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DISTANSIM
Implementation of social distancing in pedestrian simulation

Technical Report to the research project DISTANSIM funded by the mFUND program of the German Federal Ministry of Transport and Digital Infrastructure

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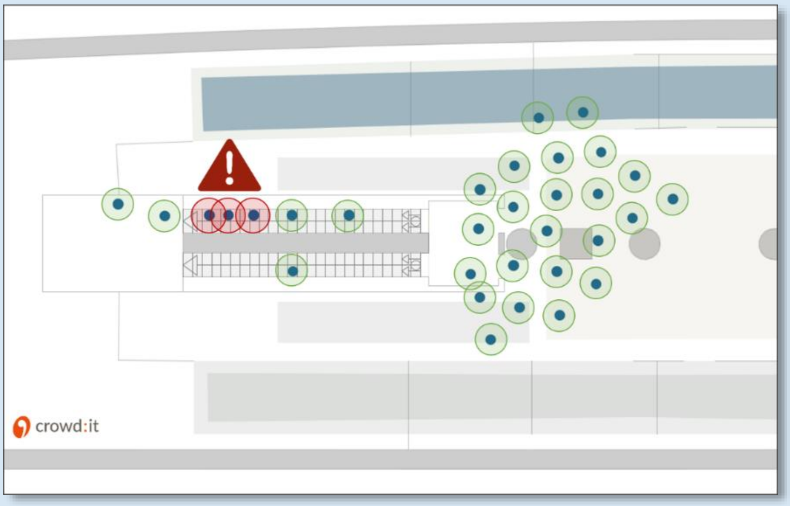

1 DISTANSIM: Implementation of social distancing in crowd simulation

Due to the spread of the Corona Virus Disease 2019 (COVID-19) pandemic, the way people move and behave in public space has changed tremendously. New hygiene and social distancing rules must be implemented, especially in usually crowded places. To investigate the effects of these rules on pedestrian dynamics, the crowd simulation company accu:rate has partnered with Technical University of Munich, Chair of Computational Modelling and Simulation, for a joint research project: DISTANSIM - funded by the mFUND program of the German Federal Ministry of Transport and Digital Infrastructure.

The objective of DISTANSIM was to investigate how to integrate social distancing regulations into pedestrian simulations. This enables users to evaluate their routing concepts for compliance with the social distancing regulations in effect, especially for public spaces such as railway stations, airports, trade fairs and event venues. Within the framework of a feasibility study, we examined the extent to which pedestrian simulation can evaluate social distancing in public places.

The project duration was two months, due to the urgency of the response to the pandemic situation. Initially, we developed the foundation for modelling social distancing based on state-of-the-art research. These modelling principles were then transferred to the simulator, where a case study was developed. We presented this case study to relevant target groups such as operators of infrastructure buildings and meeting places in order to advocate the value and applicability of pedestrian simulation.

2 Why do we need to investigate the effects of social distancing measures?

During the COVID-19 pandemic, economic and social impacts must be kept to a minimum. Social distancing is not always easy to implement. Especially in crowded places, maintaining a distance between every individual is a major challenge. To minimise economic and social impacts however, normally crowded environments, such as train stations and airports, must be operated safely.

These "nodes of the city" are used by thousands of people per day and must be efficient and safe, especially during peak hours. Hygiene measures and social distancing rules have already been introduced, but it is difficult to assess their impact on pedestrian dynamics, especially when passenger numbers are increasing. Simulating crowds under conditions of social distancing allows operators to check if their procedures function as planned, given larger passenger numbers. Capacity limits can be evaluated, and possible measures and adjustments in timetables can be considered.

3 Scope of project

To deliver results most efficiently, the project's focus was to create a tool that enables operators of infrastructure hubs, in this case, a large train station, to answer the following questions:

- What is the capacity of platforms and walkways under social distancing?
- To what extent does the situation change if, by wearing masks, the social distance is reduced?
- How long and in what locations will passengers necessarily or likely fail to maintain a social distance?

