‘Density’ and ‘Capacity’
as
COVID-19 Exit Strategy Parameter
for
Events in Belgium

Bert Bruyninckx

Pg Dip. Crowd Safety & Risk Analysis

bert.bruyninckx@360-solutions.eu

linkedin.com/in/bertbruyninckx

+32 492 93 42 58

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Abstract

Events and places of gathering were the first to close in Belgium as a result of the COVID-19 pandemic. The Belgian event industry faces a multi-billion euro loss and after weeks of lockdown the industry tries to look forward to a COVID-19 exit strategy. Physical distancing as one of the main measures during lockdown, will inevitably be a parameter in the COVID-19 exit strategy for events. Concepts as density and capacity are closely related to physical distancing. Knowledge of these parameters in combination with crowd management tools, such as the DIM-ICE model, queue modelling and simulation can help in the design of events and areas where physical distancing needs to be facilitated and can be imposed. It is advocated that it is possible, to organise business to business events such as conferences and trade fairs within the framework of physical distancing.

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1 Introduction and background to the study

1.1 The essence of distancing

Social distancing to decrease the probability of spreading the respiratory COVID-19 virus, as proposed by WHO (World Health Organization, 2020b), is a means to minimise the chance of infection by ‘…droplets generated when an infected person coughs or sneezes, or through droplets of saliva or discharge from the nose’ (World Health Organization, 2020a). Nicole et al. (2012) further state that in essence, social distancing is a manner to decrease interpersonal or intergroup interaction. Whereas, WHO nuances and suggests that keeping physical distance does not necessarily equal social distance (World Health Organization, 2020c).

WHO (2020b) suggests keeping at least 1-meter distance, in the United States, the Centre for Disease Control (CDC, 2020) takes it a step further and advises a distance of 6 feet or 1.83 meters. The Belgian government imposes a minimum distance of 1.5 meters and restricts the number of people that are allowed in supermarkets to 1 person per 10 square meters (FOD Binnenlandse Zaken, 2020). The Netherlands (Ministerie van Algemene Zaken, 2020) suggests a distance of 1.5 meters is to be kept between individuals not living under the same roof as well. In Austria, WHO guidance was adopted, and a distance of 1 meter is suggested (Federal Ministry Republic of Austria, 2020).

1.2 COVID-19 Exit Strategy for events and places of public assembly

Physical distancing measures contradict the essence of events in general. As events, in their core, contain a way of interaction between visitors, service providers and the event crew in the broadest sense.

This paper tries to shed some light on crowd management principles and tools that can aid in the COVID-19 exit strategy for events and places of public assembly in all their variety. Mitigating COVID-19 measures are likely to be a part of any exit strategy and these conditions will evolve from more restricting to less restricting.

With the aim to decrease the spread of COVID-19, restrictions could be:

1. Compulsory personal protection equipment, such as face masks.
2. Restrictions on the (relative) number of visitors and maintaining physical distance with the goal to decrease possible interaction with infected persons.
3. Limits on the duration of events to reduce the duration of possible interaction with infected persons.
4. ID registration for participants and crew.

It is clear that differentiation between the type of events or places of public assembly is to be made and that for example, initially, conferences are more likely to be allowed than dance festivals in the same way that local stores are more likely to open before shopping malls.

2 Distancing as a parameter in a COVID-19 Exit Strategy

The ‘lockdown’ exit strategy in Austria mentions a differentiation in shop size for reopening and sets a maximum of 1 person per 20 square meters (Grüll, 2020). In Belgium major festivals are not allowed until 31st of August. While the Belgian event industry faces a 4.9 billion loss, it advocates for an earlier lift on the ban on some events, such as business to business events representing more than half of the annual revenue (Merckx and Desmedt, 2020).

The question arises if ‘density’ and ‘number of people present’, or ‘capacity’, can be a parameter to decide on (re)opening places of public assembly or allowing events in some form to be organised?

Though this parameter of distancing sounds simple, it is not always profoundly understood. For a good understanding, a distinction is to be made between (1) Capacity and (2) Density.

The theoretical possibility of individuals spreading over a given area, and thus be compliant with a prescribed norm of interpersonal distance, is not necessarily what will happen. Awareness is to be raised, monitoring is most likely necessary, and, in some cases, rules might need to be enforced.

3 Understanding the concept of Capacity and Density

3.1 Capacity

Capacity as a parameter sits within the concept of Crowd Safety. Within the Belgian context, Saerens (2016) defines capacity for indoor (event)facilities and places of public assembly as the maximal number of people allowed at one time in a given area. The Royal Decree on Fire Safety (FOD Binnenlandse Zaken, 1994) refines this by adding that all compartments and their assigned escape routes need to be considered. For outdoor places of public assembly however, there is no strict regulation on Crowd Safety or capacity (Saerens, 2016) with the ‘…use of and referral to a variety of guidelines and rules’ (Bruyninckx, 2017b:6) as a result.

Parameters used to define capacity are (1) the number of exits, (2) the total exit width, and (3) the available area (Bruyninckx, 2017b). The latter relates to the number of people per net square meter (Saerens, 2016).

3.2 Density

In most cases (Still, 2014a; Gwynne and Boyce, 2016) crowd density is defined as the number of people in a set area unit (Drintewater and Gudjonson, 1989; Gwynne and Boyce, 2016), such as the number of people per one square meter. The suggestion of allowing one person per 10 square meters in Belgium or 1 per 20 square meters in Austria directly relates to a second way to define Crowd Density: The Pedestrian Area Module.

