USAGE OF CROWD MONITORING SENSOR DATA FOR CROWD SIMULATION STUDIES

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ABSTRACT

Crowd monitoring sensor data has been increasingly used for management of the crowd in real-time during events. However, this data can also be used in the planning stage of events for the development and validation of a crowd simulation model of such crowded pedestrian infrastructures. This study details the steps and results obtained when using the complex crowd monitoring sensor data and combination of multiple data sources to build a valid crowd simulation model. The crowd simulation software used in this study is Pedestrian Dynamics®, a microscopic simulation tool which models each pedestrian individually. From the baseline scenario developed with the real crowd monitoring data, multiple scenarios are developed upon where the environment is modified and the pressure on the different areas assessed. The calibrated model can not only validly represent the baseline scenario, but also provide relevant insights into the operations of the environment for different conditions.

KEYWORDS: pedestrian, simulation, sensor data, crowd.

1. INTRODUCTION

The usage of technology for monitoring crowds in large-scale pedestrian facilities and events has been growing in recent years. Technological developments can facilitate the use of sensor data, such as video cameras and Wi-Fi sensors, to estimate levels of crowding in different areas of the infrastructure. Such information is key to assist crowd managers to make well-informed decisions regarding the management of the crowd. The ultimate goal is to keep the crowd safe and give them a pleasant experience.

Real crowd monitoring data, however, can also be of importance in the planning stage such pedestrian areas by providing real data as input to or for validation of simulation studies. Crowd simulation is a powerful tool which can give the raw sensor data life through the visualization capabilities, assisting in complex analyses of the infrastructure for multiple distinct scenarios. When developing a crowd simulation model the quality of the input data is important for the validity of the results and analysis thereof. The usage of real crowd monitoring data for building a well-founded base scenario, from which multiple what-if analysis can be further built upon, can ultimately improve the robustness of the simulation results. In the present study, a case study is presented where the real data from the crowd monitoring systems of the boulevard of a major European

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football stadium is used to derive the input data for a pedestrian simulation model of the same environment.

The objective of this study is two-fold. Firstly, it aims at demonstrating the processes to build a crowd simulation model of large-scale pedestrian facilities. In this step, the derivation of the input data, based on the real crowd monitoring sensor data and its complexities, is highlighted. Secondly, the process to validate the model and the testing of different settings and what-if analysis is discussed. The insights obtained through the simulation results can assist municipalities, as well as infrastructure and event managers, in the development of safety guidelines to guarantee the safety and comfort of people.

2. METHODOLOGY

The study of the environment through simulation consisted of two major steps: (1) the analysis of the sensor data and derivation of model input and (2) the construction of the digital-twin of the environment in the simulation software. To start the development of the project, a drawing of the infrastructure and definition of the scope area are necessary. Only after that, the data can be analysed for the purpose of identifying the main origins and destinations of the environment.

The area in the surroundings of the stadium has also two large concert halls. The worst case situation in terms of crowd numbers coexisting in the boulevard area is when a so-called "triple" occurs. This refers to days when all three crowded infrastructures, the two concert halls and the arena, have events at full capacity occurring at similar times. It is chosen to use such day as the baseline for the simulation, so that the boulevard can be analysed for its maximum stress level. The assumption here is that if the environment can safely and comfortably operate at such crowding level, it is also able to do so during less busy days.

2.1. Crowd monitoring sensor data

The possibilities to use the real data for the study was dependent on the type of sensor and type of data it collects. Two types of sensors exist on the environment, video cameras and Wi-Fi and Bluetooth trackers. For each camera location there was also a Wi-Fi sensor close to it, while some sections had only Wi-Fi trackers and no cameras. The sensor locations are shown in Figure 1. In general, visitors follow a two-step route, either moving from the feeding routes to the boulevard towards the stadium gates or the entrances to the concert halls (ingress) or vice-versa (egress).

