# Agent Based Modeling to Optimize Supermarkets Spatial Dimensions

## إستخدام النمذجة القائمة على العميل لتحسين ابعاد المكان في المتاجر


**by**

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**Dissertation submitted in fulfilment**

**of the requirements for the degree of**

**MSc SUSTAINABLE DESIGN OF THE BUILT ENVIRONMENT**

**at**

**The British University in Dubai**

**May 2019**

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## Abstract

The purpose of our research is to study the impact of supermarket size and spatial dimensions on crowding. To improve supermarkets layout from the social aspect, to increase the human comfort and reduce crowding. Despite the supermarket is a major part of our life, but there is one undesirable situation that a lot of people suffer from it, which is crowding. It is the situation where the shoppers feel that the supermarket is overloaded with people at certain times. We solved this problem by providing an optimal area range for the supermarket where we reduced the crowding levels dramatically, while avoiding unnecessary increase in space dimensions. We used a simulation methodology, using Massmotion software to create and analyse the proposed scenarios. Two sets of scenarios were tested, one with 1000 shoppers per day and the other with 2000 shoppers per day. It was shown that the area range from 1450 to 1650 square meters is the optimal area of the supermarket. The results shown that an increase in the critical zones, i.e. the fresh produce, pre-prepared zone and the sixth isle of general items, had the major cause in the reduction of congestion cost, journey cost, higher LOS, such as LOS E and F. We learnt how to find the optimal area of the supermarket or any other space with minimal effect on human comfort. Our research finding shows that the uncrowded isles can be 1.3 meters width, but the crowded isles, such as the fresh produce, pre-prepared food area and the sixth isle in the general items, should be larger with minimum 2.7 times the uncrowded zones, i.e. they should have a width of 3.6 meters, as shown in the seventh scenario.

**ملخص**

الهدف من هذا البحث هو دراسة تأثير حجم المتجر والمساحات على الازدحام. لتحسين تخطيط المتاجر من الجانب الاجتماعي ، لزيادة الراحة البشرية وتقليل الازدحام. بالرغم من أن المتجر جزء رئيسي من حياتنا ، إلا أن هناك حالة واحدة غير مرغوب فيها يعاني منها الكثير من الناس ، وهو الازدحام الشديد. هذا هو الوضع الذي يشعر فيه المتسوقون بأن المتجر مليء بالأشخاص في أوقات معينة. و قد قمنا بحل هذه المشكلة من خلال توفير نطاق مثالي للمتجر حيث قمنا بتقليل مستويات الازدحام بشكل كبير ، مع تجنب الزيادة غير الضرورية في المساحات. استخدمنا منهجية المحاكاة باستخدام برنامج ماسموشن. تم اختبار مجموعتين من السيناريوهات ، واحد مع 1000 متسوق يوميًا والآخر مع 2000 متسوق يوميًا. وقد تبين أن المساحة تتراوح بين 1450 إلى 1650 متر مربع هي المنطقة المثالية للمتجر. أظهرت النتائج أن الزيادة في المناطق الحرجة ، أي المنتجات الطازجة والمنطقة المعدة مسبقًا الجزيرة السادسة للعناصر العامة ، كان لها السبب الرئيسي في خفض تكلفة الازدحام وتكلفة الرحلة و لوس اف و لوس اي. تعلمنا كيفية العثور على المنطقة المثلى للمتجر أو أي مساحة أخرى مع الحد الأدنى من التأثير على راحة الإنسان. تظهر نتائج بحثنا أن الجزر غير المزدحمة يمكن أن يبلغ عرضها 1.3 متر، لكن الجزر المزدحمة ، مثل المنتجات الطازجة ومنطقة الطعام المعدة مسبقًا والجزيرة السادسة في المنتجات العامة ، يجب أن تكون أكبر بحد أدنى 2.7 مرة من المناطق غير المزدحمة ، أي يجب أن يكون عرضها 3.6 متر ، كما هو موضح في السيناريو السابع.

## Acknowledgment

I would like to thank Prof. Riad Saraiji for leading, teaching and supporting me during the cources of the master’s degree and during my dissertation. His valuable advice and guidance played a major role in the completion of this dissertation. I would like to thank him for the support he gave to his students even in his hard times.

I would like to extend my appreciations to all the Facalty members, including Prof. Bassam AbuHijleh and Dr. Hanan Taleb, and I would like to say to them all that you were the excelent ideals to be followed.

I would like to thank my family, my mother, for her sucrifices, encouragments, support and motivations during my life and my dissertation. To my father for all the positive energy, guidance and trust in me. To my wife, for her patience and support all the time. And to my brother for motivating me. To my friends who adviced me when I asked.

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# Chapter 1:

# Introduction

# Chapter 1 Introduction:

## 1.1 Supermarkets:

In the city lifestyle, supermarket shopping is one of the major routine activities of each family and single people all over the world, since it is the only way to choose human needs' items, such as diaries. This activity is done regularly, either weekly, twice a week or more, at certain times, called the peak times. According Seth & Randall (2011) in their book "the grocer" they have mentioned the following: "2 percent of average adult life will be spent inside a supermarket".

The lifestyle, for most people and especially employees, forces them to visit the store at a certain time in a day and certain times in a week. For example, in modern days, for most families, the husband and wife are working members, hence they spend most of the day time at work, leaving few hours at the end of the day to do the rest of activities. Their off days are during the weekends; however, the weekend days are common for all city residents. The supermarket satisfies this lifestyle needs, by providing a wide range of items that can be purchased at once and in the same place. On the other hand, since the store sells in bulk, this method reduces the prices of the items, which make the supermarket more attractive for the shopper, from different locations, when compared with groceries.

The supermarket is a place where customers shop, search and find their needs from food, clothes, electronics, and home accessories. With a variety of products and brands and lower prices than other groceries due to the mass purchasing. This place consists of a series of aisles and shelves, in addition to the stands and cashiers. On the other hand, the supermarket also contains stores, staff area, and products receiving areas. The aisles are divided into different categories. It has a self-service operating system. The size is medium compared to the groceries and hypermarkets. The size of the supermarket is lesser than 5000 square meters. The items are grouped together, and each group is placed in an aisle. The supermarkets are designed with the aim to increase profitability, which is usually measured by the profitability by square meter, in addition, to provide a fast and efficient way of shopping.

The layout of the supermarket and the distribution of items are designed according to four principles. Firstly, the supermarket marketers distribute the high draw items, which are the items that attract customers, at the parameters of the supermarket, i.e. at the end and in the far areas. Secondly, they place the items with high margins at a critical location, such as the one that has a high number of customers passing by it. Thirdly, they distribute the popular items, which are known by the shoppers i.e. power items, and they place the other brands around them, to have higher viewing of the other items. Lastly, the end of the aisles is the highest in viewing, they use it for offers (Aghazadeh 2005).

### 1.2 History of shopping:

In the 1850s, each person was selling what he is specialized in, the farmer, for example, will be selling fresh fruits, vegetables, eggs and milk, i.e. the items that he produced from his farm; in other words, the seller prepared the final displayed item by himself. They will sell their items in an open market, without the display features available in today's' life. This type of selling and concept encouraged cheating at that time since the seller has control over the production of the item (Seth & Randall 2011). In 1965, John Wanamaker invented the price tags, which is the fixed prices system displayed on the item, where before that, the price was given when a customer asks for it, and the prices varied from one customer to another (Özer & Phillips 2012). In 1916, the concept of self-service grocery appeared, and it was by Piggly Wiggly (Salomann, Kolbe & Brenner 2005). The salesmen only supported the shopping activity, however, the choosing process was done by the customers. Logically, the self-service system led to the invention of the shopping cart. In the 1930s, the shopping cart was invented by Piggly Wiggly, to help the customers move freely in the supermarket and spend more. (Grandclément 2014).

In the 1940s, the supermarket concept was different. The layout was different. The layout of the supermarket was similar to the pharmacies today, where the customer enters the store and order his needed items from the seller. The seller will deliver the items to the customer. On the other hand, the store does not contain all the items, for example, the vegetables are brought from one shop and the meat from another (Seth 2011). The lifestyle back then was different. The women were not working, and they used to take care of the house, where they shop for food and house items in the morning while men are working. In addition, the home refrigerators were not invented, which forced the people to shop daily, to avoid storing extra food in the house, where it will get expired quickly and contaminate.

In the 1990s, the life style and supermarkets design changed dramatically. Both men and women started to work and that caused limited time for both. The refrigeration system was invented. The limited time and the ability to store items at the house, resulted in visiting the stores only in weekends, when they had free time. This caused traffic and crowding in weekends. Since a lot of customers couldn't be served at the same time, the supermarket design changed to self-service (Seth 2011). The invention of cars also participated in the existence of supermarkets, rather than groceries. Since it made it easier for the people to move freely, travel long distances, to carry their bulk items and choose the efficient shopping with lower prices.

### 1.3 The architecture elements of the supermarket layout:

The supermarket architecture differs from other building functions, in general, it is a large public hall, where all sales sections are placed in it, small private offices and receiving areas are located at the back or at upper floors. The entrance lobby, where shoppers keep their items and where the customer service is located. In addition, it also contains the carts. The entrance is considered a preparation stage for shopping, they provide necessary items or services for the customers to shop comfortably. The aisles, which consists of shelves racks and corridors for circulation, the function is to display items and a space to view and analyses them. The racks in the isles, usually contain 5 rows, all of them reachable by the customers. The cold items and freezing section, it is like the shelves area section in the concept but has cooling and freezing functions for the food that is subject to contamination if it was kept in normal temperatures, such as milk, yogurt, meat, and seafood. The vegetable and fruits area, that contains weighting scales area. This section must be the nearest to the receiving bay area because it contains fast moving items and it is supplied on a daily basis. The remaining areas such as the bakery, fish and meat areas have counter service options, in addition to the check-out area. In these areas, the customers are served by the supermarket employees.

### 1.4 Energy consumption in supermarkets

Indoor spaces along with their systems hugely affect sustainability, from energy consumption, materials, and water consumption. For the indoor spaces to have a positive impact on the environment, indoor spaces must have efficient use of space, energy, and water, in addition of using materials that are renewable and the indoor space should seek to improve the air quality and human comfort. On the other hand, commercial buildings have another main factor in the sustainability aspect, which the social aspects. Since a lot of people interact with each other compared to a residential building or any other type of buildings. These interactions affect human comfort, which part of social sustainability.

In the United States, one supermarket can produce more than one thousand nine hundred tons of carbon dioxide per year, and fifty kilowatts of electricity per hour per one square foot, in other words, one supermarket with 45,000 square foot consumes around 2,250,000 kWh per year, which is equal to 70 residential units. ("ENERGY STAR | the Simple Choice for Energy Efficiency" 2018). And, in The United Kingdom, the total energy produced by supermarkets equals to three percent of total energy consumption in the United Kingdom. In addition, this percentage equals to one percent of greenhouse gases emissions by United Kingdom. However, Energy Star (2018) stated that most of the energy consumed, in supermarkets in the United States, by the lighting and refrigeration system; however, in the hot climates, such as the United Arab Emirates, the air conditioning is a big part of this percentage. Generally, there are other factors affecting energy consumption, such as supermarket timings, equipment (other than the refrigeration systems), surroundings (is it surrounded by indoor spaces or outdoor spaces, which affects the cooling loads?), supermarket functions (such as bakery) and store isolation from outdoor spaces, such as the usage of air curtains. According to Tassou et al. (2011) the energy consumption is United Kingdom Supermarkets ranges from seven hundred kilowatts per square meter yearly to two thousand. The lighting equals to 20 percent approximately, while refrigeration 45 percent approximately.

Kolokotroni et al. (2019) did a survey for 593 supermarkets, 147 of them are considered small, below 750 square meters, the other 446 supermarkets are large, above 750 square meters. The small supermarkets had a mean energy consumption of 524 kWh/ sq. m. Year. However, for large supermarkets, it was 444 kWh/ sq. m. Year.

### 1.5 Sustainability:

Sustainability is the act of allowing the natural resources to pass from one generation to another without depleting and not affecting the life cycle. In a world that depends mainly on energy to support its living, we must know how it affects the environment and how to use it properly. The energy sources are divided into two categories. The first category is the clean source of energy, which is taken from natural renewable resources, such as solar energy, wind power, hydraulic power, and geothermal energy; this type of energy does not harm the environment compared with the other category. Since this energy does not produce pollutants nor it deputes the natural resources. The other category is the unclean source of energy, where the energy is produced by consuming the limited natural resources and produces harmful gases called greenhouse gases GHG, which is harmful to the ozone layer and it is the reason behind global warming. This type of energy is mainly produced by the burning of fossil fuels. The global warming affects the environment by raising the earth temperature, causing melting of icebergs, raising the water level and reducing land areas. However, it is expected that the energy consumption of the world to increase by forty-eight percent in the next 20 years.

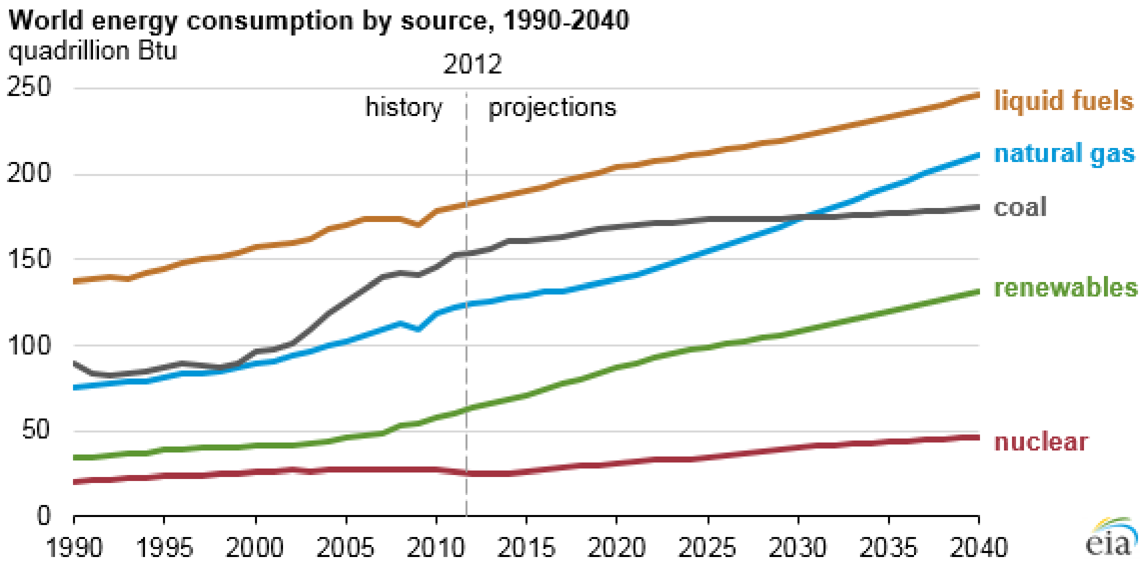



Figure 1: energy consumption by sources (Source: "U.S. Energy Information Administration (EIA)" (2018))

### 1.6 Problem Statement

In most of the researches, the main goal of designing the supermarket layout is, simply, to increase sales. That is done by maximizing the time spent at the supermarket, increasing the number of customers, exposing the customer to the maximum number of items, increasing the sales area and the number displayed items. Since, in supermarkets language, the more the customers see the more they buy. For example, we can see that the goal of power aisles is to attract customers to the supermarket and encouraging them to buy.

However, increasing all the above mentioned will result in increasing the chances of crowding. The longer time spent inside the supermarket will result in increasing the population and that will result in increasing the number of people coming to the store compared to the number of people leaving it. The longer pathway has the similar effect on crowding, since the longer pathway, will increase the spent time inside the supermarket from one side, and from another side, it will force the customers to go through items they might not need, while these areas should have a lower number of people. Increasing the number of people will increase the density. And exposing the people to the maximum number of items will result in reducing circulation areas and increasing the crowding effect.

While the supermarket is a major part of our life, but crowding is an undesirable situation that a lot of people suffer from it. It is the situation where the shoppers feel that the supermarket is overloaded with people at certain times. The shoppers dislike the situation because of the following: the noise pollution, the delays in buying the planned items, fear from disease infections, the feeling of disorganizing. Crowded supermarkets force people to avoid peak time, rather than choosing a suitable time for customers. For some people, who have diseases such as breathing Asthma or depression, it is not advisable for them to go through crowded areas. In addition, the crowded supermarkets encourage customers to shop faster, to avoid the situation.

On the other hand, researches showed that in a crowded situation, people tended to spend more compared to uncrowded conditions, the experiment consists of testing of three groups of people. The first was in uncrowded conditions, the second, in crowded conditions but the people were informed and the third was crowded conditions, but the people were uninformed. The results showed that the third category had the highest spending. (Chen, Lee & Yab 2018).

From the environmentally sustainable perspective, supermarkets are one of the highest energy consumptions, compared with other types of building, such as residential, since the systems (such as AC, refrigeration, and lighting) are switched on, most of the time. Hence, it is practical to increase the efficiency of the energy use by maximizing the usage of the space, while decreasing the crowding levels.

### 1.7 Research Aim:

The aim of this research is to study the impact of supermarket size and spatial dimensions on crowding. To improve supermarkets size and spatial dimensions from the social, to increase human comfort and reduce crowding.

## 1.8 Research objectives:

The research question is the following:

Does increasing or decreasing the space dimensions affect the crowding, can the usage of layout optimization approach increase the human comfort of shoppers? To find the answer for these questions, this research will, firstly, study the current actual supermarket layouts and the logic behind shopping, secondly, propose a series of layouts with different sizes, and lastly, compare the results together. The study area includes the items displaying areas and excludes the store, staff areas, delivery areas, and any other areas.

The following objectives are the keys to achieve the main aim of the research:

(1) Analyse the current supermarkets layouts, (2) Analyse the crowd distribution in current supermarkets. (3) Proposing layout options by increasing and reducing supermarket size, while minimizing the overlap of shoppers' personal space. (4) Crowd simulation and evaluation of the proposed scenarios to increase human comfort. (5) Comparing between the proposed scenarios from crowd comfort aspects.

## 1.9 Research Outline:

This research is divided into seven Chapters as following:

The first chapter is the introduction and background chapter, it includes the history of shopping, an introduction on the supermarket spaces, the crowding in supermarkets, how interior spaces affects the energy consumption and the effect of energy consumption on the world. In addition to research aim and objectives.

The second chapter is the literature review chapter, it includes the previous theories on crowding, the crowding in supermarkets and crowding disadvantages; in addition, it also includes studies on the availability of space and its relation to crowding, crowding evaluation, and previous studies on personal space.

The third chapter is the methodology chapter, it includes the previously used methodologies to study crowding in supermarkets and interior spaces, we studied the survey, observational and simulation approaches. In the end, we specified the chosen methodology. In addition to software exploration, evaluation, and selection.

The fourth chapter is the modelling and simulation chapter where at the beginning we defined the variables that we will study, the process, the study period and the measures that we will evaluate our results on, i.e. the crowding level.

The fifth chapter is the results and findings chapter, which is divided into two sets, the 1000 shoppers per day results and the 2000 shoppers per day results, the first one reflects normal days and the second reflects events days. The results included congestion costs, journey costs, level of service and heat maps.

The sixth chapter is the discussion chapter, where we discussed the results from the previous chapter, the two sets of results were discussed, i.e. the 1000 shoppers per day and 2000 shoppers per day results. In the end, the combination between them together.

The last chapter is the conclusion chapter, where we concluded the research findings and what we learned from the research, suggested the recommendation for future studies, presented design and sustainability implementations.

# Chapter 2:

# Literature Review

# Chapter 2 Literature review

## 2.1 Crowding:

### 2.1.1 Crowding theories:

Harrell & Hurt (1976) defined the crowding, in their research, as the prevention of the space from allowing human beings from accomplishing their goal, such as the situation when a person wants to reach the checkout but he should wait in the queue i.e. his goal is to reach the checkout and leave, and that is present when space is not enough, or the obstacles are a lot. In addition to the lower control of social interactions.

Different researches showed different definitions of crowding. Stokols & Altman (1987) defined crowding is the status when the space force the people to have lesser distances between each other, lesser than the minimum personal space and it is qualitative. According to Foryth (2003), the crowding represents the number of individuals in a given space such as a lobby. While Stokols (1972) defines crowding as the lack of space compared to the number of people flow. On the other hand, Wicher (1979) stated that it is the percentage of individuals to individual attraction; for example, the number of people compared to the elevators' number. The crowding level is measured by the invasion of personal space.

Barker (1963) defined the crowding as the shortage in resources, such as lesser number of staffs, or lesser items in the store. When people feel that, they will have crowding feelings. In other words, the supply is lesser than the demand.

Berham's (1966) had a different definition on crowding, where he stated that crowding is related to freedom. Such as the freedom to move anywhere in the store, the freedom to do a comparison to reach any items at any time or to leave at any time.

Milgram (1970) defined crowding as the condition when the social motivators are higher from the person capability of dealing with them. Such as the case when there are a lot of different people to deal with like salespeople, cashiers, and other customers. That will result in preventing some social interactions.

Freeman (1975) theory on crowding is the feeling of crowding depends on the function of the place and its linked to satisfaction. In addition, he states that different places have different perceived crowding. For examples, schools compared to the residential areas.

Schmidt and Keating (1979) proposed that crowding is the individual ability to control. The more he has control, the lesser the crowding feeling. And the controls are divided into three categories. The first is knowledge control, such as what is happening. The second is behavioral control, to avoid the crowd or not. And the third is decision control, which is matches with Berham's (1966) theory.

Knowles (1983) theory is that crowding is related to the distances between people, which is linked to the personal space theory. The lesser the distance, the higher the crowding feelings.

Manning (1985) approached a different theory from all above. He stated that crowding is related to the type of people. When different people exist in place, which will create a feeling of crowding. Such as the mix between low-class people with higher-class.

### 2.1.2 Crowding disadvantages

Evans (1984) states that crowding has a negative impact on feelings, causing stress and increasing the worrying feelings. Those feelings affect the human physical and mental health and behaviour while making them uncomfortable in the crowded space. Which may result in stopping the people from visiting the space. In the retail sector, this can affect purchasing rates. Human avoids the experience of crowding in most situations. From the tourism side in the high-density areas, tourists feel unsafe and unprotected in crowding situations and try to avoid them as well, the unsafe feeling comes from the fear of being stolen. Crowding affects physical health by increasing blood pressure and heart rates.

On the other hand, crowding can obstruct the movement of people, especially if space is limited, such as narrow corridors, where if someone is walking slowly, the person behind him should wait for him in most cases or request him to move. Resulting in more wasted time and efforts. One of the reasons behind the unsatisfied feelings of crowding is the entry of individuals the personal spaces of others, such as the case of the elevator, were the distance between individuals is less the 20 cm, which is considered an intimate space and the feeling is that the others don't have the right to enter such a space without authorization. Crowding can cause mental distraction and reduce the focusing levels, such as the working environment. And that will affect productivity levels.

As per Wicher (1979), what leads to crowding is related to the number of resources compared to the requestors. Crowding happens when the requested items such as food, elevator or product are not meeting the number of requesters. For example, when the number of meals produced is lesser than the number of hangry customers; or when the number of people waiting for the elevator is more than what the elevator can occupy, or even when the width of the corridor is not enough compared to the number of people.

The impact of congested areas on the physical environment, it increases the waiting time. Increase the feeling of discomfort. Increase the noise levels. A congested emergency exists can increase the risk. Distract the movement. Guite, Clark & Ackrill (2006) in their research paper, they made a survey on the factors that affect mental health. One of the main factors was the overcrowded areas, in addition to noisy areas.

### 2.1.3 Crowding evaluation

Crowding multipliers definition is a scale that measures the crowding levels with reference to densities. It was used in public transport such as metros, buses and bus stations, railways and rail stations. However, different countries had different crowding multipliers values. Based on the observation of the chosen choice, the assumption of the preference is made. Figure 2 and Figure 3 show the relationship between the multiplier, density and load factor when density or load factor increase the multiplier increases as well (Tirachini et al. 2016).

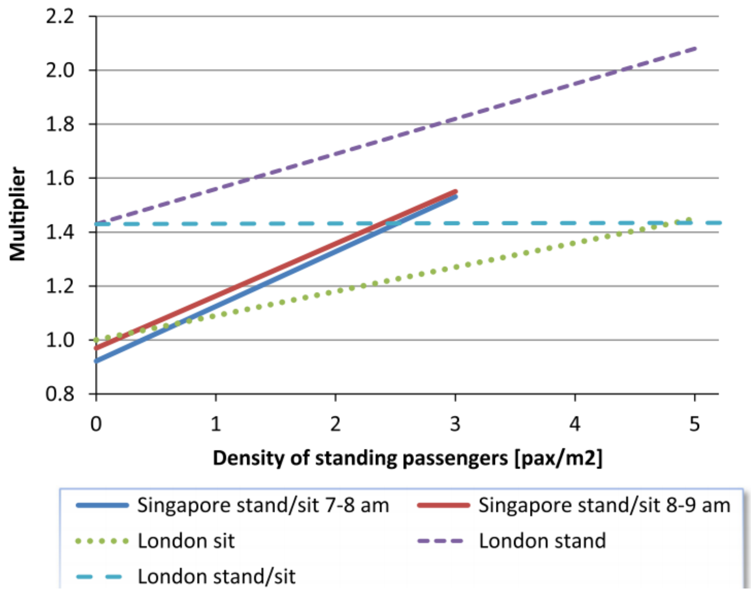



Figure 2: density vs. multiplier, Source: Tirachini et al. (2016)

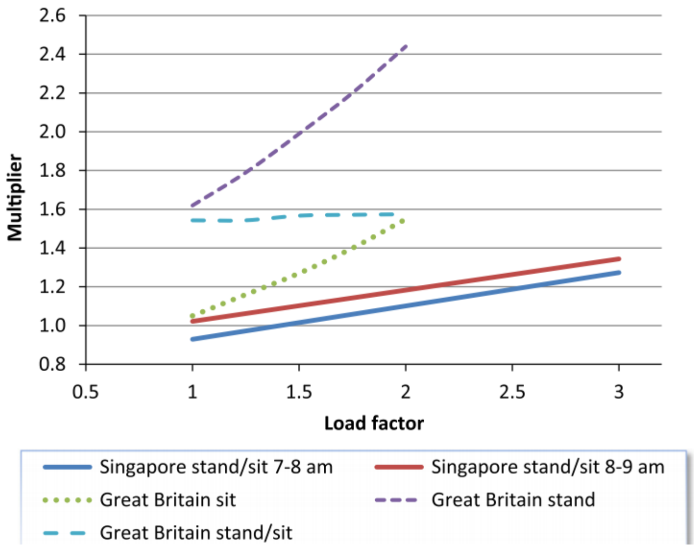



Figure 3: load factor vs. multiplier, Source: Tirachini et al. (2016)

According to Lepore (1994), crowding is a feeling of discomfort in a situation where people are forced to be close to each other and this results in increased stress and depression levels in the human body. However, the researcher states that the density level in accordance with crowding is a subjective matter and varies from human to human. The researcher concludes that crowding is a high dense situation. Machleit, Eroglu & Powell Mantel (2000) measured crowding with density levels in supermarkets. The higher density levels result in a higher perception of crowding.

## 2.2 Crowding in supermarkets:

Researches such as Harrell & Hurt (1976) showed that people feel uncomfortable in crowded areas such as supermarkets. In addition, they have illustrated some disadvantages, such as, the customers will reduce the brands comparing time in the store, they will reduce the shopping list and takes what is necessary only to finish as soon as possible and customers will try avoiding crowded times, such as weekends.

Harrell, Hutt & Anderson (1980) stated that crowding influences shoppers' behaviour in supermarkets; they did a survey, interview type, with the shoppers after leaving asking for their experience, while comparing it with store densities.

Bennett (1998) concluded in his research that crowding has a negative effect on customers. Plus, exposing to situation where it's more crowded than expected, will increase those feelings. However, some people have more tolerance than others.

### 2.3 Crowding and layout design

Aylott & Mitchell (1998) did a study on grocery stores and found out that the shopping experience is mainly affected by two things: the queuing and crowding, and it showed also that the crowding is also affected by layout design such as the width of the isles and the smooth movement of trolleys. The study was done through surveys. Figure 4 shows the relation between shopping experience, crowding and aisles width, the crowding is affected by 28% from aisle dimensions.

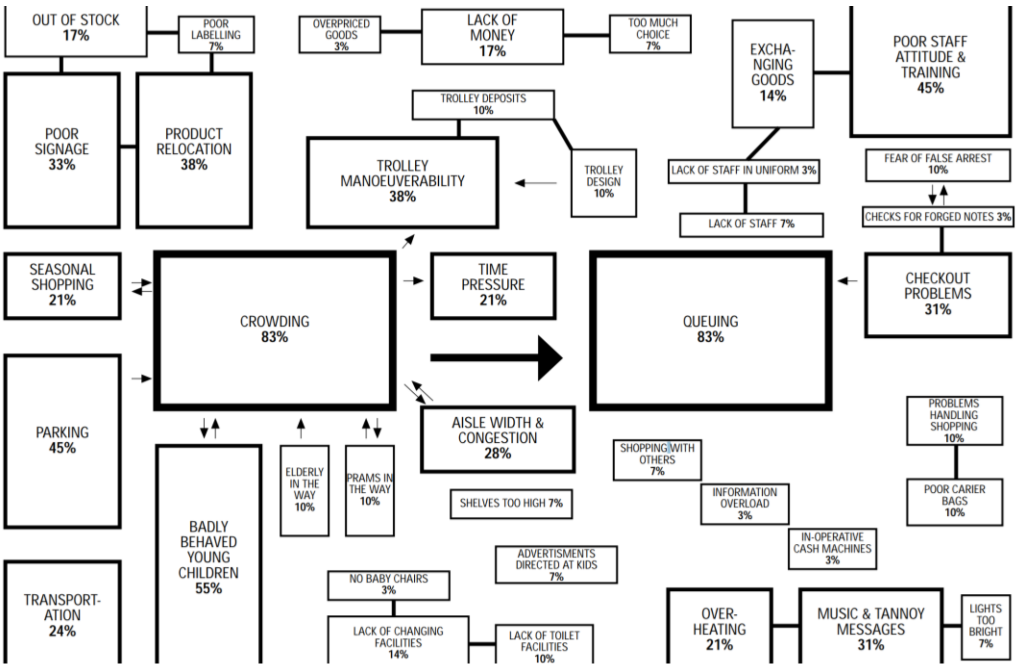



Figure 4: factors affect shopping experience, source: Aylott & Mitchell (1998)

Lee, Kim & Li (2011) studied the relation between store crowding and store layout, the included different aspects, from the results of a survey, such as the tables' organization in the store, grid-type layout, and free flow layout. They found that layout design and distribution highly affect crowding perception.

Worchel (1978) stated that crowding can be reduced without increasing the space by designing the space without overlapping the personal spaces, however, still, the perceived crowding is affected by layout design. Verma & Singh (2018) show that crowding in the supermarket is affected by several factors, one of them is the layout design.

Machleit, Eroglu & Powell Mantel (2000) in their research stated that the higher space density, i.e. lesser space available and lower areas, results in higher perceived crowding. In addition, higher human density increases perceived crowding. Figure 5 shows the relation between density and crowding.

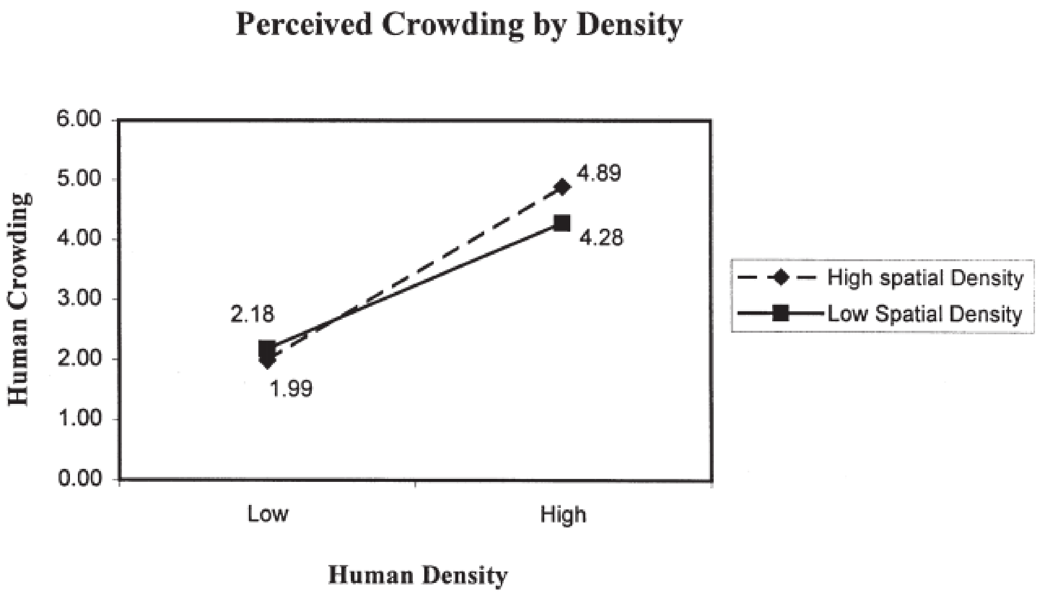



Figure 5: human density vs. human crowding (Source: Machleit, Eroglu & Powell Mantel (2000))

## 2.4 Store layout design

We will begin with the standard dimensions of store layouts. (Neufert & Kister 2012) according to neufert the stores should start with the trolleys section and end up with the cashiers. The shelves should not be placed higher than 1.8 m, in order for the customer to reach them. When supermarket size is increased the ceiling height will increase as well. According to the human dimension and interior design book, the minimum clear distance between aisles is 1.92 meters. (Panero & Zelnik 2014). One of the major important factors in designing supermarkets layouts is the clearness of the layout by the customers and the ease to find products. The clearer the layout to the customers the better human satisfaction and the higher design quality. (Theodoridis & Chatzipanagiotou 2009). The freestanding shelf dimensions are 130 cm by 125 cm.