The approach followed in this project started with conducting a literature review to evaluate the scientific basis behind the different social distancing regulations demanded in the different countries. Additionally, the literature review took into account the currently available and relevant pedestrian simulation models. Based on the literature review findings, the influence on the behaviour of pedestrians as well as a set of parameters were identified and implemented in a pedestrian simulation model, which makes it possible to simulate pedestrians' behaviour while incorporating social distancing rules.

Due to the project's short duration and the consortium's lack of in-depth virologic expertise, recommendations on infection risks due to exposure, and models of infection rates and virus spreading, were out of scope.

4 State of Research regarding SARS-CoV-2

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the strain of coronavirus that causes coronavirus disease 2019 (COVID-19), the respiratory illness responsible for the COVID-19 pandemic. The World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern on 30 January 2020, and a pandemic on 11 March 2020.

Epidemiological studies estimate each infection results in 1.4 to 3.9 new infections when no members of the community are immune, and no preventive measures taken. The virus primarily spreads between people through close contact and via respiratory droplets produced from coughs or sneezes (WHO 2020c). There are increasing signs that there is an airborne transmission of COVID-19 via aerosols, but this is still subject to scientific discussion, as evidence has not been provided (Klompas et al. 2020).

On a global scope, countries have closed their borders and have limited travel possibilities. While the virus has probably its origin in China, it has soon reached the entire world. Besides China, by the time writing this report, especially Europe and the US have been critically affected by the virus (WHO 2020b) and therefore protective measures became an urgent topic of discussion.

Under non-pandemic conditions (prior to the spread of COVID-19), the different governmental health organizations demand specific regulations (based on the scenario, like transportation and events) for the permissible number of persons per m^2 [p/m^2] (people density). For example, in Germany, the registered association Vereinigung zur Förderung des Deutschen Brandschutzes e.V. (vfdb) published a technical report for public events regardless of COVID-19 (Oberhagemann 2012). This report distinguishes between completely decoupled individuals with $2p/m^2$ and a critical density value of $6p/m^2$. With the introduction of new social distancing rules with the aim to limit the spread of COVID-19, these recommendations are not applicable anymore. Thus, we need to think of new regulations taking into account pandemic scenarios.

4.1 Social distancing: background and recommendations

Numerous terms are used across literature and news describing distancing regulations, including social, physical, and spatial distancing (Abel 2020). The debate is mainly about choosing the most suitable wording that can convey the kind of distancing required, especially that the use of the word "social" refers to the communication among the individuals, which is an essential kind of support that is needed in such circumstances (Abel 2020). In this paper, we use the term "Social Distancing" for describing the physical distance between the individuals, since based on our literature review, it is the term that is commonly used for describing the recommendations published by the different organizations.

As the stricture measures (curfew, lockdown) in the different countries were gradually lifted, multiple social distancing recommendations and regulations were published. The World Health Organization (WHO) has recommended a minimum distance of 1.0m (WHO 2020a). In Europe, the Italian Ministry of Health supported the rule of 1.0m for essential shops such as supermarkets (Lazzerini and Putoto 2020). In the same context, the UK demanded 2.0m for public places, which is double the distance recommended by WHO (Harkins 2020). Other European countries such as Spain and Switzerland also recommend a distance of 2.0m (Abel and McQueen 2020; MSCBS 2020).

In Germany, all the institutions agreed on the recommendation of 1.5m. This applies for political institutions on highest governmental level as Bundeszentrale für gesundheitliche Aufklärung (BZgA) (BZgA 2020) as well as for federal state ministries as Bayerisches Staatsministerium für Gesundheit und Pflege (StMGP) (StMGP 2020) or Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen (MAGS) (MAGS 2020). The renowned Robert Koch-Institut (RKI) (Robert Koch Institut 2020) and other guidelines as Arbeitsgruppe Veranstaltungssicherheit (AGVS) (Buschhoff et al. 2020) support the proposal of 1.5m for social distancing. Besides Europe, the Ministry of Health of the USA (CDC 2020) and the Ministry of Health of Brazil (Ministério da Saúde 2020) published social distance recommendations of approximately 2.0m (6ft).

