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How safe is it to shop? Estimating the amount of space needed to safely social distance in various retail environments

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ABSTRACT

COVID-19 has had a devastating effect on towns and cities throughout the world. However, with the gradual easing of lockdown policies in most countries, the majority of non-essential retail businesses are trying their best to bounce back both economically and socially. Nevertheless, the efforts of retail traders are hampered by uncertainty regarding what capacity measures need to be taken, and there is an urgent need to understand how social distancing can be safely followed and implemented in these spaces. This paper draws from retail space allocation, crowd science, operational research and ergonomics/biomechanics to develop a method for identifying the minimum amount of space an individual needs to socially distance in shops, markets, shopping centres and open commercial spaces, when there are other people present. The area required per person is calculated for both static space (where people are seated, standing or queuing, for example) and dynamic space (where people need to walk freely). We propose our method as a step forward in understanding the very practical problem of capacity, which can hopefully allow retail spaces to operate safely, and minimise the risk of virus transmission.

1. Introduction

Since the onset of the global COVID-19 pandemic, the whole world has witnessed an unprecedented impact on the fortunes of its towns and cities, exposing their vulnerability and fragility in a way previously unimagined by the population at large. Specific features of the virus, such as high infection rate, and long asymptomatic incubation periods, have contributed to its rapid spread, and highlighted the inherent difficulties of mobilising appropriate regulatory, societal, and sector risk mitigation systems (Bruinen de Bruin et al., 2020), which degraded the ability of decision-makers to function properly under these uncertain times (Selby and Desouza, 2019). The outbreak of the virus has led to unprecedented changes in people's lifestyles, seriously restricting the day to day freedoms that most people take for granted, with a combination of enforceable and voluntary measures being taken in most countries, such as self-isolation, social distancing, travel restrictions, and enhanced hygienic measures.

These measures, albeit necessary to contain the virus, have brought many people near to their breaking points, due to the disturbance of normal life (Ali, 2020), but they have also had a wider socio-economic impact on people's daily lives and the global economy, with fears of a new recession and financial collapse looming every day (Chakraborty and Maity, 2020; Nicola et al., 2020). Vulnerable sectors that require physical presence to operate and deemed as non-essential (such as tourism, hospitality, accommodation and retail) have suffered the most during the crisis, and their sustainability is being threatened (Barbieri et al., 2020; Dube et al., 2020; Gössling et al., 2020; Jones and Comfort, 2020).

Nevertheless, it is worth mentioning, that it is also possible to identify a few potential benefits emerging from this crisis, in terms of wisdom and preparedness for disaster management (Djalante et al., 2020), that humankind can take forward, if it so desires. Many more people are taking good hygiene precautions much more seriously, and showing more consideration for others in their communities, for example, by abiding by the social distancing rules and setting up groups of volunteers to support the shielding and the vulnerable.

As the COVID-19 spread seems to be weakening in certain parts of the world, we are witnessing the gradual easing of lockdown policies in order to restart economic activity and rebalance the economic safety of societies at both micro and macro levels (Haghani et al., 2020). More importantly, the reopening of certain sectors, such as non-essential retail shops and shopping centres, allows people to reclaim 'a bit of normality' (Butler, 2020) in their lives, after several months of minimal out-of-home interactions. While there are encouraging signs that

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transition from severe to moderate mobility restrictions has the potential to flatten the curve and contain the spread of the virus (Agarwal et al., 2020), there is a substantial risk of viral reintroduction (Leung et al., 2020) that may bring a second wave of infections (Xu and Li, 2020).