Zentes, Morschett & Schramm-Klein (2007) they stated that two main things should be considered in-store layouts, which are the clear directions for the customers, i.e. the ease to find products and the feelings the store gives to the customers. At the same time, the store is evaluated according to these two things.

The layout is designed to let the shoppers see the maximum number of items in the store. The store layout should be flexible to accommodate changes over time. The larger the supermarket, the more items get purchased by shoppers. Hence larger trolleys are needed. They stated also that the layout design is done by designing the customers' pathway in a specific direction to maximize sales. On the other hand, the store layout should be easily understood (Cil 2012).

There are several types of store layout, the racetrack, the grid layout, the free form layout, and the circulation spine layout. The grid layout is easily understood by customers and they can find the required items quickly, where it provides a main path and sub-paths for customers. On the other hand, the free form layout is time-consuming for customers and more confusing, however, the users can freely move in any direction. The race truck layout provides a single path for customers, where customers must pass through all items. The circulation spine layout consists of one main aisle passing through the store and along this spine, the products categories are placed (Cil 2012).

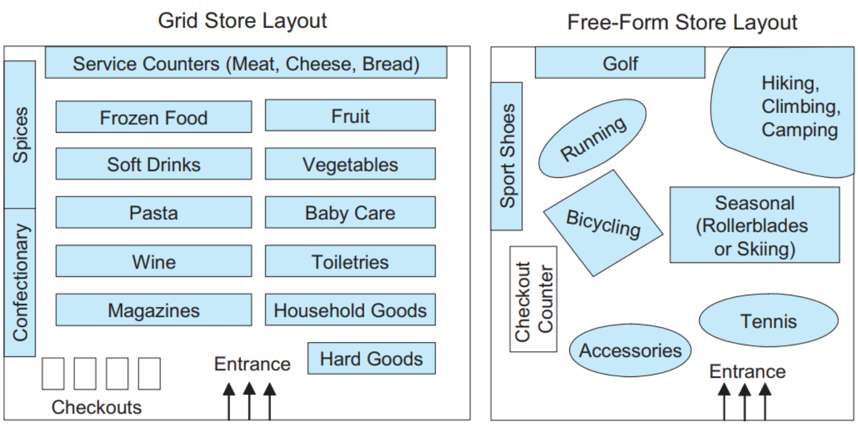



Figure 6: retail layout types (source: Cil (2012))

The researchers also stated some of the valuable areas, and these areas are considered valuable because the customers have to pass through them, such as: the entrance, the checkouts, aisles end, special offers areas and eye level shelves (Cil 2012).

One of the terminologies and techniques in designing store layouts are the creation of what is called the power aisle. The power aisle is usually located near to the entrance to create a perception that the store has lower prices and provide special offers to the customers, I.e. it is an attraction element. The power isle is, in summary, consist of large quantities of a fewer number of brands and items with a written indication of lower prices. The placement of large quantities of one item gives the impression that this product has lower price, despite that it really has a lower price or not (Smith & Burns 1996).

Supermarkets are designed in an industrial method i.e. by the product type. This is done by dividing the stores into sections, such as clothes, fruits and vegetables, electronics, and spices. The reasons for this method are two. Firstly, this provides clear guidance to the customers, since, clearance is one of the main objectives of store layouts. And secondly, people have built a mental map of the store layout according to the product divisions, and any change in this system will confuse the customers (Borges 2003).

On the other hand, some stores tried another layout system, where products are organized according to the function. For example, dinner section, where the customers will find all they need to make a dinner, or camping section, where there will be camping clothes, tents and grills, all combined for task requirement. The products are also arranged on the studied customers' habits, as shown in Figure 7 (Borges 2003).

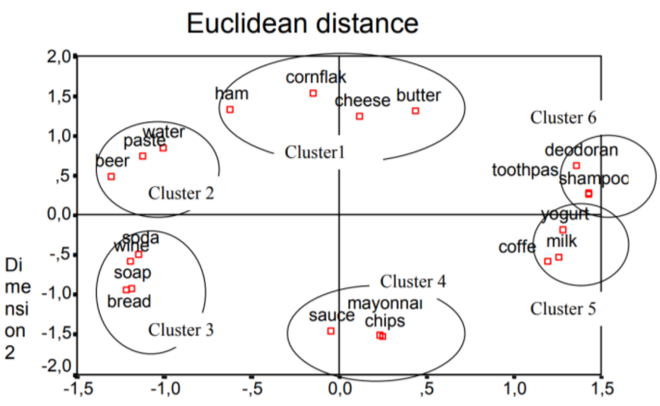



Figure 7: store layout by function (source: Borges (2003))

### 2.5 Personal space

The personal space is the invisible area that surround the human body and needed to provide psychological satisfaction, however this area is variable from human to another based on several factors, such as gender, age and culture (Sommer 1969).

#### 2.5.1 The dimensions:

Originally the human space was defined by a certain distance from all sides. As shown by Panero, Zelnik and Castán (1984), where they defined the personal space by 75 to 120 cm between two humans from all sides, as shown in Figure 8.

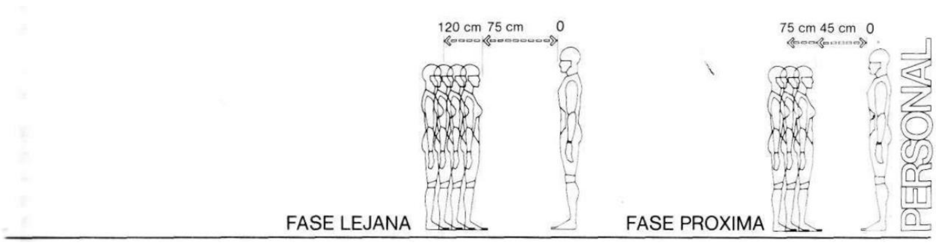



Figure 8: personal space front distance (source: Panero, Zelnik and Castán (1984))

However, human personal space has different measurements according to the human body, since most of the senses are located at the front side of the human body, the front distance of personal space is higher than the sides and the back. Balasuriya, Watanabe & Pallegedara (2018) defined the distance as shown in Figure 9, the front distance is 80 cm, whiles the sides are 30 cm each, and the back distance is the lowest, which is 20 cm.

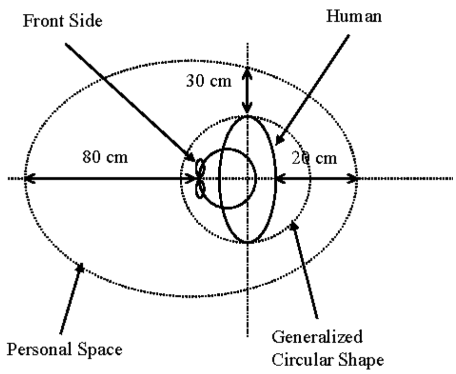



Figure 9: personal space dimensions, source: Balasuriya, Watanabe & Pallegedara (2018)

Amaoka et al. (2018) also show that the front personal distance is more than the sides and the back, as shown in the Figure 10.

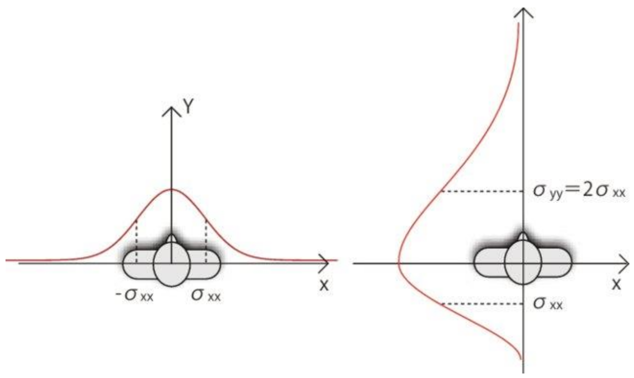



Figure 10: personal space proportions, source: Amaoka et al. (2018)

On the other hand, researches have shown that walking personal space shows an increase in the front dimensions. The human feels comfort when his pathway is clear from obstacles. Kitazawa & Fujiyama (2018) specified a distance of 4.58 m between the human and the static obstacle. However, this distance varies if the obstacle is coming toward the human, where the distance decreases to 4 meters. While if the obstacle is moving in the same direction, the minimum distance should be 1.9 meters, as shown in Figure 11 (Truong, Yoong & Ngo 2017).

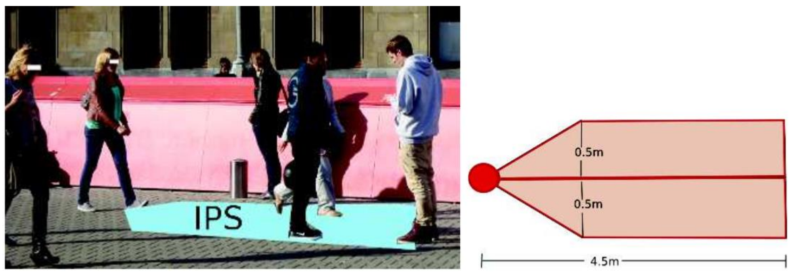



Figure 11: walking personal space

### 2.5.2 Factors affecting personal space dimensions

On the other hand, Amaoka et al. (2009) showed that the personal space is affected by the gender, age and location (indoor or outdoor), as shown in Table 1.

Table 1: factors affecting personal space, the dimensions are in centimetres

| Sex combination | Indoor | | | Outdoor | | |
|---|---|---|---|---|---|---|
| | Adult | Teenage | Child | Adult | Teenage | Child |
| M-M | 83 | 83 | 63 | 83 | 75 | 62 |
| M-F | 71 | 63 | 58 | 79 | 68 | 58 |
| F-F | 75 | 62 | 59 | 75 | 73 | 67 |

Another research showed that personal space is also affected by the nationality and culture. For example, Arabs have higher personal space compared to South Americans, which is affected by the culture of the country (Sorokowska et al. 2017). Hungary has the highest personal space value (equals to approx. 105 cm) followed by Saudi Arabia, while Argentina and Peru have the lowest (equals to approx. 60 cm). In general Europe countries, the United States and South America have lower personal space compared to Asian countries, Figure 12 and Figure 13 show different countries and their personal spaces. Figure 14 shows the relationship between gender, age, and the personal space.

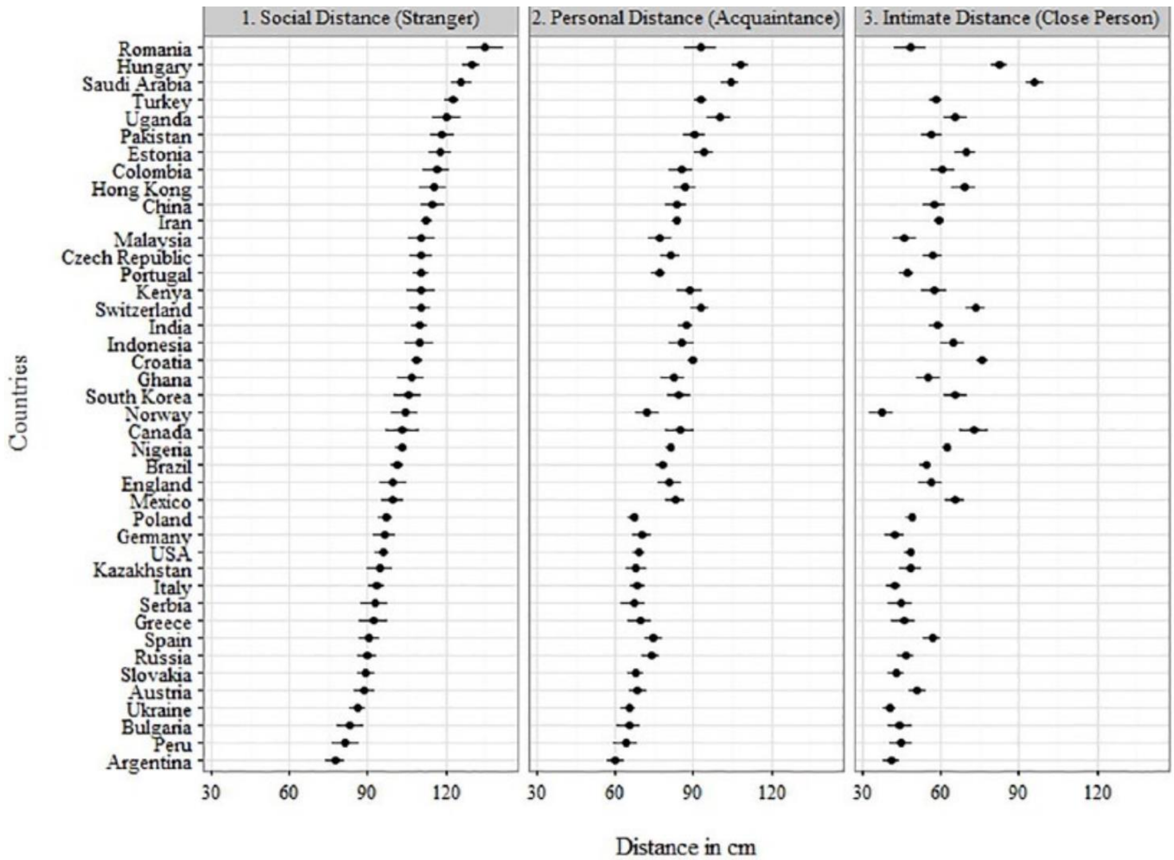



Figure 12: personal space by nationality (Source: Sorokowska et al. (2017))

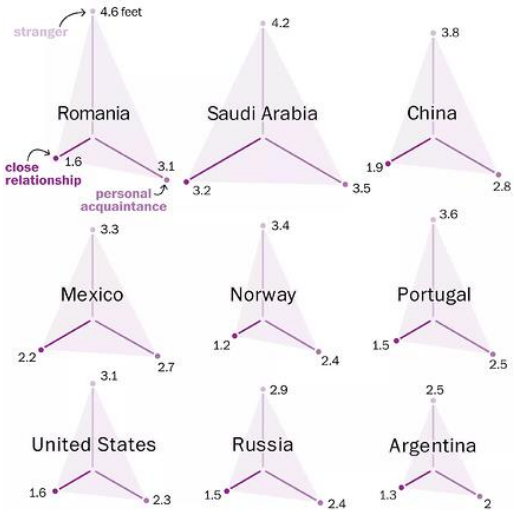
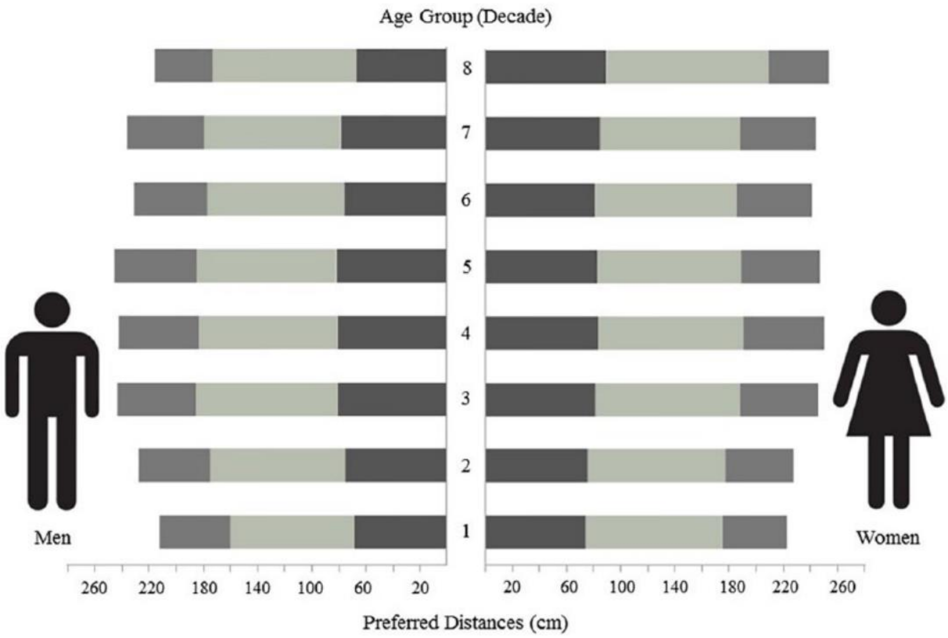



Figure 13: personal space and nationality




Dark Grey: intimate distance, light grey: personal distance and grey: social distance

Figure 14: relationship between gender, age and personal space. (Source: Sorokowska et al. (2017))

# Chapter 3:

# Methodology

# Chapter 3 Methodology

## 3.1 Methodologies used before:

In order to get the shopper behaviour in supermarkets and reflect the actual crowding, we have three options: through an observational study, the literature and previous studies or through simulation.

### 3.1.1 Through the observational study method:

The observational study includes observing a supermarket and accordingly summarizing the actual human behaviour in it.

Previous researchers did this method by tracking shoppers by placing electronic chips on their carts. These chips work as a navigator and give the exact location of the cart in the supermarket by proving coordinates. The signals are sent regularly, depends on the pre-defined time, as an example, every five seconds. The signals are sent to signal-readers distributed at different locations in the supermarket. The electronic chips have a different reference number for each one of them, which makes the data organization easier. Figure 15 shows the fixation of RFID tags on the shopping cart. We can notice that the tags are huge and require space (Joho, Plagemann & Burgard 2019).

Figure 15: RFID Tags, source: Joho, Plagemann & Burgard (2019)

The advantages and disadvantages of this methodology:

The advantages of this methodology are: it reflects accurate behaviour and show the actual conditions. There is no chance or assumptions and no errors. The disadvantages are that it costs more than the other methods, since it requires purchasing the systems, parts and the specialized persons to do it. It is time consuming. The data set is large and difficult to control. It needs supermarket owner approval to place the chips on the carts. The method does not display the shoppers without the carts. Not possible to control the fixed variables.

#### 3.1.1.1 First research: An Exploratory Look at Supermarket Shopping Paths

Larson, Bradlow & Fader (2005) used the RFID methodology to track the shopper location and pathways in the supermarket, to identify shoppers' behaviour. In the beginning, the researcher placed the tags on the shopping carts and started the system. When shoppers started to use the carts and do the shopping, the chips sent signals showing their location in coordinates (x and y), every 5 seconds.

The research resulted in twenty-seven thousand paths, and they range from 25 signals, for short paths, to one thousand five hundred signals, for long paths. The system stops tracking the cart, once it's beyond the limit point, which is set behind the checkout point. Then they used a methodology called "k-medoids", which is an algorithm used to cluster the data into groups, the groups might be clustered by time or path patterns.

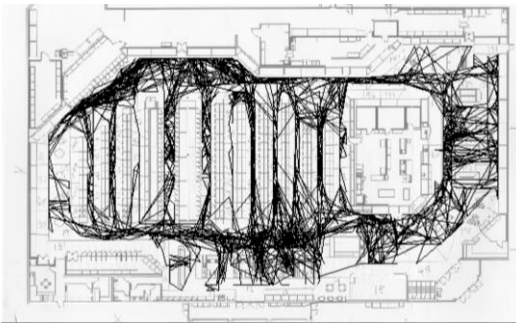


Figure 16: RFID path tracking, source: Larson, Bradlow & Fader (2005)

#### 3.1.1.2 Second research: Clustering of customer shopping paths in Japanese grocery stores

In this research, done by Sano et al. (2016), they used RFID (radio frequency identification technology) in a supermarket in Japan, where it resulted in nine shopping patterns and the period of time the shopper spent in each area. The researchers placed electronic chip tags on the carts to trach the shoppers' pathways. The data was gathered in two months. The signals showing the coordinates (x and y) of the cart was sent every second. The spacing of coordinates is 10 centimetres vertically and horizontally. The supermarket was broken into sixteen areas. Almost 7000 shopping paths were collected. Similar to the previous research, they used the K-medoid method for clustering. The medoid is calculated through Equation 1, and it is a method to group the data set into smaller groups that have similar points and the dissimilar points are very less.

Equation 1: K-medoid

$$medoid = \arg\min_{x \in X} \sum_{y \in \{X - \{x\}\}} d(x, y)$$

medoid= cluster

arg min= Argument of the minimum

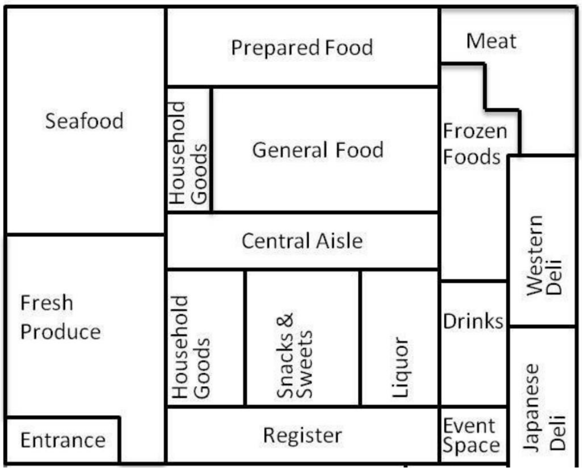



Figure 17: Japanese supermarket layout source: Sano et al. (2016)

#### 3.1.1.3 **Third research: Comparing two supermarket layouts: The effect of a middle aisle on basket size, spend, trip duration and endcap use.**

In this study (Trinh & Bogomolova 2019), the researchers observed two actual supermarkets, to study the effect of central isle on the shoppers' flow and purchasing behaviour. One supermarket had the central isle, while the other was without it. They observed three factors: the time, money and quantities of items.

They started by selecting the store, they have chosen two stores that matches in size, location, design and surrounding, however, they differ in the central isle only. Then they broke the store into zones, in order to make it easier for them to locate the shoppers. The number of shoppers observed was almost 7500 shoppers, in half a day.

The researchers stood in different locations and observed the direction of shoppers and their action, while recording both physically on pre-printed maps.

At the end, the results were analysed and compared. The time spent at the supermarket were analysed using the following equation:

$$f\left(\lambda; \mu, \sigma\right) = \frac{1}{\lambda\sigma\sqrt{2\pi}} \exp\left\{-\frac{(\log\ \lambda-\mu)^2}{2\sigma^2}\right\}$$

"Where, μ is the mean and σ is the standard deviation of the normal distribution *Y* where Y=log(λ)" (Trinh & Bogomolova 2019).

### 3.1.2 Through surveys:

In the survey methodology, the researchers selected an area of research, prepared a questionnaire, based on previous studies. Then, they asked the shoppers or the targeted sample for their experience when shopping at supermarkets'. This was done through a rating system either from 1 to 5 or 1 to 7. After that, the researchers came with results, where they used software to analyse them.

#### 3.1.2.1 First research: perceived retail crowding and anxiety: impact on shopping satisfaction and impulse buying

The sample of this study is 441 of supermarket customers, studying the perceived crowding by shoppers. The perceived crowding included spatial crowding and human crowding. The propose of the research is to study the effect of crowding on customers anxiety (Eroglu, Machleit & Barr 2005). The researchers started with the preparation stage, where they prepared a questionnaire in order to collect information in the next stage. Then, they made the questionnaire available online, and they distribute it through social media. Each shopper was instructed to spread the survey and instruct the next shopper to spread it as well. The questionnaire for the crowd is divided into two sections, as following, the human crowding and spatial crowding:

Human crowding:

"The store seemed very crowded to me",

"The store was a little too busy",

"There wasn't much traffic in the store during my shopping trip" (reverse coded),

"There were a lot of shoppers in the store", Spatial crowding:

"The store seemed very spacious" (reverse coded),

"I felt cramped shopping in the store",

"The store had an open, airy feeling to it" (reverse coded),

"The store felt confining to shoppers".

However, to prevent any false information, the researchers included in the survey some additional information on the shoppers, such as the university email ID, while they stated that it will be confidential. The online file was kept for two weeks before ending the questionnaire survey. Then, they did the quality assurance testing and validation through EFA (exploratory factor analysis) and CFA (confirmatory factor analysis).

As mentioned earlier, the sample is 441 shoppers, 241 of them are females and the rest are males. The age of shoppers ranges from 35 to 64. 114 shoppers ages from 45 to 54, while, 230 are above 44 years old, and 210 are below 44 years old. Then, the measuring stage, the measuring was done with a scale from 1 to 5, where 5 is the shopper fully agrees with the statement and 1 fully disagree with the statement. Lastly was the results analysis stage, where the researchers analysed all collected data through a software.

#### 3.1.2.2 Second research: Effect of Store Design on Perceived Crowding and Impulse Buying Behaviour

The researcher (Gogoi 2017) studied the effect of perceived crowing on the behaviour of shoppers. It was done through a questionnaire survey in India, in Pune city. The sample of this study is 1000, 96 percent was used. Most of the sample are males, 680 males, while the remaining are females. Half of the sample are married, and the other half are unmarried. The analysis was done through IBM SPSS Statistics 22 and LISREL software. The reliability was tested by coefficient alpha. The survey questions were as following, and it was divided into eight sections, however, we selected from them the ones related to our research, which is crowding:

The first three questions were about the store design:

SD1 the store design gives a crowded store outlook

SD2 the store looks crowded from outside

SD3 I think the store is crowded

The next three questions were about human crowding:

HC1 I found the store too busy during my shopping trip

HC2 the store traffic was high

HC3 I found a lot of shoppers in the store

However, the last three questions selected were about spatial crowding:

SC1 the store looks more congested due to the design and layout

SC2 the store feels very spacious when I shop in the store

SC3 I felt confined when shopping in the store

The measuring with the scale from 1 to five, where 5 is fully agree and 1 is fully disagree. The above questionnaire along with the ratings defined the level of human or special crowding in the supermarket.

#### 3.1.2.3 Third Research: Examining the Differential Impact of Human Crowding Versus Spatial Crowding on Visitor Satisfaction at a Festival.

The researcher (Kim, Lee & Sirgy 2015) took the sample from a festival conducted for seventeen days. The researcher approached the visitors and asked them a set of questions. And then collected the data and analysed it. The researcher took the sample from a different day, such as weekends and working days and at different timing, to diverse the sample collection. The sample size was 423 surveys. 97 percent of the data were used. The questions were taken from a previous study on supermarkets and modified them to match the purpose of research. The following statement evaluation was used to evaluate the human crowding:

"There was much traffic at the festival";

"There were a lot of people at the festival";

"The festival was a little too busy"; and

"The festival seems very crowded to me."

The following questions were used to evaluate the spatial crowding:

"I felt suffocated at the festival," and

"I felt cramped at the festival."

"Moving around at the festival was inconvenient."

For assessment, the researcher did the quality assurance testing and validation through EFA (exploratory factor analysis) and CFA (confirmatory factor analysis). After that, they used AMOS 18 software for analysis.

The disadvantages of this methodology are that it does not specify the exact areas, where the crowding is happening, while it gives a general view on the store image, it is either considered crowded or not. In addition, this methodology does not provide the flexibility to experiment with different options and to study how changing the design can affect the crowding levels and perception. It also does not provide the reason behind the crowding, except the high number of people or dense space by either human or obstacles. It does not track the actual shopping pathways. The advantage of this methodology is: it gives the actual perceived crowding from the end user point of view, without assuming, hence the methodology gives accurate results.

### 3.1.3 Through simulation:

This methodology is done by modelling the supermarket with the crowd simulation tool. This tool mimics the actual human behaviour, with a pre-defined logic. This method produces results and analysis. It can be used to mimic human behaviour at normal conditions or during evacuation. And this is can be used to improve physical environment design, timing and provide solutions for congestions.

The advantages and disadvantages:

The advantages of this methodology, it provides the flexibility to edit and change the physical environment, while in other methodologies it is costly and not practical. The disadvantages are it is lesser accurate than the observational methodology.

#### 3.1.3.1 First research: Analysis of Crowd Movement in the Prophet (SAW) Mosque in the City of Madinah, Saudi Arabia

The researchers (Alshehri et al. 2015) studied and analysed the crowding in the Prophet Mohammad mosque, to provide a solution to the crowded areas in the mosque and to improve the flow of people. They started the research by data collecting, they collected the data from videos, where they focused on the speed, the time spent in each area and the logic behind the movement, such as what is the first area they visited. The sample size, taken from the video, was 100 persons. The next stage was the mass-motion simulation. They started the simulation stage, by the modelling stage, where they draw the mosque in three dimensions. Then they moved to sit the logic and simulation data, where they specified the number of agents (the number of agents was variable, I.e. they tried different numbers). Finally, the results stage. In this stage, the researchers analysed the density maps, density graphs, and the duration of the journey.

#### 3.1.3.2 Second research: Using Mass-motion to analyse crowd congestion and mitigation measures at interchange subway stations.

In this research (King, Srikukenthiran & Shalaby 2013), they used mass motion software to simulate crowd at a subway station to reduce the congestion. The simulation helped the researchers to study the timing, queuing and congestion areas. They started the research by the data collection part. Collecting data about the subway station, the timings of trains and the number of passengers at different times. In addition to collecting data on the physical environment of the station, this includes the circulation types, such as staircases, elevators and ramps. The data were collected by the researchers, with their observations only. The next stage was the modelling stage.in this stage, they modelled the station and the logic, such as train arriving times, number of agents entering the model and all the data collected in the stage before got converted to the model. The last stage was changing in options, which is the number of trains and arrival timing and analysing the results with relation to crowding and congestion. In order to find the best trains arriving pattern.

#### 3.1.3.3 Third research: New York’s Fulton Centre

In the design process of Fulton Centre ("New York’s Fulton Center - Oasys" 2019), they used mass-motion to predict the congestion areas ant try to prevent them, before building the centre. The developers predicted the number of visitors will equal to 300,000 visitors per day, however they added 20 percent as a safety factor. The design team modelled the stops, pathways and all other aspects. The passengers’ data were collected earlier (before modelling stage) and they used it in the modelling and simulation process. The software showed the results and analysis for the model, where they could highlight and modify the model (such as the timings or capacities) to improve the flow and to increase the efficiency.

### 3.2 The chosen methodology:

In our research we used the simulation methodology, to have an accurate result and to study different options. We built on a previous observational study of a supermarket and we built the model and did the simulation accordingly. The research that we based our modelling and simulation is by Sano et al. (2016).

### 3.3 Simulation software:

#### 3.3.1 Introduction:

Agent based modelling: some researchers call it particle behaviour and others call it: collective intelligence models. (Kontovourkis 2012). Agent based modelling is a field cover any time of behavioural movements such as animals, insects and even humans. However, in our case, the human movement is the area of our study. Kontovourkis (2012) suggested two ways to model the human behaviour, the first is based on ‘social interaction’ and how humans communicate with each other, and the second is based on searching on the path, which is called ‘way finding’.

Turner & Penn (2002) added the vision as the main elements in agent-based modelling. They suggest that what the human sees in their way affects their movement. The human representative takes the surrounding information and makes decisions according to rules. Moreover, they made a code that matches their concept for moving behaviour based on vision field, as shown in Figure 18.

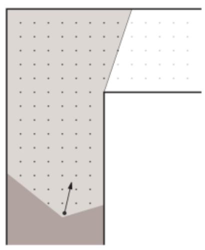


Figure 18: agent vision, source: Turner & Penn (2002)

The first step in SJOBERG et al. (2018) methodology is defining every element in the model, as an example, defined walls means the user can not cross them. Any element exists in the area influences human behaviour. An analysis was done on the elements and their effect on human behaviour. Some elements provide physical and visual barriers, while others prevent the movement but not the visual sight. The second step was defining the input data. The input consists of the size of agents i.e. the quantity, the position of starting (where the agent will start from), and the location where the agent is heading (such as the exit) and the last input is defining the elements. The third step is the algorithm stage. Where the algorithm mimics the human behaviour and movement in the space. As defined earlier, the algorithm is a system, a set of rules, to deal with the given data; a way to decide between the paths given to the agent. The number one influence on the decision is the visual field. The visual field was created by extending beams from the agent to the nearest visual barrier, as shown in the below image. The researchers defined the vision field by 180 degrees divided by two on both sides of agent direction. The line length defines the distance of the object from the agent. The fourth step is the decision. The decision is made according to two factors, firstly, the dimension of the line length and the angle of the line from the aimed location. The lesser the angle, the more properly the agent will take the route; the longer the line, the more properly the user will take the path.

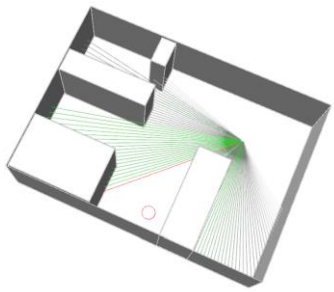


Figure 19: agent vision beams, source: SJOBERG et al. (2018)

Macal & North (2018) stated that the process of doing the agent-based modelling simulation, which is used for crowd analysis and simulation is done through the following steps: firstly, listing the goals and answering the question of why; secondly is the analysis stage, such as the connections and relations; thirdly, studying the different scenarios; fourthly, testing the results.

