CALIBRATION OF THE PEDESTRIAN INGRESS MODEL IN THE VACCINATION CENTER

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ABSTRACT

In recent years, there has been a need to optimize the operation of high-capacity facilities. The covid-19 pandemic has increased this need even more. The presented paper proposes new procedures for the calibration of agent-based pedestrian models based on video analysis, which have the potential to respond to these needs. In paper is demonstrated the calibration process based on machine learning methods. A model of a vaccination centre waiting room was designed in two settings - *basic*, which does not include waiting points analysis and *advanced*, which includes waiting point analysis. Three validation tests were performed and shown, that the proposed calibration approach increases the accuracy of the waiting room model.

INTRODUCTION

In general, microscopic occupant models can be used for egress (evacuation) or ingress (operation) modeling. Ingress modeling is a discipline that has potential to improve the operational phase of high capacity facilities. For example, COVID-19 pandemic is forcing facility managers to optimize operation of vaccination or testing centers for which ingress modeling can be a useful tool. Calibration of these models is often based on input experimental data with different context from historical and cultural point of view (Galea et al., 2010) and other different conditions (e.g. construction layout, capacity). Thanks to advances in the use of computer vision methods that have occurred in recent years, a huge amount of anonymized data on occupant dynamics can be collected in facilities where the model is being designed. Surveillance monitoring systems provide video recordings of facilities operations and computer vision techniques such as convolutional neural networks allow automatic extraction of facility users (occupant) trajectories from video recordings. These data can be used for further analysis and extraction of behavior patterns and model parameters, such as occupant count, walking speed, waiting points etc. The main advantage of this approach is that the model calibration is based on local input data and considers characteristics of real facility occupant.

This paper deals with calibration and validation of an agent-based ingress model of the waiting room operation of Brno vaccination center in Czech Republic based on 30 minutes video recording analysis. Data analysis is based on pre-processed trajectories which were provided by RCE Systems Company. The video recording is taken at opening time of the center so input flow is very low. Analysis of provided trajectories includes:

- walking speed analysis,
- waiting points location analysis,
- ratio of usage of waiting points by occupant,
- ratio of occupant who passed through the waiting room without waiting,
- ratio of occupant who used one waiting point,
- ratio of occupant who used two waiting points.

Model of the waiting room is designed in software Pathfinder in two calibration settings – „calibrated", which includes waiting points definition and „default", where no waiting points are defined. Model results were compared with each other and real video footage data in three validation tests: *validation test 1* – visual check of trajectories similarity, *validation test 2* – time of passage and *validation test 3* – trajectory lengths analysis.

The main goal of this work is to improve the calibration process of agent-based ingress models. Results showed that the presented approach improves results of simulation. This calibration method can be used by facility managers and engineers for capacity assessment of the whole facilities, analysis of flow variations and its impact on partial processes (e.g. entrance check-up, medical check-up), bottlenecks analysis, density estimation and so on. Based on model outputs the operation can be optimized and different scenarios can be tested.