Given these potential risks and fears, the retail sector has to navigate through this crisis and adjust to a “new normality” in which capacity will be limited in stores (Aydinli et al., 2020), and more shoppers will continue shopping online even after the lockdown measures are lifted (Nazir, 2020). In the UK, the combination of shifting consumer behaviours and ordered closures has had a detrimental impact to the point that 20,000 high street retail outlets have been forecast to close in the following months (Li et al., 2020). This estimation can be easily surpassed, as people are increasingly uncertain about returning to their old shopping patterns. The greater risk of exposure in the sector due to the supply chain requirements and the design of the built environment (Deziel et al., 2020) can put a halt on consumers’ return to the high street, as according to Maybe* (2020), 47% of UK shoppers are feeling nervous to return to the shops, and 54% said that they would visit their town centres less often. Additionally, research by SpringboardMarketing (2020) (also in the UK) shows that consumers will not be willing to return to shopping if other people are not following safety measures (36%), or the retailers are not doing enough to ensure public safety (24%). Unsurprisingly, the same survey shows that observing social distancing (28.7%), limiting the number of people in stores (26.3%), and providing hand sanitizers (21.7%) in the location would make shoppers feel at ease.

In the new normal, safety becomes the number one priority for shopping destinations, as consumers would like to keep a safe distance from each other in the stores, and not experience ‘crowding stress’ (Aydinli et al., 2020). Social distancing, increased hygiene procedures and the wearing of face-coverings will become normal practices, but also effective communication and understanding of the required measures is of primary importance, in order to avoid a second wave that would not only put public health at risk, but would also give another huge blow to an already troubled sector. Going forward and in keeping with social distancing, agreeing capacities across retail environments will help reassure visitors returning to high streets. The capacity levels maximise occupancy in businesses, which is important for rebalancing the economy.

Thus, in this paper, we propose an all-encompassing methodology for establishing maximum occupancy levels for three retail environments (typical high street stores, larger retailers/managed commercial spaces, outdoor commercial spaces/out-of-town shopping centres), by estimating a lower bound (i.e. the minimum amount of square metres needed) or the amount of space a single individual needs to be allocated to social distance in both fixed (i.e. people in queues) and dynamic spaces (i.e. inside a shop where people need to move around freely). Our paper proposes, theoretically, how much space a person needs in each of the environments, as well as the space required to queue or remain static in an environment. Our analysis involves enclosing each person in a circular region, with a predetermined space in which 1) they can move independently of other people (dynamic space), and 2) they are held in queues or seated etc., and cannot move independently (fixed space). By combining crowd science and ergonomics methods within the retail space context, we establish the minimum parameters that store managers and retailers need to take into account to ensure the safety and wellbeing of their shoppers and employees.

2. Social distancing

A number of recent studies identify the positive impact of social distancing in reducing the risk of transmission of COVID-19 (and other similar past pandemics, such as influenza). These studies agree that social distancing measures, such as physical distance in stores, workplaces, and town centres, isolating ill people, tracing contacts, and avoiding crowds are effective in reducing transmission (Fong et al., 2020; Mahtani et al., 2020; Remuzzi and Remuzzi, 2020). Similarly another study, investigating the effects of physical distance in health-care and non-health-care settings, establishes that physical distancing of at least 1 m is strongly associated with protection (Chu et al., 2020).

Recent research has also explored the economic costs of social distancing initiatives and policies in response to COVID-19. Although social distancing can bring economic losses linked to, for example, raised unemployment or reduced capacity and expenditure in town centres, Greenstone and Nigam (2020) identify economic benefits linked to reduced fatalities and medical care. In regards to this, however, social distancing measures that bring about reduced capacity in stores and lower expenditure, are seen as being necessary by the public. That is, research shows that perception of safety is key in bringing back footfall and restoring commercial and leisure activity in high streets and town centres. For example, a study by Rukuni and Maziriri (2020), carried out in South Africa, finds that retail spaces using sanitization and social distancing measures are translated into customer satisfaction, which in turn is translated into behaviours such as consumption or expenditure.