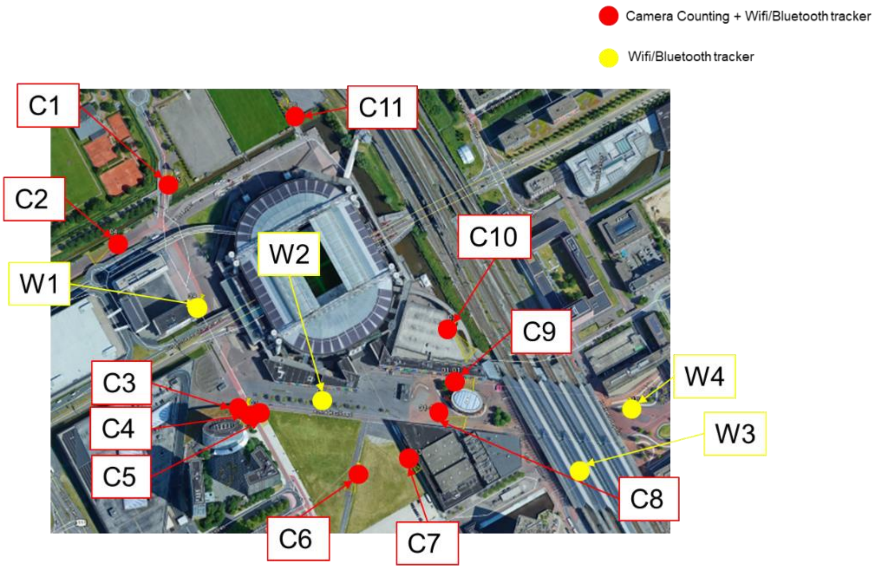

Figure 1 - Location of crowd monitoring sensors (Based on Google Maps view)

The video camera systems were able to collect local data on the total number of visitors per minute per cross-section. This gives indication of the most used areas of the infrastructure, but it does not provide insights into the paths followed by the pedestrians. Meanwhile, the Wi-Fi sensors could track devices in its vicinity. After anonymized, this device ID could be back-tracked and global routes derived from it. By analysing such information, not only the main shares to each feeding point of the environment could be derived, but also some highly used paths.

As expected, mismatches in the data retrieved from the camera systems and those by the Wi-Fi sensors were observed. Camera counting has overall higher accuracy than Wi-Fi sensors, as the accuracy of the latter is dependent on the penetration rate. From the comparison of the data retrieved from the two systems, it was found that the penetration rate was between 6% and 60%. The actual rate was dependent on the time of day and location. Hence, the Wi-Fi data was corrected based on these two conditions.

It was possible to identify one of the steps of visitor’s routes, that is the main feeding points to the boulevard. However, due to the location of the sensors, just based on these it was still unclear how visitors distributed over the different stadium gates. Another layer of analyses is therefore added by including the ticketing information. Per gate of the stadium, the number of tickets scanned per time interval and the total share of visitors to each gate were used to derive the second step in the visitor’s route. Given that each of the two concert halls has a single entrance, no extra analysis steps were needed for the visitors to these areas.

In addition to the recorded visitor numbers and distribution across exits, there are also visitors who pass through the area but are not visiting any of the events; the regular passersby. An analysis of their movements was also made based on the camera and WiFi-Bluetooth measurements. Figure 2 shows the origin-destination matrix derived for these.

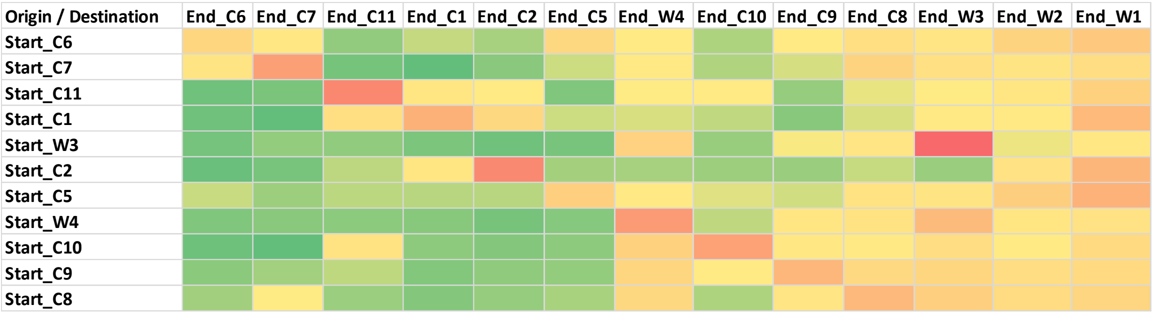

Figure 2 - Origin-destination matrix of regular passersby

2.2. Crowd simulation software

The crowd simulation software used in this study was Pedestrian Dynamics® by InControl Enterprise Dynamics. Pedestrian Dynamics is comprehensive crowd simulation tool, designed for the creation and execution of large pedestrian simulation models in complex infrastructures. It is a microsimulation software which models each pedestrian individually via entities called agents.

In reality, pedestrian behavior can be divided in three behavior levels (HOOGENDOORN, 2001). On the strategic level, pedestrians decide which activity to perform and define their activity set. The following level is called tactical, where pedestrians choose the order they will perform the activities and which route they will take to move between these. Finally, the third and last level is the operational level which controls how pedestrians followed a planned route and avoid collision with objects or other pedestrians.

In Pedestrian Dynamics, while the behavior on the first two levels are direct inputs to the model, the operational level decisions are based on theoretical algorithms. The route following behavior is based on the concept of the Explicit Corridor Map (ECM) (GERAERTS, 2010) and the Indicative Route Method (IRM) (KARAMOUZAS *et al.*, 2009). The collision avoidance algorithm lets each agent choose a desired velocity which prevents them from colliding with others in its Field-of-View (FoV) (Figure 3). The collision avoidance algorithm is based on the vision-based model developed by Moussaïd *et al.* (2011). The software is validated and verified by international guidelines (IMO, 2016).