The Pedestrian Area Module, referred to as PAM throughout, represents the available space per person (Fruin, 1987); this is, in fact, the inverse of the definition of Drintewater and Gudjonson (1989). Although possibly challenging to visualise and comprehend (Still, 2014a), the PAM does give an idea of the distance between individuals. A third way is the ratio of the area occupied by people (Predtechenskiĭ and Milinskii, 1978). This percentage of occupancy is a dimensionless density (Schadschneider et al., 2018).

Crowd Density is regarded as a proximate cause for phenomena such as crowd crushes, shockwaves, progressive crowd collapse and the such (Still, 2014a), leading to compressive asphyxia and possible death (Fruin, 1993; Kroll et al., 2017). Crowd Management plans should, therefore, avoid densities in static areas above 5 people per square meter or 0.17 square meter per person if expressed as PAM.

4 Capacity, density and average density in the context of social distancing

4.1 Capacity

4.1.1 Capacity as a function of distancing

The rules on physical distancing alter the parameter of ‘available area’ in the capacity calculation. Under normal circumstances, the process would be (1) to define the available area, (2) establish an appropriate maximal or desired density, and (3) apply the density to the available space (Sports Grounds Safety Authority, 2018). Considering distancing, the PAM, as a function of the physical distance norm needs to be put in the equation.

It is essential not to neglect the other parameters: (1) the number of exits and (2) the total exit width when defining capacity, in general the lowest value dictates capacity.

4.1.2 The total number of people as a factor

As the number of visitors at an event is proportional to the possible different person to person interactions, the number of total visitors is a factor to consider as well.

Next to this, the total number of people present at an event, all need to make use of the same facilities or need the same service during their visit. The number of people requiring service is a factor to consider in the context of queueing, waiting time and waiting area.

4.2 Density

4.2.1 Body space requirements

To consider density in the context of social distancing, first thing is to establish an average value for the body ellipse, taking into account that people come in all shapes and sizes (Still, 2000; Johansson et al., 2008; Gwynne and Boyce, 2016).

Different values have been assigned to the space requirement for the average person. Fruin (1987) sets the body ellipse on an area of 57.9 cm by 33 cm, and both Weidmann (1993) and Oberhagemann (2012) define 0.15 square meter as the space requirement of the average person. Still (2000) advocates that Fruin’s values are generous and proposes an area of 53.0 cm by 28.0 cm representing the 95-99 percentile anthropomorphic size margin or an average area of 50.0 cm by 30.0 cm. For the Belgian population Motmans (2005) measured, as proposed by Fruin (1987) and Still (2000), shoulder width and body depth and found an average of 43.8 cm shoulder width and 23.7 cm body depth, the 99th percentile was measured on 51.3 cm by 30.7 cm.

Weidmann (1993) advocates that the body shape projection on the ground is an oval which Fruin (1987) refers to as the ‘Body Ellipse’. The actual body space requirements are calculated in the table below for both an elliptical projection and a rectangular projection (Dridi, 2015). The Table and Figures on page 9 give a visual representation in a one square meter plane of the body areas, as suggested.

Nr.	Source	Shoulder width	Body depth	Elliptical Area (m²)	Rectangle Area (m²)
1	Fruin	0.579	0.330	0.150	0.191
2	Weidmann	0.500	0.300	0.118	0.150
3	Still* **99%**	0.530	0.280	0.117	0.148
4	Still** **Avg.**	0.500	0.300	0.118	0.150
5	Motmans**	0.438	0.237	0.082	0.104
6	Motmans*	0.513	0.307	0.124	0.157

* 95-99 percentile anthropomorphic size margin
** Average, ideal weight

Table 1: Body Space Requirements – Values

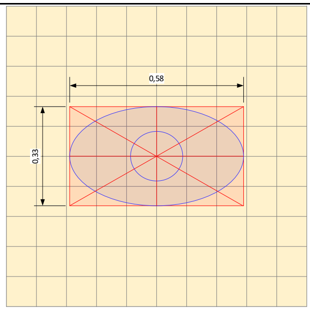
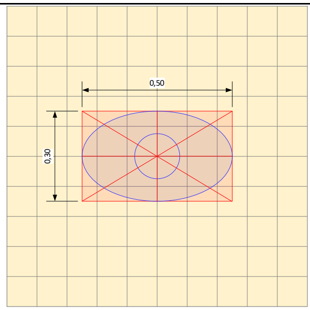
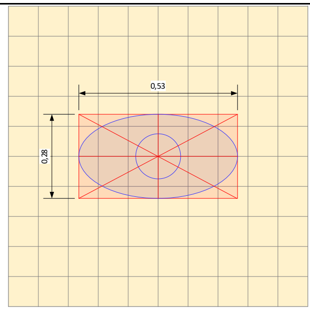
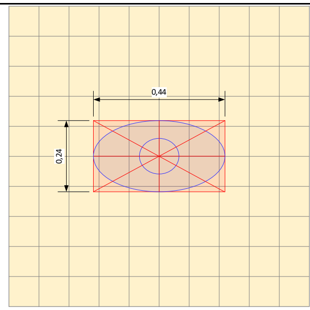
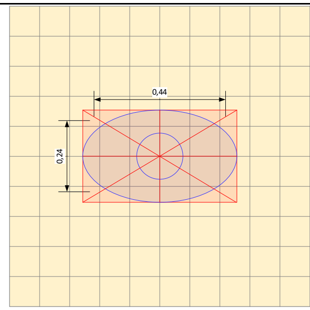
	Fruin	**Weidmann Still Avg.**	**Still 99%**	**Motmans Avg.**	**Motmans 99%**
Visual	 *Figure 1: Fruin Body Area*	 *Figure 2: Weidmann Body Area*	 *Figure 3: Still 99% Body Area*	 *Figure 4: Motmans Avg. Body Area*	 *Figure 5: Motmans 99% Body Area*
Elliptical	0.150	0.118	0.117	0.082	0.124
Rectangle	0.191	0.150	0.148	0.104	0.157

Table 2: Body Area Values and Visuals

4.2.2 Body Space and distancing

Distancing implies the distance between individual bodies, when considering density as a function of distancing, the body area is to be taken into account.