In this regard, the World Health Organisation (2020) recommends we maintain a distance of at least 1 m between customers in shops, restaurants, etc. However, different countries worldwide have set varying social distancing regulations to limit the transmission of the virus. For example, the United Kingdom and Spain have initially put in place 2 m distancing rules, whilst Germany, Italy and Greece, have established a 1.5 m rule; and a 1 m rule has been adopted in China and Denmark (GOV.UK, 2020a; Shukman, 2020). At the time of writing, the English government has announced a “1-metre-plus” approach from July 4, which allows people to of be 1 m away from each other as long as other measures are put in place (Stewart, 2020).

Under these regulations, retailers are faced with the task of regulating the number of customers. In the UK for example, current government guidance asks retailers to define: “the number of customers that can reasonably follow social distancing within the store and any outdoor selling areas.” (GOV.UK, 2020b). It also urges shopping centres to take responsibility for “regulating the number of customers in the centre and the queuing process in communal areas on behalf of their retail tenants.” However, no further guidance is given regarding how to calculate the number of people that can reasonably follow social distancing in these environments.

This is a complex issue requiring consideration of the size of the floorspace, the layout and positioning of goods, entrance and exit points, and point of sale arrangements, as these will all impact on what the final capacity may be for an individual retail environment.

In addition to individual stores and shopping centres, most town centres include locations where retailers are located in other managed spaces – such arcades and markets. Of course, town centres also consist of other environments, such as transport hubs and greenspace – but these are outside the scope of this paper. Instead, we develop a methodology for establishing occupancy levels for three retail environments:

- Typical high street store space (individual retailers under 500 m^2)
- Larger retailer or managed commercial space (individual retailers over 500 m^2 or commercial space where a number of stores trade together)
- Outdoor commercial spaces (e.g. open markets) or out-of-town shopping centres

In this paper we obtain a lower bound (i.e. the minimum amount of square metres needed) or the amount of space a single individual needs to be allocated to social distance in both fixed (i.e. people in queues) and dynamic spaces (i.e. inside a shop where people need to move around freely).

It is important to explain that our proposal cannot account for the specific features and morphological characteristics of individual places. Those responsible for each of the environments must undertake their own assessment of their spaces. Instead, our paper proposes, theoretically, how much space a person needs in each of the environments, as well as the space required to queue or remain static in an environment. Our analysis involves enclosing each person in a circular region, with a predetermined space in which 1) they can move independently of other people (dynamic space), and 2) they are held in queues or seated etc., and cannot move independently (fixed space).

3. Theoretical underpinning

In common with most place management problems, which are of a very practical nature, theory needs to be drawn from a variety of disciples. Our problem is how to calculate the number of people that can reasonably be expected to enter retail environments, to enable social distancing. To solve this problem, we have found useful theory from retail space allocation, crowd science, operational research and finally, ergonomics and biomechanics.

Retail space allocation has a long tradition of research as businesses try to improve the performance of their stores. Two of the objectives of retail space allocation are to "attract the optimum number of shoppers into the store" as well as "balance the need for profitable trading with the concern for the needs and wants of the shopper" (Buttle, 1984, pp. 5–6). These fundamental principles of retail space allocation have guided our approach as we solve the problem from both the retailer perspective (who will want to optimise the use of their store space) and the consumer perspective (who will want to social distance safely while still enjoying a pleasant retail experience).

Crowd science is an emerging field of research that offers a systematic approach to risk analysis and place crowd safety in congested places of public assembly (Still et al., 2020). Whilst the focus of much research in this area has been on major events, such as sports or music festivals, many of the techniques developed can be applied to the problem of social distancing in town centre environments and at a more limited spatial scale, such as store environments. Of particular relevance is the identification of two types of space – dynamic, where people need to move freely – such as around shops, shopping centres, markets and high streets/town centres; and fixed spaces, where people's movement is restricted, such as if they are seated or standing in queues.