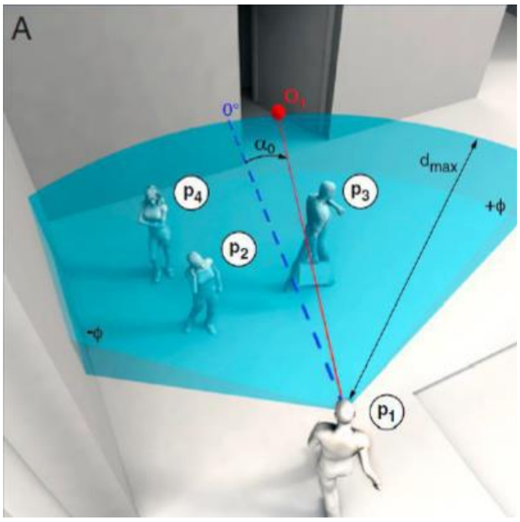

Figure 3 - Field of view collision avoidance (Moussaïd, Helbing and Theraulaz, 2011)

2.3. Simulation model

The environment is built based on a CAD drawing of the environment, directly imported into Pedestrian Dynamics®. From the analysis of the sensor data, the input for the strategic and tactical level decisions could be derived. Both ingress and egress patterns of each of the three event areas were defined. Following, two main possible routes were identified. The event visitor route refers to the route from one of the entrances to the boulevard to one of the stadium gates or one of the two concert halls. The non-event related route goes from one entrance to the boulevard to another directly. Figure 4 shows two snapshots of the final simulation model, one in 2D and another in 3D.

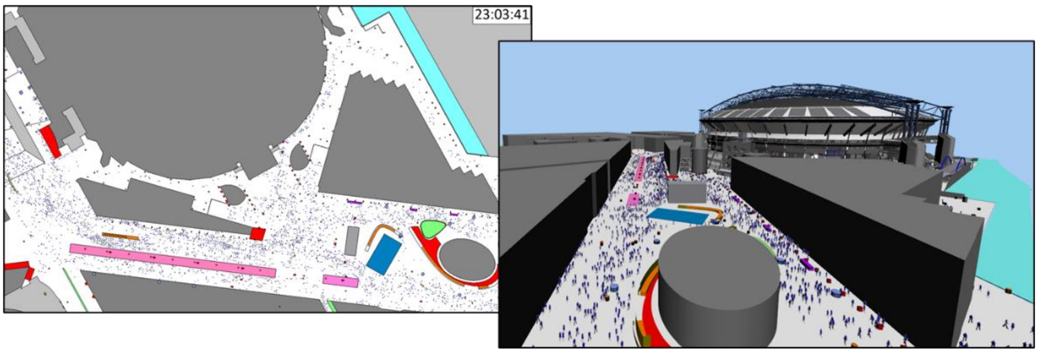

Figure 4 – 2D (left) and 3D (right) snapshot of the final simulation model of the boulevard with the crowds

2.4. Output analysis and KPI's

The analysis of the environment through simulation is based on three key performance indicators (KPI's): maximum densities (persons/m^2), densities over time and throughput (persons/min). The values which define the different Levels of Service are based on Fruin (1971) studies for walkway and are used to color the environment according to the level of crowding observed. Fruin's levels of service are illustrated in Figure 5.

F	> 2.153 person/m²
E	> 1.076 person/m²
D	> 0.718 person/m²
C	> 0.431 person/m²
B	> 0.308 person/m²
A	> 0 person/m²

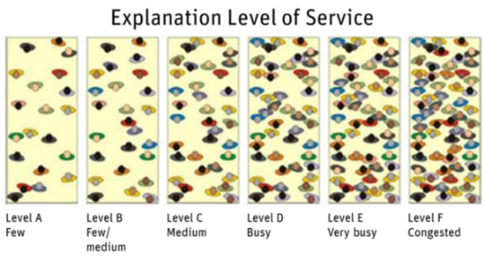

Figure 5 - Fruin's Levels of Service (Fruin, 1971)

2.5. Testing of alternatives

Once the environment and input data was finalized, a multitude of scenarios could be tested. The scenarios analysed consisted of adding temporary obstacles to the path, such as food trucks and construction fences, which ultimately reduce the overall capacity of the environment. Also, the implementation of green pockets was tested, large areas where trees were to be installed which divided the walkable space into narrower routes.

3. RESULTS AND ANALYSIS

The results are separated into the validation and testing of alternatives steps.