STATE OF ART

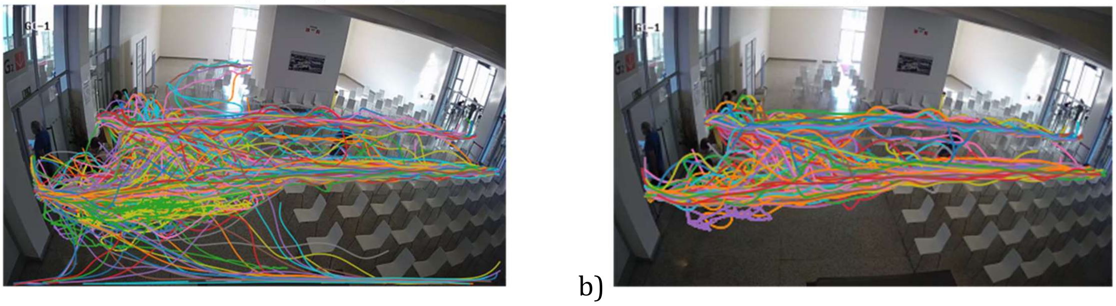
The complexity of the occupant movement model increases with the complexity of the geometry (number and width of entrances and exits, fragmentation of space) and the number and type of occupants (age, handicap, motivation, ...). Calibrating the model with real data makes it possible to describe the actual behaviour of occupants in a given environment. Although this is an important element of model creation, there is not yet a standardized uniform approach that would determine what parameters should be used for calibration (Lovreglio, 2015; Gödel, 2022). Calibration can be divided according to the type of model into microscopic, mesoscopic and macroscopic. Microscopic models deal with individual occupant and their mutual interactions (Guo., 2010). In contrast, macroscopic models describe the behaviour of the flow of occupant as a whole (Taherifar, 2019). Mesoscopic models are a combination of the two mentioned above. Interactions are mainly modeled by statistical distributions (or e.g. using game theory) and kinetic theory is used to describe the behaviour of the flow of occupants (Borrmann, 2012; Liu, 2017; Bellomo, 2021).

Today, a common procedure for obtaining data for calibration is the analysis of video footage from cameras. These can be processed, for example, using machine learning methods to obtain occupant movement trajectories that can be analysed manually or automatically. The position of occupants, their distribution and route navigation can then be determined and thus extend, for example, the social force model (Liu, 2018). Occupant movement models are often used when modeling situations at pedestrian crossings (Luo, 2021), in public transport halls or platforms (Aaboud, 2022; Qu, 2022), educational institutions and during the COVID 19 pandemic, as well as for checking the ability to ensure sufficient distances between occupants (Alam, 2022).

Validation, unlike calibration, is used to verify the accuracy of the model. One of the validation methods is comparing empirical data with simulation results (Kuligowski). Quantitative microscopic validation deals with individual occupant' characteristics (walking speed, time of passage, trajectory) (Lovregio, 2014). We can compare these quantities with video footage analysis results. There are also validation tests used to prove that a given simulation tool produces reliable results that match with empirical data (Thornton, 2011).

METHODS

The input for the research was 226 trajectories from the RCE Company from the vaccination center at the Brno exhibition grounds (Figure 1a). These trajectories were sorted by start and destination position by clustering analysis (DBScan method) and only the trajectories belonging to center clients (not personal) progressed to further processing (Figure 1b). Each trajectory was formed by a time series containing information about occupant ID, position (x, y), time, instantaneous walking speed, tangential and lateral acceleration. Sampling was carried out after 0.04 s. However, these contained faulty points in places where, for example, two occupants passed each other and the occupant detection system on the camera footage was confused. A system was created that can recognize these points and correct the trajectory. A separate article will be devoted to this system.



a) b)

Figure 1: Smoothed trajectories detected by computer vision algorithm (left) and filtered trajectories of center clients (right).

The goal of the analysis was to obtain information from the trajectories that sufficiently and at the same time generally describes the movement of occupants in the vaccination center. The effort was to make the extraction of this data as automated as possible and require as little external intervention as possible.

Waiting points analysis

The first step was to detect waiting points. It is common for occupants not to stand still while waiting, but to move around a smaller area at a reduced speed if they have the option. According to the ČSN 73 0802 standard and the speed distribution of occupants according to Weidmann (Weidmann, 1993), the limit value of the waiting was set at 0.4 m/s. However, filtering points based on instantaneous walking speed of the occupant proved inappropriate, as the walking speed values are distorted by the oscillation of the center of gravity of the occupant detection and estimated instantaneous walking speed is higher than the real value. For these reasons, waiting was defined as where the instantaneous walking speed is less than 0.4 m/s or 0.4 m/s and the distance from the position 1 s ago is less than 0.4 m. Figure 2 shows determined waiting points.