Operational research is a general analytic approach to solving management decision-making problems. To help establish 'COVID-safe' occupancy levels for retail environments, we have borrowed methodology from a branch of operations research known as "cutting and packing" (Dyckhoff, 1990), which is concerned with fitting objects efficiently into a given space. Cutting and packing problems can arise from very different areas of practice, ranging from *cutting* stock (e.g. cutting windows from a large stock sheet of glass, or finding the best layout for a dress pattern to conserve material), to *packing* goods into boxes for delivery, or loading containers for shipment overseas. However, they all belong to the same logical structure. In the context of social distancing in light of the COVID-19 pandemic, however, our interest is focussed on a subset of problems concerned with "tessellation": an arrangement of shapes that fit closely together. In order to apply this to everyday spaces, we explore the capacity of both types of space identified above; *fixed* space and *dynamic* space.

3.1. Ergonomics and biomechanics

So far, our discussion has focussed on principles that allow retailers to optimise the space they have available, whilst at the same time giving individuals freedom of movement with a social distancing 'buffer'. The question now is how much freedom of movement is required?

In order to answer this question, we have reviewed theory in both ergonomics and biomechanics, which investigates people's walking behaviour. In particular we are interested in walking speeds in our different town centre environments, and time needed to stop walking.

In smaller retail environments (that we define to be individual retailers with a floorspace of under 500 m^2), people will walk the slowest as they are likely to be looking around and space will be more constrained – here we assume people will walk at 1.3 m/s (Finnis and Walton, 2008).

In larger retail settings (above 500 m^2), or in managed commercial space, such as shopping centres, markets or arcades, people may walk a little quicker, as many typically bypass a proportion of the available walking space to arrive at the particular area or retailer where they are starting their shopping. In these environments we assume a walking speed of 1.46 m/s (Finnis and Walton, 2008). This is the typical walking speed of adults.

Finally, in outdoor commercial space (e.g. open markets) we have to assume that many people are entering to get from A to B. Therefore, to err on the side of caution, we assume a walking speed of people commuting which is 1.57 m/s (Finnis and Walton, 2008).

To calculate the freedom of movement we should allow in each retail environment that people will need 0.5 s to stop walking (Tirosh and Sparrow, 2004).

4. Theoretical development

Drawing from the contributing disciplines outlined above (using tessellations, ergonomics and freedom of movement) we now present our calculations for capacity in both static and dynamic spaces.

4.1. Capacity in static space

Many shops are allocating space for queuing, internally and externally, using floor stickers, or temporary barriers, or a combination of both. In order to be 2 m from the next individual (following the UK government advice), each person needs to be surrounded by an empty circle of area πr^2, with r = 1, as shown in Fig. 1. Nevertheless, the equation remains πr^2 and r can be substituted with any social distance guidance (in metres) divided by 2.

For this configuration to work, it is necessary for people to move in unison, otherwise if the person on the right, for example, moves towards the person on the left they reduce the social distancing space to less than 2 m (see Fig. 2).

The idea that people will move in unison is completely impractical in dynamic space, considering the different movement choices by individuals making their way through, for example, a supermarket – but is possible in static space, if the space is clearly marked out and managed, and people do not need to move around (see Fig. 3).

The demarcation of this space in this scenario is likely to follow some form of square or rectangular tessellation (Fig. 4), where people are held in individual straight rows, parallel rows or 'snaking rows' (Fig. 5).

In square or rectangular tessellations, the density of the circles[1] is 0.7854 (Williams, 1979, p. 49). In other words, 78.5% of the space can be utilised.

Based on a square tessellation, in fixed space each person will require a space of:

$$\frac{\pi r^2}{0.7854}\ m^2 \quad (3.9797\ \text{m}^2\ \ when\ \ r = 1\ \text{m})$$

However, this gives no room for independent movement without encroaching on another's space. We now introduce the importance of

[1] We calculated the density of the circles in a given space based on circle packing theory, meaning that all arrangements of circles inside a given boundary do not overlap. Tessellations correspond to particular circle packings (Williams, 1979, p. 35-41) that are subject to the layout of space. Circle packing is used here in a way that allows the optimal use of space (meaning the maximum amount of space that can be covered in a store/public space/street when all obstacles and other parameters are calculated).