Table 1 lists the most popular recommendations for social distancing across the world. After reviewing the different experiments published in literature, the 1- to 2m rule of social distancing is mainly concerned with the droplet precautions and assumes that droplets do not travel further than 2m (Bahl et al. 2020). However, several other experiments (Zhu et al. 2006; Xie et al. 2007; Parienta et al. 2011; Bourouiba et al. 2014; Wei and Li 2015; Lee et al. 2018) have reported that droplets could travel up to eight meters, taking into account the different scenarios like coughing and sneezing as well as environmental conditions, including indoors, outdoors, wind speed, humidity...etc.

At the same time, most countries require now using face masks when using public transportation, inside shops, and work environments. Face masks represent a helpful barrier for containing droplets and limit their transmittance, which reduces the probability of inhaling those droplets by the surrounding persons. In this regard, when wearing masks, the 2m distance can be considered as effective for the inter-person distance (Setti et al. 2020). According to recent findings, the ventilation of spaces with fresh air plays a significant role in reducing the risk for spreading infections (Liu et al. 2020).

Institution/Source	Recommended social distance (m)
World Health Organization (WHO) (WHO 2020a)	1.0
Robert Koch Institut (RKI) (GER) (Robert Koch Institut 2020)	1.5
Bundeszentrale für gesundheitliche Aufklärung (BZgA) (GER) (BZgA 2020)	1.5
Bayerisches Staatsministerium des Innern, für Sport und Integration (StMI) (GER) (StMI 2020)	1.5
Bayerisches Staatsministerium für Gesundheit und Pflege (StMGP) (GER) (StMGP 2020)	1.5
Glasgow Centre for Population Health (GCPH) (UK)(Harkins 2020)	2.0
Italian Ministry of Health (Ministero della Salute 2020)	1.0
Federal Office of Public Health (FOPH) (Switzerland) (FOPH 2020)	2.0
Centers for Disease Control and Prevention (CDC) (US) (CDC 2020)	2.0
Research Institute for Exhibition and Live-Communication (R.I.F.E.L.) (GER) (R.I.F.E.L. 2020)	1.5
Spanish Ministry of Health (MSCBS 2020)	2.0
Ministry of Health of Brazil (Ministério da Saúde 2020)	2.0

Table 1. A selected list of Inter-personal social distance recommendations (where a medical mask is recommended for low-risk situations while a respirator mask is recommended for high-risk situations (Bahl et al. 2020)*)*

At the time of writing this report, the Arbeitsgruppe Veranstaltungssicherheit (AGVS) proposed recommendations for the densities of visitors at public events (Buschhoff et al. 2020). When using a social distance value of 1.5m between visitors, the author extrapolates to a density of 1p/4m^2 with a progressive increase to 1p/m^2 and finally 2p/m^2. The Research Insititute for Exhibition and Live-Communication (R.I.F.E.L.) in Berlin has recently published information regarding public events during the COViD-19 pandemic and refer to 1p/3m^2 plus a safety factor of 20% (R.I.F.E.L. 2020). Furthermore, on federal state level in Germany, recommendations for people density regulations are given depending on the circumstances.

In Bavaria, for retail areas the StMGP announced 1p/20m^2 (StMGP 2020) whereas in North Rhine-Westphalia the MAGS distinguishes between waiting areas e.g. for hairdressing salons with 1p/10m^2 and fitness centres with 1p/7m^2 (MAGS 2020). An appropriate number of individuals in a certain area is based on multiple factors, including the nature of the location (e.g. a shopping or a fitness center), and the purpose of the individuals' visit.