If we consider the rectangle body projection of 0.5 m by 0.3 m, as suggested by Weidmann and Fruin, and apply a 1.5-meter distance to the next person in front, behind and left/right (spreading 1) every person needs a personal rectangle of 2.0 m by 1.8 m. In the Figure below the orange rectangle shows this personal space and represents a PAM of 1 person per 3.6 square meter, a density of 0.28 people per square meter.

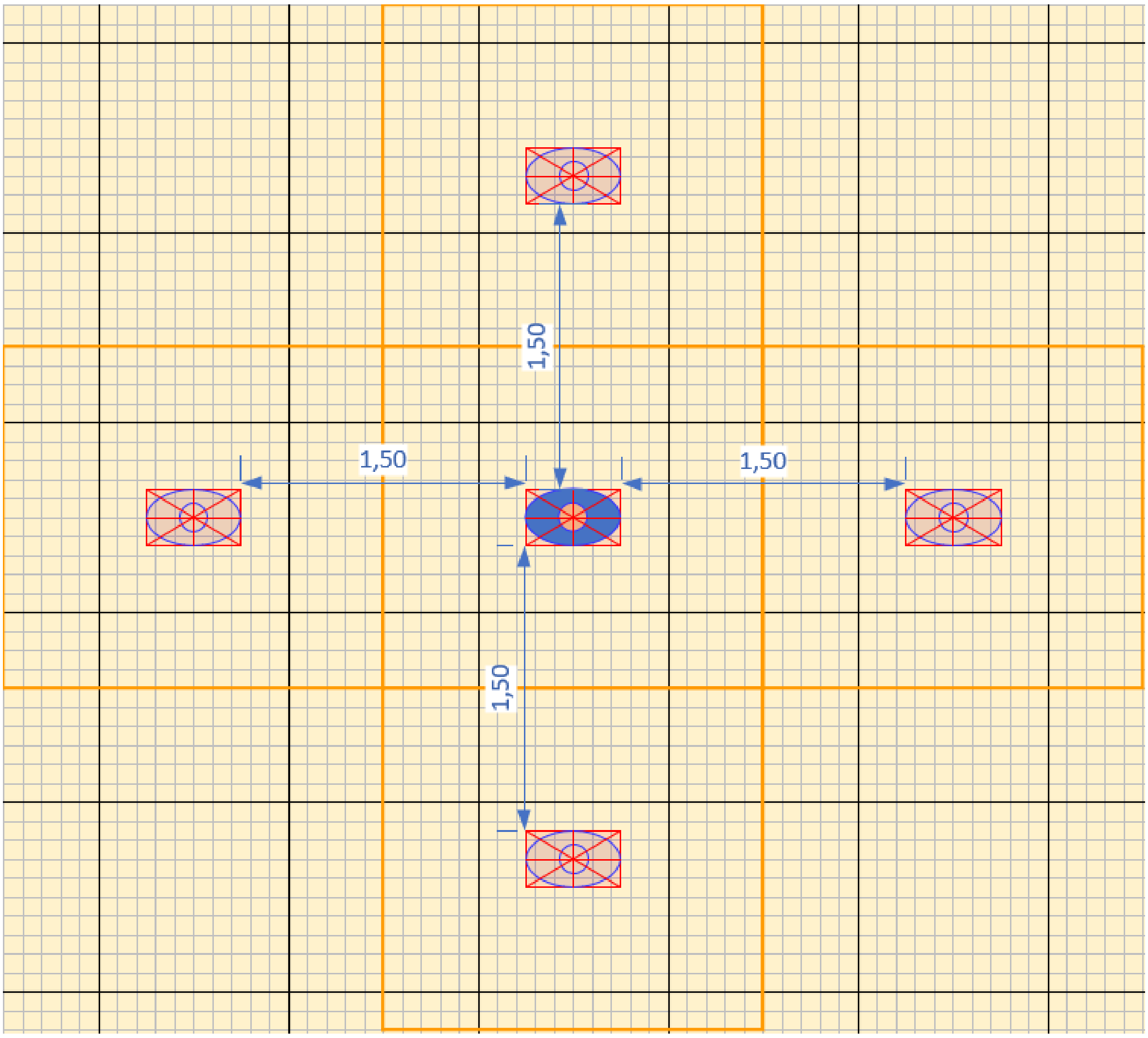


Figure 6: Personal Area Module (PAM) with 1.5 m distancing, based on rectangle body projection of 0.5m by 0.3m

When considering different 'Body Area Values' the 'Pedestrian Area Module', in the case of 1.5 m distancing, changes and varies between 3.37 and 3.80 m². The results are conveyed in [Table 3].

Source	Shoulder width	Body depth	Rectangle Area (m²)	PAM (Rectangle) m²
Fruin	0.579	0.330	0.191	3.80
Weidman	0.500	0.300	0.150	3.60
Still* 99%	0.530	0.280	0.148	3.61
Still Avg.**	0.500	0.300	0.150	3.60
Motmans**	0.438	0.237	0.104	3.37
Motmans*	0.513	0.307	0.157	3.64

* 95-99 percentile anthropomorphic size marge
** Average, ideal weight

Table 3: Pedestrian Area Module (PAM) in case of 1.5m distancing

When we consider the pedestrians diagonal in front and behind in the case of 1.5 m distancing, the diagonal distance between people is 2.12 m.