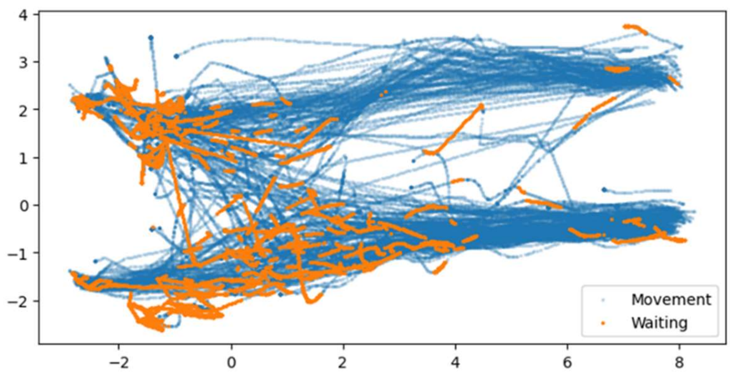


Figure 2: Perspective transformation of trajectories and single points divided to walking and waiting points.

Walking speed analysis

For the points of movement, the distribution of instantaneous speeds was determined and its approximation by a normal distribution (Figure 3), because according to (Buchmueller, 2006), walking speed of individuals in unimpeded occupant flows corresponds to the normal distribution.

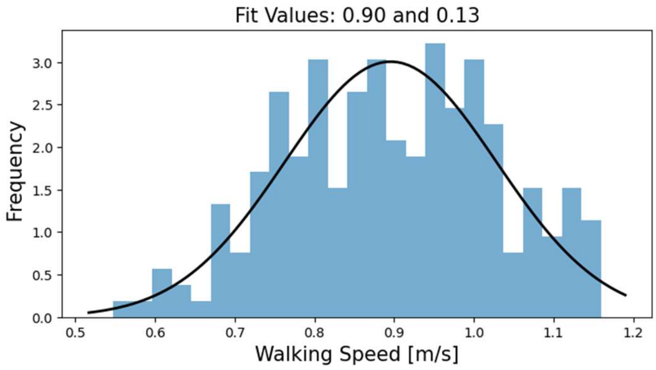


Figure 3: Histogram of walking speed measured in the waiting room.

Furthermore, it was necessary to determine the number of waiting places and their position in the space. A 2D Gaussian Kernel density estimation was performed and the number of sites was determined as the number of kernels of the Gaussian distributions (Figure 4). This value was then used as one of the parameters for K-means clustering (Figure 5). It is a non-hierarchical cluster analysis with a predefined number of clusters. Its advantage is simplicity and fast convergence to the result. For each cluster found in this way, the coordinates of the center of mass and their standard deviation were determined, so that the waiting area was described not only as a mere point in space. These two parameters were used as input data for waypoints components in Pathfinder.

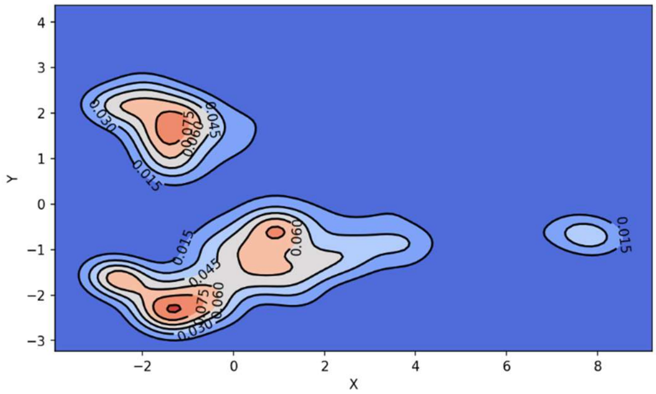


Figure 4: 2D Gaussian Kernel density estimation

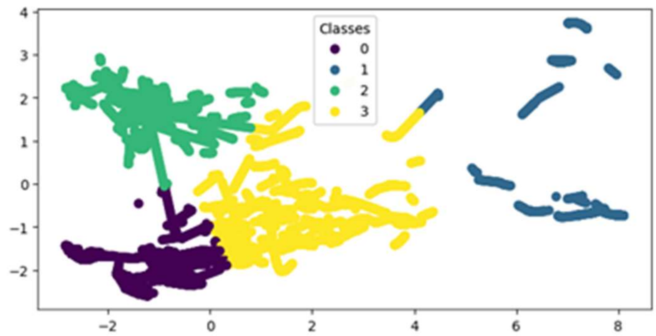


Figure 5: Cluster analysis of waiting points.