4.2 Pedestrians' flow and behaviour in train stations

Pedestrians' behaviour in train stations involves various activities, from waiting to boarding and alighting. In this context, the pedestrians' movement speed and distancing have a high influence on the circulation and aggregation of pedestrian flows.

Before the spreading of COVID-19, numerous researchers (Zhou et al. 2019; Yang et al. 2019) have performed field studies and analysed video recordings in order to evaluate the pedestrians' behaviour in the different environmental variables, like pedestrians' density and the arrival time of trains. The research findings show that pedestrians tend to take more time when boarding on trains than when leaving (Zhou et al. 2019). Additionally, pedestrians form mainly three kinds of waiting behaviour at the train doors based on their social relationship and its corresponding common distance (Yang et al. 2019; Zhou et al. 2019):

(1) Queuing (applicable for social and public distance): pedestrians stand in a queue leaving a reasonable inter-personal distance.
(2) Clustering (applicable for intimate, personal, and social distance): pedestrians tend to form small groups, resulting in some smaller distances.
(3) Scattering (applicable to all): pedestrians are randomly mixed due to delays or external factors.

These observations provide an insight on the pedestrians' behaviour without taking into account the impact of any physiological factors or social distancing regulations. Therefore, as the observations capturing the pedestrians' reactions to the new regulations are lacking, conducting new field experiments is necessary to understand how the pedestrians' flow could be influenced.

In more detail, video captures and sensor data from public transportation facilities (outdoors and indoors) should be collected, pre-processed, and analysed to extract the pedestrians' behaviour in the different scenarios. The scenarios would first involve identifying the different categories of relationships, including family members, friends, or strangers, as well as identifying a rough estimation of the individuals' age. Then, based on these categories, the physical distances as well as adhering to wearing face masks are identified and evaluated. Some of the open research questions are:

- How is the pedestrians' mobility affected by the social distancing regulations and psychological reactions during boarding and leaving from public transportation?
- Do the individual pedestrians show more commitment to the social distancing rules when they are alone?
- Do family groups follow the rules more than a group of friends?
- What is the influence of age?
- How does the individuals' behaviour differ in outdoor public transportation (e.g. busses and trams) in comparison to indoors (e.g. train stations)?
- What is the influence of the transportation delays and the order of timetables on pedestrians' behaviour?
- Could the design of waiting areas (e.g. in train stations and busses) be improved to help pedestrians to avoid unintended close contact?

To find answers to these questions, intense research including detailed observation of real-world behaviour is necessary.

4.3 Existing Work on Pedestrian Simulation Models and COVID-19

The spreading of COVID-19 is a new phenomenon to scientists from all disciplines. Pedestrian simulations play a vital role in supporting the evaluation of the different scenarios, where numerous variables are present. Accordingly, multiple researchers tried to model the different social distancing measures and also evaluate their effectiveness.

Multiple researchers have investigated simulating the virus spreading considering different aspects. First, EXPOSED (Ronchi and Lovreglio 2020), a simulation model that makes it possible to implement several contact scenarios such as physical-, face-to-face contact or individuals being in the same building (Ronchi and Lovreglio 2020). The model computes the total amount of contacts and yields a quantitative result that can be used for scenario comparison or similar.

Additionally, D'Orazio et al. (2020) have developed another model that is based on real examples of COVID-19 outbreaks and uses the existing data, such as the Diamond Princess cruise, to calibrate the simulations (D'Orazio et al. 2020). This way, the authors have investigated the effectiveness of masks based on simulation results. Further evaluation in comparison with future research might lead to a better understanding of this measure. In a third even more complex approach, in addition to the direct contact between agents, Bouchnita and Jebrane (2020) have investigated the indirect contact between agents and surfaces (Bouchnita and Jebrane 2020). Accordingly, multiple factors such as age and other risk factors were taken into account.