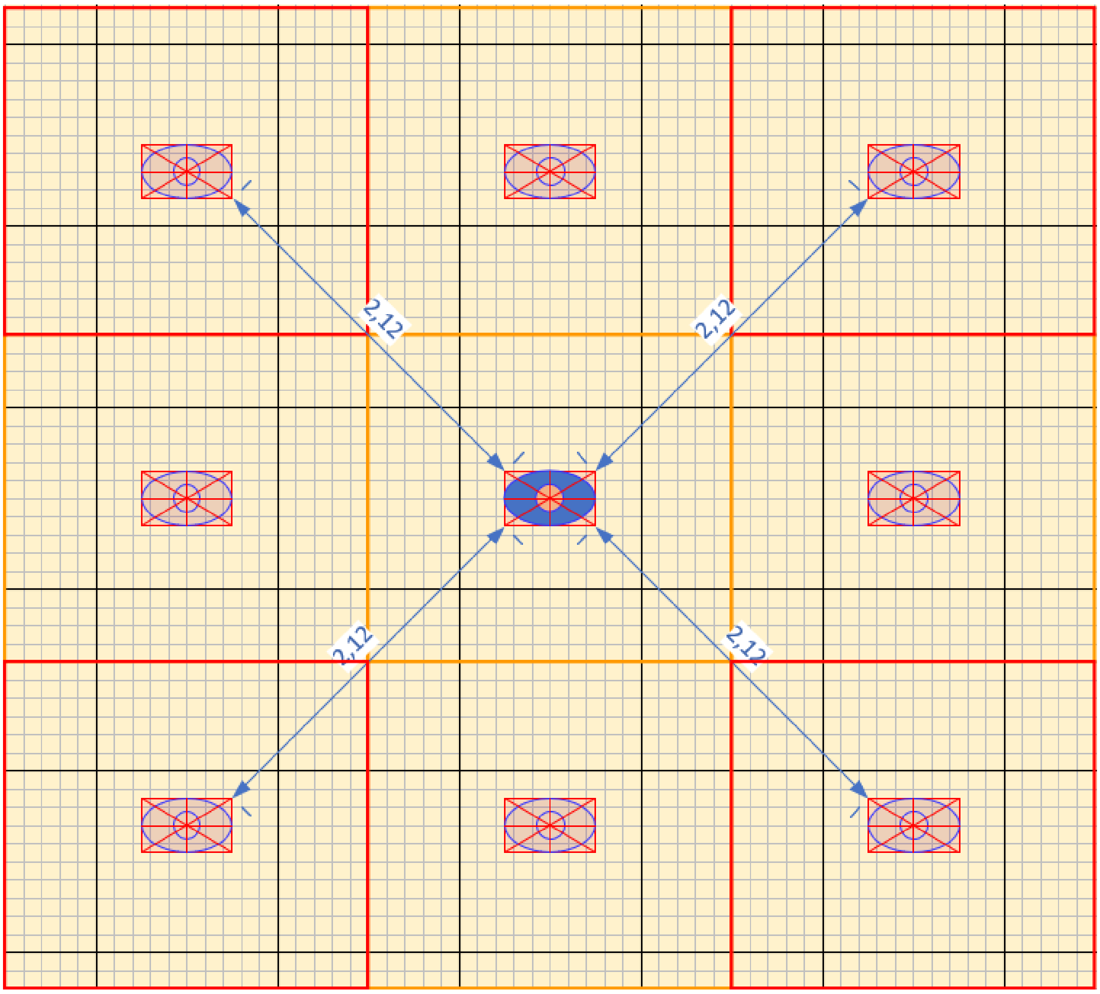


Figure 7: Diagonal distance with 1.5m distancing, rectangle body projection of 0.5m by 0.3m and checkboard spreading

If the same principle is used, but the spreading is based on the people diagonal, at 45° in front or behind (Spreading 2), the diagonal space is used more efficiently. The increased diagonal distance efficiency comes at the cost of greater perpendicular distances of 2.62 and 2.42 m.