Analysis showed that 37 % of occupants walked through waiting room without waiting and 63 % of occupants waited in waiting room. The trajectories of those waiting were further divided according to the number of stops into one or two waits, and the percentage representation of occupants for both of these groups was determined (77 % wait once and 23 % wait twice). A histogram of waiting times (Figure 6) and the distribution of waiting places (Table 1) was determined for waiting once and twice.

Table 1: Distribution of waiting point usage by occupants.

Waiting point	Waiting 1/1 [%]	Waiting 1/2 [%]	Waiting 2/2 [%]
0	11.2	9.7	29.1
1	3.8	25.8	-
2	42.5	3.2	41.9
3	42.5	61.3	29

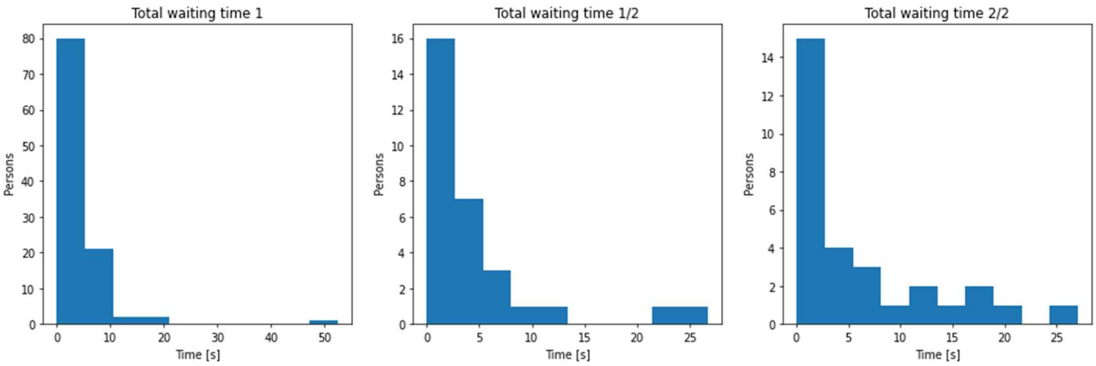


Figure 6: Histograms of waiting times for one waiting and two waiting.

The last step was to determine the distribution of patient arrivals in time for both entrances (Figure 7).

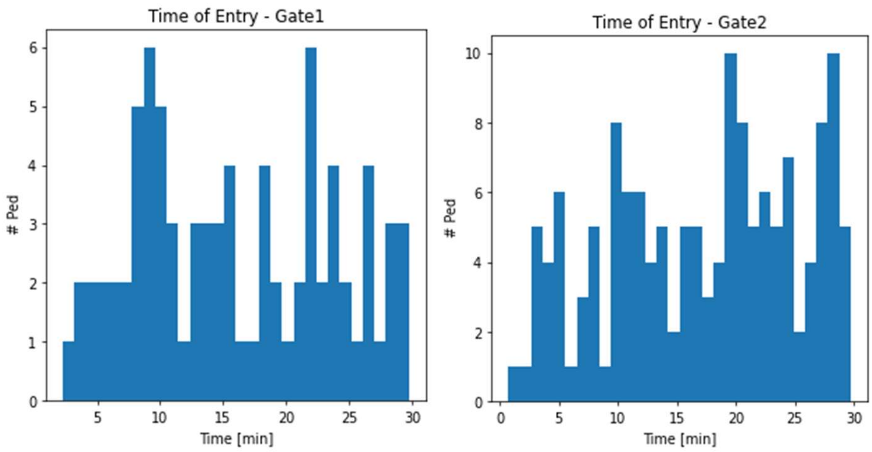


Figure 7: Input flow of occupant at Gate 1 and Gate 2.