Who are the agents? How do they think? What are their actions based on? How do they interact with the environment and other agents? All the answers for these questions will assist in building the model. Then, the author described that agents' actions can be determined with the literature review.

### 3.3.2 Software exploration

Macal & North (2018) has another research on agent-based modelling named: agent-based modelling and simulation: desktop ABMS. They modelled supermarket shoppers using excel.

Using of excel has advantages and disadvantages, such as it is simple but has some limitations. It was used to study the human behaviour and the interaction between the human, other humans and the environment. The researcher then puts a set of rules such as the users will not hit each other, and they are shopping for one item only. The system is done through four steps, firstly defining the environment, secondly defining the agents and their behaviours, thirdly, the period before not finding items disappointment, and fourthly, the results and human satisfaction level, which is measured by the clarity of layout.

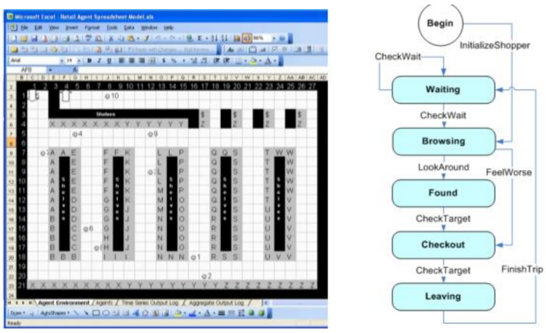



Figure 20: excel agent modelling, source: Macal & North (2018)

Rhino Software has a plugin called grasshopper. Grasshopper is graphical algorithm editor used by architects and other professions that don’t have the skills to work with programming language. There are several plugins in grasshopper that deals with agent-based simulation and crowd simulation, such as, **Quelea, Nursery, Culebra, Boid and Pedsim.**

#### 3.3.2.1 **Quelea**

Quelea is agent-based plugin used to create behaviours and has ready behaviours such as eating. The plugin is not specialized in human behaviours, but with any type of behaviour, such as rain behaviour. The software can be used by defining the environment, circulation, attractions and forces, then running the simulation. It can be used for 2D and 3D. 2D is most appropriate for human behaviour, while the 3D is for other types of behaviour such as the birds swarm.

The developer used Quelea to study the crowded areas in a school. He divided the areas into two parts: the students moving areas and the public moving areas. He depends on his research on the movement speed of agents to study crowded areas, where the agents slowdown, that means there is interaction with other agents. However, the agents flow randomly in the space.

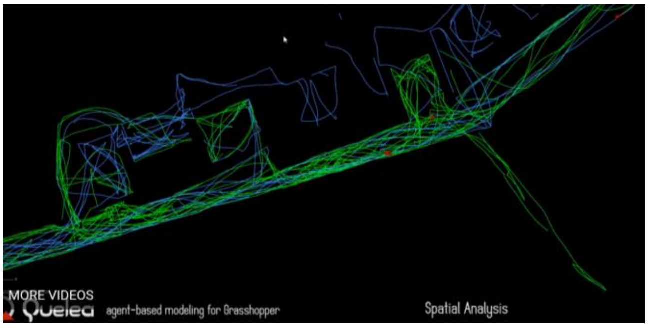



Figure 21: Quelea agent-based modelling (a)

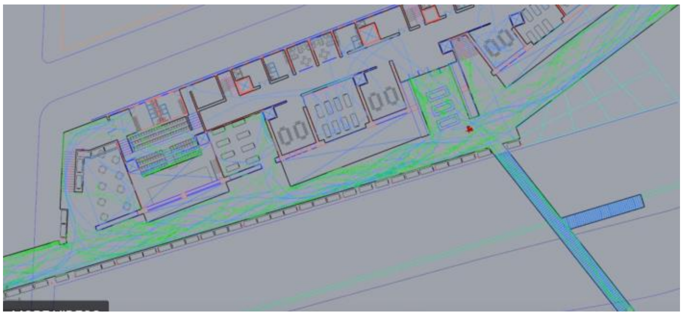


Figure 22: Quelea agent-based modelling (b)

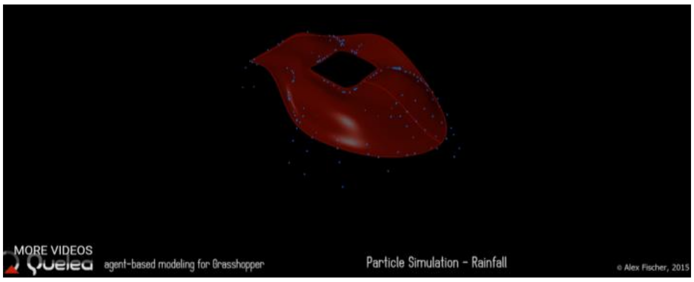



Figure 23: Quelea agent-based modelling (c)

### 3.3.2.2 **PedSim**

Pedsim is specialized in pedestrian simulation only. It mimics human moving behaviour in two-dimensional plan. It works by defining the starting and the ending points. Attraction points can be placed in the way, and if it came in the viewing field the people will move towards it. After finishing from the attraction, they will go back to the original path towards the exit point.

Figure 24: Pedsim simulation software

Ped-sim was used, by the developer, to compare two supermarkets layouts to study the time consumed in the shopping area. The first one with straight line and the second is not straight, as shown in below images.

The present values were as following: 50 percent of customers coming from left side and the other 50 percent from the right side. The 50 percent were divided into two categories, the one that having shopping behaviour and welling to stop and the other are the opposite i.e. they are not willing to buy. 15 percent of the 50 are willing to buy, while the remaining 35 are not interested i.e. they are just pedestrians forming the crowd.

The results were that the straight-line layout forced the shoppers to spend less time compared to the non-straight layout. On the other hand, the straight-line layout forced the non-shopper to spend more time compared to the non-straight layout.

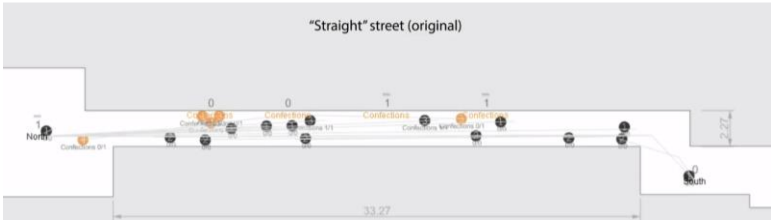



Figure 25: Pedsim straight line scenario


Figure 26: Pedsim not straight-line scenario


Figure 27: Pedsim results

The developer used the plugin to study another scenario, where he placed target in the pedestrian walkway/ route. Those targets attract the humans if the fall in their vision field.

The parameters were as following: two types of people, the first are interested in restaurants and the second in supermarket. He placed more than one restaurant and grocery in the layout, however, the people will go to the first one they see.

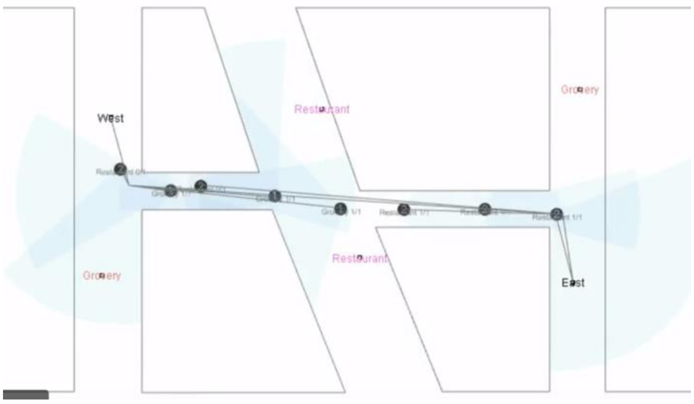



Figure 28: Pedsim simulation example 2a

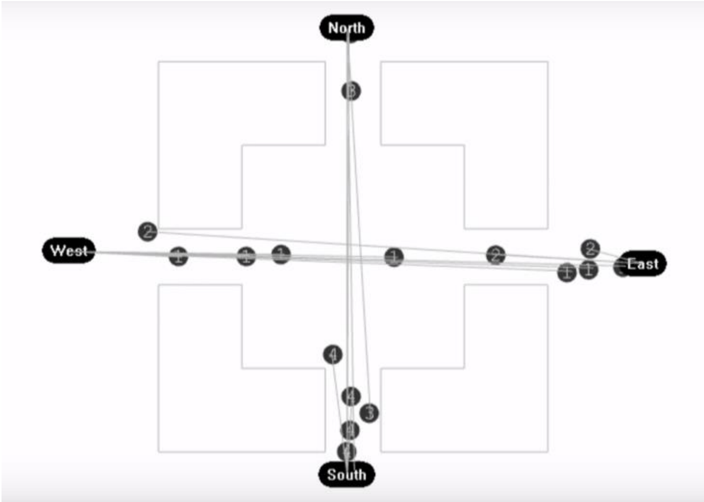



Figure 29: Pedsim simulation example 2b

Agents avoiding others

Sollazzo et al. (2018) in their research stated that the answer for some architectural problem can be done through ‘Dynamic space configuration’. Which means that the space is designed based on advanced level of analysis such as the sunlight, visibility and pedestrian movement in the space. For the pedestrian movement the researchers used pedsim software, by placing attracting forces for agents inside the space, specifying the running time, the pedestrian walkway lines and the level of engagement in the space (such as exhibitions) and the results include locations of entrance/ exit doors and the location of location of the forces.

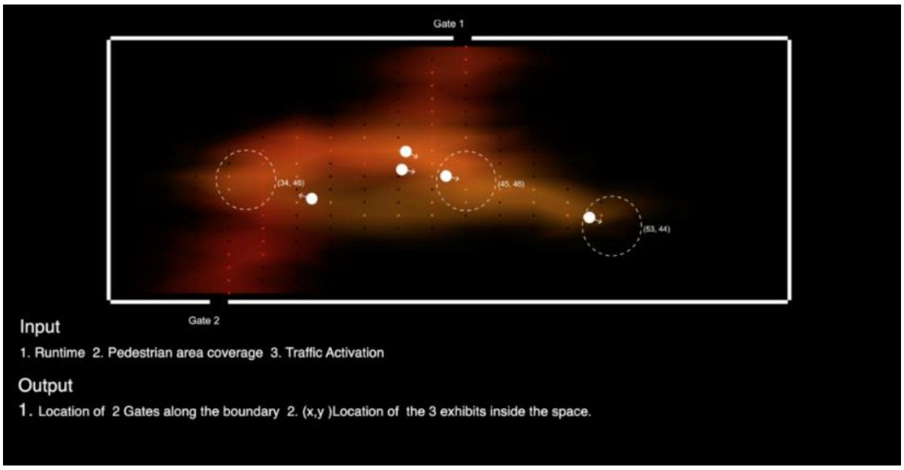



Figure 30: pedsim simulation example 3a

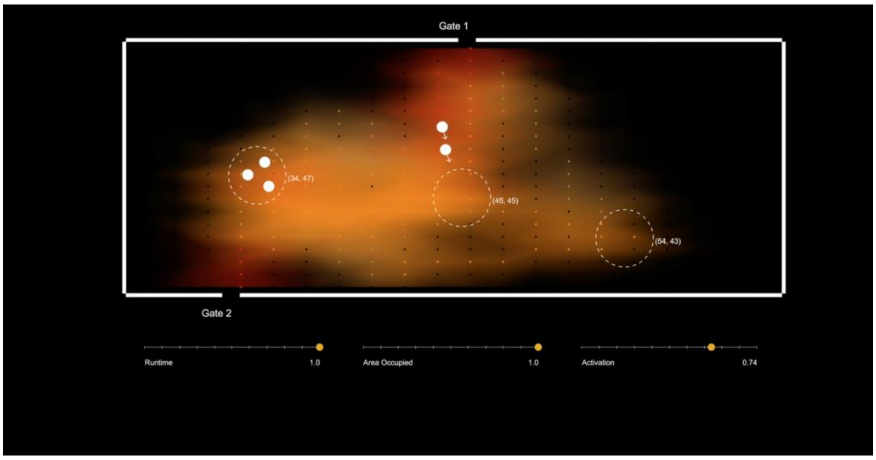



Figure 31: pedsim simulation example 3b

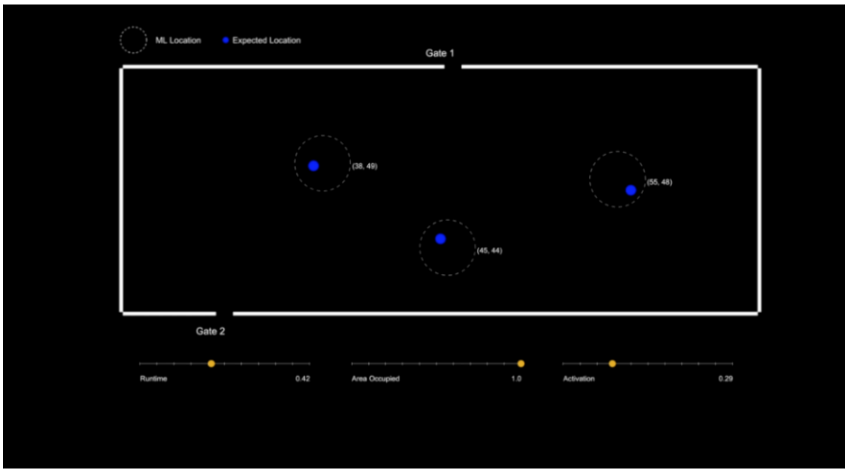



Figure 32: pedsim simulation example 3c

### 3.3.2.3 **Simwalk:**

SimWalk is crowd simulation software, an agent-based modelling software that mimics human behaviour in public areas. It was used to study the crowd in airports, railways and shopping mall. The cost of the software ranges from 6500 dollars to 22,500 dollars.

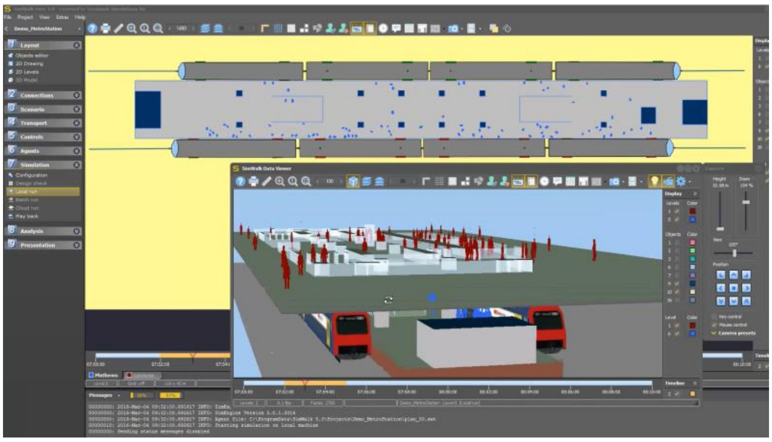


Figure 33: Simwalk simulation

3.3.2.4 **Mass-motion:**

It a crowd simulation software, were it create models, simulate crowd movements and analyse the model elements. It mainly visualizes the crowd flow. It is used for public areas, such as airports, stadiums, and shopping malls.

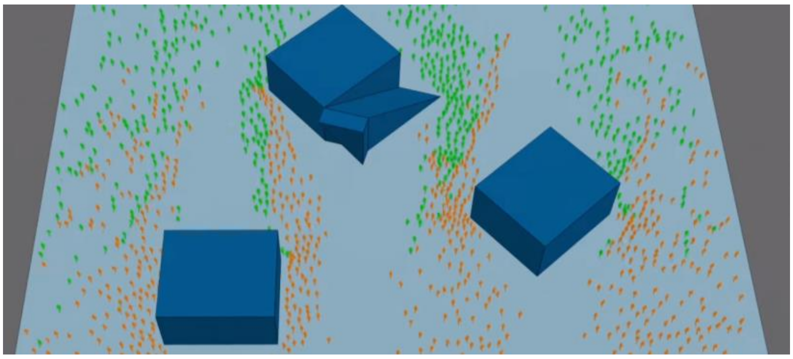


Figure 34: Massmotion simulation a

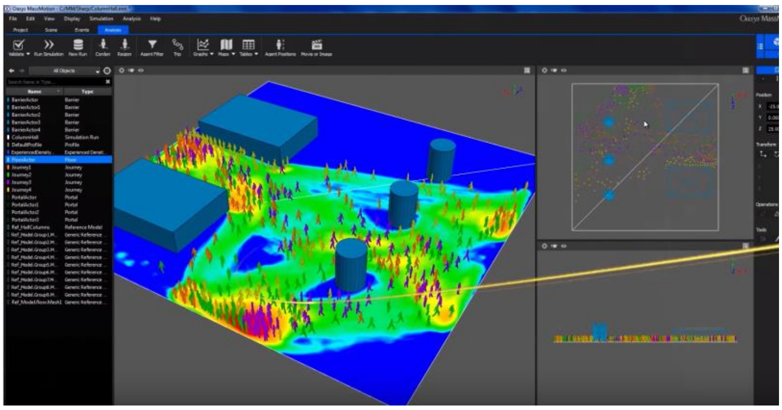


Figure 35: Massmotion simulation b

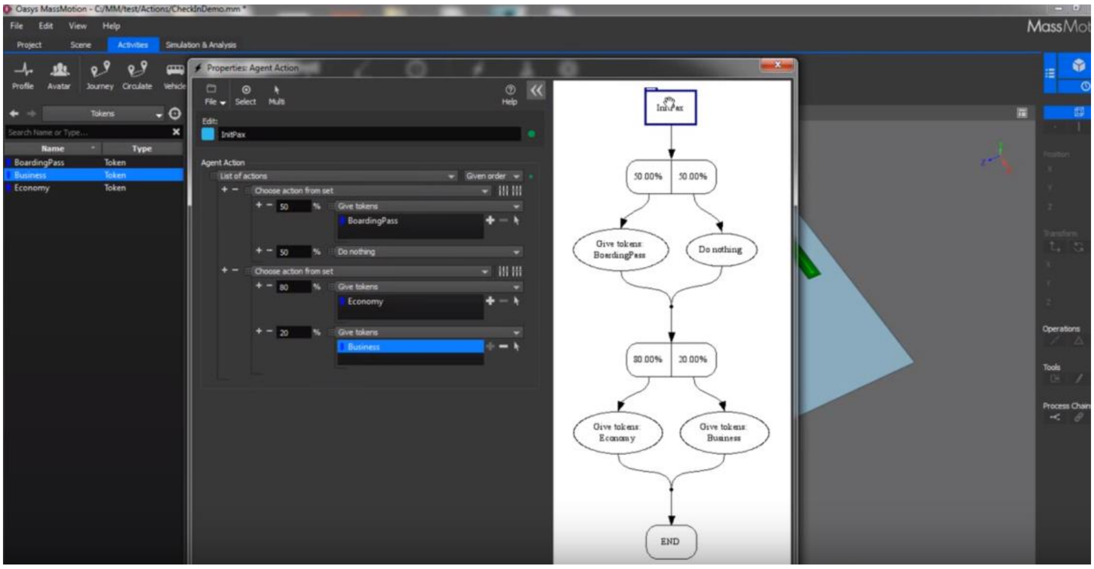



Figure 36: Massmotion simulation c

The program works, by either directly modelling the environment using mass motion, or importing the model from other software, such as Revit, Rhinoceros or AutoCAD, however, after importing the model needs configuration. The second step, is the analysis parameters step, were we create a logic for the crowd, for example: 80 percent of them will do specific behaviour while the other will do another behaviour; this step includes the time needed for each action. Then, the software will simulate the people, and it can show the crowded areas that need re-designing. The software can show how many people and their classification.

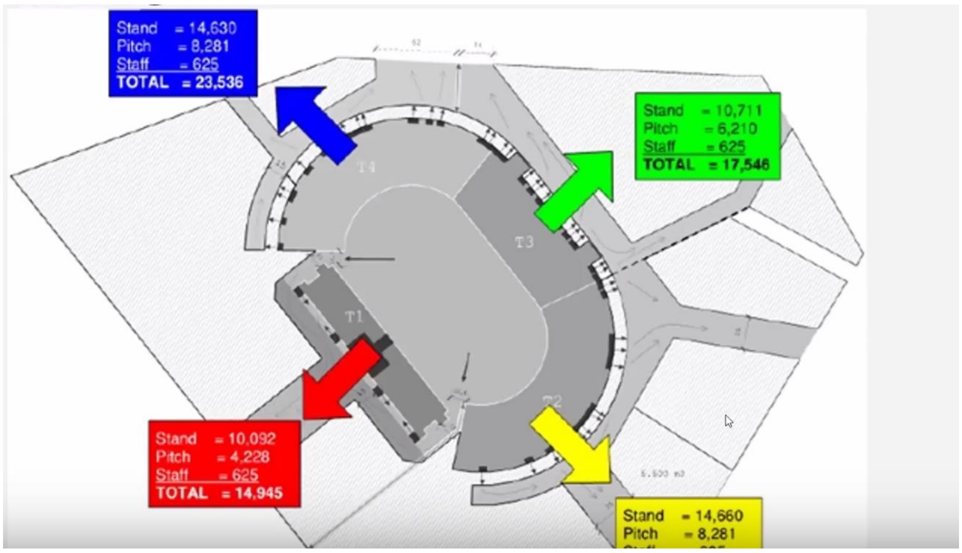



Figure 37: Massmotion simulation d

### 3.3.3 Software evaluation

The selection of software was done according to Table 2.

Table 2: software selection criteria

| No. | Criteria | Quelea | Ped-sim | Sim-walk | Mass-motion |
|---|---|---|---|---|---|
| 1 | The ability of the software on mimicking human behaviours | no | yes | yes | yes |
| 2 | Avoiding other humans | no | yes | yes | yes |
| 3 | Avoiding the physical barriers. | no | yes | yes | yes |
| 4 | Get attracted to forces. | no | yes | yes | yes |
| 5 | The easiness of using the software. | easy | Not easy | Not easy | easy |
| 6 | The ability of simulating multiple agents. | yes | yes | yes | yes |
| 7 | The ability of software to define logic | no | no | yes | yes |
| 8 | The software overall performance. | acceptable | good | good | perfect |
| 9 | The cost of the software. | free | free | 6500 Dollars | 2400 Dollars |
| 10 | Was it used for grocery, supermarkets or malls before? | no | yes | yes | yes |
| 11 | The ability of software to provide density maps and crowding analysis | Not acceptable | good | Very good | excellent |
| 12 | Availability of tutorials and references | no | no | no | yes |

### 3.3.4 Software selection

From the evaluation in Table 2, we decided to use mass-motion software for crowd simulation part of our research, since it is an excellent software to provide densities and crowd analysis, in addition it can mimic the human behaviour by defining the logic to match the function of the space.

# Chapter 4:

# Modelling and simulation set-up

# Chapter 4 Modelling and simulation set up:

## 4.1 The variables:

Table 3 shows variables of the project, illustrating which ones are fixed and which unfixed. The fixed variables are defined at which point they are fixed. The dependent and independent section shows if the variable is dependent on other variables or not.

Table 3: the model variables

| The variable | (dependent/ independent) | Status (fixed/ unfixed) | values | Reason/ remarks |
|---|---|---|---|---|
| No. of people visiting the supermarket | | Fixed | 1000 and 2000 shoppers per day | The actual no. of shopper visiting the store per day is 1000 and 2000 shoppers per day. |
| Crowding level | Depended | unfixed | | Its results vary, depending on the layout effect on crowd level |
| Isle width | independent | unfixed | 1.3 - 1.8 - 2.3 - 2.8-3.0- 3.5- 3- 3.5- 3.5- 4.0 - 4.3- 4.6- 5.1 meters | Adding 0.5 meter |
| No. of Isles | | fixed | 14 isles | Based on actual supermarket |
| Isle length | Independent | fixed | | Based on actual supermarket |
| Shelves height | independent | fixed | 1.8 meter | Because we are focusing on circulation and crowd layout, while this number is the standard dimension of the height of the unit |
| Shelves orientation/ angle | Independent | fixed | 90 degrees | |
| Corridor location | independent | fixed | Matching actual | |
| Customer path | dependent | unfixed | | Depends on items location |
| Entrance location | dependent | fixed | On the left side | Depends on exit location |
| Exit location | dependent | Fixed | On the right side | Depends on entrance location |
| No. of exit counters | independent | Fixed | 6 Nos. | Based on actual conditions |
| Layout dimension | dependent | unfixed | | Depends on isles width. |

### 4.2 The Process:

The chosen research that we built our study on, are chosen to the availability of the following information: the section names (such as, drinks, meat, vegetables and fruits sections), the availability of paths data, and the type of shoppers and the counts for each type.

We started by modelling the supermarket physical environment, where we dividend it by sections matching the actual, i.e. the same aisles' length and width. We installed standard shelves dimensions, 45 depth x 90 length x 180 cm height.

Then, we modelled the actual shoppers' paths in the supermarket. The types of shoppers' paths are 4 types according to Sano et al. (2016) research, which we based our research on. The first type circulates in the outer perimeter areas. The second type circulates in the inner area, the left side. The third type partially circulates in the perimeter area. And the last type circulates in the inner areas. Table 4 summarizes the four paths. The total number of paths were approximately 4750 paths.

Table 4: path types according to circulation

| **Sequence** | **Path 1 (75.2% of total no. of shoppers)** | **Path 2 (7.5% of total no. of shoppers)** | **Path 3 (10% of total no. of shoppers)** | **Path 4 (6.5% of total no. of shoppers)** |
|---|---|---|---|---|
| **1** | Vegetables and fruits | Vegetables and fruits | Vegetables and fruits | Vegetables and fruits |
| **2** | Sea food | Household | Sea food | Household |
| **3** | Household | Vegetables and fruits | Household | Central isle |
| **4** | General food | Central isle | Frozen items | General food |
| **5** | Frozen items | Household | Central isle | Central isle |
| **6** | Central isle | General food | Sweets and snacks | Sweets and snacks |
| **7** | drinks | Central isle | Checkout | Checkout |
| **8** | Drinks2 | Sweets and snacks | | |
| **9** | Sweets and snacks | Checkout | | |
| **10** | Checkout | | | |

After that we added servers on each item in the store, these servers are the places were the shopper will choose the item and put it in the cart. And according to the researches, the process of choosing items will take approximately 22 seconds (Lindberg et al. 2013), hence, we used this period in our logic as a delaying period in each server.

The research stated the time spent in each section of the store. Accordingly, we specified for the shopper the time to be spent in each section. By moving from server to server in the section to reach the actual time spent. We calculated the time spent in each section by multiplying the percentage of the spent time in each section by the total trip duration. For example, if the total trip is 15 minutes, as specified in Sano et al. (2016) research, and the time spent in the vegetable section is 20 percent, which means, the time spent in vegetable section is 3 minutes. The number of servers visited were calculated by dividing the time spent in each section on 22 seconds. Then, the instruction was given to the shoppers to visit the section for the resulted number before moving to the next section. From the example above, if the time spent in vegetable section is 3 minutes, dividing the 3 minutes on 22 seconds, which will result in approximately 8 items or servers.

In the simulation, the shoppers do not follow the exact paths drawn by observational methodology in Sano et al. (2016) research, but have the same path logic, such as visiting the vegetable section at the beginning then moving to the sea-food section, while keeping the meet and frozen items to the last, to keep them, as much as possible, cold and frozen before reaching home, to avoid food contamination.

### 4.3 The study period setup

When starting the simulation, the shopper will start entering the supermarket in very low quantities, and the population at that time is very low. Then, the population starts to build-up and the no. of shoppers is increasing, to reach to a point where it is not increasing more, this point is the beginning of the study period. The model is mature at this point. And it stays at the peak till the point where the no. of shoppers, entering the supermarket, starts to drop, and this point is the end of the study period, after this period, the post study period, the population decreases till it reaches zero. The dotted red line in Figure 38 shows the study period. We defined the study period as 6 hours, from 12:00 PM to 6:00 PM.

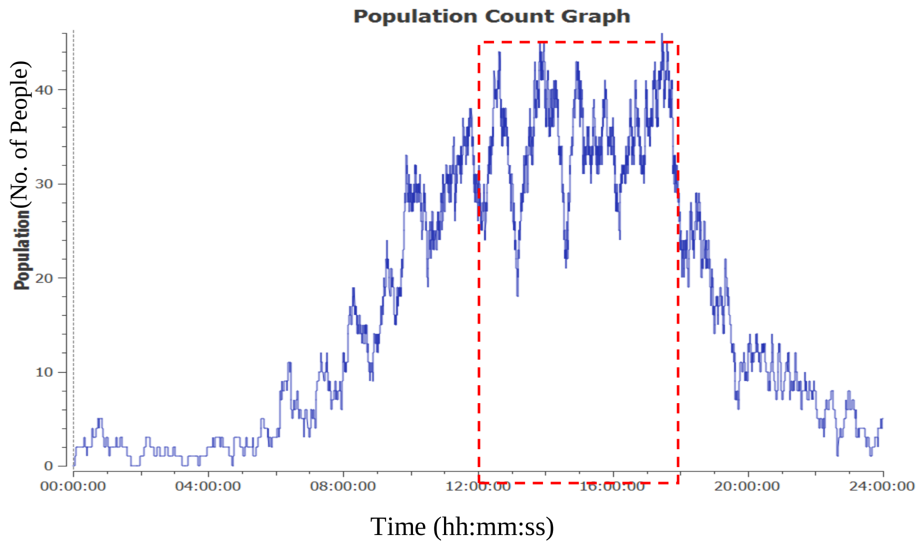



Figure 38: study period for population (no. of people) vs. time of the day (hh:mm:ss)

### 4.4 Shoppers Count

Based on many researches, the number of people visiting the store per day ranges from 600 to 1000 customers per day (Cosmas Jaravaza and Chitando, 2019) (Guthrie et al. 2006). In our model, we set the number of shoppers entering the simulation to 1000 shoppers at the first set of results, then we increase it to 2000 shoppers per day to reflect the peak days, these numbers are distributed on 24 hours with weights, the weights reflect the number of people at each hour, and the simulation duration is 24 hours.

The model population started to increase gradually in the first hour, and when the time reached 12:00 hours, the model entered the study period, and it stayed in this period till the completion of 6 hours. After 18:00 hours, the population decreased till it reached zero. The graph below summarizes the population over the time.

According to previous studies done by SKYHOOK (2019), shown in Figure 39, the peak hours are from 7:00 hours to 19:00 hours. We used this graph to control the number of shoppers according to time, weight for the time were added to mimic the actual conditions, as shown in Table 5. Number of shoppers were modified to 1000 shoppers per day as stated by Cosmas Jaravaza and Chitando, (2019) and Guthrie et al. (2006), and the simulation duration increased to 24 hours instead of 6 hours. We used Walmart supermarket as a reference, but we considered that it closes from 12:00 AM to 6:00 AM.

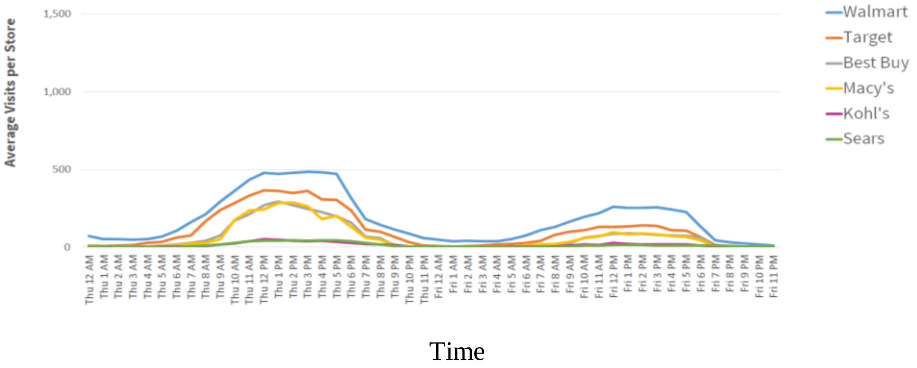



Figure 39: average visits per store vs. time of the day, source: SKYHOOK (2019)

Table 5: supermarket visits' weight per hour

| Start time | duration | Weight |
|---|---|---|
| 00:00:00 | 1 Hour | 0 |
| 01:00:00 | 1 Hour | 0 |
| 02:00:00 | 1 Hour | 0 |
| 03:00:00 | 1 Hour | 0 |
| 04:00:00 | 1 Hour | 0 |
| 05:00:00 | 1 Hour | 0 |
| 06:00:00 | 1 Hour | 50 |
| 07:00:00 | 1 Hour | 100 |
| 08:00:00 | 1 Hour | 150 |
| 09:00:00 | 1 Hour | 350 |
| 10:00:00 | 1 Hour | 400 |
| 11:00:00 | 1 Hour | 450 |
| 12:00:00 | 1 Hour | 500 |
| 13:00:00 | 1 Hour | 500 |
| 14:00:00 | 1 Hour | 500 |
| 15:00:00 | 1 Hour | 500 |
| 16:00:00 | 1 Hour | 500 |
| 17:00:00 | 1 Hour | 500 |
| 18:00:00 | 1 Hour | 350 |
| 19:00:00 | 1 Hour | 200 |
| 20:00:00 | 1 Hour | 162 |
| 21:00:00 | 1 Hour | 125 |
| 22:00:00 | 1 Hour | 87 |
| 23:00:00 | 1 Hour | 50 |

### 4.5 The simulation measures

The analysis of the software produces diagrams, plans and schedules. And these are the results of the simulation. The graphs include the following: shoppers' density, population and flow counts. The plans show the shoppers count, path, time to exit, Average LOS (t), experienced LOS (t), instantaneous density and maximum LOS. While the schedules produce shoppers time, trip time and social cost.