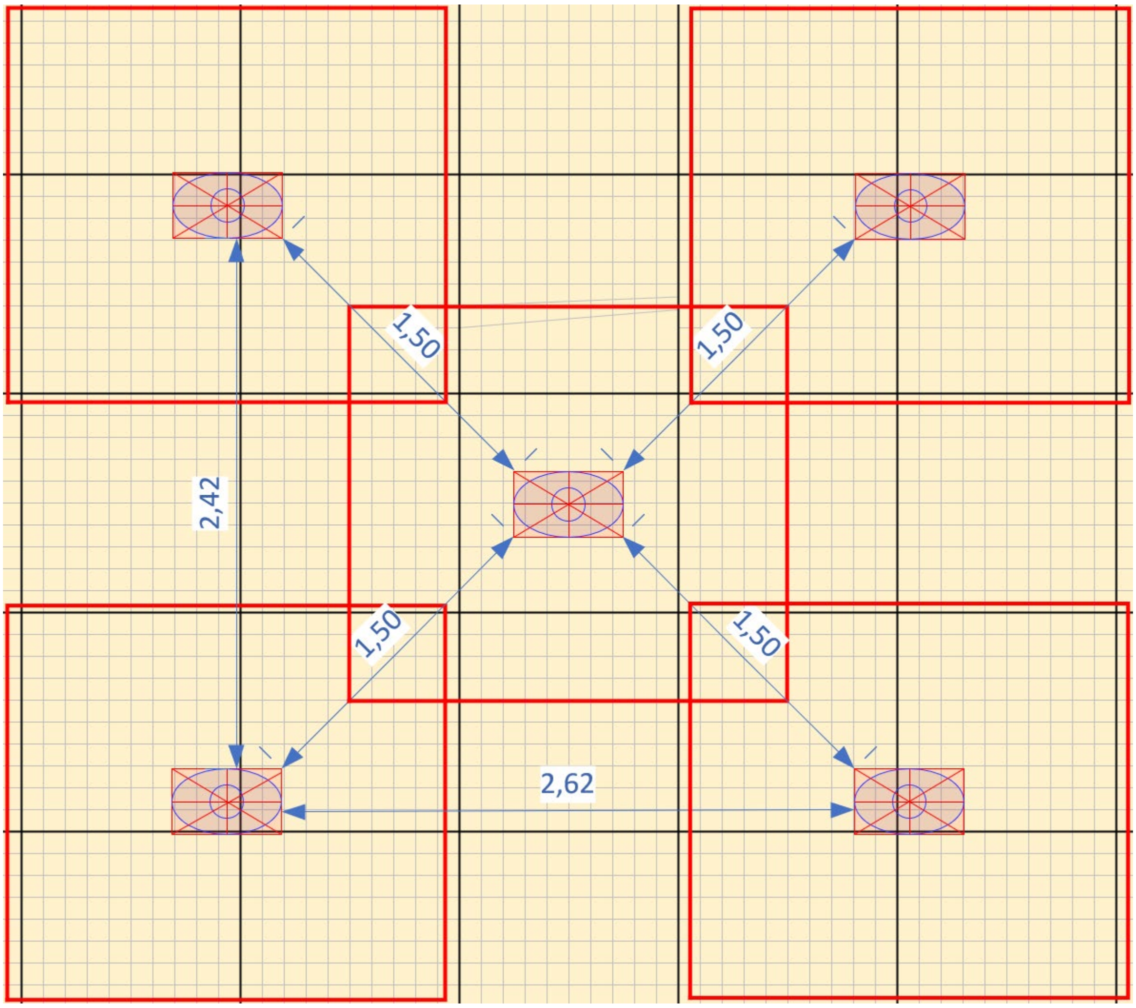


Figure 8: Spreading 2, based on diagonal distance shows to be inefficient

Despite the apparent inefficiency of Spreading 1, in the checkboard pattern, it is the most space-efficient way to fill up an area while maintaining the proposed distance of 1.5 meter, a density of 0.28 persons per square meter with a ‘Pedestrian Area Module’ of 3.6 m² representing an occupant ratio of 4.2%.

As body size is the base of this calculation, it is a factor that needs to be embedded. The table on page 13 summarizes the Spreading 1, the checkboard combined with results for different body sizes.

Source	Rectangle Area/p (m²)	PAM	Density	Ratio
Fruin	0.191	3.80	0.26	5.02%
Weidman	0.150	3.60	0.28	4.17%
Still* **99%**	0.148	3.61	0.28	4.11%
Still** **Avg.**	0.150	3.60	0.28	4.17%
Motmans**	0.104	3.37	0.30	3.08%
Motmans*	0.157	3.64	0.27	4.33%
* 95-99 percentile anthropomorphic size marge ** Average, ideal weight				

Table 4: Summary of PAM, Density and Ratio with 1.5 m distance for different body sizes

4.2.3 Different levels of distancing

When various levels of distancing are applied the density and ratio change accordingly. For Weidmann’s Body Area of 0.15 m², the values are shown in [Table 5] and [Figure 9].

Distance	PAM	Density	Ratio
0.50	0.80	1.25	18.75%
0.75	1.31	0.76	11.43%
1.00	1.95	0.51	7.69%
1.25	2.71	0.37	5.53%
1.50	3.60	0.28	4.17%

Table 5: PAM, Density and Ratio as a function of Social Distance, based on Weidmann's body area.