3.1. Validation

The simulation software allows for drawing flow counter lines at any location in the model. These flow counters in the model were placed at the same location as the camera positions in reality. The number of agents passing these lines per interval (5 min) are derived from the simulation and the data is exported to Excel. For each of the locations where crowd monitoring sensor data was collected, the simulated and real flow patterns were compared. Figure 6 illustrates this comparions where simulated values are seen to closely follow the real pattern. Based on this results and expert judgment the model was validated and could be used for further analysis and what-if scenarios.

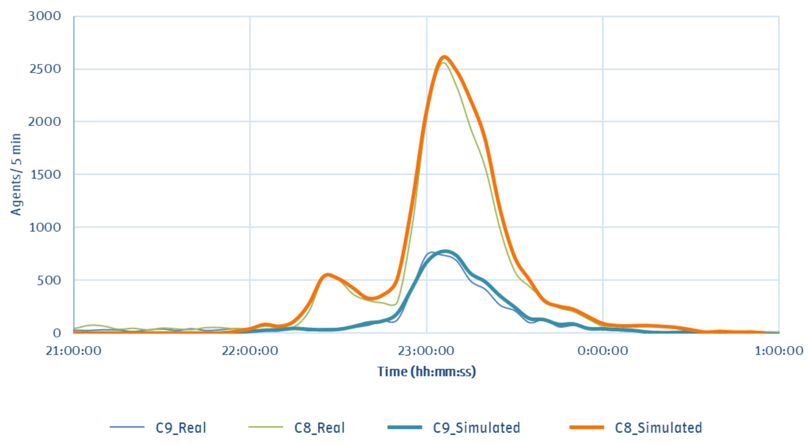

Figure 6 - Validated real vs. simulated flows (pers/5min) for locations C8 and C9

3.2. Scenario analysis

The analysis of the environment for the distinct conditions highlighted the main bottlenecks, that is, the locations where the highest densities appeared. Figure 7 shows the density map, or the highest densities that have occurred in each area of the boulevard. The red and purple areas have densities above 1 pers/m2, which are classified under the very busy and congested levels (FRUIN, 1971). These critical areas appear around the pink obstacles, which are the food trucks, indicating a non-optimal location choice for those temporary obstacles.

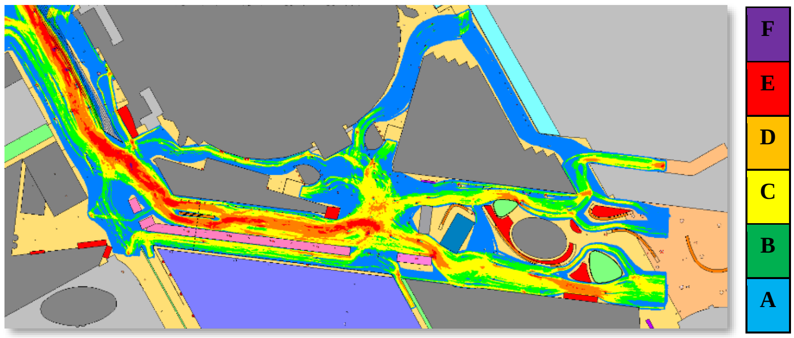

Figure 7 - Density map of the most crowded area of the boulevard

When adding the green pockets, it can be seen in Figure 8 that densities can become even higher as congestion sets in due to the narrower paths and multiple flow directions trying to coexist.

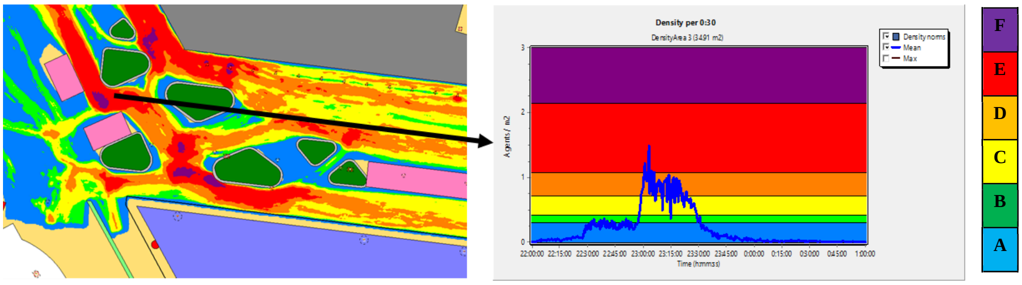

Figure 8 - Pattern of density (right) for the area indicated in the density map (left)

4. CONCLUSIONS

The analysis of the crowd monitoring sensor data can provide a multitude of possibilities for improving the safety and comfort of crowded environments. This data can be used to develop and validate a crowd simulation model from which a robust baseline scenario can be built in which alternatives can be tested in a safe environment. By identifying bottlenecks beforehand, decisions regarding the changing of the infrastructure can be made based on data-driven results, saving on build costs. Future studies on this topic could focus on the derivation of which specific situations can be validly assessed via simulation.

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