The population graph shows the number of shoppers at each minute, which depends on the number of people entering the simulation minus the number of people exiting. The agent flow count chart shows the number of people passing through a point. The higher number of people pass through the point, the higher flow count. The density graph shows different densities in the simulation with reference to time. In other words, it shows the densities at each specified time.

The density is calculated by dividing the number of persons by the area; the area is considered as circles, and the area of these circles differs depending on the behaviour, for example, the walking circle area equals to 3.24 square meter, waiting area equals to 2.7 square meter, while queuing area equals to 1.21 square meter, these areas are assumptions in the Massmotion software.

#### 4.5.1 The social cost measure:

The shoppers' social cost is a way to measure the efforts made by shoppers, such as standing congestion, walking or waiting in a queue. The cost is calculated according to the business case development manual, transport of London. The costs are calculated in UK Pounds; hence the cost is calculated by pounds per hour. The TfL (Transport for London) calculated the Value of Time according to the Transport analysis guidance, where it used the country GDP (Transport Analysis Guidance 2019). The total social cost is the sum of total journey cost and total congestion cost, as shown in Equation 2. Table 6 shows that the congestion cost is 7 Pounds per hour. However, the walking weight equals to 2.0, hence the walking journey cost factor equals to 14.7 pounds per hour. The server queue weight equals to 3.5, hence the server queue cost equals to 25.07 pounds per hour. However, the server process multiplier equals to 2.5, the server queue cost equals to 18.4 pounds per hour (Transport for London 2019). The total journey time is defined as the sum of all journeys time for all agents during the simulation period.

Equation 2: total social cost equation (pounds)

Total social cost (pounds)= congestion cost (pounds)+ journey cost (pounds)

Table 6: the cost and weight for congestion, walking, server queue and server process.

| Name | Weight (factor) | Cost (pounds per hour) |
|---|---|---|
| Congestion | 1.0 | 7.3 |
| walking | 2.0 | 14.7 |
| Server queue | 3.4 | 25.1 |
| Server process | 2.5 | 18.5 |

According to mass-motion developers, the congestion factor is calculated depending on the density, which is the number of shoppers in 1 square meter. The congestion factor is calculated according to Table 7.

Table 7: congestion factor for walking and waiting according to density

| Density (people/ square meter) | Congestion factor walking | Congestion factor waiting |
|---|---|---|
| Density <= 0.5 | 0.0 | 0.0 |
| 0.5 < density < 2 | 0.5 x 0.667 x (density – 0.5) ^2 | 0.667 x (density – 0.5) ^2 |
| Density >= 2 | 0.5 x 1.5 = 0.75 | 1.5 |

### 4.5.2 Level of service measure:

LOS is a shortcut for Level of Service, which is reflected in a mapping colour system, it is the relation between the number of persons flow per minute per square feet (volume) and the space available for each person. The colour ranges from blue to red, where blue is not dense and red is very dense. The LOS system was developed by Fruin (1971) to evaluate the volume/capacity ratio. The system consist of six levels ranges from level A to level F.

LOS A equals to 3.24 and above square meters for each person, in the same time, it equals to 0.309 persons per square meter, the pedestrians can move freely without any obstacles and they can choose steps width and speed. LOS B ranges from 3.23 to 2.32 square meters for each person, in this case, the density will range from 0.308 to 0.431 persons per square meters, and the pedestrian will have a little difficulty with others. LOS C ranges from 2.31 to 1.39 square meters for each person, the density from 0.430 to 0.719, passing other pedestrians is not possible. LOS D ranges from 1.38 to 0.93 and the density from 0.718 to 1.075 persons per square meter, in this situation, the other pedestrian will affect the walking and it is considered crowded. LOS E ranges from 0.92 to 0.46 square meters for each person and the density from 1.075 to 2.174 persons per square meter, walking in the opposite direction is impossible and it is considered extremely crowded. LOS F equals to below 0.46 square meters for each person, the pedestrians don't have any control in the situation.

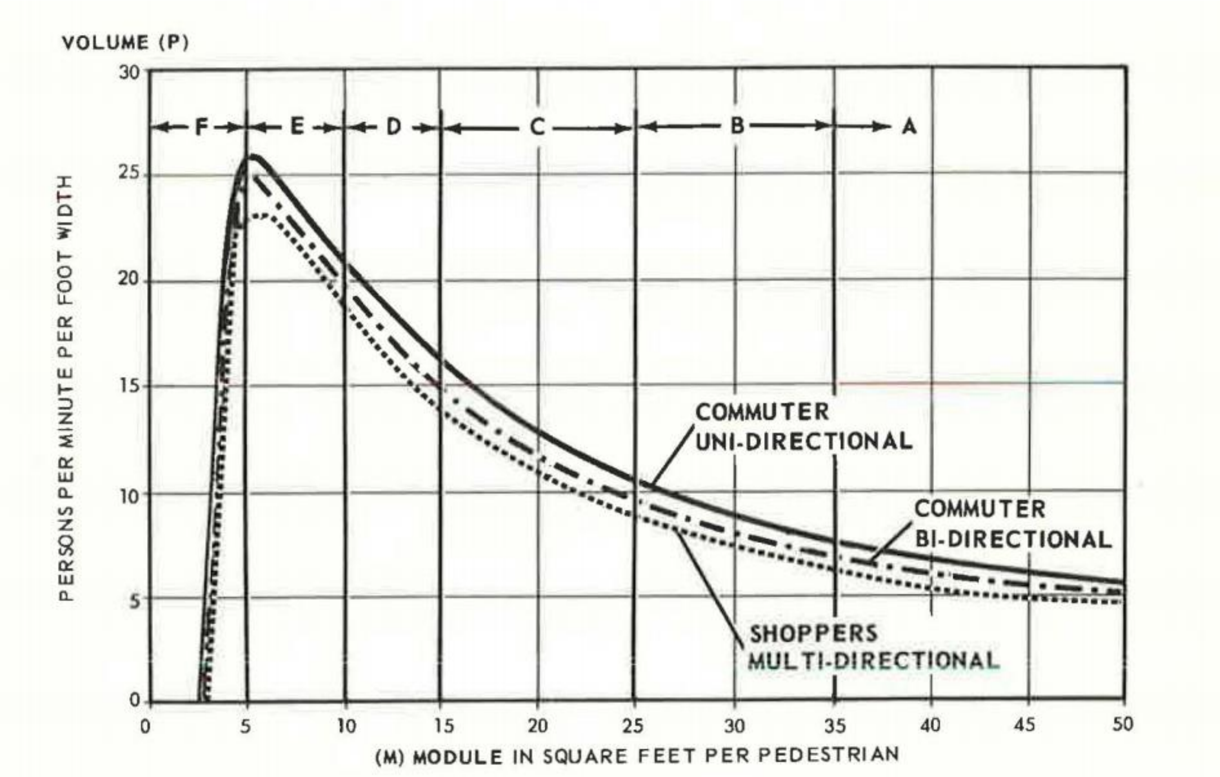



Figure 40: LOS ranges, source: Fruin (1971)

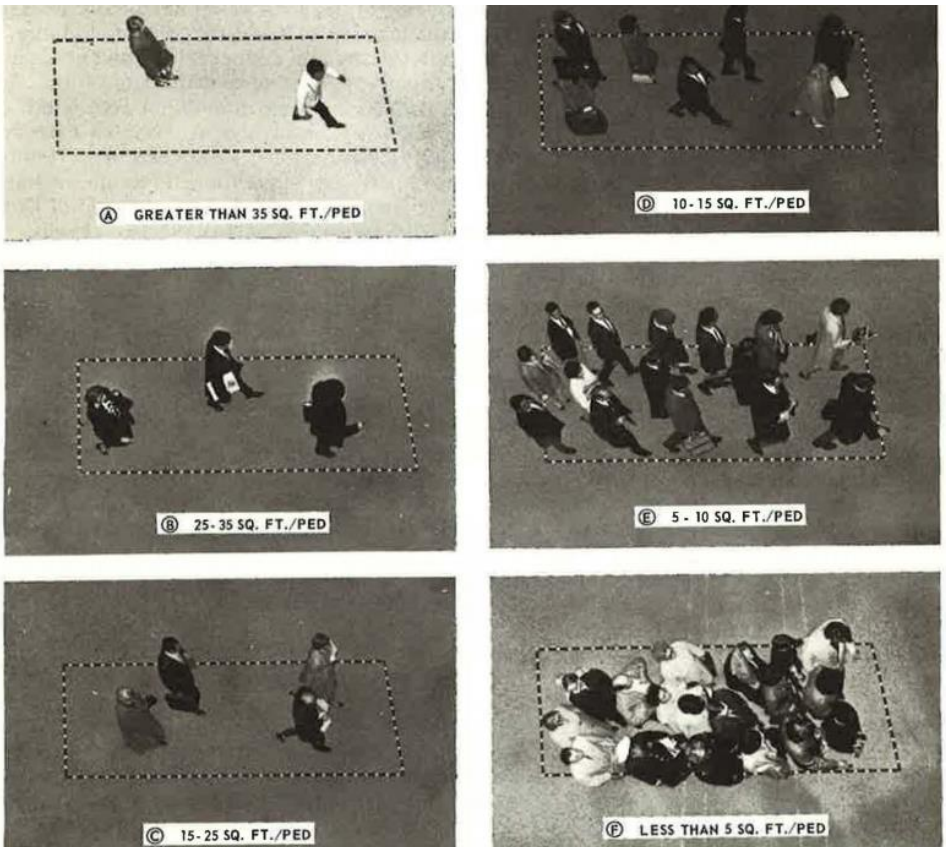



Figure 41: LOS examples, source: Fruin (1971)

Table 8 is LOS for walking, while Table 9 is for queuing

Table 8: LOS for walking

| LOS | Density (person/$m^2$) | Space ($m^2$/person) | Colour |
|---|---|---|---|
| A | Density <= 0.309 | Space >= 3.24 | |
| B | 0.309 < Density<= 0.431 | 3.24 > Space >= 2.32 | |
| C | 0.431 < Density <= 0.719 | 2.32 > Space >= 1.39 | |
| D | 0.719 < Density <= 1.075 | 1.39 > Space >= 0.93 | |
| E | 1.075 < Density <= 2.174 | 0.93 > Space >= 0.46 | |
| F | 2.174 < Density | 0.46 > Space | |

Table 9: LOS for queuing

| LOS | Density (person/$m^2$) | Space ($m^2$/person) | Colour |
|---|---|---|---|
| A | Density <= 0.826 | Space >= 1.21 | |
| B | 0.826 < Density <= 1.075 | 1.21 > Space >= 0.93 | |
| C | 1.075 < Density <= 1.538 | 0.93 > Space >= 0.65 | |
| D | 1.538 < Density <= 3.571 | 0.65 > Space >= 0.28 | |
| E | 3.571 < Density <= 5.263 | 0.28 > Space >= 0.19 | |
| F | 5.263 < Density | 0.19 > Space | |

### 4.5.3 The average LOS (*t*) measure:

It is a plan that calculates and shows the average crowding density as level of service, at each point in the plan for the specified simulation period, i.e. it is the sum of all densities in the specified simulation period at a certain point in the plan, divided by the simulation period. The collection of all the point makes the average LOS (t) plan. It is calculated through Equation 3:

Equation 3: average LOS (t)

$$\text{Average LOS } (t) = \frac{\sum_{n=1}^{t} density(n)}{t}$$

LOS: Level of Service at a certain point in the plan

t: simulation period

n: simulation frame (ex. Seconds or minutes)

The average LOS (t) plan also shows the most crowded areas in the supermarket on average. The density, in the equation is calculated by dividing the number of people over the area; the area equals to 3.25 square meter and the shape of it is circle. The average LOS (t) was used in other researches, such as the research done in Saudi Arabia for the prophet Mohammad mosque (Alshehri et al. 2015)

### 4.5.4 The experienced LOS (*t*) measure:

The experienced LOS (*t*), for each point in the plan, is calculated through squaring the density level at each simulation frame, the summing all the values, after that dividing the result by the sum of all densities at that point for the specified simulation period.

The benefit of the experienced LOS (*t*) plan, it shows the areas of crowding, instead of smoothing the values, such as the case in the average LOS (t) plan. The square root in the equation signifies the crowded areas. The density, in the equation is calculated by dividing the number of people over the area; the area equals to 3.25 square meter and the shape of it is circle. It is calculated through Equation 4:

Equation 4: experienced LOS (t)

$$\text{Experienced LOS } (t) = \frac{\sum_{n=1}^{t} density(n)^2}{\sum_{n=1}^{t} density(n)}$$

LOS: Level of Service at a certain point in the plan

t: simulation period

n: simulation frame (ex. Seconds or minutes)

### 4.5.5 The maximum LOS measure:

The maximum LOS is the maximum LOS the area had reached during all the specified period, i.e. the study period. The colours reflect the LOSs, red is the highest, which is LOS F and the blue is the lowest, which is LOS A. There is in between: LOS B (cyan colour), LOS C (green colour), LOS D (yellow colour), LOS E (orange colour), all arranged in alphabetical order from lowest to highest.

## 4.6 Implications:

We are going to do the simulation by first proposing the several store dimension, setting up the simulation, such as the duration of the simulation, specifying the no. of shoppers, which is the 1000 and 2000 shoppers per day, run the simulation, exporting the results/ measures for the study period only from 12:00 PM to 6:00 PM.

The total social cost, journey cost and congestion cost will be used to evaluate the crowding levels in the supermarket, while increasing and decreasing the area. We will study the average no. of people falling in each LOS, i.e. LOS A, B, C, D, E and F, during the study period, to double track and evaluate the increase and decrease in them and in crowding levels. The average, experience and maximum LOS maps will be used to locate the areas of crowding and to watch the increase and decrease of crowding in these areas.

# Chapter 5:

# Results

# Chapter 5 Results

In this section, a total of fourteen scenarios were made, with different space dimensions and areas, some of them are smaller than the actual supermarket, where we reduced the isle widths, while the others are larger. We will start explaining the results when using 1000 shoppers per day, next, we will explain the results when using 2000 shoppers per day. We took the average, experienced and maximum LOS maps, in addition to the average no. of shoppers in LOS, journey cost, congestion cost and social cost, for each scenario. The results are taken during the study period, which was defined earlier in the previous chapter.

## 5.1 1000 shoppers per day

### 5.1.1 The first scenario:

This scenario is the lowest in area and dimensions, all isles are set to 1.3 meters width, including the fresh produce, seafood, frozen items sections. Table 10 shows the scenario dimensions and total area. The total area equals to 1254.3 square meters.

Table 10: first scenario dimensions

| Isle name | Dimension |
|---|---|
| Northern isle | 2.5 m |
| Mid isle | 1.3 m |
| Southern isle | 2.0 m |
| Central isles (total 12 isles) | 1.3 m |
| Sixth isle of general items and drinks 2 (total 2 isles) | 1.3 m |
| Eastern isles (total 4 isles) | 1.3 m |
| Western isles (total 4 isles) | 1.3 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 33.9 m |
| Total width | 37.0 m |
| Total area. | 1254.3 square meters |

#### 5.1.1.1 Shoppers' social cost:

The total social cost for this scenario reached 4314 pounds per study period, which is for 6 hours from 12:00 PM to 6:00 PM, as shown in Table 11, while the congestion cost equals to 54 pounds per study period, and the total journey cost equals to 4259 pounds per study period.

Table 11: first Scenario social cost for all agents during the study period (study period: 6 hours, from 12:00 PM to 6:00PM)

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 78:45:04 | 157:30:08 | 7:26:48 | 1162 | 54 | 1217 |
| Server Queue | 15:33:27 | 52:53:45 | 0:00:00 | 390 | 0 | 390 |
| Server Process | 146:42:38 | 366:46:36 | 0:00:00 | 2706 | 0 | 2706 |
| Total | 241:01:09 | 577:10:28 | 7:26:48 | 4259 | 54 | 4314 |

### 5.1.1.2 **Average LOS (t)**

In Figure 42, we can notice a small quantity of LOS B in the fresh produce area, while the remaining areas has LOS A.

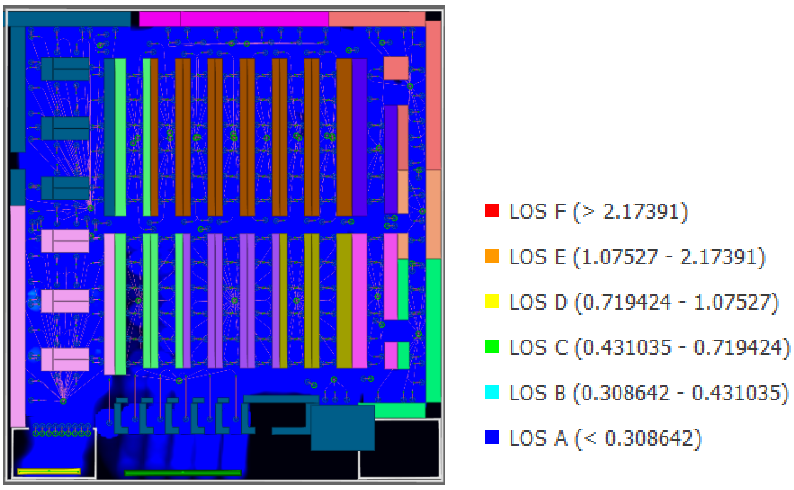



Figure 42: first scenario average LOS (t) map

### 5.1.1.3 **Experienced LOS (t)**

Figure 43 shows that the fresh produce area has LOS B, C and D, while the seafood area has LOS B and C, the sixth isle of general items has LOS C, the pre-prepared area has LOS B and C and the remaining areas ranges from LOS A to LOS B.

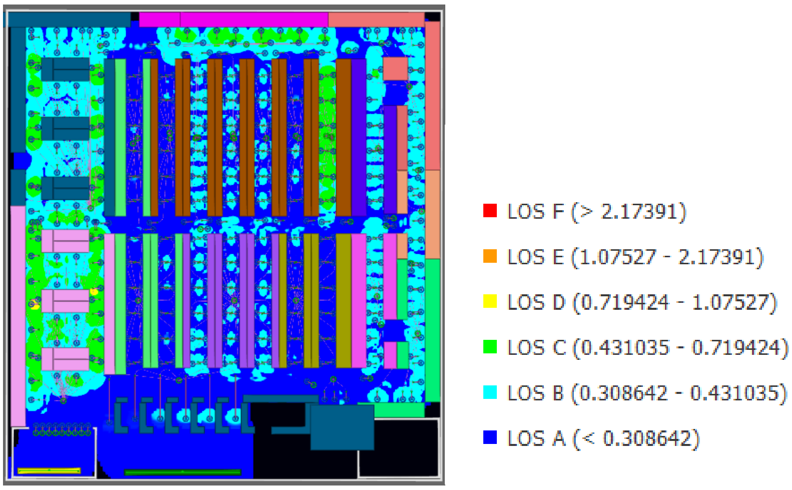



Figure 43: first scenario experienced LOS (t) map

#### 5.1.1.4 **Maximum LOS**

From Figure 44, we can notice that LOS F appeared in two locations in the fresh produce and in the sixth isle of general items areas. While the seafood, frozen items, meat and pre-prepared food areas reached LOS E, the remaining areas ranged from LOS A to LOS D.

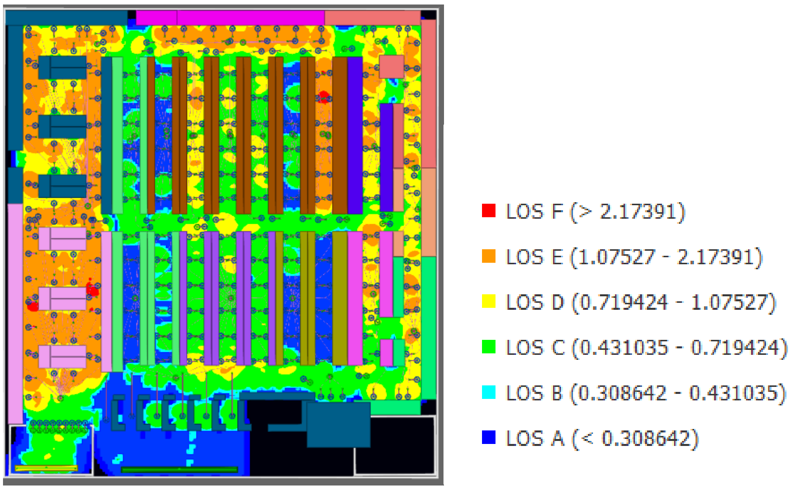



Figure 44: first scenario maximum LOS map

#### 5.1.1.5 **Shopper density graph**

Figure 45 shows LOS F in regular basis during the simulation, while LOS A is minimal, and the LOS C is the dominant colour during the study period. Table 12 shows that the average no. of shoppers falling in each LOS during the study period, where they reached 0.7 on average in LOS F and 0.4 in LOS A.

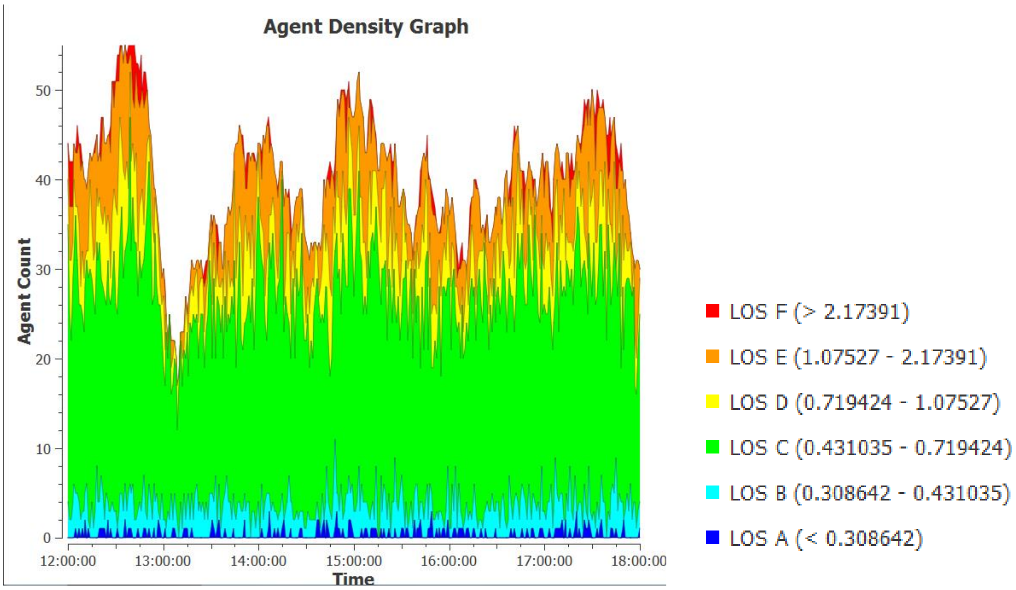



Figure 45: first scenario shoppers' densities graph

Table 12: first scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 167 | 1143 | 8540 | 2028 | 2353 | 252 |
| Average (Total shoppers/ simulation frame period) | 0.4 | 3.1 | 23.6 | 5.6 | 6.5 | 0.7 |

### 5.1.2 The second scenario:

This scenario is considered the lowest area the model can reach, since the isles width became 1.3, and if we reduced more, it will be lower than the international standards. Hence the total length reached 37.7 meters, and the total width reached 37 meters. The total area of this scenario equals to 1394.9 square meters. Table 13 illustrates the second scenario model dimensions.

Table 13: second scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 2.5 m |
| Mid isle | 1.3 m |
| Southern isle | 2.0 m |
| Central isles (total 12 isles) | 1.3 m |
| Sixth isle of general items and drinks 2 (total 2 isles) | 1.3 m |
| Eastern isles (total 4 isles) | 2.1 m |
| Western isles (total 4 isles) | 2.1 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 37.7 m |
| Total width | 37.0 m |
| Total area. | 1394.9 square meters |

#### 5.1.2.1 **Shoppers' social cost:**

The total cost, in this scenario, reached 4055.428 pounds for the 6 hours in the peak time. The congestion time equals to one hour and fifty-three minutes, and that resulted in 14 Pounds for congestion cost. The total journey time, which equals to 226 hours and nine minutes, resulted 4041 pounds per the six hours for the journey cost.

Table 14: Second Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 64:39:03 | 129:18:06 | 1:53:17 | 954 | 14 | 968 |
| Server Queue | 15:09:12 | 51:31:17 | 0:00:00 | 380 | 0 | 380 |
| Server Process | 146:43:18 | 366:48:16 | 0:00:00 | 2707 | 0 | 2707 |
| Total | 226:31:34 | 547:37:40 | 1:53:17 | 4041 | 14 | 4055 |

### 5.1.2.2 **Average LOS (t)**

Figure 46 shows the average LOS (t) of this scenario, as noticed the dominant colour in the map is blue, while very minimal isles have a combination of blue and black, such as the household isles and one isle in the general items area.

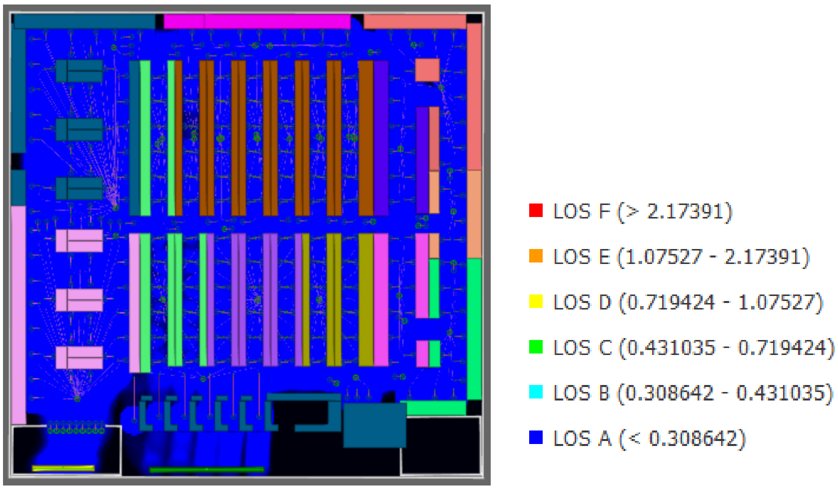



Figure 46: second scenario average LOS (t) map

### 5.1.2.3 **Experienced LOS (t)**

Figure 47 shows the experienced LOS (t) map. It shows that the blue colour covers most of the areas, while the green is in three main areas, the isle No. 6 of general items, the fresh produce area and pre-prepared food area.

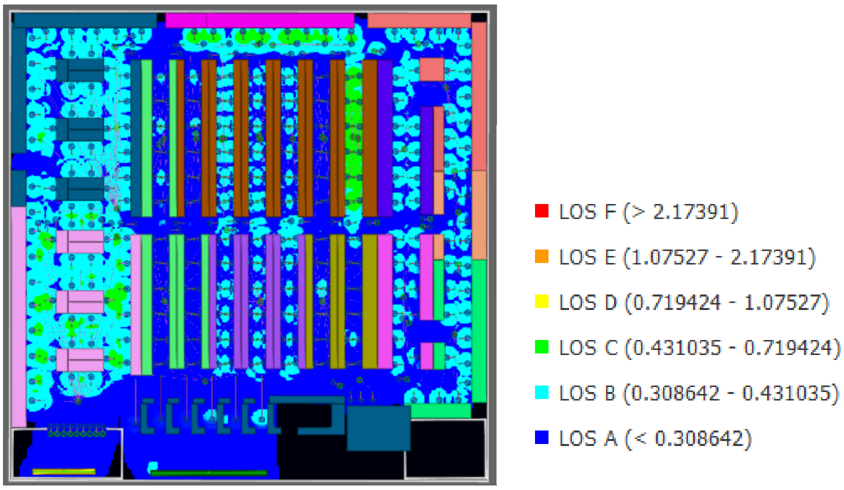



Figure 47: second scenario experienced LOS (t) map

### 5.1.2.4 **Maximum LOS**

Figure 48 shows that the LOS F appeared in the isle no. 6 of general items area only. The fresh produce, seafood, pre-prepared food and the LOS E as a dominant colour. The southern part of household items had the LOS A as dominant colour. The remaining areas ranged between LOS D and LOS C.

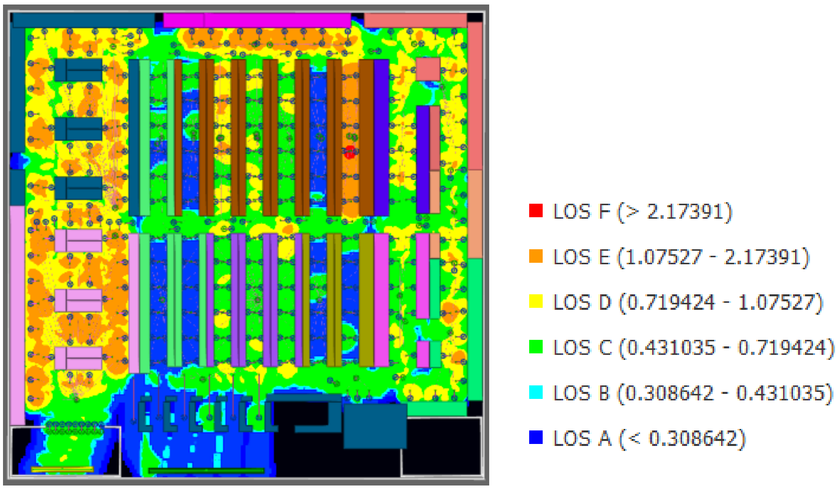



Figure 48: second scenario maximum LOS map

### 5.1.2.5 **Shopper density graph**

In Figure 49 the LOS A is very minimal. Between 12:00 to 13:00, at 14:00, at 15:15 and at 17:15 hours LOS F is appearing at the graph. The major colour is LOS C. Table 15 calculates the average LOS (t) in the last row, taken from Figure 49,

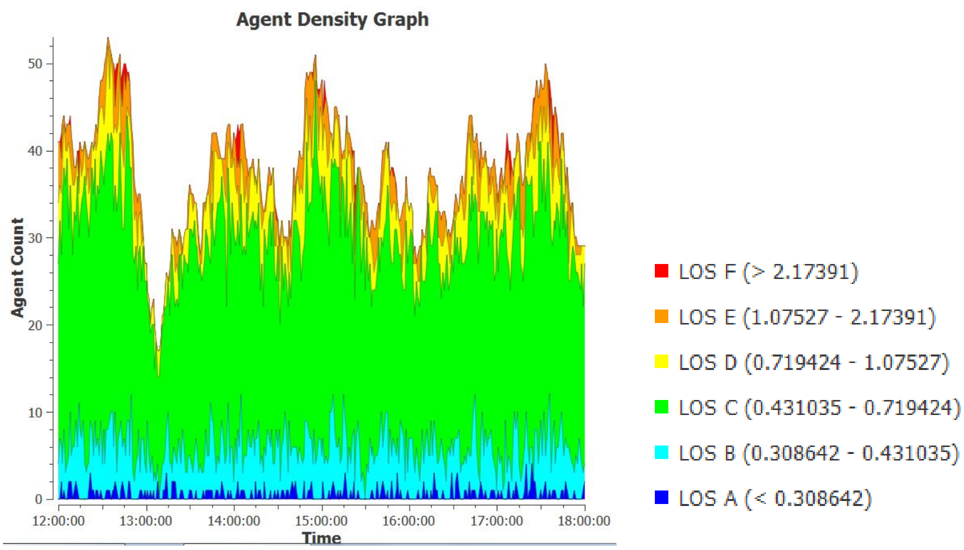



Figure 49: second scenario shoppers' densities graph

Table 15: second scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 219 | 1902 | 8828 | 1694 | 889 | 76 |
| Average (Total shoppers/ simulation frame period) | 0.6 | 5.26 | 24.45 | 4.69 | 2.46 | 0.21 |

### 5.1.3 The third scenario:

In this scenario, the north isle width equals to 3 meters, and the mid isle width is 1.8 meter. The total length is 37.7 meters, while the width is 38 meters. The total area increased 37.7 square meters, and it is 1432.6 square meters now. Table 16 summarizes the model dimensions.

Table 16: third scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 3.0 m |
| Mid isle | 1.8 m |
| Southern isle | 2.0 m |
| Central isles (total 12 isles) | 1.3 m |
| Sixth isle of general items and drinks 2 (total 2 isles) | 1.3 m |
| Eastern isles (total 4 isles) | 2.1 m |
| Western isles (total 4 isles) | 2.1 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 37.7 m |
| Total width | 38.0 m |
| Total area. | 1432.6 square meters |

#### 5.1.3.1 **Shoppers' social cost:**

Table 17 summarizes the results of this scenario, the total cost became 4050.231.the congestion time is one hour and forty-seven minutes, that resulted in a congestion cost equals to 13 pounds during the 6 hours simulation. The journey time equals to 226 hours and 23 minutes; hence, the journey cost became 4037 pounds during the six hours simulation.