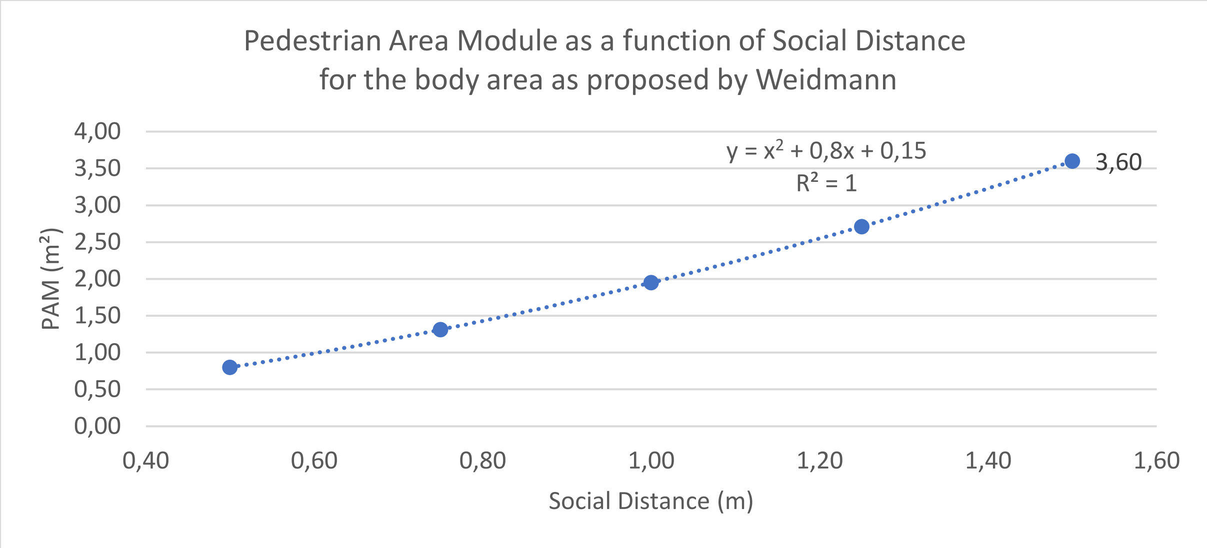


Figure 9: Distance versus PAM for Weidmann's body size

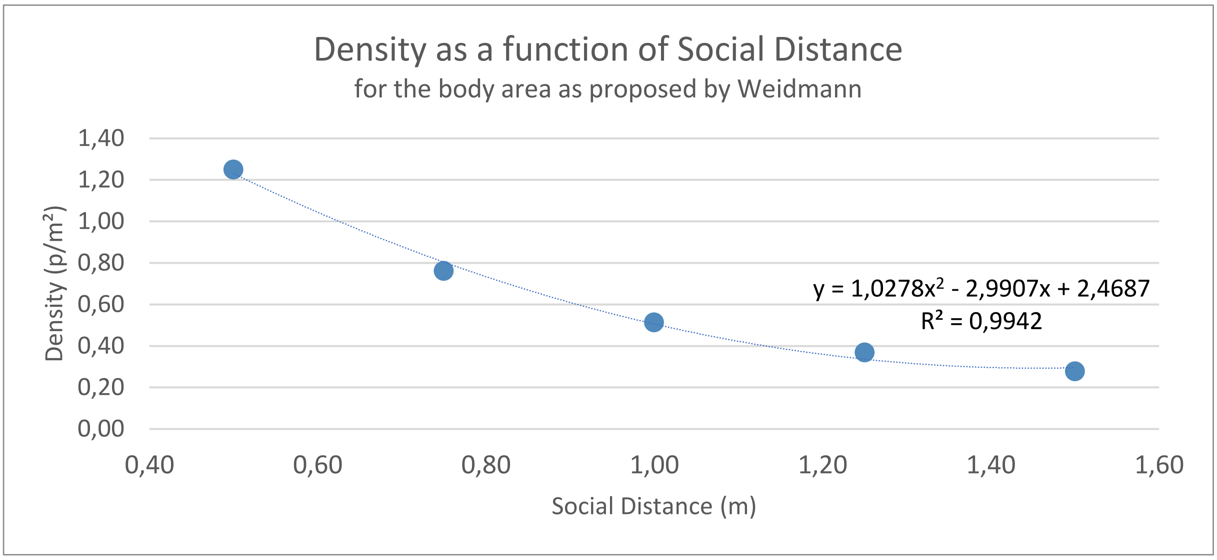


Figure 10: Distance versus PAM for Weidmann's body size

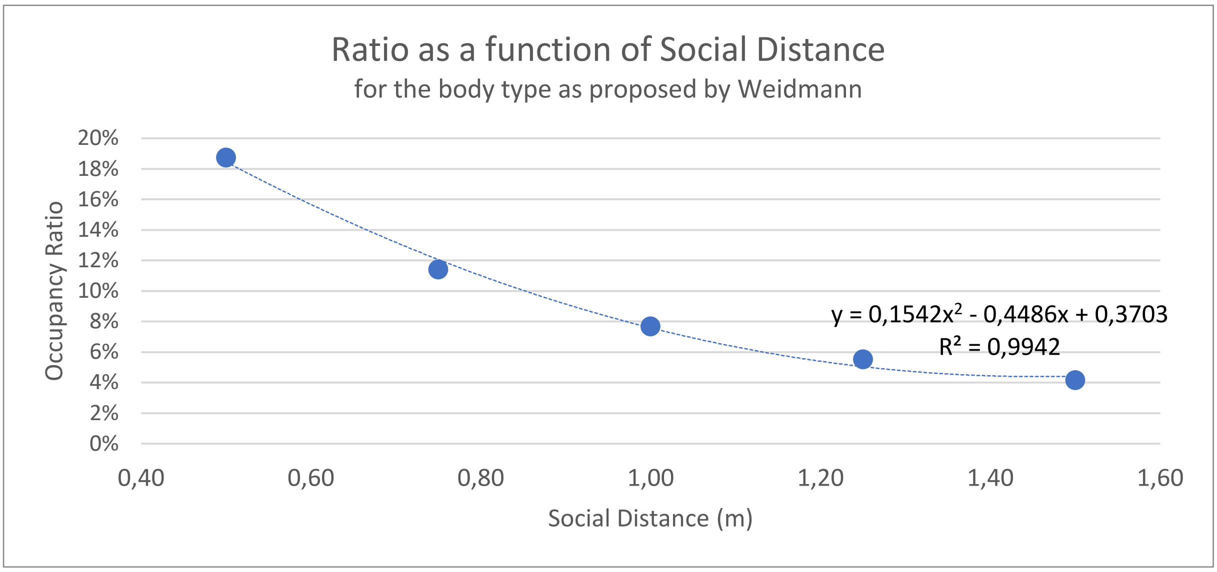


Figure 11: Distance versus Ratio for Weidmann's body size

4.3 Average Density

4.3.1 In general

Despite that in almost any case, a crowd does not spread out evenly over the available space (Still, 2000), crowd density is often expressed as an average (Hoskins, 2011). Where possible, the considered event, building or area of study is to be segmented into smaller parts when assigning preferable density values or thresholds. Preferable, density in the first place differs between static and dynamic areas. Secondly, the purpose and duration of assembly at that particular area needs to be taken into account. Likeminded music fans might not be bothered by being in front of a stage for an hour in high density. Whereas, those in the local supermarket usually require more space than on a short elevator ride.