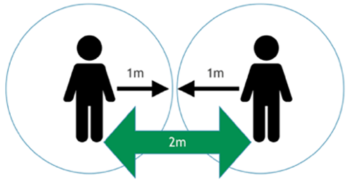

Fig. 1. Social distancing of 2 m between two individuals.

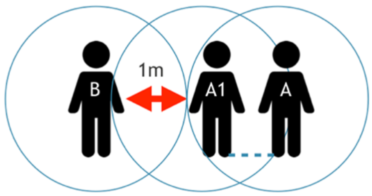

Fig. 2. Person A moves towards Person B (from position A to position A1), reducing social distancing space to 1 m.

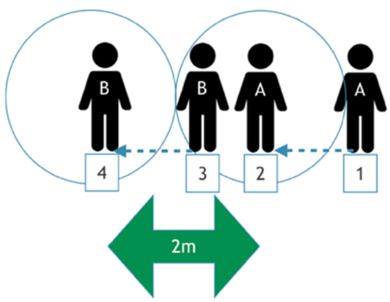

Fig. 3. Person A moves towards Person B, from queue spot 1 to queue spot 2. Person B moves from queue spot 3 to queue spot 4. 2 m of social distancing space is maintained.

Fig. 4. A square tessellation.

independent movement, which is a key characteristic of the dynamic space of retail and town centre environments.

4.2. Capacity in dynamic space

Whilst it is common to measure the floorspace of retailers and managed commercial areas, such as shopping centres and markets, this total area does not equate with the total walkable space for people. Shops are full of merchandise and other 'obstacles' when it comes to practicing social distancing. In addition, they have other areas which are not accessible, such as space behind tills, storerooms and toilets etc. There are also areas of fixed space to be considered, where people are queuing for example, and these needed to be subtracted from the dynamic space available.

Similarly, all outdoor commercial space (e.g. open markets) cannot be assumed to be 'walkable' – there will be areas given over to car-parking, and traffic etc. as well as other, more aesthetic obstacles, such as flowerbeds, fountains and statues etc.

In all environments we define dynamic space as the space that is accessible and can be used for social distancing. The dynamic space will be different in every environment and those responsible will have to measure the areas that are open and accessible to the public, subtracting the areas that are not accessible/usable for social distancing or are given over to fixed space.

In relation to COVID-19 the term "packing" (i.e. fitting elements in a space in the most efficient way, in relation to the aforementioned "cutting and packing" problems) is somewhat at odds to the aim of "distancing". Nevertheless, this branch of theory within operational research still offers us a useful starting point for our analysis of capacity in dynamic space, as it did for static space. In order to identify the most efficient way of allocating space to people, retailers, shopping centre and market managers - as well as place managers - are going to want to optimise the floorspace they have available in the more dynamic spaces, where people need to move around freely (e.g. establish a maximum number of people they can safely allow into their space).

In the following discussion, we use a different method of 'packing' circles, known as a hexagonal tessellation. This is because square or rectangular packings tend to take up more space, even though they are the most likely arrangements in fixed space (people are going to be held or seated in rows). Therefore, if we assume retailers and other place managers will want to optimise the space they have available, we continue our analysis using the hexagonal packing of circles. Of course, in practice, dependent on the individual characteristics of the space in question, a hexagonal packing may not be possible. The purpose of this paper is to establish the lower bounds of space needed to social distance, in different environments, not the particular occupancy levels in individual spaces.

With a hexagonal packing or a hexagonal tessellation, the density of circles in Fig. 6 is approximately 0.9069 (Steinhaus, 1999, p. 202) (Steinhaus, 1999, p. 202), compared to that in Fig. 4 is 0.7854 (Williams, 1979, p. 49). In other words, the proportion of the available space that the packed circles occupy is 90.7% with a hexagonal packing, compared to 78.5% with a square or rectangular packing. However, the same restrictions of movement still apply in a horizontal packing, if the distance between people is only 2 m (see Fig. 7).