Table 17: third Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 64:44:57 | 129:29:54 | 1:47:14 | 955 | 13 | 968 |
| Server Queue | 14:55:02 | 50:43:07 | 0:00:00 | 374 | 0 | 374 |
| Server Process | 146:43:23 | 366:48:28 | 0:00:00 | 2707 | 0 | 2707 |
| Total | 226:23:22 | 547:01:29 | 1:47:14 | 4037 | 13 | 4050 |

#### 5.1.3.2 **Average LOS (t):**

Figure 50 shows the average LOS (t) of this scenario, as noticed the dominant colour in the map is blue, while very minimal isles have a combination of blue and black, such as the household isles and one isle in the general items area.

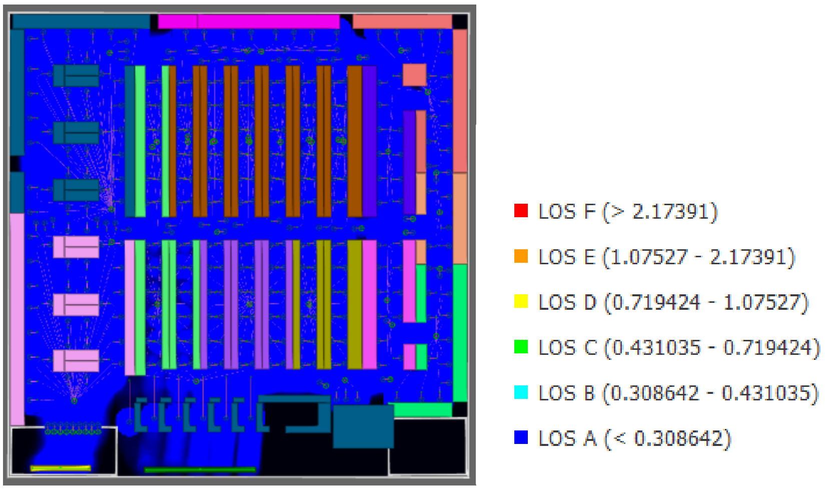



Figure 50: third scenario average LOS (t) map

### 5.1.3.3 **Experienced LOS (t):**

Figure 51 shows the experienced LOS (t) map. It shows that the blue color covers most of the areas, while the green is in three main areas, the isle No. 6 of general items (the major one), the fresh produce area and pre-prepared food area.

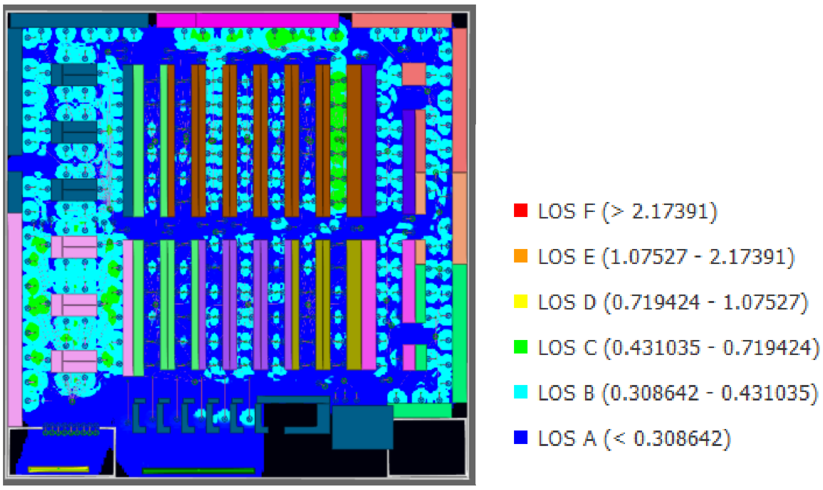



Figure 51: third scenario experienced LOS (t) map

### 5.1.3.4 **Maximum LOS:**

Figure 52 shows that the LOS F is still appearing in the isle no. 6 of general items area only. The fresh produce, seafood, pre-prepared food and the LOS E as a dominant colour. The remaining areas ranged between LOS D and LOS C, including the southern household area.

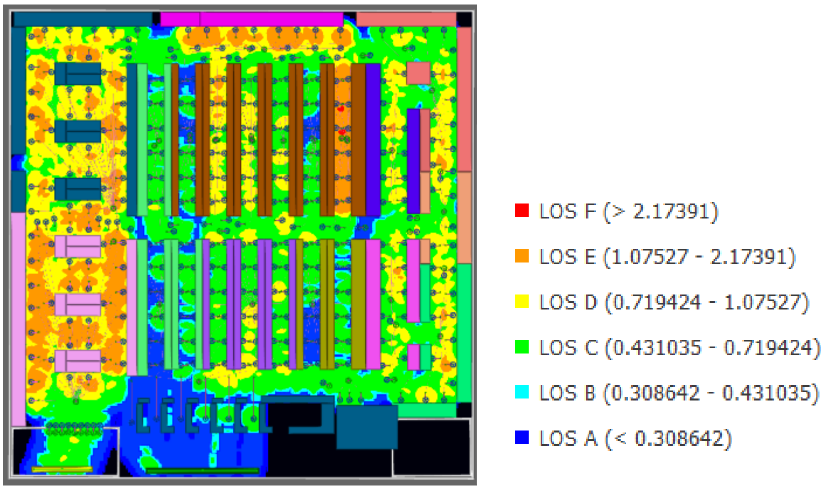



Figure 52: third scenario maximum LOS map

5.1.3.5 **Shopper density graph:**

Figure 53 shows the LOS F in two time, during the study period in the simulation, which is lower than the previous scenario. The LOS F appeared at 13:00 and at 14:00 hours. The LOS A colour increased when comparing it with the previous scenario. Table 18 convert Figure 53 into average numbers.

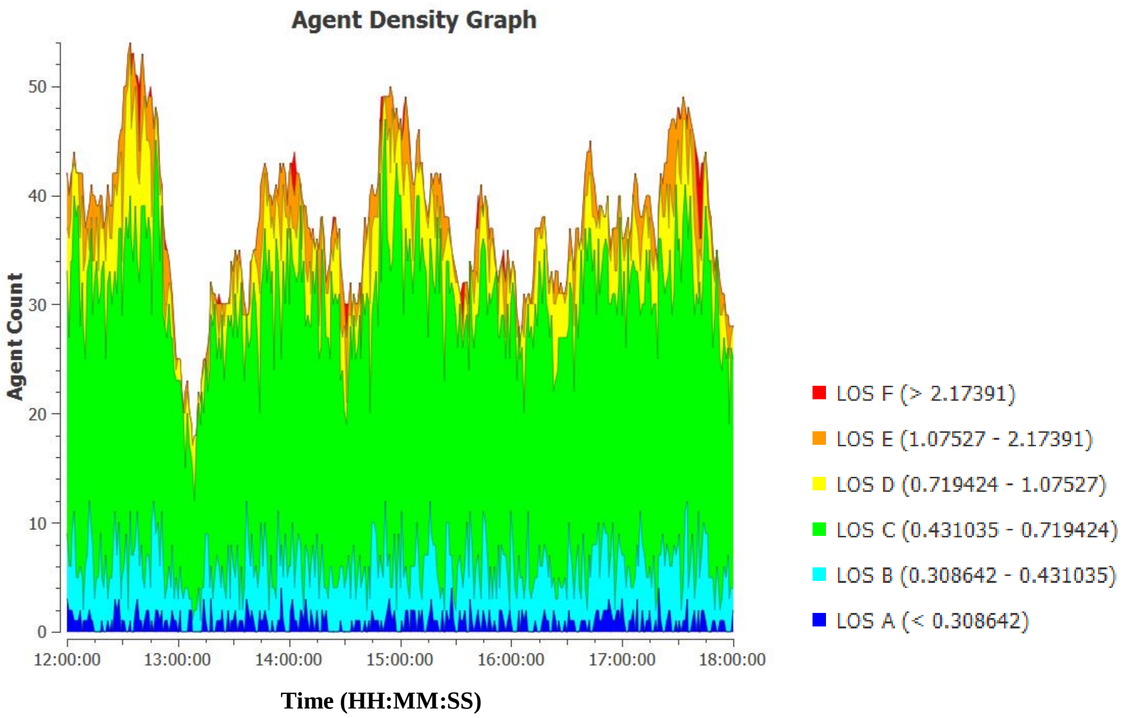



Figure 53: third scenario shoppers' densities graph

Table 18: third scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 333 | 1839 | 8877 | 1653 | 841 | 61 |
| Average (Total shoppers/ simulation frame period) | 0.92 | 5.09 | 24.59 | 4.57 | 2.32 | 0.16 |

### 5.1.4 The fourth scenario:

In this scenario, we did not modify the total length or width, i.e. they remained the same, however, we modified the width of the 6th isle of general items and increased it by 0.5 meters, on the other hand, and we decreased the width of seafood isle by 0.5 meters. Table 19 summarizes the new dimensions.

Table 19: fourth scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 3.0 m |
| Mid isle | 1.8 m |
| Southern isle | 2.0 m |
| Central isles (total 12 isles) | 1.3 m |
| Sixth isle of general items (total 1 isle1) | 1.8 m |
| Drinks 2 isle (total 1 isle) | 1.3 |
| Eastern isles (total 4 isles) | 2.1 m |
| Western isles 1a (total 1 isles) (fresh, left) | 2.5 m |
| Western isles 1b (total 1 isles) (seafood, left) | 2.0 m |
| Western isles 2a (total 1 isles) (fresh, right) | 2.1 m |
| Western isles 2b (total 1 isles) (seafood, right) | 2.1 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 37.7 m |
| Total width | 38.0 m |
| Total area. | 1432.6 square meters |

#### 5.1.4.1 Shoppers' social cost

Table 20 shows the fourth scenario results. The total cost dropped from 4050.231 Pounds, in the previous scenario to 4029.203 Pounds. The congestion cost got reduced from 13 pounds, in the previous scenario, to 6.6 pounds, which is almost the half. The journey cost reduced from 4037 to 4022 pounds. The congestion time reduced from one hour and 47 minutes to fifty-four hours only. The journey time reduced from over than 226 hours and twenty minutes to 225- and sixteen-minutes hours. Table 20 summarizes the fourth scenario values.

Table 20: fourth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 63:27:47 | 126:55:33 | 0:54:14 | 936 | 6 | 943 |
| Server Queue | 15:07:37 | 51:25:54 | 0:00:00 | 379 | 0 | 379 |
| Server Process | 146:40:49 | 366:42:04 | 0:00:00 | 2706 | 0 | 2706 |
| Total | 225:16:13 | 545:03:31 | 0:54:14 | 4022 | 6 | 4029 |

### 5.1.4.2 **Average LOS (t)**

Figure 54 shows the average LOS (t) of this scenario, as noticed the dominant colour in the map is blue, while very minimal isles have a combination of blue and black, such as the household isles.

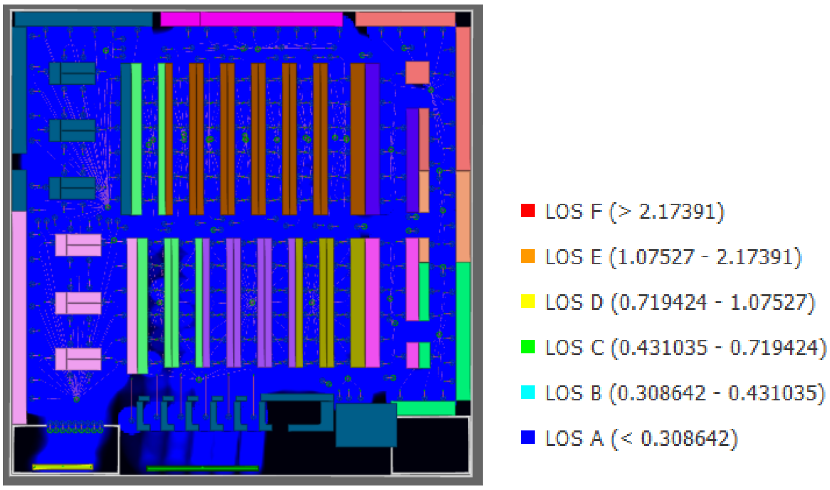



Figure 54: fourth scenario average LOS (t) map

### 5.1.4.3 **Experienced LOS (t):**

Figure 55 shows the experienced LOS (t) map. It shows that the LOS A colour covers most of the areas, while the LOS C is in three main areas, the isle No. 6 of general items (the major one), the fresh produce area and pre-prepared food area. However, the LOS C is lower from the previous scenario in the sixth isle of general items.

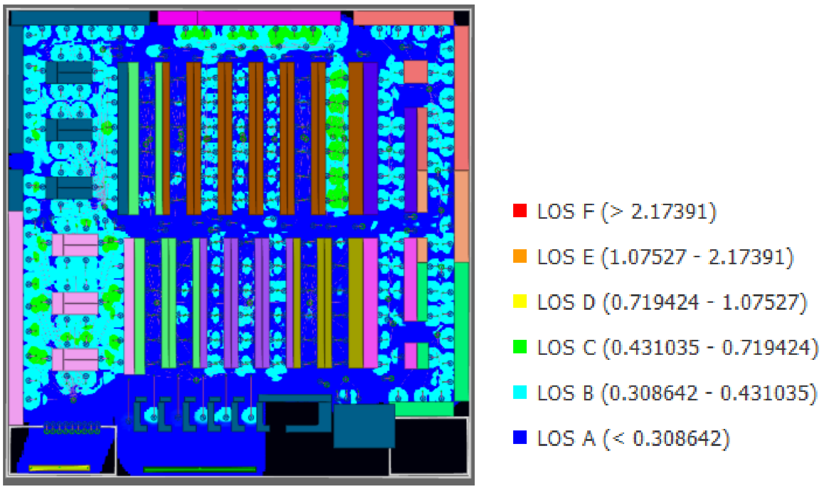



Figure 55: fourth scenario experienced LOS (t) map

### 5.1.4.4 **Maximum LOS:**

Figure 56 shows that the LOS F is still appearing and increased in the isle no. 6 of general items area. The fresh produce, seafood, pre-prepared food and the LOS E as a dominant colour. The remaining areas ranged between LOS D and LOS C, including the southern household area.

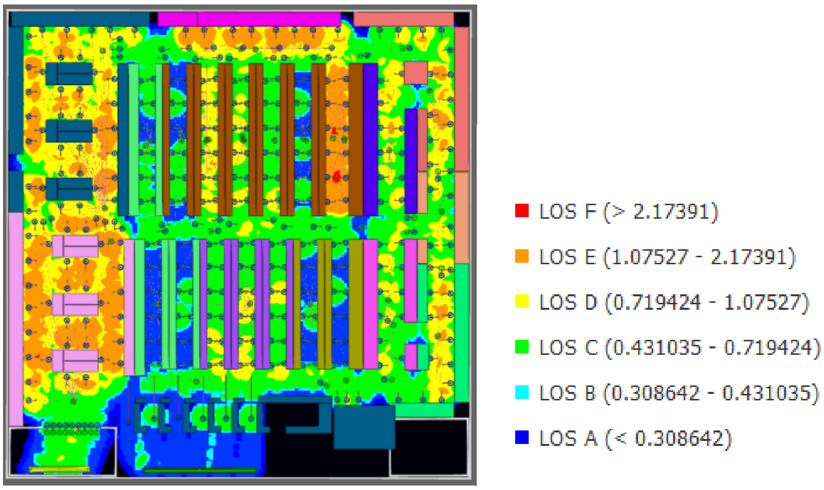



Figure 56: fourth scenario maximum LOS map

### 5.1.4.5 **Shoppers' density graph:**

Figure 57 shows the LOS F is almost disappeared, during the study period in the simulation, which is lower than the previous scenario. The LOS A colour increased when comparing it with the previous scenario. Table 21 convert Figure 53 into average numbers.

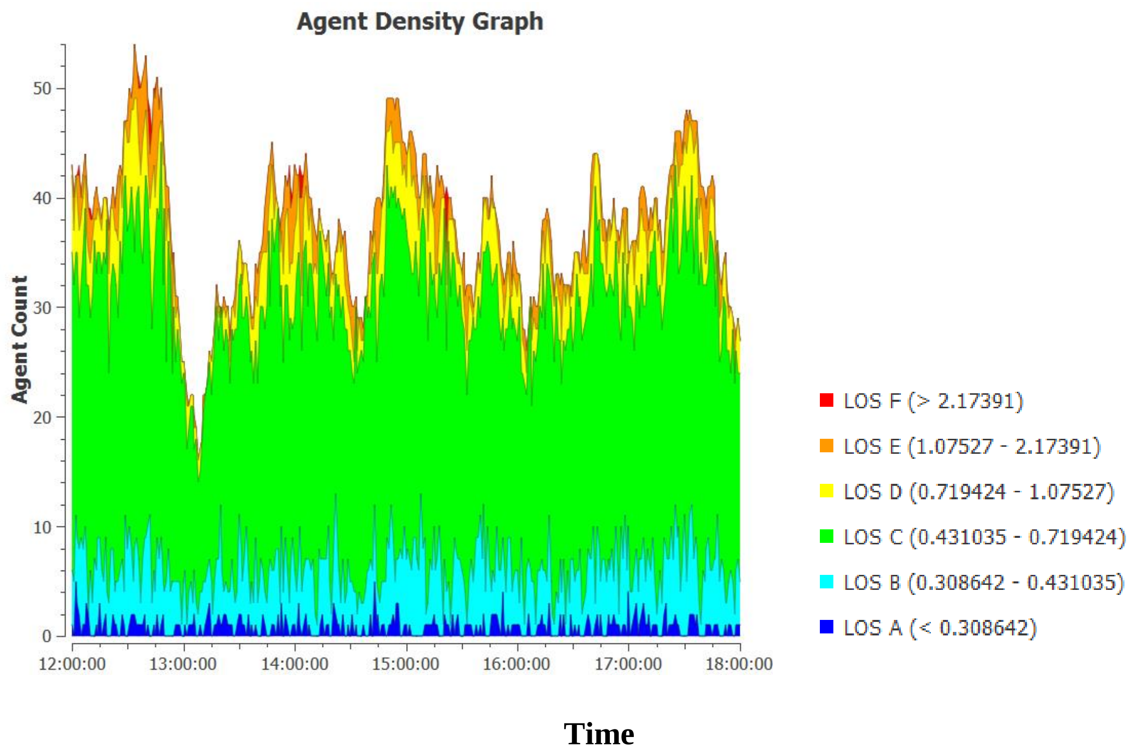



Figure 57: fourth scenario shoppers' densities graph

Table 21: fourth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 301 | 1938 | 8983 | 1546 | 742 | 23 |
| Average (Total shoppers/ simulation frame period) | 0.83 | 5.36 | 24.88 | 4.28 | 2.05 | 0.06 |

### 5.1.5 The fifth scenario:

In this scenario, we again increased the sixth isle of general items over the frozen items isle, the frozen items isle got reduced by 0.5 meter. The total area equals to 1432.6 square meters. The schedule below illustrates the new dimensions. In this scenario, we are trying again to improve the densities in the sixth isle, by increasing the isle width. Table 22 summarizes the fifth scenario dimensions.

Table 22: fifth scenario dimensions

| Isle name | Dimension |
|---|---|
| Northern isle | 3.0 m |
| Mid isle | 1.8 m |
| Southern isle | 2.0 m |
| Central isles (total 12 isles) | 1.3 m |
| Sixth isle of general items (total 1 isle1) | 2.3 m |
| Drinks 2 isle ( total 1 isle) | 1.3 |
| Eastern isles 1b (total 1 isle) | 1.6 m |
| Eastern isles (total 4 isles) | 2.1 m |
| Western isles 1a (total 1 isles) (fresh, left) | 2.5 m |
| Western isles 1b (total 1 isles) (seafood, left) | 2.0 m |
| Western isles 2a (total 1 isles) (fresh, right) | 2.1 m |
| Western isles 2b (total 1 isles) (seafood, right) | 2.1 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 37.7 m |
| Total width | 38.0 m |
| Total area. | 1432.6 square meters |

#### 5.1.5.1 **Shoppers' social cost:**

Table 23 shows the fifth scenario results. The total cost dropped from 4029 Pounds, in the previous scenario to 4018 Pounds. The congestion cost got reduced from 6.6 pounds, in the previous scenario, to 5 pounds. The journey cost reduced from 4022 to 4013 pounds. The congestion time reduced from fifty-four hours to forty minutes only. The journey time reduced from 225- and sixteen-minutes to 225 hours. Table 23 summarizes the cost of the fifth scenario.

Table 23: fifth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 63:33:13 | 127:06:27 | 0:40:55 | 938 | 5 | 943 |
| Server Queue | 14:42:46 | 50:01:24 | 0:00:00 | 369 | 0 | 369 |
| Server Process | 146:41:23 | 366:43:27 | 0:00:00 | 2706 | 0 | 2706 |
| Total | 224:57:22 | 543:51:18 | 0:40:55 | 4013 | 5 | 4018 |

### 5.1.5.2 **Average LOS (t) plan:**

Figure 58 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the household isles.

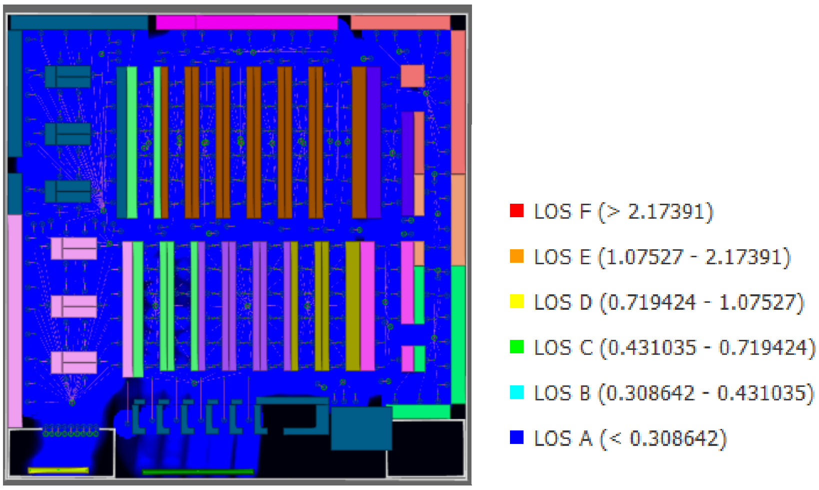



Figure 58: fifth scenario average LOS (t) map

### 5.1.5.3 **Experienced LOS (t) plan**

Figure 59 shows the experienced LOS (t) map. It shows that the LOS A colour covers most of the areas, while the LOS C is in two main areas, the fresh produce area and pre-prepared food area; it disappeared in the isle No. 6 of general items.

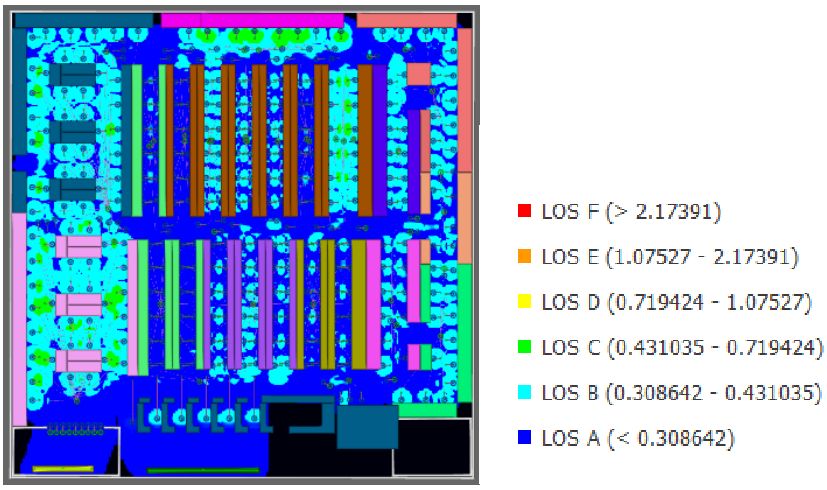



Figure 59: fifth scenario experienced LOS (t) map

#### 5.1.5.4 **Maximum LOS plan**

Figure 60 shows that the LOS F disappeared in the isle no. 6 of general items area. The fresh produce, seafood, pre-prepared food and the isle no. 6 of general items area has LOS E as a dominant colour. The remaining areas ranged between LOS D and LOS C, the southern household area LOS A is the dominant. The maximum LOS plan shows a slight increase of LOS E in the frozen items area, while it slightly decreased in the sixth isle of the general items.

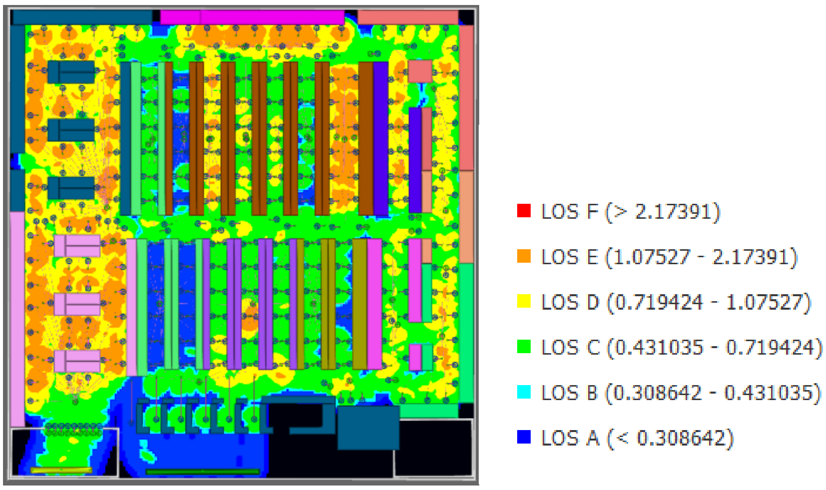



Figure 60: fifth scenario maximum LOS map

#### 5.1.5.5 **Shoppers' density graph:**

Figure 61 shows the LOS F is almost disappeared, during the study period in the simulation, which is lower than the previous scenario. The LOS A colour almost the same when comparing it with the previous scenario. Table 24 converts Figure 61 into average numbers.

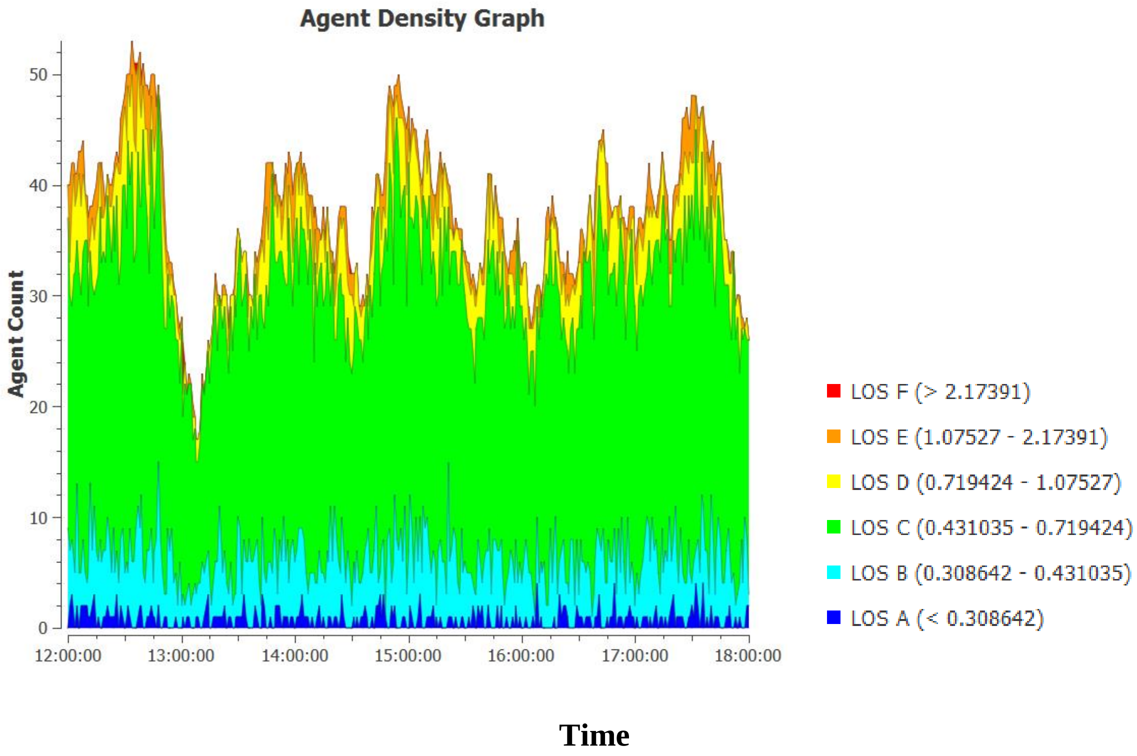



Figure 61: fifth scenario shoppers' densities graph

Table 24: fifth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 299 | 1961 | 9121 | 1481 | 646 | 7 |
| Average (Total shoppers/ simulation frame period) | 0.83 | 5.43 | 25.27 | 4.10 | 1.79 | 0.019 |

### 5.1.6 The sixth scenario:

In this scenario, we increased the isle no.6 of the general items' width and the pre-prepared zone area. The total area increased accordingly from 1432.6 to 1485.5 square meters, the difference is 52.9 square meters. Table 25 summarizes the sixth scenario dimensions.

Table 25: sixth scenario dimensions

| Isle name | Dimension |
|---|---|
| Northern isle | 3.0 m |
| North isle – pre-prepared food section | 4.0 m |
| Mid isle | 1.8 m |
| Southern isle | 2.0 m |
| Central isles (total 12 isles) | 1.3 m |
| Sixth isle of general items (total 1 isle1) | 3.3 m |
| Drinks 2 isle (total 1 isle) | 1.3 |
| Eastern isles 1b (total 1 isle) | 1.6 m |
| Eastern isles (total 4 isles) | 2.1 m |
| Western isles 1a (total 1 isles) (fresh, left) | 3.0 m |
| Western isles 1b (total 1 isles) (seafood, left) | 2.0 m |
| Western isles 2a (total 1 isles) (fresh, right) | 2.6 m |
| Western isles 2b (total 1 isles) (seafood, right) | 2.1 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 38.7 m |
| Total width | 38.0 m |
| Pre-prepared food additional width | 1.0 m |
| Pre-prepared food additional length | 14.9 m |
| Total area. | 1485.5 square meters |

#### 5.1.6.1 Shoppers' social cost:

Table 26 shows the sixth scenario results. The total cost increased from 4018 Pounds to 4032 Pounds, due to the increase journey time and cost. The congestion cost got reduced from 5 pounds, in the previous scenario, to 4.1 pounds. The journey cost increased from 4013 to 4027 pounds. The congestion time reduced from forty minutes to thirty minutes only, for all agents during the study period. The journey time increased from 225 to 225 hours and thirteen minutes.

Table 26: sixth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 62:47:55 | 125:35:51 | 0:33:42 | 926 | 4 | 931 |
| Server Queue | 15:40:04 | 53:16:12 | 0:00:00 | 393 | 0 | 393 |
| Server Process | 146:45:49 | 366:54:33 | 0:00:00 | 2707 | 0 | 2707 |
| Total | 225:13:48 | 545:46:36 | 0:33:42 | 4027 | 4 | 4031 |

### 5.1.6.2 **Average LOS (t):**

Figure 62 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles.

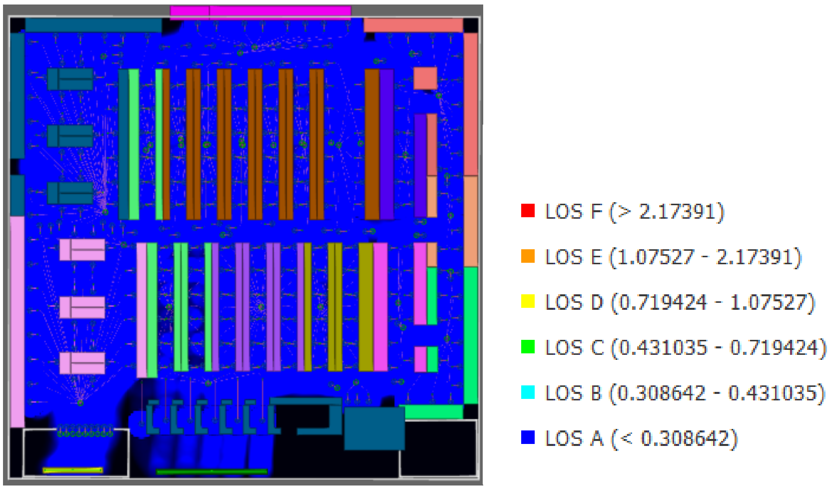



Figure 62: sixth scenario average LOS (t) map

### 5.1.6.3 **Experienced LOS (t)**

Figure 63 shows the experienced LOS (t) map. It shows that the LOS A color covers most of the areas, while the LOS C is in two main areas, the fresh produce area and pre-prepared food area; it disappeared in the isle No. 6 of general items.

