(\Delta x + \Delta y)$
  - cells located on the axes of symmetry are correctly calculated
  - other cells possesses a higher distance regarding to the Euclidian reference
Navigation - Grid-Based Movement Direction (II)

- deduction of direction field
  - characteristics depends on the sequence of calculated cells
  - complementary fields occur by counterrotating creation

- combination of complementary direction fields leads to correct direction field regarding to the Euclidean distance
Passengers at Airport Terminals

- airport terminal as main infrastructure for handling passengers
  - aggregation of different traffic modes (modal split, hub-and-spoke)
  - complex spatial process arrangements and guidance
  - highest security requirements in traffic sector

- fundamental movement decisions of passengers based on:
  - remaining time to departure
  - individual experiences and expectations
  - travel motivation
  - available information

38 minutes 38 minutes 73 minutes
arrival check-in security boarding

Diagram:
- walking in public area > 5 min
- directly to security control

Graph:
- Occurrence (%)
- Time to departure (min)
- 100%
- 75%
- 50%
- 25%
- 0%

- 120 -100 -80 -60 -40 -20
Data Collection - Video-Based Passenger Tracking (DRS)

- recording and analysis of movement trajectories
  - segmentation of picture
  - adaptation of lighting
  - analysis of masking
  - determination of position
  - identification of passengers

- **people tracker**
  - prototype application
  - trajectory extraction
  - manual correction
  - export of passenger related trajectories
Data Collection - Video-Based Passenger Tracking, Results

- results
  - women vs. men
  - tourist vs. business
  - size of the group
Data Collection - Process Times (STR)

- focused on check-in counter
  - arrival distributions
  - amount of group members and pieces of baggage
  - personnel (level of experience)
  - bulky baggage
  - handling disturbances

- functional adaptation of measurements
  - stochastic distributions

\[ F(\alpha, \beta, \Delta x) = 1 - e^{-\left(\frac{x-\Delta x}{\beta}\right)^\alpha} \]

- \( \chi^2 \) test as quality index
Implementation - Application Environment

- development of software-prototype
  - goal: proof of concept of passenger movement and handling model
  - visualization
  - model- and scenario analyses
  - derive functional/infrastructural requirements

- visual computing tools platform (VCTP)
  - Java-based, eclipse IDE
  - separation of model and visualization
  - comprehensive interface definitions

- virtual terminal environment
  - geometry of terminal infrastructure
  - flight plan, passenger characteristics
Implementation - Applications

- investigations of boarding procedures
  - *outside-in, back-to-front, block, random*
  - analyses of variance- and significance
  - aircraft used: A320, B777, and A380

- validation tests at Stuttgart airport
  - determination of specific process behavior
  - variation of amount of check-in counter and security lanes

- passenger related process evaluation
  - relation of waiting to remaining time using Dresden airport as reference
  - analysis of check-in and security control
Summary and Outlook

- **summary**
  - development of a reliable stochastic movement model
  - optimized *flood fill* algorithm
  - data collections at airport terminals provide a solid base for calibration of passenger and handling process characteristics
  - validation of the model approach against specific airport scenarios
  - *visual computing tools platform* as versatile application environment for multi-agent simulations, *people tracker* as validation tool

- **outlook**
  - consideration of human perception (signage, information flow, guidance)
  - navigation of passengers considering partial information
  - model of information reception and decision making (*cue driven* approach)
  - group dynamic effects
  - evacuation simulation
Don’t panic!

Thank you.

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