To overcome this problem, we start to model the space required by an individual person in a different way, to balance free movement with social distancing as people do not stand still or move in unison in dynamic space.

To do this, we give each individual partial freedom to move independently from each other. We can represent this situation by drawing an inner circle within an outer circle, as shown in Fig. 8. A person can move independently within the inner circle, and the outer circle will ensure correct social distancing is maintained. The size of the radius inner circle, x must be determined according to the freedom of independent movement required.

Based on a hexagonal tessellation, each person will require a space of:

$$\frac{\pi(x+1)^2}{0.9069}\ m^2 \qquad (13.856\ \mathrm{m}^2\ \mathit{when}\ x = 1\ \mathrm{m})$$

The next step is to include freedom of movement, so that people can move around, by setting the value of x, the radius of the inner circle. *Setting x as walking speed/stopping time, gives us the following values for x in the different town centre environments:*

- Typical high street store space (individual retailers under 500 m^2):

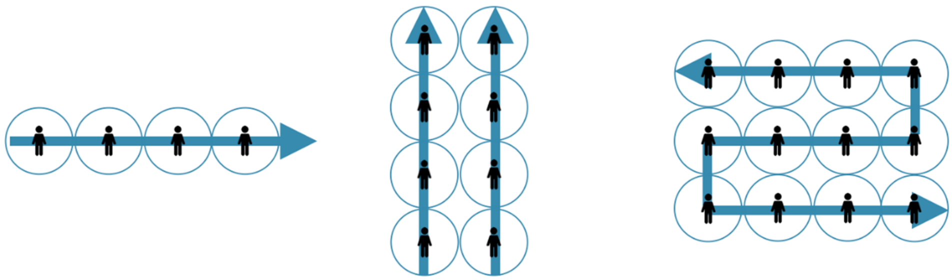

Fig. 5. Queuing configurations based on square or rectangular tessellations.

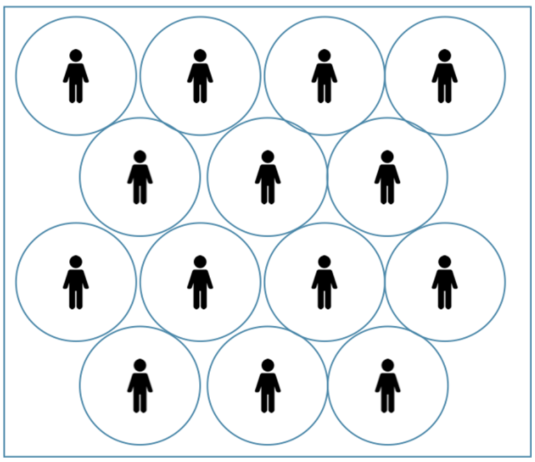

Fig. 6. A hexagonal tessellation.

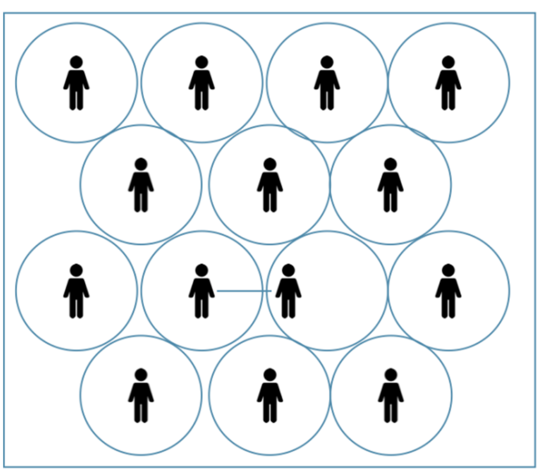

Fig. 7. Violation of 2 m social distancing space caused by movement when r = 1 m.