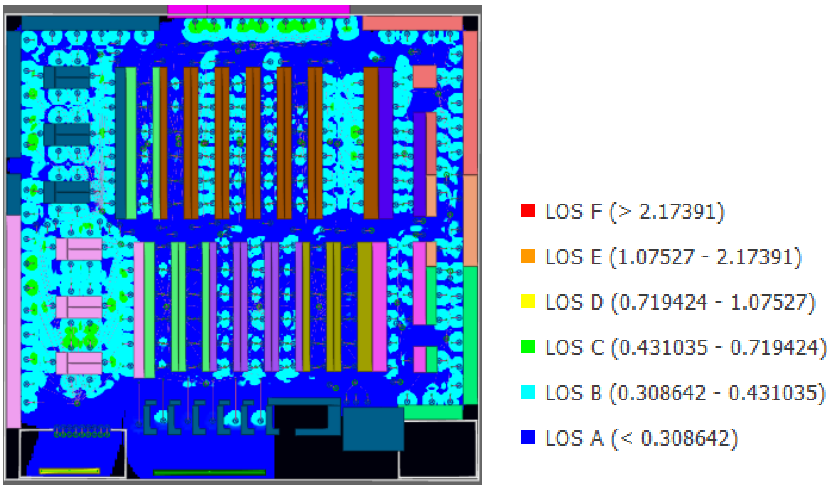



Figure 63: sixth scenario experienced LOS (t) map

#### 5.1.6.4 **Maximum LOS:**

Figure 64 shows that the LOS F disappeared in the isle no. 6 of general items area. The fresh produce, seafood, pre-prepared food and the isle no. 6 of general items area has LOS E as a dominant colour. The remaining areas ranged between LOS D and LOS C, the southern household area LOS A is the dominant. The maximum LOS plan shows a slight decrease of LOS E in all areas.

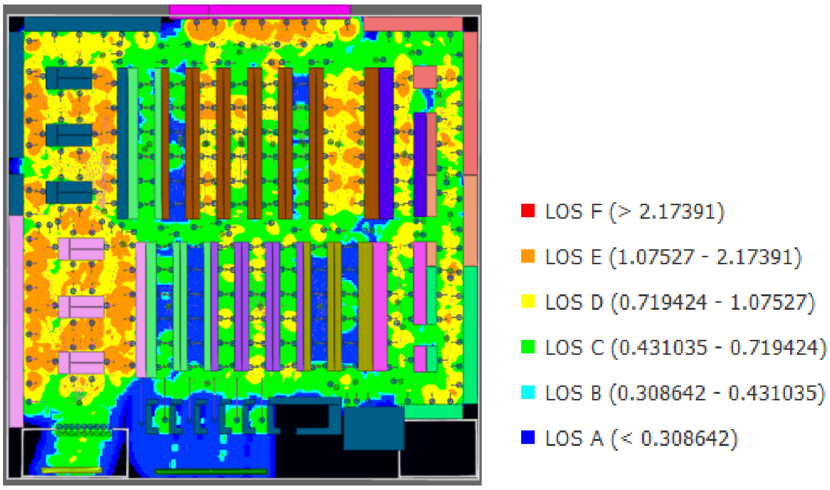



Figure 64: sixth scenario maximum LOS map

#### 5.1.6.5 **Shoppers' density graph:**

Figure 65 shows the LOS F disappeared, during the study period in the simulation, which is lower than the previous scenario. The LOS A colour almost increased when comparing it with the previous scenario. Table 27 converts Figure 65 into average numbers.

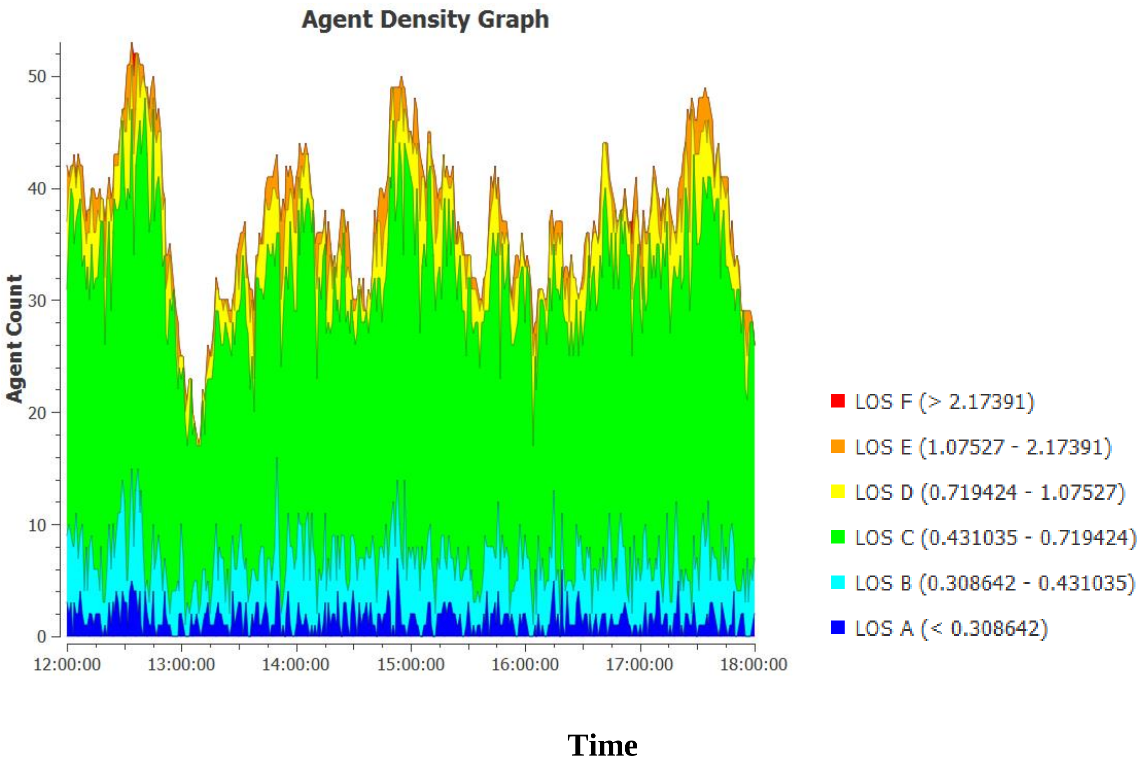



Figure 65: sixth scenario shoppers' densities graph

Table 27: sixth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 557 | 1870 | 9126 | 1409 | 562 | 5 |
| Average (Total shoppers/ simulation frame period) | 1.54 | 5.18 | 25.28 | 3.90 | 1.56 | 0.014 |

### 5.1.7 The seventh scenario:

In this scenario, we increased the width only over the previous scenario, and it became 40 meters. We increased the width by 2 meters. This increase was distributed over the fresh produce and sea food section, every vertical isle was increased by 0.5 meter. The total area became 1628 square meters. Table 28 summarizes the scenario dimensions.

Table 28: seventh scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 5.0 m |
| Mid isle | 1.8 m |
| Southern isle | 2.0 m |
| Central isles (total 12 isles) | 1.3 m |
| Sixth isle of general items (total 1 isle1) | **4.3 m** |
| Drinks 2 isle (total 1 isle) | 1.3 |
| Eastern isles 1b (total 1 isle) | 1.6 m |
| Eastern isles (total 4 isles) | 2.1 m |
| Western isles 1a (total 1 isles) (fresh, left) | 3.9 m |
| Western isles 1b (total 1 isles) (seafood, left) | 2.9 m |
| Western isles 2a (total 1 isles) (fresh, right) | 3.6 m |
| Western isles 2b (total 1 isles) (seafood, right) | 2.2 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 40.7 m |
| Total width | 40.0 m |
| **Total area** | **1628 square meters** |

#### 5.1.7.1 Shoppers' social cost:

Table 29 shows the seventh scenario results. The total cost increased from 4018 Pounds to 4031 Pounds, due to the increase in journey time and cost. The congestion cost got reduced from 3.8 pounds, in the previous scenario, to 2.8 pounds. The journey cost increased from

4014 to 4028 pounds. The congestion time decreased from thirty minutes to twenty-three minutes only. The journey time increased from 224 to 225 hours.

Table 29: seventh Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 62:58:15 | 125:56:30 | 0:23:02 | 929 | 2 | 932 |
| Server Queue | 15:39:16 | 53:13:30 | 0:00:00 | 392 | 0 | 392 |
| Server Process | 146:39:05 | 366:37:44 | 0:00:00 | 2705 | 0 | 2705 |
| Total | 225:16:36 | 545:47:43 | 0:23:02 | 4027 | 2 | 4030 |

5.1.7.2 **Average LOS (t):**

Figure 66 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles.

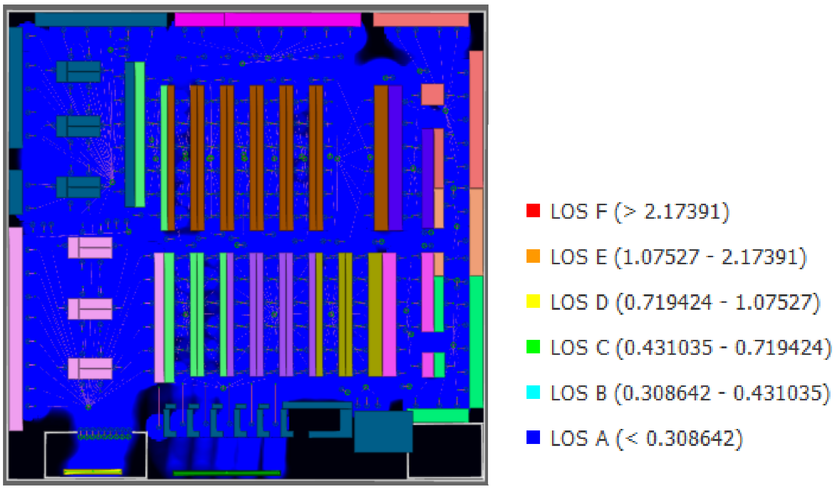



Figure 66: seventh scenario average LOS (t) map

### 5.1.7.3 **Experienced LOS (t)**

Figure 67 shows the experienced LOS (t) map. It shows that the LOS A colour covers most of the areas, while the LOS C is in one area, the pre-prepared food area and small amount in the fresh produce area.

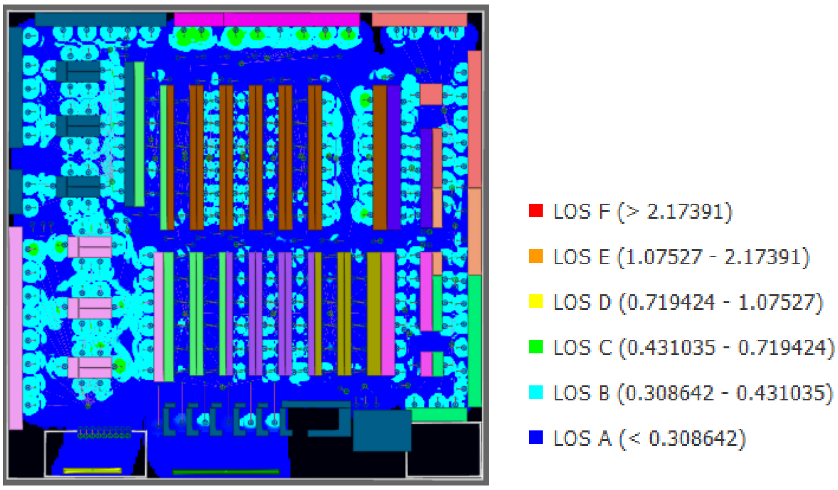



Figure 67: seventh scenario experienced LOS (t) map

### 5.1.7.4 **Maximum LOS:**

Figure 68 shows that the fresh produce, seafood, pre-prepared food and the isle no. 6 of general items area has LOS E as a dominant colour, however, it is lesser than the previous scenario. The remaining areas ranged between LOS D and LOS C, the southern household area LOS A is the dominant.

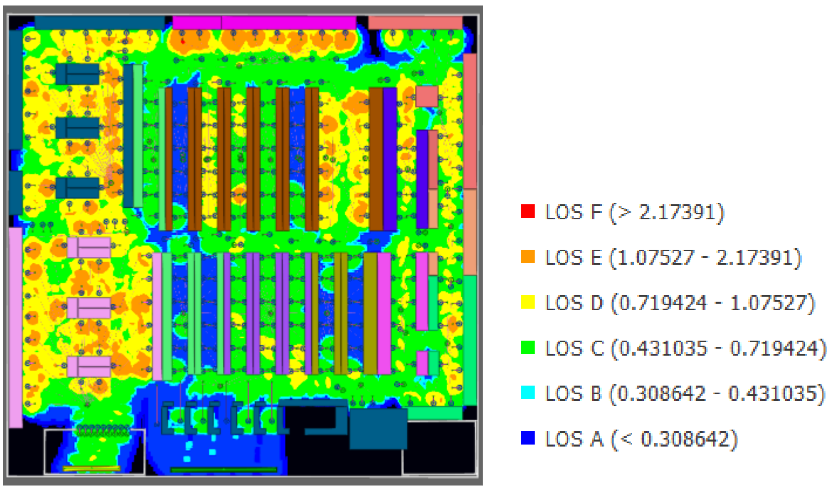



Figure 68: seventh scenario maximum LOS map

5.1.7.5 **Shoppers' density graph:**

Figure 69 shows the LOS E decreased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C. Table 30 converts Figure 69 into average numbers.

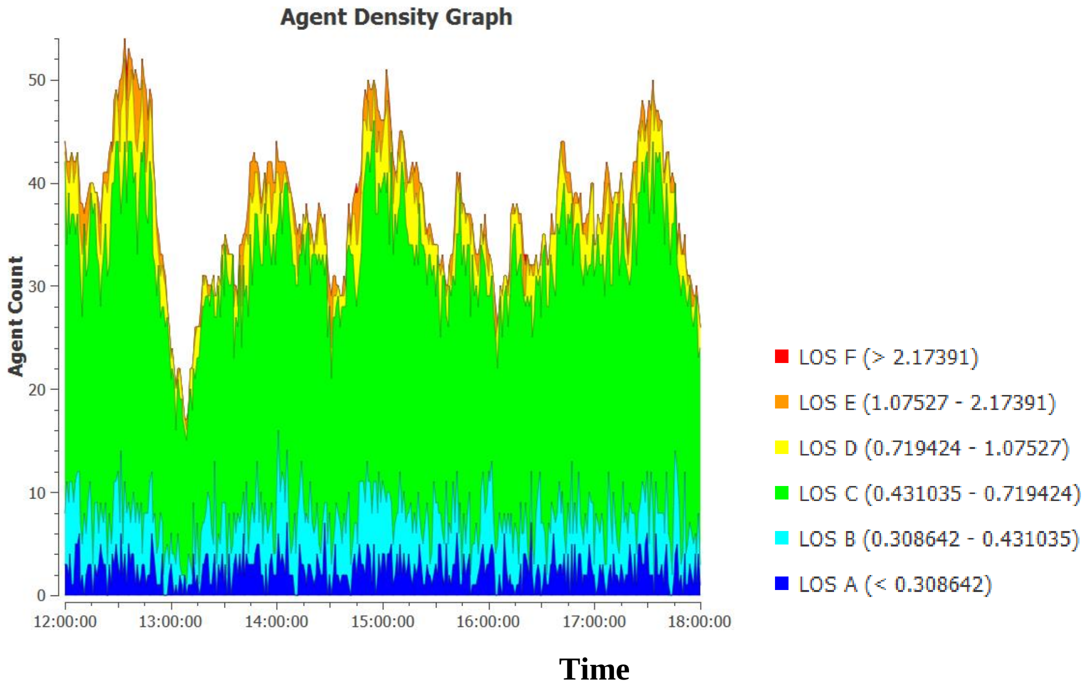



Figure 69: seventh scenario shoppers' densities graph

Table 30: seventh scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 896 | 1800 | 9082 | 1267 | 495 | 6 |
| Average (Total shoppers/ simulation frame period) | 2.48 | 4.98 | 25.15 | 3.50 | 1.37 | 0.01 |

### 5.1.8 The eighth scenario:

The eighth case scenario is a modification on the ninth scenario, where the sixth isle were lowered to match the remaining isles, where it was reduced from 2.1 to 1.8, 30 cm difference. The total area equals to 43.2 meters (the length), multiplied by 38.5 meters (the width), which equals to 1663.2 square meters. Table 31 summarizes the dimensions:

Table 31: eighth scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 3.0 m |
| Mid isle | 1.8 m |
| Southern isle | 2.5 m |
| Central isles (total 12 isles) | 1.8 m |
| Sixth isle of general items and drinks 2 (total 2 isles) | 1.8 m |
| Eastern isles (total 4 isles) | 2.6 m |
| Western isles (total 4 isles) | 2.6 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 43.2 m |
| Total width | 38.5 m |
| Total area. | 1663.2 square meter |

#### 5.1.8.1 Shoppers' social cost:

Table 32 shows the eighth scenario results. The total cost decreased from 4031 Pounds to 4021 Pounds, due to the decrease in journey time and cost. However, the congestion cost got increased from 2 pounds, in the previous scenario, to 4 pounds. The journey cost decreased from 4027 to 4016 pounds. The congestion time increased from thirty minutes to thirty-five minutes. The journey time decreased from 225 hours and sixteen minutes to 225 hours.

Table 32: eighth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: | Generalized Journey Time | Sum of Congestion | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social |
|---|---|---|---|---|---|---|

| | minute: second) | (hour: minute: second) | Time (hour: minute: second) | | | Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 63:18:37 | 126:37:14 | 0:35:09 | 934 | 4 | 938 |
| Server Queue | 14:58:38 | 50:55:22 | 0:00:00 | 375 | 0 | 375 |
| Server Process | 146:40:56 | 366:42:21 | 0:00:00 | 2706 | 0 | 2706 |
| Total | 224:58:11 | 544:14:56 | 0:35:09 | 4016 | 4 | 4020 |

#### 5.1.8.2 **Average LOS (t):**

Figure 70 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles. The black areas increased in this scenario.

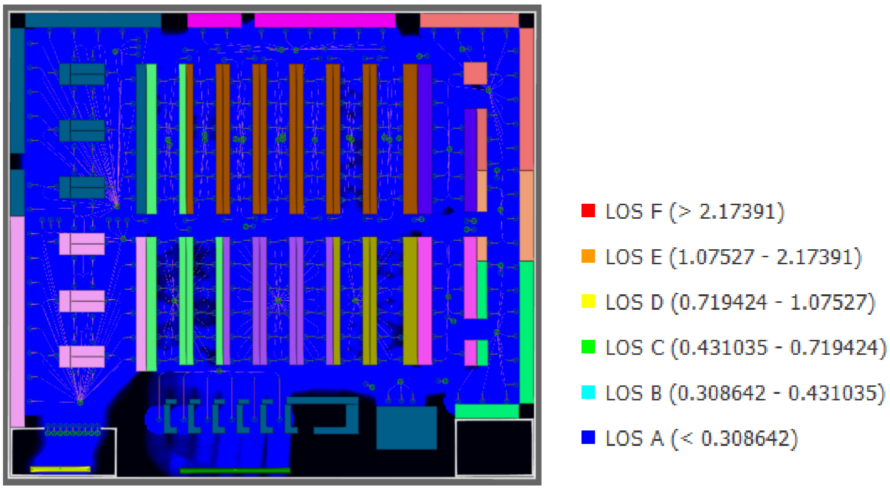



Figure 70: eighth scenario average LOS (t) map

#### 5.1.8.3 **Experienced LOS (t)**

Figure 71 shows the experienced LOS (t) map. It shows that the LOS A colour covers most of the areas, while the LOS C increased in three areas, the pre-prepared food, the sixth isle in the general items, and the fresh produce area.

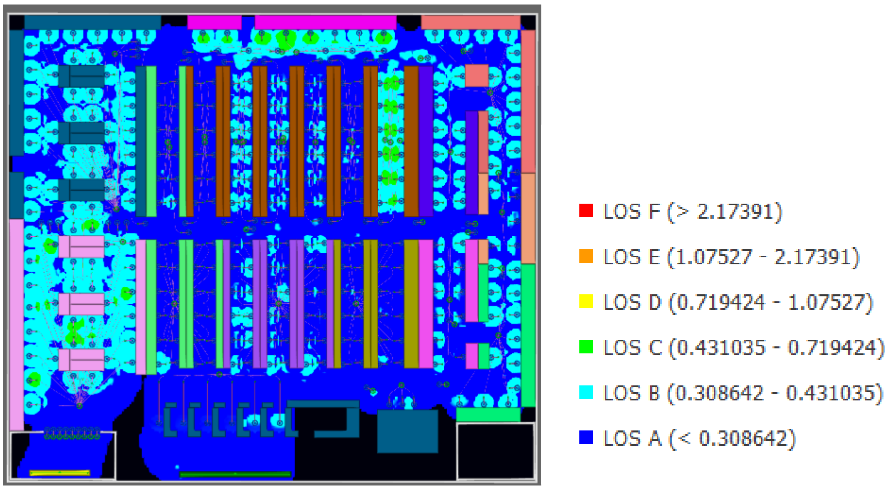



Figure 71: eighth scenario experienced LOS (t) map

#### 5.1.8.4 **Maximum LOS**

Figure 72 shows that the fresh produce, seafood, pre-prepared food and the isle no. 6 of general items area has LOS E as a dominant colour, however, it is more than the previous scenario. The remaining areas ranged between LOS D and LOS C, the southern household area LOS A is the dominant.

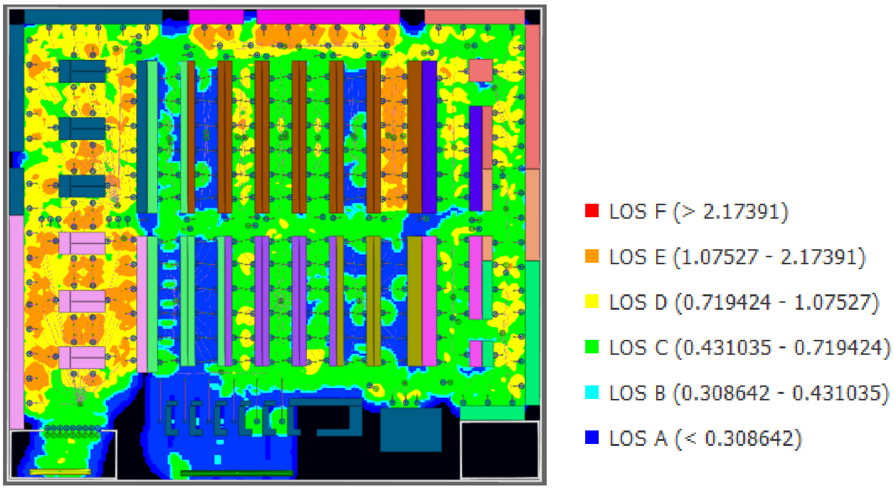



Figure 72: eighth scenario maximum LOS map

#### 5.1.8.5 **Shopper density graph:**

Figure 73 shows the LOS E increased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C. Table 33 converts Figure 73 into average numbers.

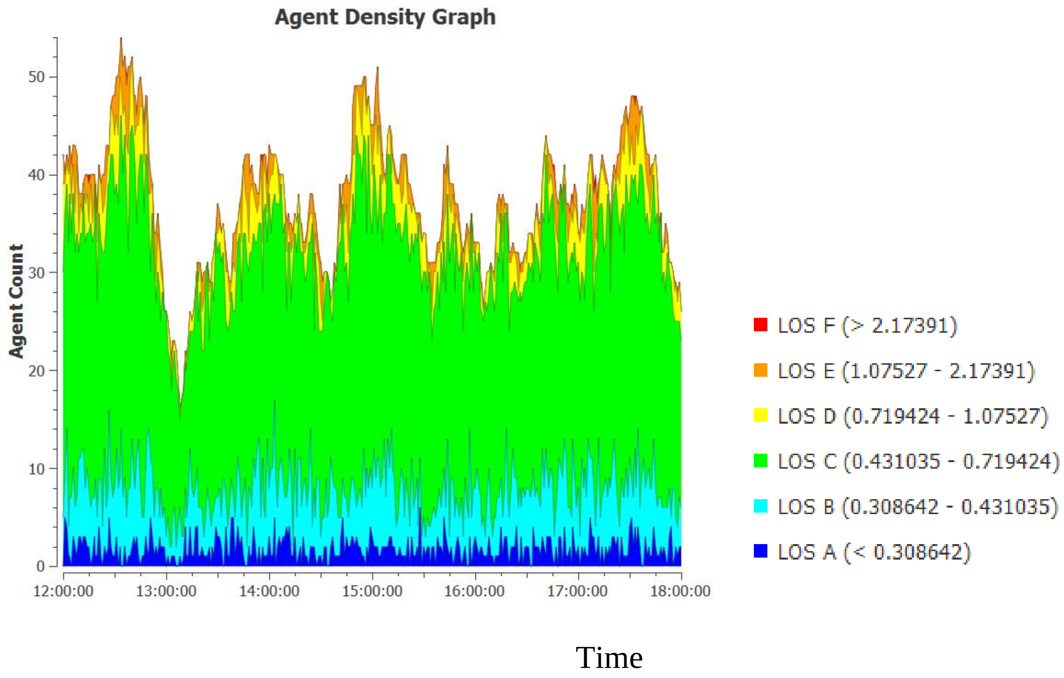



Figure 73: eighth scenario shoppers' densities graph

Table 33: eighth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 633 | 2186 | 8851 | 1234 | 606 | 8 |
| Average (Total shoppers/ simulation frame period) | 1.75 | 6.05 | 24.51 | 3.41 | 1.67 | 0.02 |

### 5.1.9 The Ninth scenario:

This scenario is the base case scenario, i.e. has the same dimensions of the case study. In this scenario, the total length is 43.5 meters and the total width is 38.5 meters. The total area is 1674.75 square meters. The isles width in this scenario are 1.8 meters. In the fresh produce, the isles width is 2.6 meters horizontal and 2.86 meters vertical. The northern isle is 3 meter wide. The centre isle is 1.8 meter wide. The Sothern isle is 2.5 meter. The frozen items and deli sections isles are 2.6 meters wide. Table 34 below summarizes the scenario dimensions:

Table 34: ninth scenario dimensions

| Isle name | Dimension |
|---|---|
| Northern isle | 3.0 m |
| Mid isle | 1.8 m |
| Southern isle | 2.5 m |
| Central isles (total 12 isles) | 1.8 m |
| Sixth isle of general items and drinks 2 (total 2 isles) | 2.1 m |
| Eastern isles (total 4 isles) | 2.6 m |
| Western isles (total 4 isles) | 2.6 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 43.5 m |
| Total width | 38.5 m |
| Total area. | 1674.75 square meter |

#### 5.1.9.1 **Shoppers' social cost:**

The total cost, in this scenario, reached 5049.993 pounds for the 6 hours in the peak time. The congestion time equals to one hour and three minutes, and that resulted in 7.7 Pounds for congestion cost. The total journey time, which equals to 275 hours and nine minutes, resulted 5042 pounds per the six hours for the journey cost. Table 35 summarizes the costs.

Table 35: ninth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 62:50:06 | 125:40:11 | 0:28:59 | 927 | 3 | 931 |
| Server Queue | 15:13:35 | 51:46:11 | 0:00:00 | 382 | 0 | 382 |
| Server Process | 146:35:47 | 366:29:27 | 0:00:00 | 2704 | 0 | 2704 |
| Total | 224:39:27 | 543:55:49 | 0:28:59 | 4014 | 3 | 4017 |

### 5.1.9.2 **Average LOS (t)**

Figure 74 shows the average LOS (t) of this scenario, as noticed the dominant colour in the map is blue, while some isles have a combination of blue and black, such as the household isles and some part in the general items area.

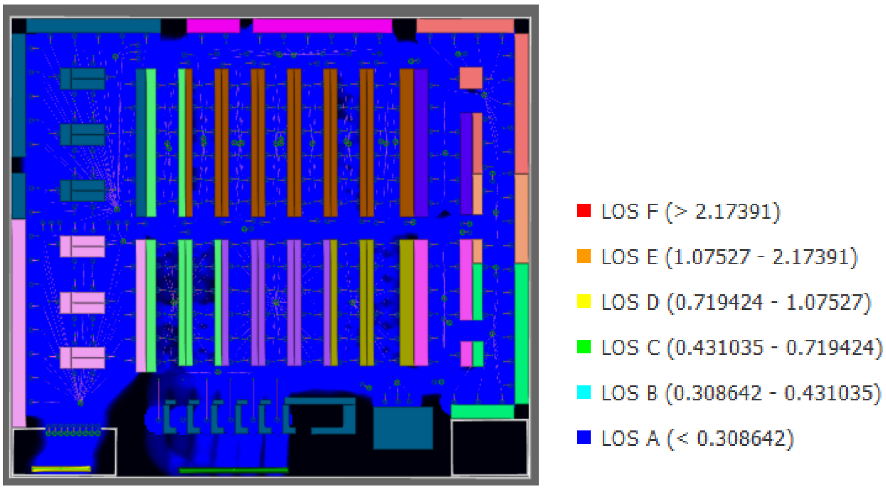



Figure 74: ninth scenario average LOS (t) map

### 5.1.9.3 **Experienced LOS (t)**

Figure 75 shows the experienced LOS (t) map. It shows that the blue colour covers most of the areas, while the green is in three main areas, the isle No. 6 of general items, the fresh produce area and pre-prepared food area.

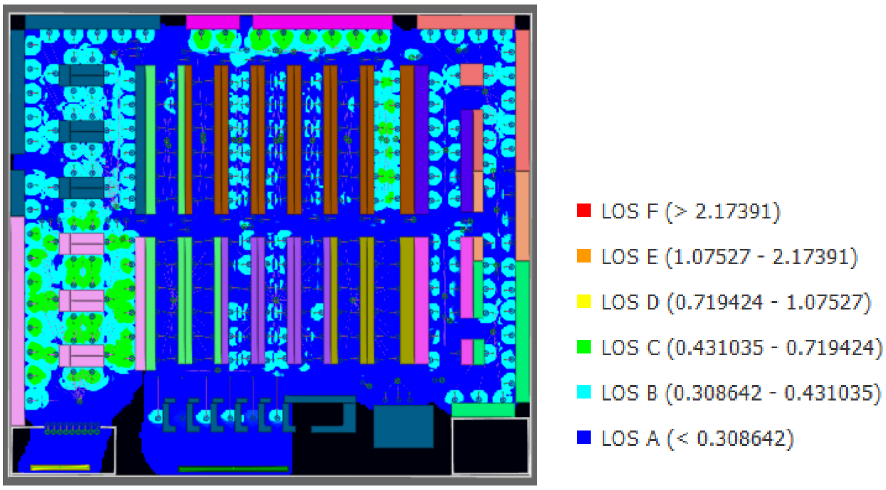



Figure 75: ninth scenario experienced LOS (t) map

### 5.1.9.4 **Maximum LOS**

Figure 76 shows that the fresh produce area had some of LOS F, which is the most crowded area. The pre-prepared food area and the isle No. 6 of general items had LOS E. the seafood area had LOS D. the household area LOS A. the remaining areas LOS A and C.

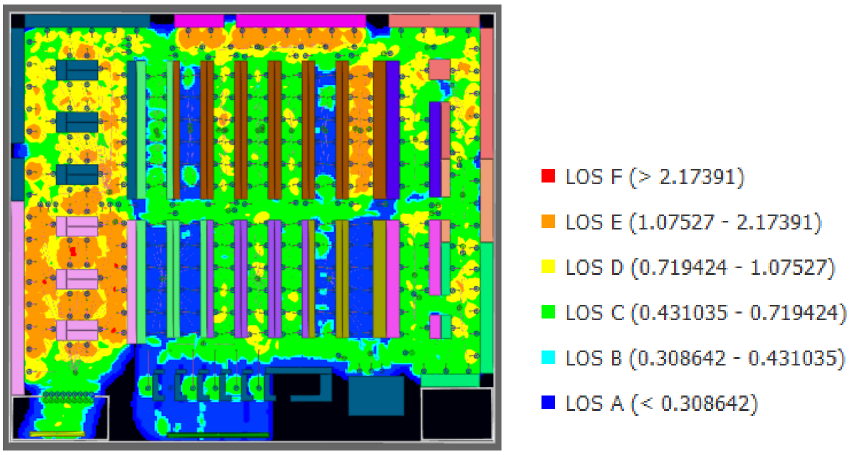
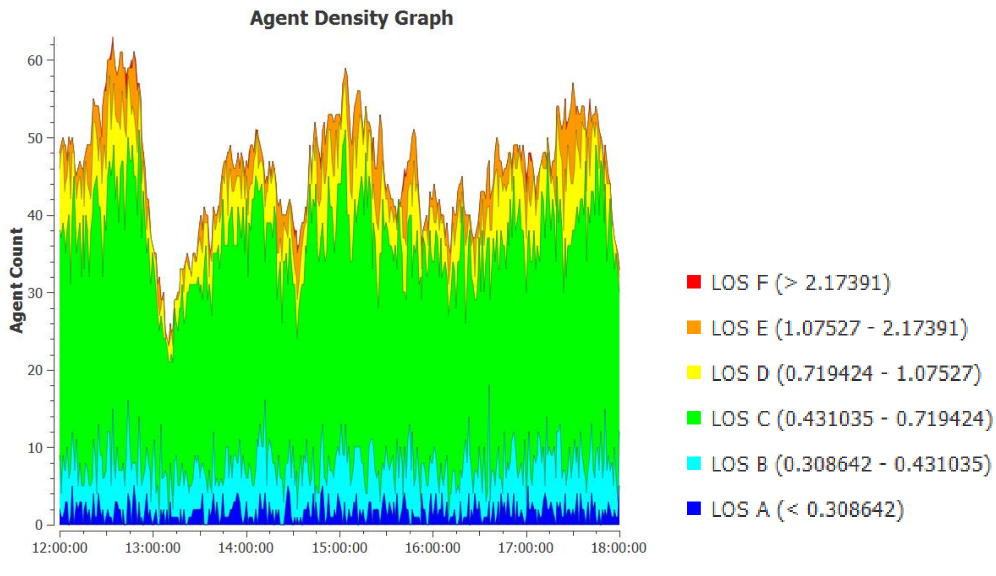



Figure 76: ninth scenario maximum LOS map

### 5.1.9.5 **Shoppers' density graph:**

Figure 77 shows the LOS E increased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C. Table 36converts Figure 77 into average numbers.