The presented pedestrian simulation models are mainly concerned with the transmission of the virus through the chain of agents. In this study, we have developed a model for integrating social distancing into a pedestrian dynamics simulator in order to evaluate the effects on people flow and maximum occupancy rates in transportation hubs. The model is exemplarily integrated in the commercial simulator crowd:it.

5 Pedestrian Simulation Models incorporating Social Distancing

The simulation of pedestrian flow is mostly used to examine environments with high densities of people. The COVID-19 pandemic presents a unique challenge for pedestrian simulation. Models must be adapted to examine the dynamics of low densities under social distancing regulations. Depending on the model, these adaptations can vary and have to be explicitly examined.

In this study, we examine a socially distanced extension of the Optimal Steps Model (OSM) (Seitz and Köster 2012). This model is used by the open-source simulator VADERE (www.vadere.org) as well as in crowd:it, a commercial simulation tool. In order to make the extensions applicable for all implementations of the OSM, we consulted with a team at Hochschule München throughout the entire project in weekly jour fixes and developed generalised solutions.

The OSM is easily enhanced because simulated agents imitate real-world stepping behaviour. Each simulated person has a dynamic step length that depends on his walking speed and direction, and his avoidance of obstacles and other people. These dependencies are described by utility functions such as “How much closer can I get to the next destination?” or “How much distance can I keep from other pedestrians and obstacles?”. Thus, each simulated step adjusts to current environmental conditions. To implement social distancing, we need only alter the reaction of agents to their environment. That is, we alter these utility functions to act more strictly where necessary.

To define how social distancing applies in a simulated setting, accu:rate utilised the research results above. The international social distance recommendations vary from 1.0m to 2.0m. For the purposes of this study, we assume the social distance follows German regulations, namely 1.5m. The methods presented below are independent of the 1.5m, which is used only for demonstrable purposes; other social distances could be considered.

There are two opposing methods to model social distancing. One is to fix the social distance between agents and force them to remain at all times some distance *x* from one another. We name this ***hard social distancing***. For practical purposes, this does not offer realistic results. As we hear from practitioners within the field of crowd management, social distances are often undercut in certain environments and circumstances. As such, the other, more flexible model, that allows agents to break social distancing norms, and move closer than *x* to one another under certain conditions, is preferable. We call this ***soft social distancing***. This is the version we shall adopt in this report, and the reason for doing so is outlined in more detail below.

5.1 Implementation of a Social Distancing Pedestrian Model

In order to simulate social distancing in an agent-based simulator, the repulsive behaviour of agents (i.e. utility functions) must be altered. That is, the effect one agent has on another must be calculated differently. For crowd:it, this involves changing the repulsion model suggested by Sivers (Sivers and Köster 2015). The behaviour of this repulsion model is correct, it need only be altered so that agents are repulsed by one another at further distances than normal.

The challenge is to allow flexibility in crowd:it's repulsion model. There is, in any simulation, repulsion between agents, and it is straight-forward to implement hard social distancing, and have agents maintain some social distance *x* at all times. But agents must have the ability to "break" social distancing norms if needs must. We must increase repulsion between agents but allow them to return to normal interaction to move through narrow doorways. Without flexibility, unrealistic behaviour ensues as agents may get stuck attempting to maintain a constant social distance, even when a doorway, though which they wish to pass, is not as wide as this social distance.

The crowd:it repulsion model consists of two repulsive forces: the repulsion of agents that stand within each other's personal space, and the repulsion of agents that stand within each other's intimate space. These spaces reflect the measurements of Hall (Hall 1966). The repulsion model insists on the adjustment of four parameters; two in each of these force equations, see (Sivers and Köster 2015). To adjust these four parameters, real-world experiments must be conducted, and their results compared to an identically constructed simulation. Unfortunately, such experiments have yet to be conducted, as such we construct contrived scenarios. These scenarios then form the basis of an objective function. The objective function is a set of measurements on the scenarios, whose values we wish to minimise.