MODEL DESIGN

Model of the waiting room was designed in Pathfinder (v. 2022.2.0803). One simulation was performed for every setting.

GEOMETRY

Geometry of the waiting room model can be seen on **Chyba! Nenalezen zdroj odkazů.**8 and is very simple. Navigation mesh contains one room component, two occupant sources (doors) and two exits.

As already said, video footage contains data from the vaccination center at 7PM, so the input flow is very low and clients don't have to use seats in the waiting room.

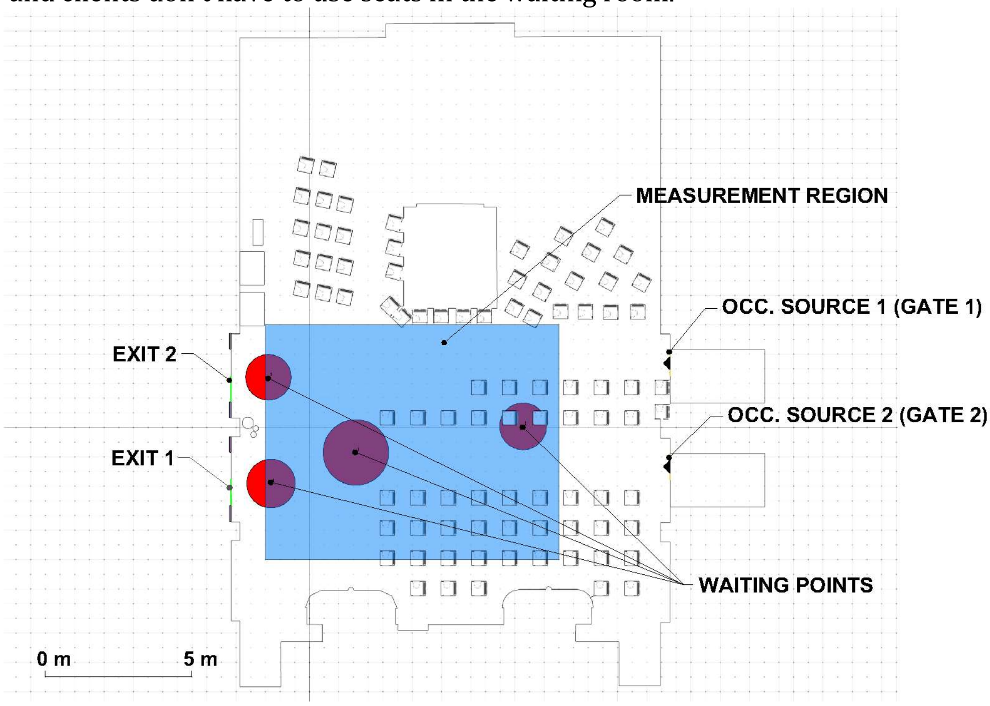


Figure 8: Model geometry with waiting points (red circles) and measurement area (green rectangle).

INPUT FLOW

Flow at occupant sources is based on time at which the occupant encounters input doors and it is set as a step function. For every single time of encounter, four values were generated. For example, if the encounter time of occupant is 50 seconds, to create step function with flow 1 os.s^{-1} we generate t1: 50 – 0.051 s, t2: 50 - 0.05, t3: 50 + 0.1. t4: 50 + 0.101 with 10 generated occupants (see Figure 9), so that approximately between 49.5 and 50.5 one occupant is generated.

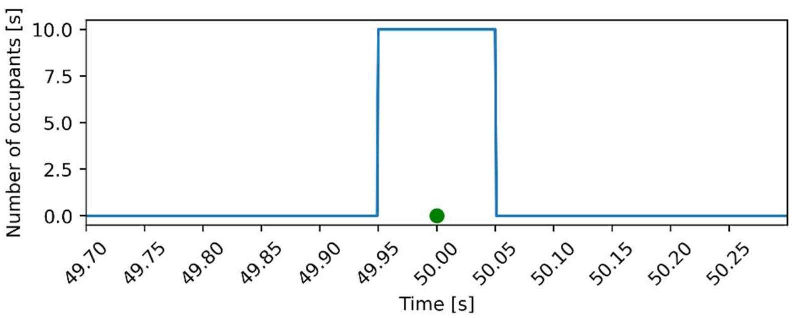


Figure 9: Step function used for generating occupant at occupant sources.