Time (hh:mm:ss)

Figure 77: ninth scenario shoppers' densities graph

Table 36: ninth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 661 | 2189 | 8870 | 1249 | 539 | 2 |
| Average (Total shoppers/ simulation frame period) | 1.83 | 6.06 | 24.57 | 3.45 | 1.49 | 0.00 |

### 5.1.10 The tenth scenario:

In the tenth scenario we increased the isles width by 0.5 meter over the previous case scenario, hence, the total increase in length is 5.5 meters, while the total increase in width is 1.5 meters; the total supermarket dimensions became 49 for the length and 40 for the width; the total area became 1960 square meters, as shown in Table 37.

Table 37: tenth scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 3.5 m |
| Mid isle | 2.3 m |
| Southern isle | 3.0 m |
| Central isles (total 14 isles) | 2.3 m |
| Sixth isle of general items and drinks 2 (total 2 isles) | 2.6 m |
| Eastern isles (total 4 isles) | 3.1 m |
| Western isles (total 4 isles) | 3.1 m |
| Western vertical isles (total (total 4 isles) | 2.3 m |
| Total length | 49 m |
| Total width | 40 m |
| Total area. | 1960 square meter |

#### 5.1.10.1 Shoppers' social cost:

From Table 38, the total cost, in this scenario, decreased to 4039 pounds for the 6 hours in the peak time. The congestion time equals to twenty-two minutes, and that resulted in 2.8 Pounds for congestion cost. The total journey time, which equals to 225 hours and forty-six minutes, resulted 4037 pounds per the six hours for the journey cost. All the measures are lower than the previous scenario.

Table 38: tenth scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 63:14:32 | 126:29:04 | 0:22:52 | 933 | 2 | 936 |
| Server Queue | 15:49:04 | 53:46:48 | 0:00:00 | 396 | 0 | 396 |
| Server Process | 146:42:22 | 366:45:56 | 0:00:00 | 2706 | 0 | 2706 |
| Total | 225:45:58 | 547:01:48 | 0:22:52 | 4037 | 2 | 4039 |

#### 5.1.10.2 **Average LOS (t):**

Figure 78 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles. The black areas increased in this scenario.

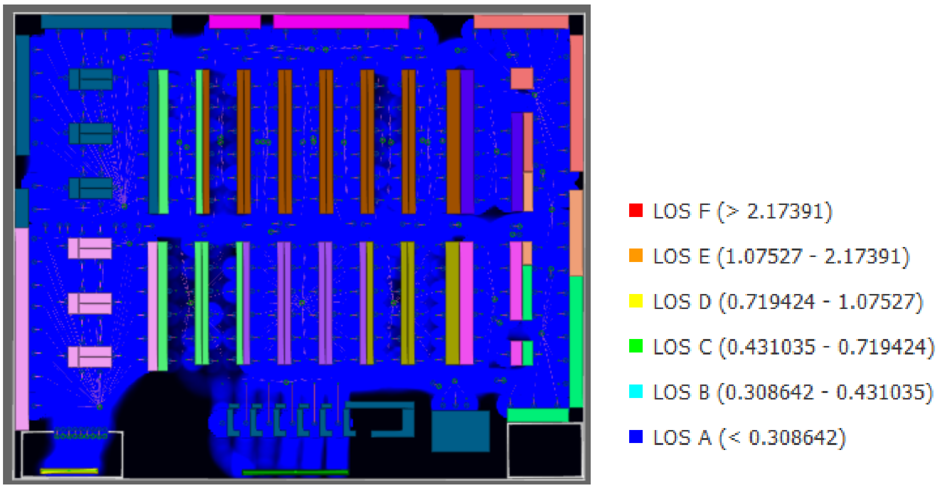



Figure 78: tenth scenario average LOS (t) map

#### 5.1.10.3 **Experienced LOS (t):**

Figure 79 shows the experienced LOS (t) map. It shows that the blue colour covers most of the areas, while the green (LOS C) is in three main areas, the isle No. 6 of general items, the fresh produce area and pre-prepared food area. However, LOS C is lower than the previous scenario.

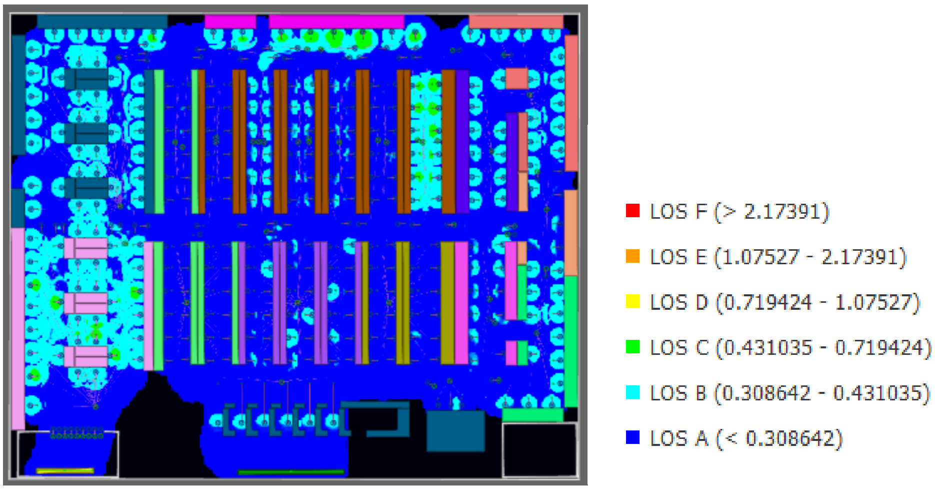



Figure 79: tenth scenario experienced LOS (t) map

#### 5.1.10.4 **Maximum LOS:**

Figure 80 shows that the LOS F in the fresh produce area, which appear in the previous scenario, disappeared in this scenario. The pre-prepared food area and the isle No. 6 of general items had LOS E. The seafood, meat and frozen areas had LOS D. The household area had LOS A. The remaining ranges between areas LOS A and C.

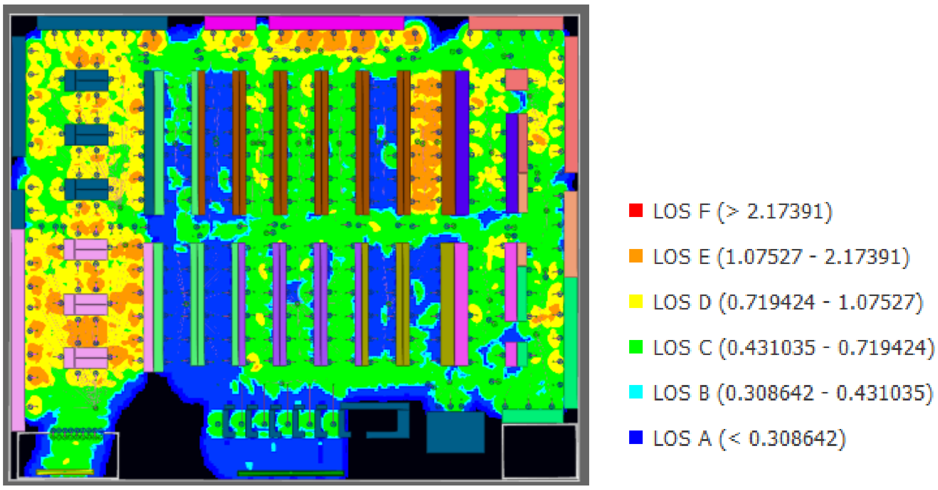



Figure 80: tenth scenario maximum LOS map

#### 5.1.10.5 **Shoppers' density graph:**

Figure 81 shows the LOS E decreased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C. Table 39 converts Figure 81 into average numbers.

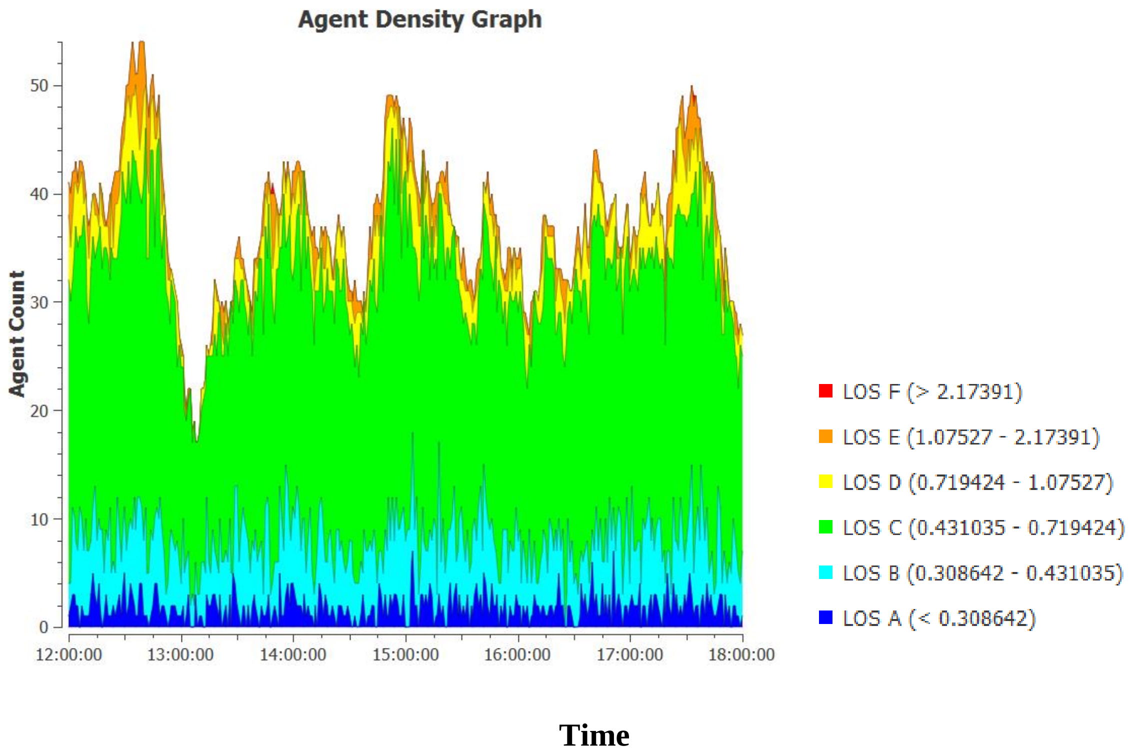



Figure 81: tenth scenario shoppers' densities graph

Table 39: tenth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 982 | 2008 | 8906 | 1230 | 454 | 6 |
| Average (Total shoppers/ simulation frame period) | 2.72 | 5.56 | 24.67 | 3.4 | 1.25 | 0.01 |

### 5.1.11 The eleventh scenario:

In the eleventh scenario we increased the isles width by 1 meter each, so the total width increased by 11 meters over the ninth scenario, while we increased the length by 3 meters only over the ninth scenario, the three meters are distributed on the three isles. The total length is 54.5 meters and the total width is 41.5 meters. The total area is 2261.75 square meters. Table 40 summarizes the modification, on the second case scenario, in the dimensions and areas. The total area increased by 587 square meters. Table 40 summarizes the scenario dimensions.

Table 40: eleventh scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 4.0 m |
| Mid isle | 2.8 m |
| Southern isle | 3.5 m |
| Central isles (total 14 isles) | 2.8 m |
| Sixth isle of general items and drinks 2 (total 2 isles) | 3.1 m |
| Eastern isles (total 4 isles) | 3.6 m |
| Western isles (total 4 isles) | 3.6 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 54.5 m |
| Total width | 41.5 m |
| Total area. | 2261.75 square meter |

#### 5.1.11.1 Shoppers' social cost:

From Table 41, the total cost in this scenario, increased to 7088 pounds for the 6 hours in the peak time. The congestion time equals to twenty-three minutes, and that resulted in 2.8 Pounds for congestion cost, which is similar to the previous scenario. The total journey time, which equals to 399 hours and twenty-two minutes, resulted 7085pounds per the six hours for the journey cost. The increase in journey time, increased the journey cost and total cost.

Table 41: eleventh Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| **Walk** | 65:15:50 | 130:31:40 | 0:18:30 | 963 | 2 | 965 |
| **Server Queue** | 15:30:25 | 52:43:25 | 0:00:00 | 389 | 0 | 389 |
| **Server Process** | 146:58:35 | 367:26:28 | 0:00:00 | 2711 | 0 | 2711 |
| **Total** | 227:44:50 | 550:41:32 | 0:18:30 | 4064 | 2 | 4066 |

#### 5.1.11.2 **Average LOS (t):**

Figure 82 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles. The black areas increased in this scenario.

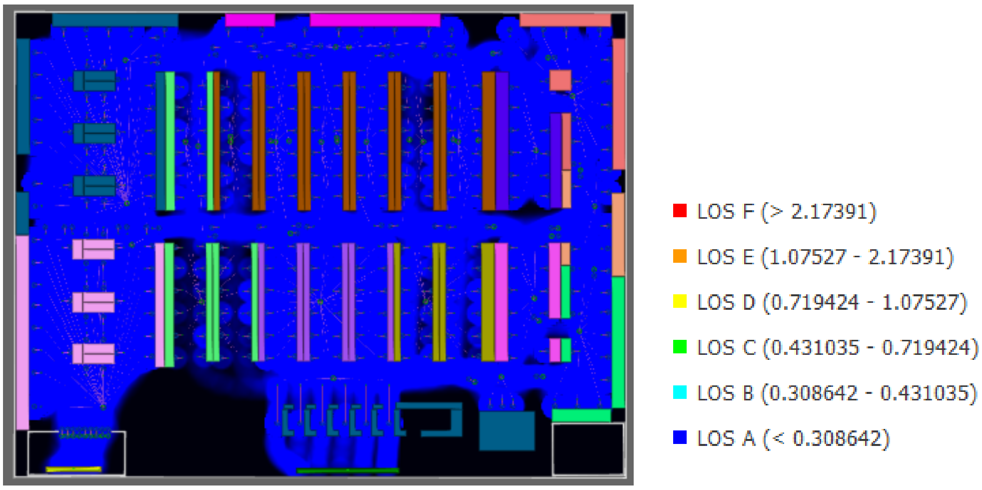



Figure 82: eleventh scenario average LOS (t) map

#### 5.1.11.3 **Experienced LOS (t):**

Figure 83 shows the experienced LOS (t) map. It shows that the blue colour covers most of the areas and it increased, while the green (LOS C) is in two main areas, the fresh produce area and pre-prepared food area, while the isle No. 6 of general items converted to LOS B. Hence, LOS C is lower than the previous scenario.

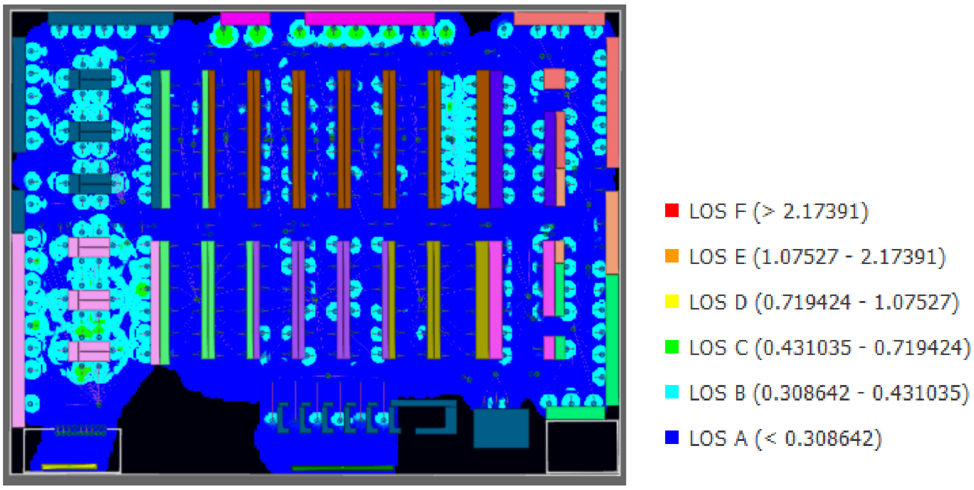



Figure 83: eleventh scenario experienced LOS (t) map

#### 5.1.11.4 **Maximum LOS:**

Figure 84 shows that the fresh produce, the pre-prepared food area and the isle No. 6 of general items had LOS E. The seafood, meat and frozen areas had LOS D and LOS E. The household area had LOS A. The remaining ranges between areas LOS A and C.

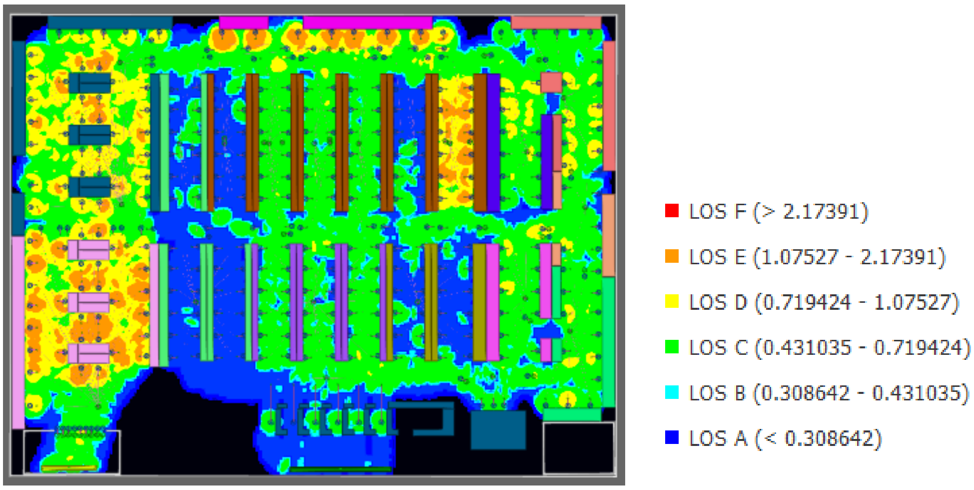



Figure 84: eleventh scenario maximum LOS map

#### 5.1.11.5 **Shoppers' density graph:**

Figure 85 shows the LOS E decreased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C. Table 42 converts Figure 85 into average numbers.

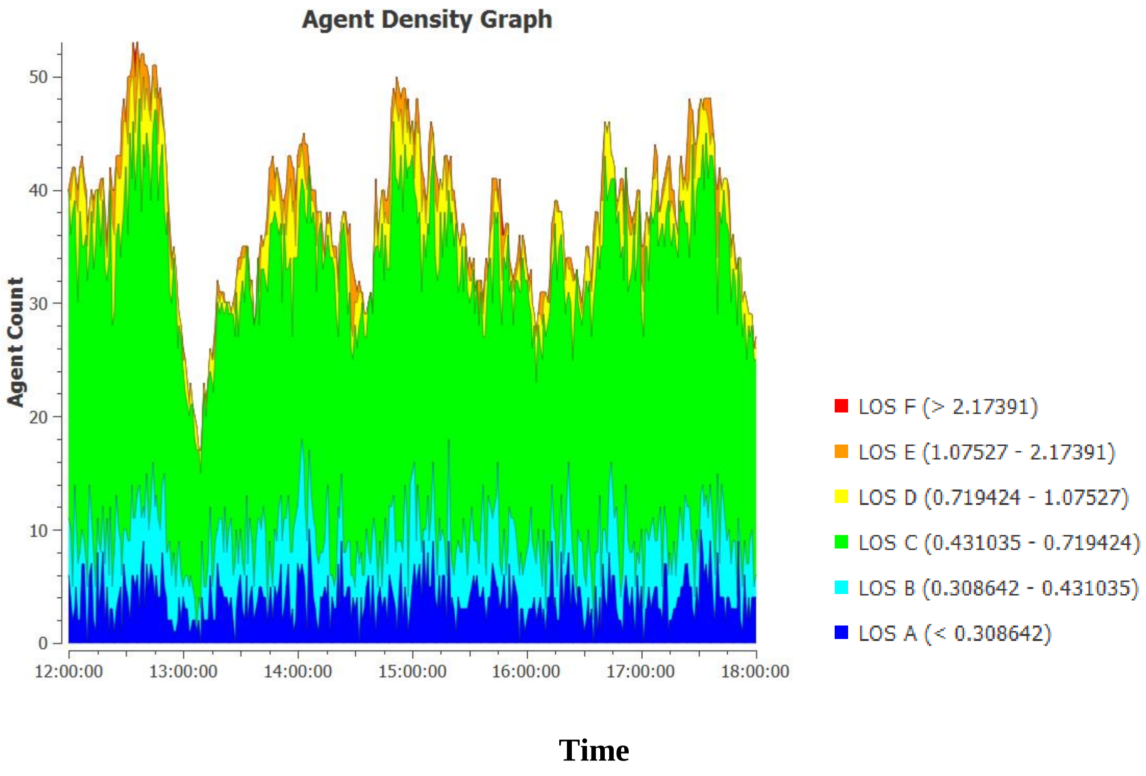



Figure 85: eleventh scenario shoppers' densities graph

Table 42: eleventh scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 1438 | 1901 | 8837 | 1078 | 417 | 4 |
| Average (Total shoppers/ simulation frame period) | 3.98 | 5.26 | 24.47 | 2.98 | 1.15 | 0.01 |

### 5.1.12 The twelfth scenario:

In this scenario we increased the isles width by 0.5 meters over the eleventh scenario, hence the total increase is 5.5 meters in the length and the total length is 60 meters, while we increased the width by 1 meter over the fourth case scenario, the total width is 42.5 meters. The total area increased by 288.25 square meter over the fourth case scenario, and it is 2550 square meters now. Table 43 summarizes the scenario dimensions.

Table 43: twelfth scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 5.0 m |
| Mid isle | 2.8 m |
| Southern isle | 3.5 m |
| Central isles (total 14 isles) | 3.3 m |
| Eastern isles (total 4 isles) | 4.1 m |
| Western isles (total 4 isles) | 4.1 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 60 m |
| Total width | 42.5 m |
| Total area. | 2550 square meter |

#### 5.1.12.1 **Shoppers' social cost:**

In Table 44, the total cost in this scenario, decreased to 4078 pounds for the 6 hours in the peak time. The congestion time equals to sixteen minutes, which is lower than the previous scenario, and that resulted in 2 Pounds for congestion cost. The total journey time, which equals to 228 hours and forty-three minutes, resulted 4076 pounds per the six hours for the journey cost. The decrease in journey and congestion times, decreased the journey cost and total cost.

Table 44: twelfth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| **Walk** | 66:34:18 | 133:08:36 | 0:16:15 | 982 | 2 | 984 |
| **Server Queue** | 15:25:24 | 52:26:22 | 0:00:00 | 387 | 0 | 387 |
| **Server Process** | 146:43:48 | 366:49:30 | 0:00:00 | 2707 | 0 | 2707 |
| **Total** | 228:43:30 | 552:24:27 | 0:16:15 | 4076 | 2 | 4078 |

#### 5.1.12.2 **Average LOS (t):**

Figure 86 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles, the drinks 2 area and the 5th isle of general items area. The black areas increased in this scenario.

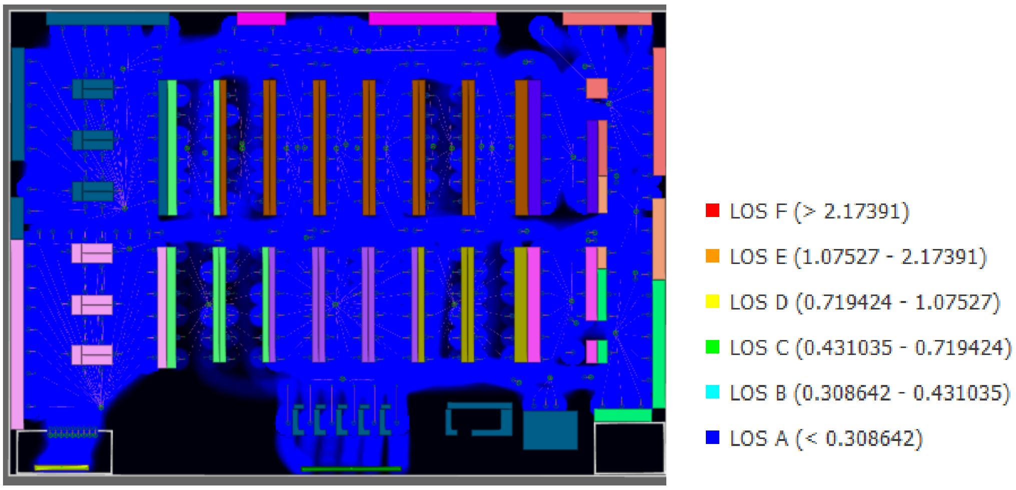



Figure 86: twelfth scenario average LOS (t) map

#### 5.1.12.3 **Experienced LOS (t):**

Figure 87 shows the experienced LOS (t) map. It shows that the blue colour covers most of the areas and it increased, while the green (LOS C) is rarely available in two main areas, the fresh produce area and pre-prepared food area. Hence, LOS C is lower than the previous scenario.

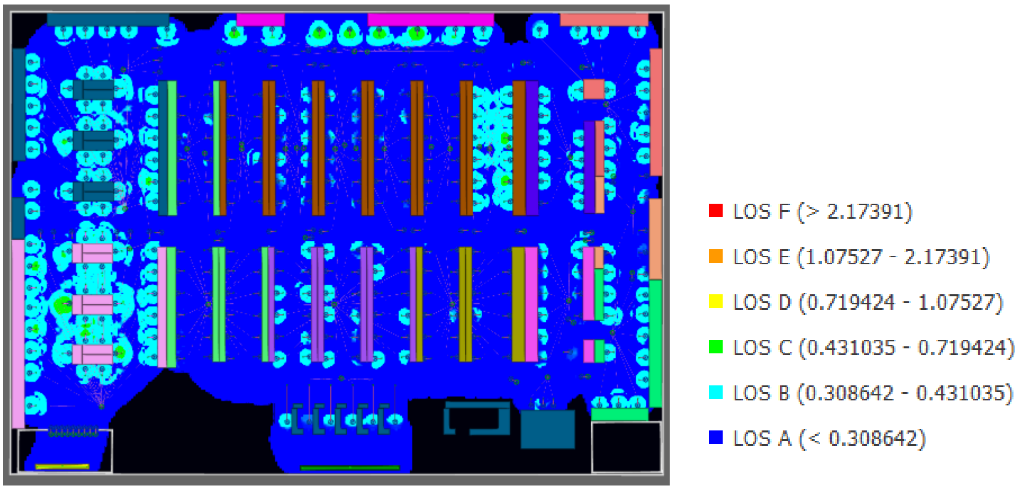



Figure 87: twelfth scenario experienced LOS (t) map

#### 5.1.12.4 **Maximum LOS:**

Figure 88 shows that the fresh produce, the pre-prepared food area and the isle No. 6 of general items had LOS E, but lower than the previous scenario. The seafood, meat and frozen areas had LOS D and LOS E, and lower than the previous scenario. The household area had LOS A. The remaining ranges between areas LOS A and C.

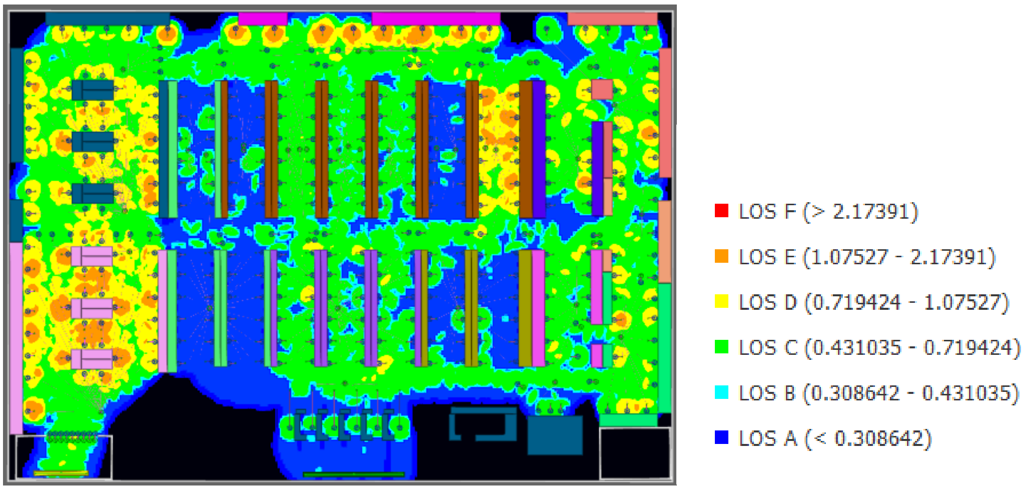



Figure 88: twelfth scenario maximum LOS map

#### 5.1.12.5 **Shoppers' density graph:**

Figure 89 shows the LOS E slightly decreased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C. Table 45 converts Figure 89 into average numbers.

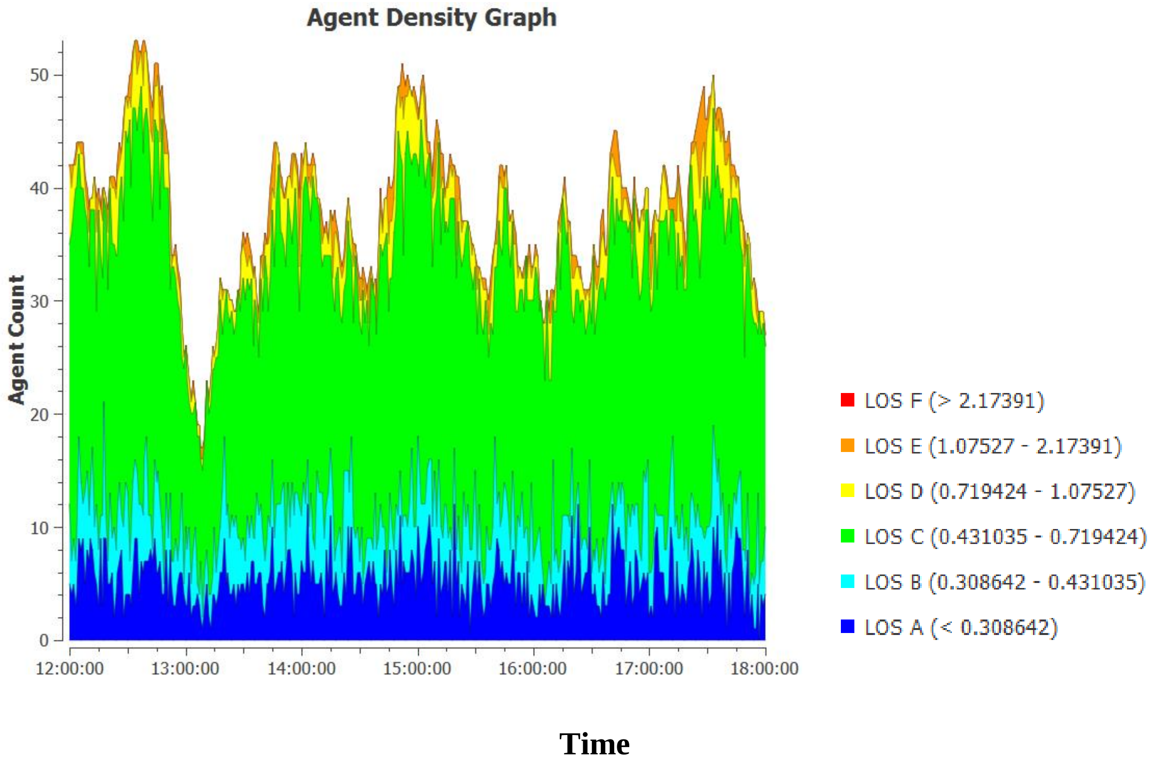



Figure 89: twelfth scenario shoppers' densities graph

Table 45: twelfth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 1956 | 1849 | 8494 | 1068 | 392 | 0 |
| Average (Total shoppers/ simulation frame period) | 5.41 | 5.12 | 23.52 | 2.95 | 1.08 | 0 |

### 5.1.13 The thirteenth scenario:

In the thirteenth scenario we increased the isles width by another 0.5 meter, so the total length increased by 5.5 meters over the twelfth scenario, while remained the same. The total length is 65.5 meters and the total width is 42.5 meters. The total area is 2783.75 square meters. Table 46 summarizes the scenario dimensions.

Table 46: thirteenth scenario dimensions

| Isle name | Dimension |
|---|---|
| Northern isle | 5.0 m |
| Mid isle | 2.8 m |
| Southern isle | 3.5 m |
| Central isles (total 14 isles) | 3.8 m |
| Eastern isles (total 4 isles) | 4.6 m |
| Western isles (total 4 isles) | 4.6 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 65.5 m |
| Total width | 42.5 m |
| Total area. | 2783.75 square meter |

#### 5.1.13.1 Shoppers' social cost:

In Table 47, the total cost in this scenario, increased to 4100 pounds for the 6 hours in the peak time. The congestion time equals to seventeen minutes, which is almost similar to the previous scenario, and that resulted in 2 Pounds for congestion cost. The total journey time, which equals to 230 hours and forty-three minutes, resulted 4098 pounds per the six hours for the journey cost. The costs of the thirteenth scenario are near to the previous scenario.