4.3.2 Average Density and Distancing

In the case where physical distance must be kept, the calculated average density must be interpreted as the actual and overall density at all times and applied everywhere on the event. Every person must have a PAM according to the proposed distance at any time, as it is doubtful that people will spread evenly over the available area (Still, 2000). If at all possible, this must be facilitated or even enforced. It is clear that spectator crowds are more problematic then conference or trade fair crowds.

5 Crowd Science & Modelling Tools

5.1 Crowd Science Tools for Crowd and Event Modelling

Crowd Science as defined by Still (2009) captures the essence of crowd dynamics and adds the elements of risk assessment, emergency planning, information systems, human psychology and spatial awareness. The crowd management tools developed to manage crowds under non-COVID-19 circumstances can be used to manage crowds and crowd flow in the context of physical distancing and other COVID-19 measures.

Crowd models, as any model, break down a complex process or event, in a series of parts to simplify the (crowd)related problems. Models are ‘…a condensed representation of the real world, composed with only the use of singled out relevant determining aspects’ (Bruyninckx, 2017a).

The following list of tools can be used to model crowds in any context and gain insight into problems and possible solutions:

1. The DIM-ICE Metamodel as proposed by Still (2009, 2014a);
2. RAMP Analysis (Still, 2014a)
3. Density Maps (Still, 2014a)
4. Queue analysis and calculations with attention to available space
5. Crowd psychology and the concept of social identity (Reicher, 2008; Drury et al., 2019) and psychological crowds (Templeton et al., 2015, 2018)
6. Crowd Simulation

5.2 DIM-ICE Metamodel

5.2.1 Framework

The framework as created by the DIM-ICE Metamodel provides a series of crowd modelling tools (1) DIM-ICE model, (2) RAMP Analysis, and (3) Risk and Congestion Mapping. At the least, the model process assists in understanding, visualizing and communicating key crowd dynamic elements to all stakeholders (Still, 2014a).

5.2.2 DIM-ICE

The DIM-ICE model as proposed by Still (2009, 2014a) considers ‘Design, Information and Management’ (DIM) as the three primary means to influence crowds. These parameters can be used to facilitate and enforce physical distancing measures. The ‘ICE’ component refers to the ‘Ingress, Circulation and Egress’ phase of an event or activity. This reflects that both risk and measures can differ, dependent on the event phase.

The combination of the DIM and ICE components, the primary influence methods, and the phases in a matrix, results in a systematical checklist for risk assessment. This enables the measuring and development of crowd (Still, 2014a), and physical distancing management.

5.2.3 RAMP Analysis

RAMP analysis provides insight into the relationship between site design and ICE. It is the study of Routes, Areas, Movement and visitor Profile and their dynamics.

RAMP Analysis outlines:

1. Directions, routes and flow paths with consideration of Ergodic Theory (Still, 2000), “least effort” and “focal routes” (Still, 2014a). In the context of distancing Hamiltonian Paths or Cycles, one-way flows and minimal point of interaction can be studied.
2. Flow rates for these routes in the suggested phases.
3. The calculated effective area of the site and whether an area holds static crowds or is more dynamic. Here the Design can be considered against different physical distancing norms.
4. Possible areas of congestion or queueing and fill times. Extra attention needs to go to the available area and the physical distancing norms at play.
5. The visitor profile and likely behaviour.

As a modelling tool, the RAMP Analysis process leads to a methodical and systematic approach.

5.2.4 Density, Congestion and Risk Mapping

This technique comprises the mapping of density or risk zones. As risk and density can vary over time, the representational maps need to be placed in time. As a base, the findings of both the RAMP analysis and DIM-ICE model can be used. When applying different distancing norms in the mapping process, possible problematical areas are highlighted.

The result is a visual representation of the severity, location, time, and risk dynamic (Still, 2014b) enabling communication easiness of a complex idea to stakeholders.

5.3 Queue Modelling

Congestion can often be brought back to queueing systems, either at reception, ticket machines, entrances, turnstiles, food and beverage points or any other place where people need to wait for a certain service. With some imagination, even the gathering of a crowd in front of a stage, or whilst waiting for the performance to end, can be seen as a queueing system. In that the function is the service (time) applied when queueing to enter the staging area and whilst waiting to egress. In any case ingress and egress systems are to be studied in the context of queueing and congestion.

A queueing system, in its most basic form, is defined by the arrival rate, the service rate and its number of servers (Kendall, 1953). Where the mathematical formulae can be used in the field of telecommunication and engineering, they are not likely to be correct when it comes to the queueing of humans. The accurate calculation relies on good primary data, data that is not always available and that is under the influence of many external sources. Even more, human behaviour itself comes with a significant degree of uncertainty. Most queueing systems related to crowds can be reduced to the M/M/1 model, in that, the queue discipline is likely to be “First Come, First Served” (Still, 2016). The general queueing formulae are not suited for application within the field of crowd safety (Bruyninckx, 2017a) as this merely determines the measures of performance of the system (Taha, 2011).

A simplified formula $N = T(A - D)$ represents a single queue single server model, allowing for a quick and easy calculation of the queue build-up over time and can be used in almost any case (Still, 2014a, 2016).

Symbol	Meaning
N	The number of people in the queue
T	The number of time units
A	The arrival per time unit
D	The Departure per time unit

Table 6: Simple Queueing Formula

With the ability to predict the queue build-up, this introduces the possibility to manage the expected spatial consequences of the queue in the context of distancing. For complex queuing systems, simulations tools, as suggested next, can assist as well.