CALIBRATION

Model were designed in two main settings: *model A – basic* and *model B – advanced*.

Model A – basic

For a qualitative validation test a simulation with default Pathfinder setting was performed. This setting contains the same input flow as the calibrated model and walking speed distribution, but no behaviour patterns (no waiting points). This setting (or its variations with different walking speed settings) would be probably used in situations when the model user has no detailed input data about the operation of a given object, decision-making processes or behavioural patterns.

Model B – advanced

Four waiting points (red circles at **Chyba! Nenalezen zdroj odkazů.**8) were placed in the room based on the coordinates of the center of mass and their standard deviation.

RESULTS

Three validation tests were performed. Validation test 1 considers all 226 trajectories. Sample of 166 trajectories from video footage and both simulation settings were chosen for validation tests 2 and 3. These trajectories were filtered based on this criteria:

- trajectories start from video footage correspond to trajectory start in simulation.
- trajectories length from video footage ends outside of measurement region.

Validation test 1

Qualitative validation of occupant trajectories can be made based on Figure 10. One can see a clear difference between simulation with default setting and simulation of calibrated model which produces from visual point of view more similar trajectories to real data.

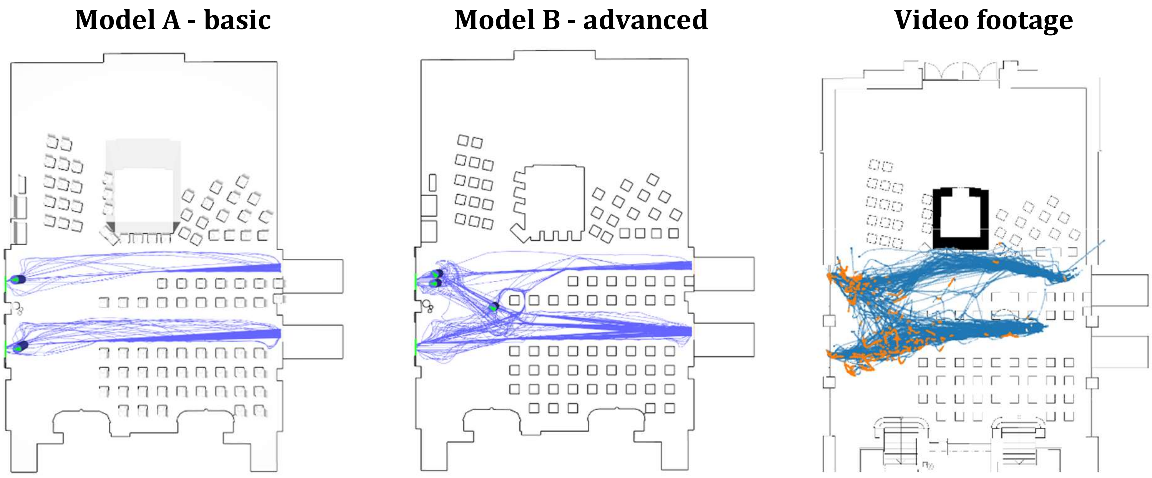


Figure 10: Visual qualitative validation of trajectories similarity for simulations and video footage.

Validation test 2

Quantitative validation of the time the occupants passed the measurement region (Figure 11). There is clear similarity between "Video footage" (Mean: 15.21, SD: 10.96) and "Model B – advanced" (Mean: 15.36, SD: 6.32). "Model A - basic" density curve (Mean: 11.38, SD: 1.24) shows very low variance, which is given by narrow shape of trajectories without waiting points.