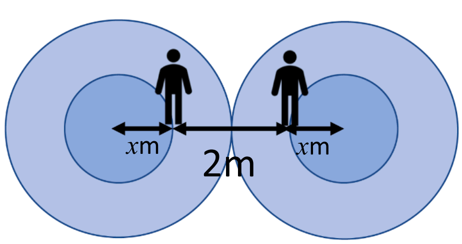

Fig. 8. Social distancing with some freedom for independent movement. A person can move anywhere within the inner circle of radius *x* without reference to neighbours.

0.65 m

- Larger retailer or managed commercial space (individual retailers over 500m^2 or commercial space where a number of stores trade together): 0.73 m
- Outdoor commercial space (e.g. open markets): 0.79 m

We now establish the area required per person for social distancing in different retail environments.

Using our formulae $\frac{\pi(x+r)^2}{0.9069}m^2$ and $\frac{\pi r^2}{0.7854}m^2$ for dynamic and static space respectively, where r is half the social distance required, Table 1 showcases the following lower bounds of space for people to social distance in different retail environments, rounding up to the nearest square metre.

Although these capacity figures are less than operators and place managers are used to, it is important to get some perspective and recognise that they will still allow trade and visitation. For example, any of these figures would allow fitting about 200 people in a third of a footfall pitch. We appreciate that it will be difficult to estimate usable space in some environments, and managers should also look for other tools and templates to do this. Ultimately, it is important that whoever is responsible for the space understands it, as this is part of the COVID-19 risk assessment process that all businesses should undertake, and that managing social distancing is an expectation on local authorities and other managers of public space.

5. Conclusions

This paper has allowed us to propose lower bounds for space allocation, to facilitate social distance across a number of retail environments and in two types of space – static and dynamic. We hope this will be a useful first step for retailers, shopping centre managers, market managers and place managers who will need to calculate the numbers of people who can social distance in their environments.

It is important to stress that the lower bounds that we propose, on their own, will not enable managers to calculate ‘capacity’. Each individual environment will need to be assessed to establish the amount of fixed space, dynamic space, and also take into account other factors, such as entrance and exit arrangements, pinch points etc. We hope to offer further insight here, in future papers, based on published academic research.

Crowd dynamics involves understanding the behaviour of groups of people, monitoring and management (Still, 2000). Services management and marketing, in a retail environment, involve the redesign of layout and processes, staff training, clear signage, clear communications with customers, and other interventions (Baron et al., 2009). This will involve managing people at entrances and exits and other places, such as at tills or collection points. In larger environments it may involve controlling the flow of pedestrians around the store or space. At pinch points, such as narrow aisles, where people cannot safely pass, it may mean floor or other signage to encourage people to walk in one-direction.

These changes are in addition to the other interventions to stop the transmission of the virus (increased hygiene, the wearing of face-

Table 1
Lower bounds of space needed for people to safely social distance in different retail environments.

Social distance (in metres)	Type of space	Area required per person (rounded up to the nearest m^2)
2	Static space	4
2	Retail under 500 m^2	10
2	Retail or managed commercial space over 500 m^2	11
2	Outdoor commercial space	12
1.5	Static space	3
1.5	Retail under 500 m^2	7
1.5	Retail or managed commercial space over 500 m^2	8
1.5	Outdoor commercial space	9
1	Static space	1
1	Retail under 500 m^2	5
1	Retail or managed commercial space over 500 m^2	6
1	Outdoor commercial space	6

coverings in some environments). Getting all this right is especially important during the COVID-19 crisis, to keep the rate of transmission down and ensure customers, and staff, feel safe.

We believe that a pragmatic approach is best in these circumstances, as it makes the manager of the different environments responsible for agreeing available space and numbers of people for safe social distancing and, at the same time, it encourages managers to make the most of the dynamic space available in their environments. That may mean taking out some gondolas or merchandise in some retail environments, reducing the number of traders in some markets, or 'barrows' in shopping centres, and pedestrianising areas or reducing kerb-side parking in town centres, for example. The aim will be to provide an optimal mix of attractions and space for social distancing.

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