5.4 Crowd Flow Simulation

5.4.1 A short introduction to Crowd Flow Simulation

Simulation and more simple modelling techniques are used to study building performance, help develop crowd management plans, demonstrate compliance with legislation. Crowd models or simulations are composed with only the use of singled out relevant determining aspects of the building (and scenario) and are a condensed representation of the real world. As with any model, the goal is to break down a complex (process) event in a series of parts to simplify the crowd-related problems.

Numerous crowd simulation software solutions are available on the market. To understand the differences and similarities between these simulation tools, it is essential to understand the basics of the underlying techniques and methods of each tool. Still (2007, 2014a), Kuligowski et al. (2010) and Duives et al. (2013) wrote extensively on this subject. Kuligowski et al. (2010) lists and categorises numerous simulation tools based on their characteristics. Although this publication dates from 2010 and does not cover more recent tools, the categorisation of the tools in the document is still accurate.

5.4.2 The Goal of Simulation

Over the past 25 years simulation software has entered the field of crowd safety & crowd risk analysis. Historically, crowd simulation tools were developed to demonstrate that the design concepts of buildings were safe and that occupants can leave, evacuate efficiently (Gwynne et al., 1999). In more recent times, the scope of simulation has been broadened. A variety of tools are developed mainly to:

1. Simulate how crowds use their environment; (Challenger et al., 2010a, 2010c), this Spatial Analysis combined with the analysis of a building or event network graph offers insight and helps the optimization process (Still, 2014a).

2. Determine levels of comfort, safety, and security for crowds in public spaces and urban planning and architecture (Agraa and Whitehead, 1968; Lovas, 1994; Farenc et al., 2000; Challenger et al., 2010a).
3. Prepare and evaluate large-scale evacuation processes (Still, 2000) in event-related situations (Almeida et al., 2016; Ronchi and Nilsson, 2016; Ronchi et al., 2016), urban environments (Alvarez, 2016), and stadia (Klüpfel et al., 2003; Klüpfel, 2007; Zarket et al., 2014)
4. Assess: (1) the level of probability of use of escape routes, (2) bottlenecks and (3) the level of crowd safety, with the use of performance-based analysis (Kuligowski and Peacock, 2005; Kuligowski et al., 2010)
5. Produce visual output, easing communication, simulation is particularly useful to study dynamic crowd behaviour (Challenger et al., 2010a, 2010c).
6. Test when and where a system or network will fail (Challenger et al., 2010a, 2010c; Still, 2014a).
7. Research in detail specific phenomena such as persistent standing or pressure within the crowd, using a sensitivity analysis. Sensitivity research can focus on determining the critical factors by experimenting with all various parameters to see how sensitive they are to initial assumptions. This explicit method requires less human analysis than the implicit method and is besides being more quantitative a more objective methodology (Harding et al., 2010).

Depending on the goal of the simulation, either Crowd Behaviour, Spatial Analysis, Network Analysis or a bespoke Sensitivity Analysis tool can be used. Each of these methods has its particularities and combining all these methods and approaches into the same model or simulation is practically impossible.

5.4.3 Crowd flow simulation in the context of distancing.

In the context of COVID-19 measures and in particular, the physical distancing component simulation, provides insight in density, queueing and preferred routes in the as-is situation, before COVID-19. When embedding distancing in the simulation, quantitative data on density, queueing time, route choice, and so on can be gathered.

Next to generating data, simulation provides the advantage of testing different versions of site design, server distribution, number of servers, entry and exit location, meaning all design-related issues and possibilities can be studied and compared. The simulation helps in designing Hamiltonian paths or routes, one-way flows and minimising interaction between (cross)flows. Different scenarios can be explored; the quantitative data helps in making the optimal choice in site design in the context of COVID-19 (physical distancing) measures.

5.5 Crowd Psychology – the ingroup experience

Reicher (2011) differentiates between (1) physical crowds, and (2) psychological crowds. A fundamental difference is that psychological crowds share a social identity, without the loss of individual identity and turning irrational as suggested by Le Bon (1895) and without loss of control or self-interest. Behaviour and interest in a psychological crowd are focused on the collective self (Drury and Reicher, 1999).

In case of emergency, often physical crowds transform into psychological crowds as a result of ‘…an experience of common faith’ (Reicher, 2011).

This sense of common faith and the need to align with measures to cope with that fate, can be used in managing the crowd at events. It is critical though that those imposing the rules are seen as ingroup as well. This can be achieved by early and correct communication, along with proper explanation on why rules are implied and why they affect us all. Ideally distancing, and compliance with other COVID-19 measure, become the group norm for the event.

Crowd behaviour remains structured, making cooperation and compliant behaviours more common (Challenger et al., 2010b) as resisting the urge to irrationality is the norm (Dean, 2009).

6 Conclusion

Physical distancing will be a parameter in the COVID-19 exit strategy for events and places of public assembly. A profound knowledge of the concept of density and capacity is necessary when considering the implementation of physical distancing measures ion these occasions and locations.

Implementing physical distancing can be a realistic measure for some categories of events. With the use of crowd management tools such as RAMP Analysis, queue modelling and crowd flow simulation, for example business to business events such as conferences or trade fairs, can be (re)designed to facilitate physical distancing. Together with the communication of the necessary information and maximal management efforts, the (re)design of an event or place of public assembly can implement physical distancing.

These concepts are to be embedded in the event reality, not only for the circulation phase but maybe even more in the Ingress and Egress phase.

7 References

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