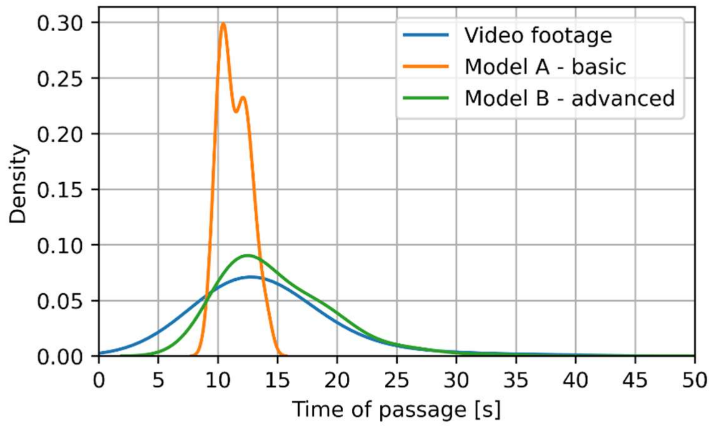


Figure 11: Validation test of occupant time of passage through measurement region.

Validation test 3

Trajectory lengths were measured in the measurement region (Figure 8). Density graph at Figure 12 shows differences in trajectory lengths from video footage and both model settings. "Model B – advanced" (Mean: 10.66, SD: 1.02) shows higher variance in data than "Model A – basic" (Mean: 9.98, SD: 0.24). "Video footage" data (Mean: 15.21, SD: 10.96) shows much higher variance, which is given by several reasons. One can see, that "Model B – advanced" data are more similar to real "Video footage" data, which talks in favour of proposed calibration approach.

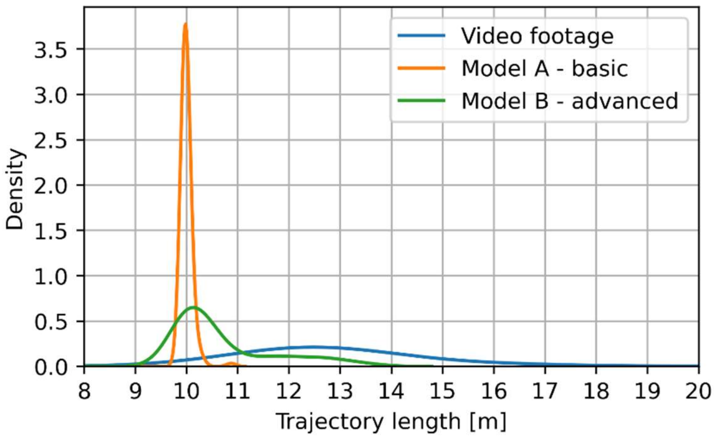


Figure 12: Validation test of trajectory lengths in measurement region.

CONCLUSION

The paper deals with calibration of ingress agent-based model of vaccination center waiting room based on video footage analysis. Machine learning methods were used for parameters extraction from video. Model of the waiting room was designed in two settings, where "Model A - basic" represents more conventional calibration approach and "Model B - advanced" is considering behavioural patterns extracted from video footage. One simulation was performed for every model and three validation tests were performed: 1) visual qualitative validation of trajectories shape, 2) quantitative validation of time of passage, 3) quantitative validation of trajectory lengths. These tests showed that "Model B – calibrated" produces more realistic shapes of trajectories than "Model A – basic". We argue that disparity between trajectory lengths of both models and video footage data (Figure 12) is given mainly by three causes: 1) error which occurs during perspective transformation of real trajectories, so that real trajectories appear to be more curved than they really are, 2) error given by occlusion during camera detection, which leads to more curved trajectories, 3) trajectory

length increases even at waiting points, where trajectory curve is oscillating around the waiting point. We also argue that these errors don't disqualify used data set for calibration and it is clear that trajectories from "Model B – advanced" produces more realistic behavior of occupants than basic calibration approach used in "Model A – basic".
Further research will deal with possible solutions for automatic prediction of model output quantities in real time during operation of given studied object.

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