In order to find the correct measurements – even without a quantitative comparison to experimental results, we led several discussions with crowd simulation experts from Hochschule München and made use of the findings from TUM. We concluded that the following conditions must be met:

- Objective 1: Minimise how long agents spend too close to one another
- Objective 2: Avoid artefacts. These could include the unnecessary movement of agents attempting to maintain their social distance, skipping left and right incessantly.
- Objective 3: Avoid local minima. That is, avoid agents finding equilibrium in stationary positions, as this will cause unrealistic behaviour.

Here, we focus on microscopic objectives, which, when optimised, will lead to observable macroscopic behaviour.

The scenario upon which our objective function is built, is a bottleneck. Figure 1 illustrates our chosen scenario. Fifty agents arrive in the scenario, standing some social distance from one another within the red polygon. They then move immediately towards their exit: the green polygon. Between their "place of birth", and their "place of exit" is a narrow corridor. Five of these scenarios exist, each with a different corridor width.

By creating areas of analysis within the simulation, we can measure the time how long each agent is within some social distance of another. The bottleneck scenario lends itself to two such areas. The first is within the corridor, after the bottleneck occurs. The second is before the corridor, where the bottleneck occurs (see Figure 1). A one metre space is left unanalysed; this area is a transitive space, where agents move from bottleneck behaviour to corridor behaviour.

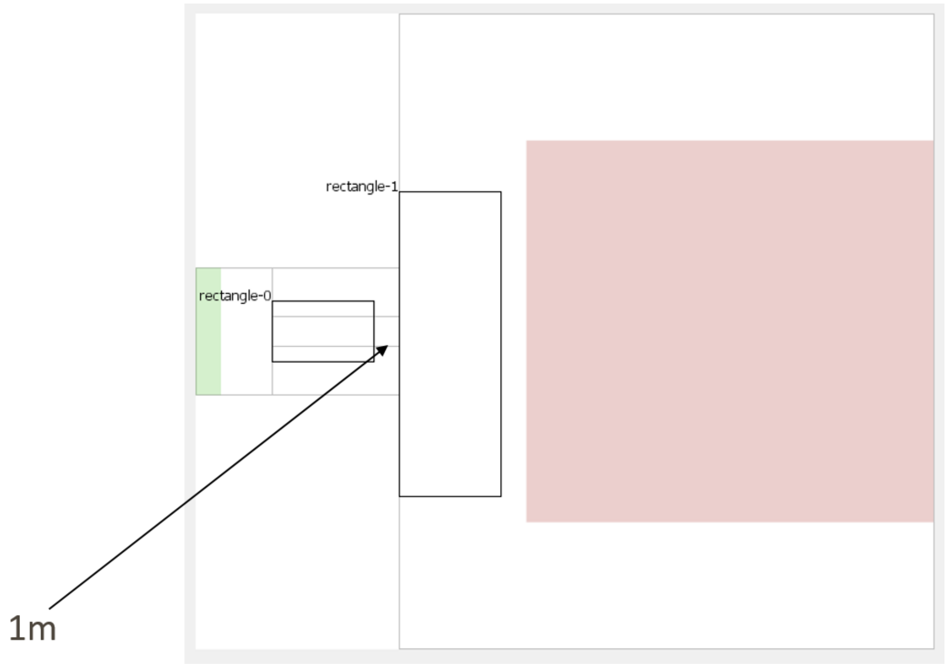

Figure 1: The bottleneck scenario with its respective areas of evaluation: rectangle-0 and rectangle-1.

Agents should spend little to no time within each other's personal and intimate spaces. This satisfied objective 1. However, in rectangle-1, before the corridor, we allow agents some time to move closer together, so that they can move into the corridor. It is in rectangle-1 that the flexibility of our repulsion model is tested.

In addition to the reduction in agent proximity, our scenarios must reduce artefacts. In this respect, we minimise how often an agent changes direction in rectangle-1, satisfying objective 2. Further, for objective 3, we require that at least half the agents move into the corridor, that is, into rectangle-0. This discards any scenarios that see most agents stationary in rectangle-1. Although these scenarios may yield low error values, they do not sufficiently represent reality. This, incidentally, is the delineation between hard and soft social distancing.

Further, to combat issues of counter-flow, where agents fail to pass one another in a narrow corridor, when travelling in different directions, a second scenario forces two agents to pass one another along a 1.2m wide corridor. If the agents fail to pass, the respective parameter set is discarded.

Because the objective function of our optimisation is derived from the crowd:it simulation model, it is necessarily non-differentiable, non-continuous, non-linear and noisy. As such, a random search is carried out across the 40,432 parameter sets, which were identified as being potential candidates (based on previous work identifying the extremes of each parameter).

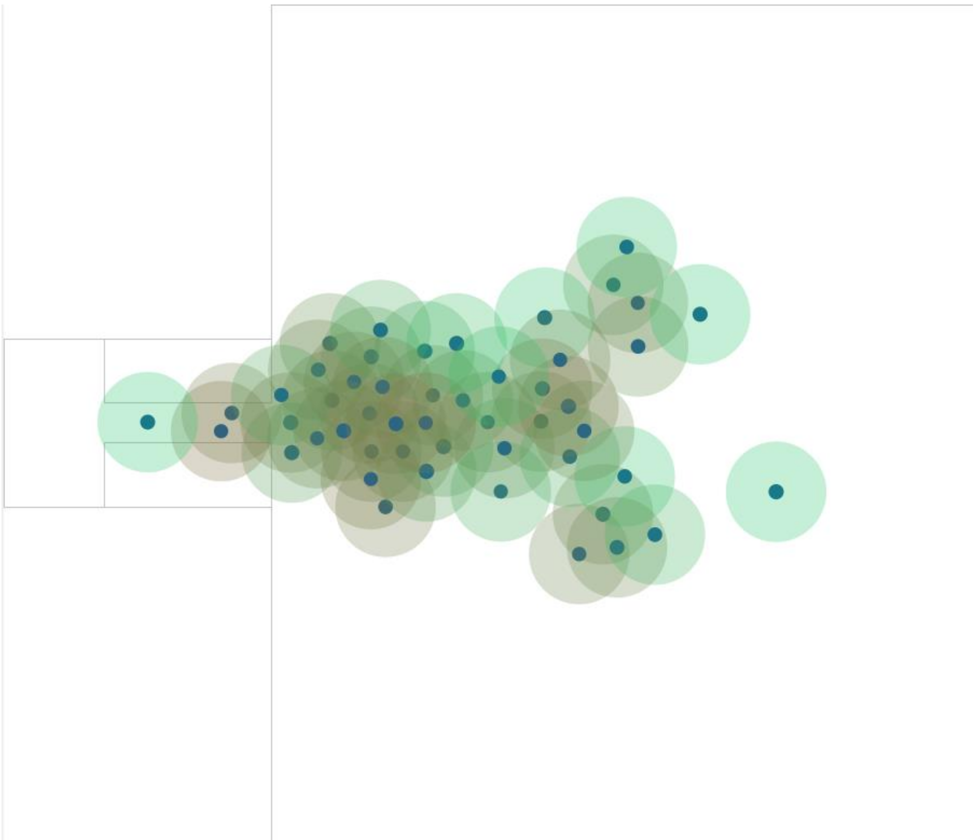

Figure 2: An actualization of the bottleneck scenario with agents encircled by a social distancing indicator of 1.5m. The redder this indicator, the longer agents fail to maintain a social distance.

5.2 Case Study: Train station

To demonstrate the utility of the simulator, it must be used on an existent and concrete problem. Having created calibration scenarios, we now move to the problem of train station platforms. One of Munich's train stations is used as a proof-of-concept scenario. Here, we combined the social distancing model described above with our commercial model. This is a result of initial tests that used the social distancing model alone. We concluded that the proven commercial model is still required occasionally within the scenario, to repair broken behavioural patterns. Our proof-of-concept scenario highlighted that pedestrian simulation models require a mechanism to shift between a social distancing repulsion model and a normal repulsion model. This is because in certain situations and environments no matter the flexibility of the social distancing repulsion model, agents will become entangled in high densities and complex geometries. As such, crowd:it requests that agents carry out normal repulsion behaviour if they are surrounded by too many other agents, or if they have not moved for some time. This reflects observations that in unusual circumstances, such as waiting a long time within a very dense crowd to enter an escalator, social distancing norms reduce in salience. However, a scientific investigation of this phenomenon is outstanding and must be carried out to provide a solid foundation for this approach.

When simulating this scenario, clear bottlenecks occur when passengers are forced to maintain a hard social distance. That occurs particularly before the East escalators. Here, counterflow occurs between passengers that want to leave the platform and those who wish to enter. These simulations provide pragmatic solutions to inevitable problems: create one-way stations, allowing passengers to leave the station on the East side and enter on the West.

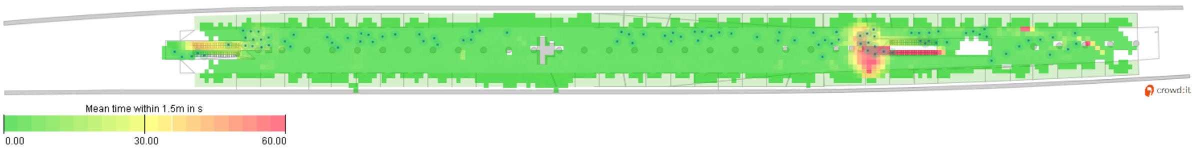

Figure 3: A heatmap of the subway station indicating areas where social distancing was broken for an extended period. The longer the time, the redder the areas.

6 Summary and Future Work

In this brief research project, we have conducted a literature review that is focused on two main aspects of the COVID-19 state-of-the-art. First, evaluating the scientific basis for the social distancing regulations demanded by the different organizations worldwide. In this regard, the scientific experiments and recommendations were studied. Secondly, the currently available pedestrian simulation models were reviewed to identify their main purpose, i.e. a virus transmission model vs. the evaluation of the applicability of the required social distancing rules.

Based on the outcome of the literature review, we have developed a method for the integration of social distancing within agent-based pedestrian simulation models. This integration was performed on the commercial simulation software crowd:it, and tested against a real-world scenario. This test demonstrated the applicability of simulating crowds that adhere to social distancing regulation.

The current literature indicates that there are no universal parameters or standards that should be used by models. To ensure that the risk of virus transmission is minimised, governments have regulated safety distances that must be adhered to within certain environments and circumstances. To facilitate normal agent behaviour in crowd:it, agents who maintain social distances may break these rules given the correct circumstances. Now, with the enhanced model operators can answer the following:

- How much capacity is available on platforms or trains under the assumption of social distancing?
- What effects does this have on train timing?
- How long and in what locations will passengers necessarily/likely fail to maintain the social distance?

Simulating crowds that adhere to social distancing regulation and analysing public spaces, such as train stations, airports, offices, and stadiums, can support operators enormously in understanding which protocols would best facilitate social distancing.

We see a great potential in the information we can retrieve from such simulations. However, more extended research is necessary to provide evidence to the assumptions we made, especially with respect to social behaviour under distancing regulations. To this end, an extensive observation of real-world scenarios and a subsequent detailed analysis of behaviour is required.

In further research projects, it would be of interest to combine the simulation models with infection models in order to show to what extend and with which probability people might get infected in certain areas depending on the number of infectious people walking around.

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