Table 47: thirteenth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 68:28:01 | 136:56:01 | 0:17:27 | 1010 | 2 | 1012 |
| Server Queue | 15:12:15 | 51:41:38 | 0:00:00 | 381 | 0 | 381 |
| Server Process | 146:40:49 | 366:42:03 | 0:00:00 | 2706 | 0 | 2706 |
| Total | 230:21:04 | 555:19:42 | 0:17:27 | 4098 | 2 | 4100 |

#### 5.1.13.2 **Average LOS (t)**

Figure 90 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles, the drinks 2 area and the 5th isle of general items area. The black areas increased in this scenario.

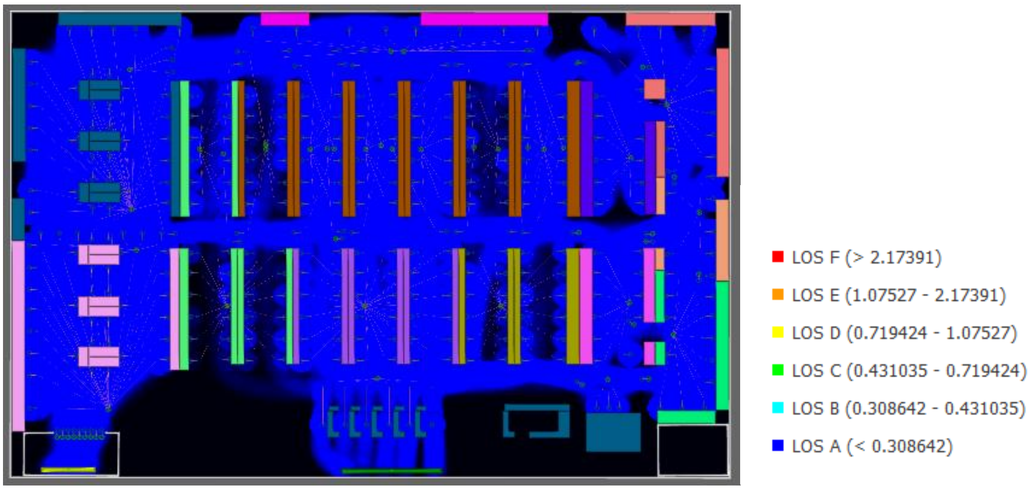



Figure 90: thirteenth scenario average LOS (t) map

#### 5.1.13.3 **Experienced LOS (t):**

Figure 91 shows the experienced LOS (t) map. It shows that the blue colour covers most of the areas and it increased, while the green (LOS C) is rarely available in all areas. Hence, LOS C is lower than the previous scenario.

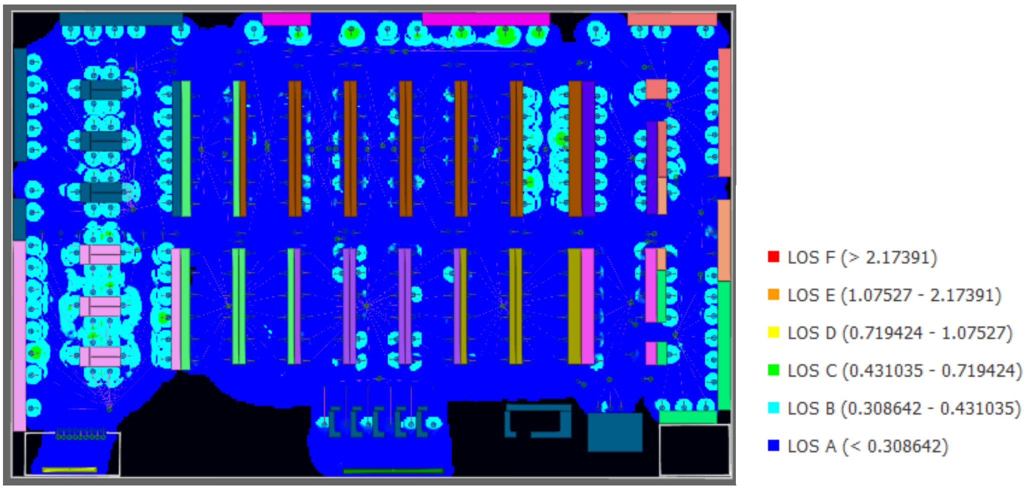



Figure 91: thirteenth scenario experienced LOS (t) map

#### 5.1.13.4 **Maximum LOS:**

Figure 92 shows that the fresh produce, the pre-prepared food area and the isle No. 6 of general items had LOS E, but lower than the previous scenario. The seafood, meat and frozen areas had LOS D, and lower than the previous scenario. The household area had LOS A. The remaining ranges between areas LOS A and C.

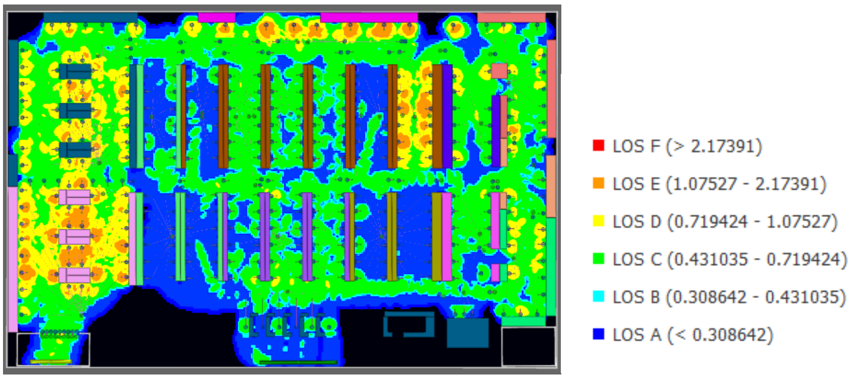
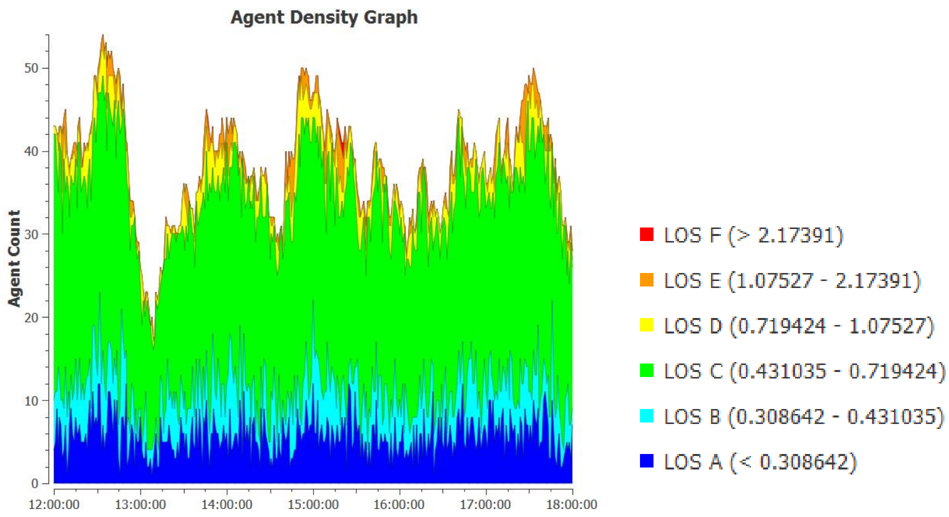



Figure 92: thirteenth scenario maximum LOS map

#### 5.1.13.5 **Shoppers' density graph:**

Figure 93 shows the LOS E slightly decreased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C and then LOS A. Table 48 converts Figure 93 into average numbers.




Time (hh:mm:ss)

Figure 93: thirteenth scenario shoppers' densities graph

Table 48: thirteenth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 2079 | 1903 | 8443 | 1013 | 402 | 8 |
| Average (Total shoppers/ simulation frame period) | 5.75 | 5.27 | 23.38 | 2.8 | 1.11 | 0.02 |

### 5.1.14 The fourteenth scenario:

In the fourteenth case scenario we increased the isles width by another 0.5 meter, so the total width increased by 5.5 meters over the thirteenth scenario, while the length remained the same. The total length is 71 meters and the total width is 42.5 meters. The total area is 3017.5 square meters. Table 49 summarizes the modification, on the sixth case scenario, in the dimensions and areas. The total area increased by 233.75 square meters.

Table 49: fourteenth scenario dimensions

| **Isle name** | **Dimension** |
|---|---|
| Northern isle | 5.0 m |
| Mid isle | 2.8 m |
| Southern isle | 3.5 m |
| Central isles (total 14 isles) | 4.3 m |
| Eastern isles (total 4 isles) | 5.1 m |
| Western isles (total 4 isles) | 5.1 m |
| Western vertical isles (total (total 4 isles) | 2.8 m |
| Total length | 71.0 m |
| Total width | 42.5 m |
| Total area. | 3017.5 square meter |

#### 5.1.14.1 **The shoppers' social cost:**

In Table 50, the total cost in this scenario, increased to 4134 pounds for the 6 hours in the peak time. The congestion time equals to twelve minutes, which is the lowest among all scenarios, and that resulted in 1.5 Pounds for congestion cost. The total journey time, which equals to 232 hours and thirty-one minutes, resulted 4133 pounds per the six hours for the journey cost.

Table 50: fourteenth Scenario social cost for all agents during the study period

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 70:20:31 | 140:41:02 | 0:12:26 | 1038 | 1.5 | 1039 |
| Server Queue | 15:28:27 | 52:36:45 | 0:00:00 | 388 | 0 | 388 |
| Server Process | 146:42:39 | 366:46:38 | 0:00:00 | 2706 | 0 | 2706 |
| Total | 232:31:37 | 560:04:25 | 0:12:26 | 4133 | 1.5 | 4134 |

#### 5.1.14.2 **Average LOS (t):**

Figure 94 shows the average LOS (t) of this scenario, as noticed, still the dominant colour in the map is LOS A, while very minimal isles have a combination of blue and black, such as the southern side of household isles, the drinks 2 area and the 5th isle of general items area. The black areas increased in this scenario.

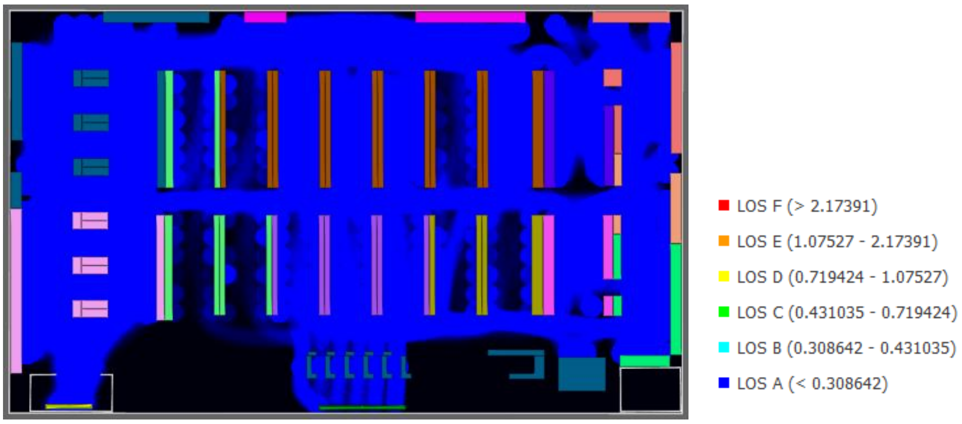



Figure 94: fourteenth scenario average LOS (t) map

#### 5.1.14.3 **Experienced LOS (t)**

Figure 95 shows the experienced LOS (t) map. It shows that the blue colour covers most of the areas and it increased, while the green (LOS C) disappeared from almost all areas. Hence, LOS C is lower than the previous scenario.

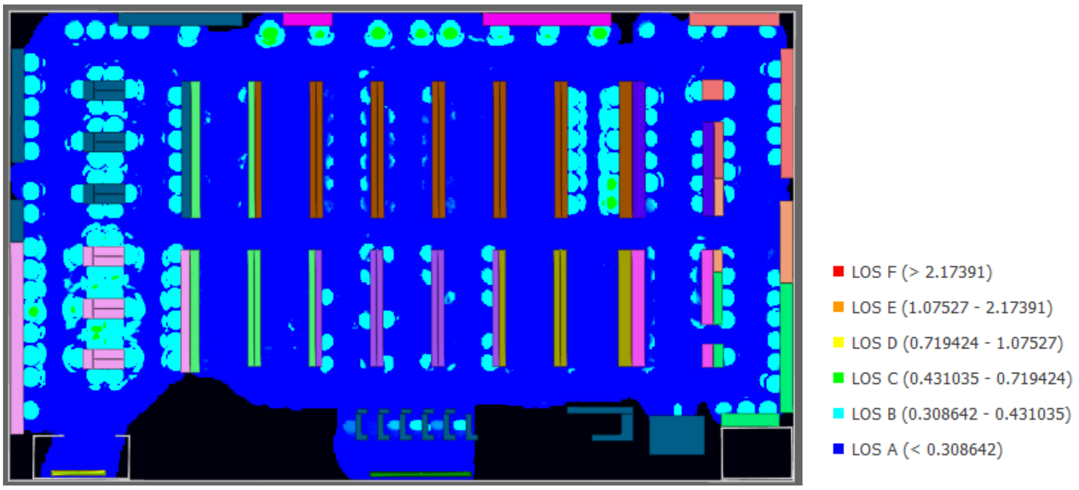



Figure 95: fourteenth scenario experienced LOS (t) map

#### 5.1.14.4 **Maximum LOS**

Figure 96 shows that the fresh produce, the pre-prepared food area and the isle No. 6 of general items had LOS E, but lower than the previous scenario. The seafood, meat and frozen areas had LOS D, also lower than the previous scenario. The household area had LOS A. The remaining ranges between areas LOS A and C.

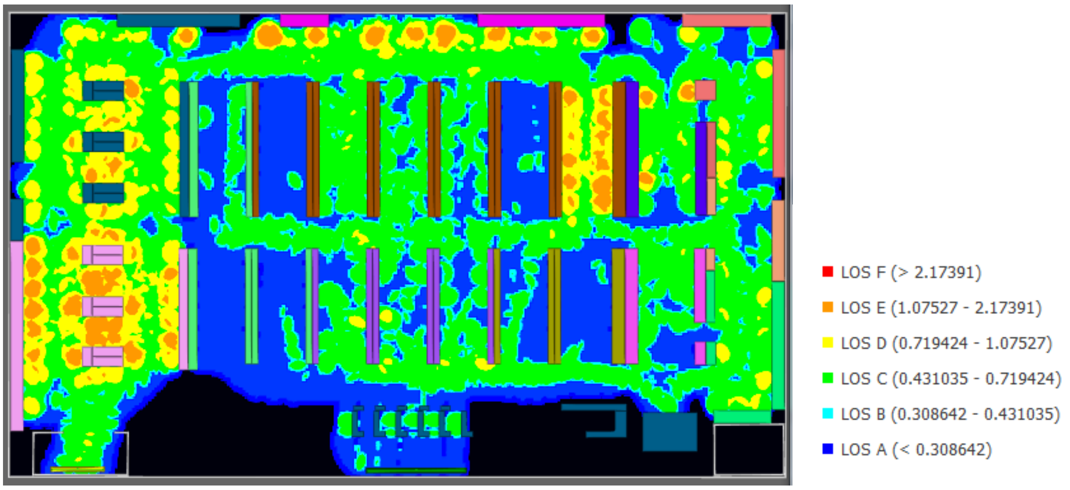
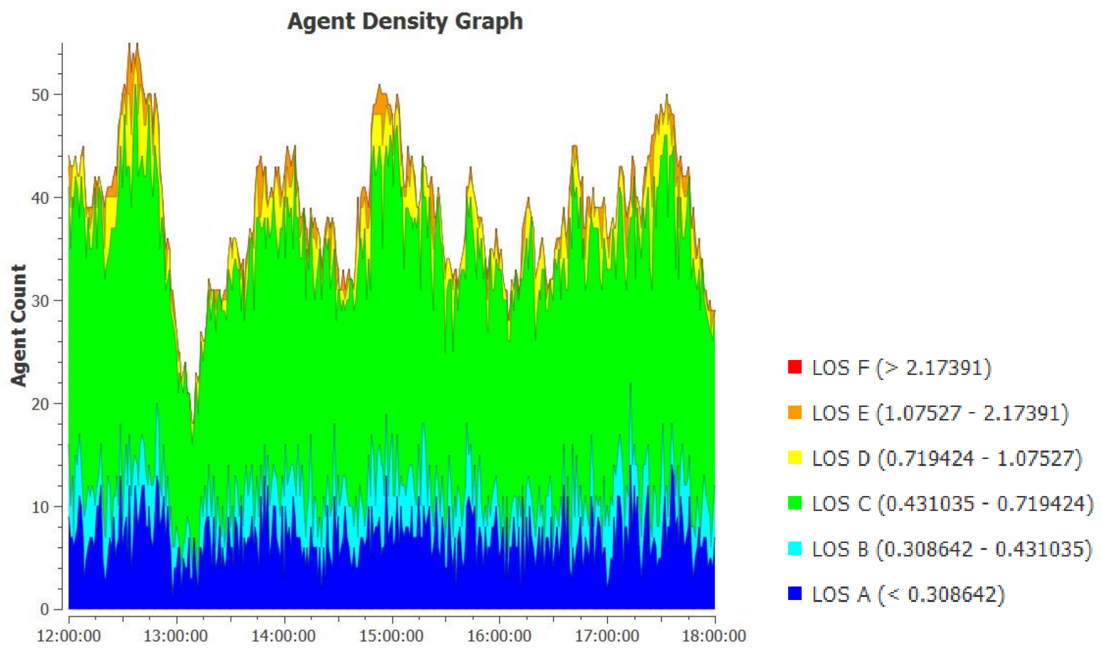



Figure 96: fourteenth scenario maximum LOS map

### 5.1.14.5 **Shopper density graph:**

Figure 97 shows the LOS E slightly decreased, during the study period in the simulation. The LOS A colour increased when comparing it with the previous scenario. However, the dominant colour is LOS C and then LOS A. Table 51 converts Figure 97 into average numbers.




**Time(hh:mm:ss)**

Figure 97: fourteenth scenario shoppers' densities graph

Table 51: fourteenth scenario average shoppers' densities

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 2526 | 1523 | 8542 | 1019 | 357 | 0 |
| Average (Total shoppers/ simulation frame period) | 6.99 | 4.21 | 23.66 | 2.82 | 0.98 | 0 |

### 5.2 2000 shoppers per day.

We increased the population to 2000 shoppers per day, to reflect the actual situation of an event, such as the peak time on Friday. In this area we took seven scenarios, they are marked in green from Figure 98 to Figure 100.

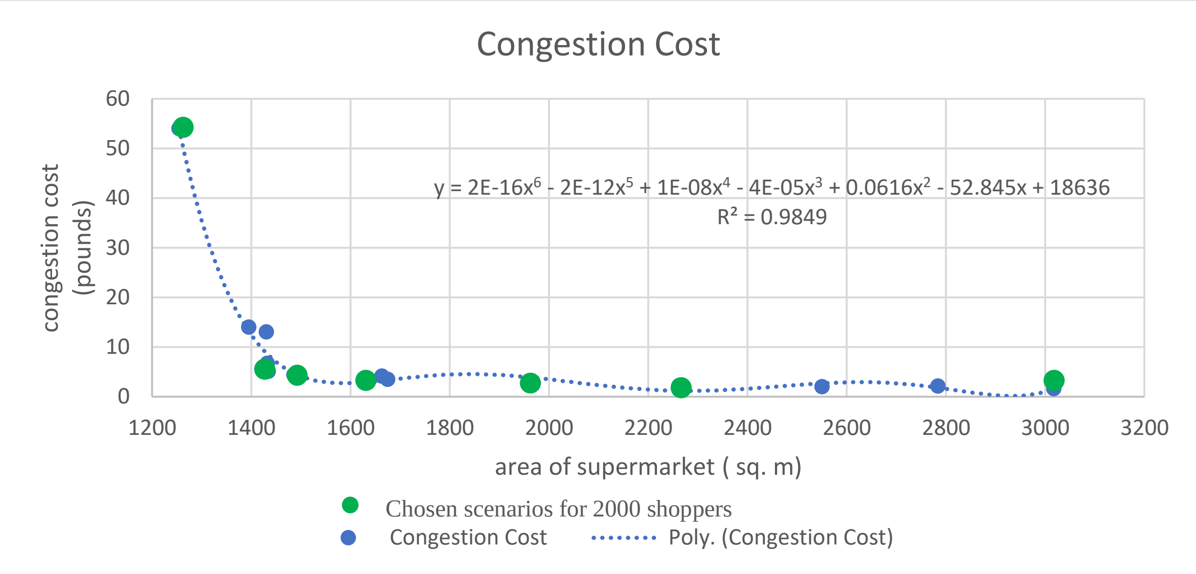



Figure 98: chosen scenarios in congestion cost vs. area of supermarket for 2000 shoppers per day study

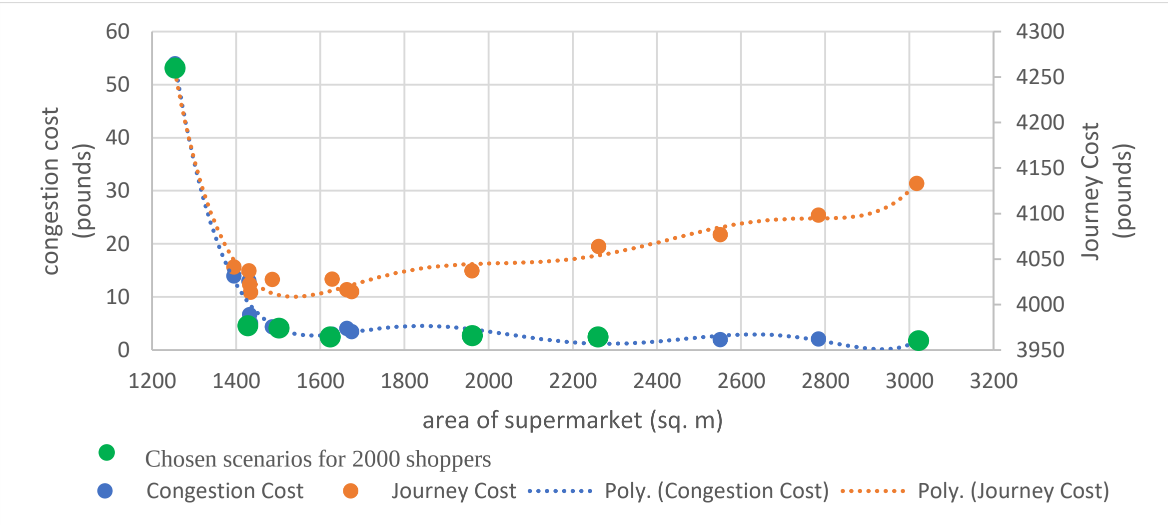



Figure 99: chosen scenarios in congestion cost vs. journey cost for 2000 shoppers per day study

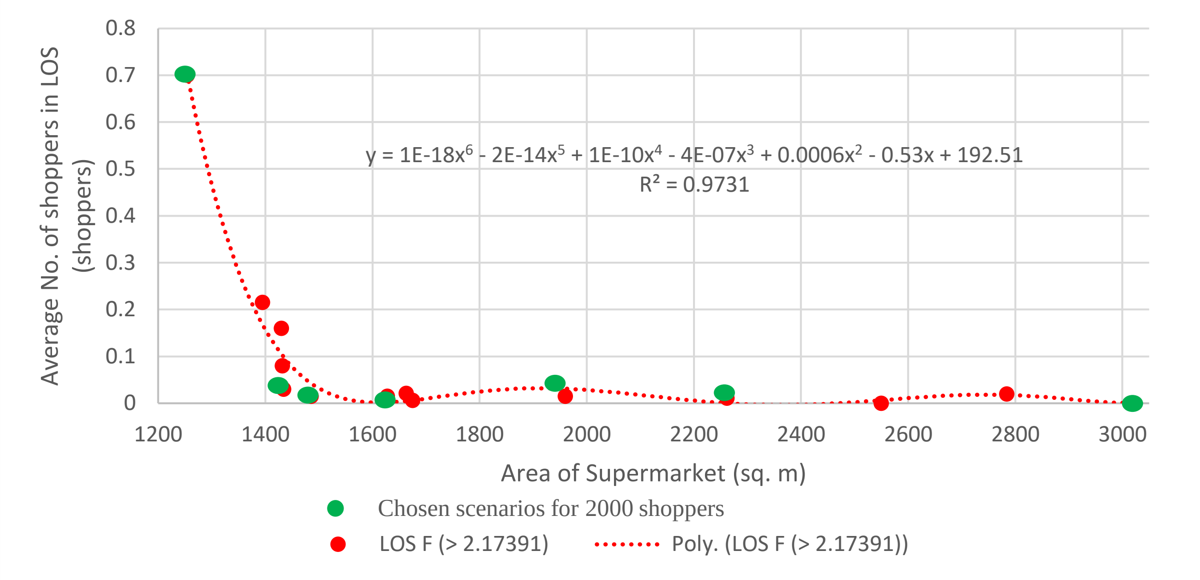



Figure 100: LOS F 2nd study area

### 5.2.1 The first scenario results for 2000 shoppers per day:

#### 5.2.1.1 **Shoppers' social cost:**

Table 52 shows that the total social cost for this scenario is 9604 pounds per simulation study period, 319 pounds of them for congestion cost, while 9285 pounds for journey cost, and these values are the highest among all scenarios.

Table 52: first scenario social cost for 2000 shoppers per day

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 191:52:26 | 383:44:53 | 43:15:13 | 2832 | 319 | 3151 |
| Server Queue | 63:03:52 | 214:25:07 | 0:00:00 | 1582 | 0 | 1582 |
| Server Process | 264:00:49 | 660:02:03 | 0:00:00 | 4871 | 0 | 4871 |
| Total | 518:57:07 | 1258:12:03 | 43:15:13 | 9285 | 319 | 9604 |

### 5.2.1.2 **Average LOS (t) plan:**

In Figure 101 the LOS C appeared in three main areas, the fresh produce area, the pre-prepared food area and the sixth isle of general items, however, the remaining area has LOS A, while the seafood area had LOS B.

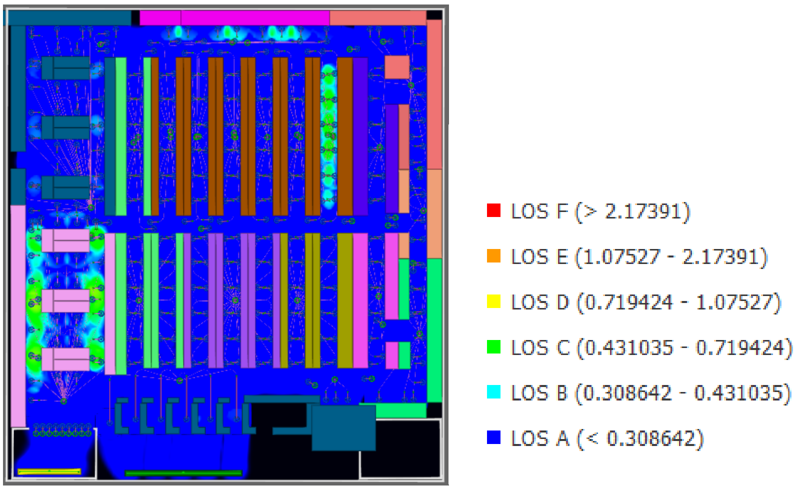



Figure 101: first scenario average LOS (t) map for 2000 shoppers per day

### 5.2.1.3 **Experienced LOS (t) plan**

Figure 102 shows that the fresh produce area had LOS E, D and C, while the seafood, pre-prepared food and the sixth isle of general items had LOS D and C, the remaining areas ranged from LOS A to LOS B.

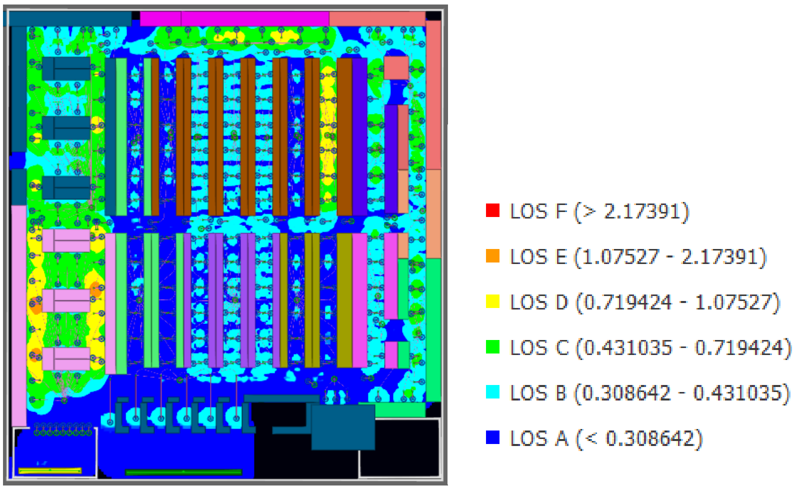



Figure 102: first scenario experienced LOS (t) map for 2000 shoppers per day

### 5.2.1.4 **Maximum LOS plan**

The LOS F appeared mainly tin three areas, the fresh produce, seafood, the pre-prepared food and the sixth isle of general items areas.

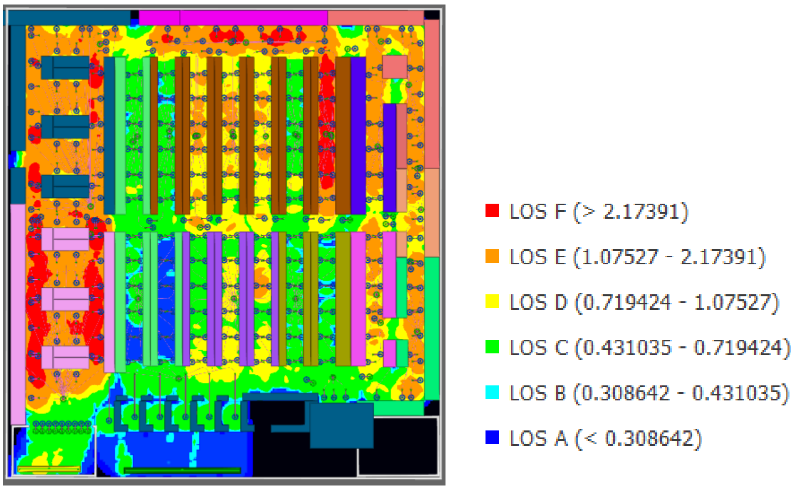



Figure 103: first scenario maximum LOS map for 2000 shoppers per day

### 5.2.1.5 **Shoppers' density graph:**

The average no. of shoppers in LOS F raised to 8.6 shoppers on average, as shown in Table 53, while the average no. of people in LOS A became 0.62 shoppers on average. Figure 104 shows that LOS F is constant during the study period.

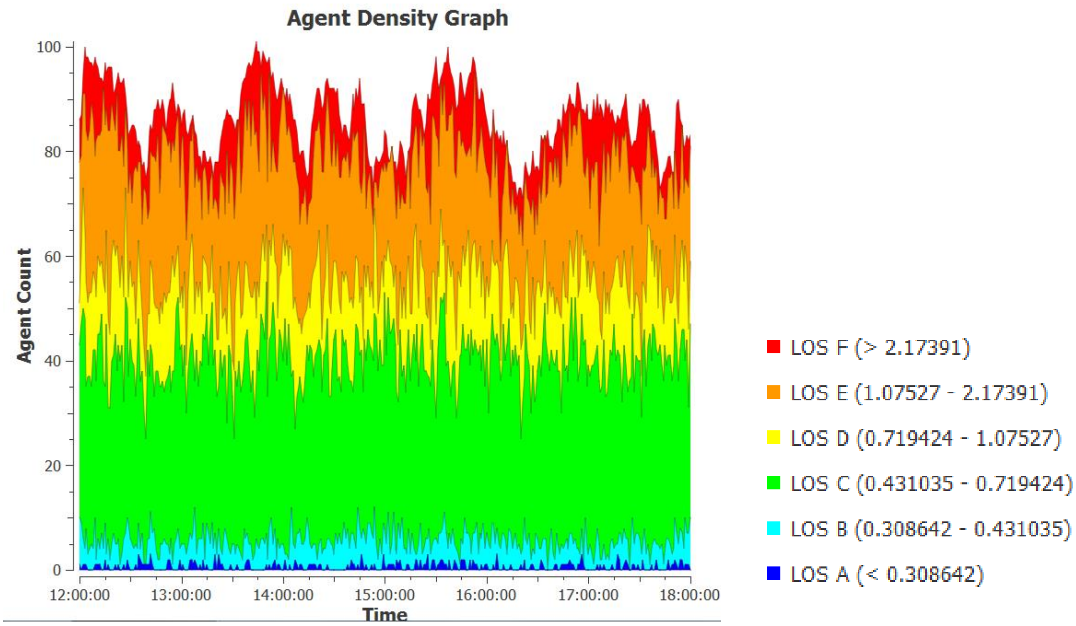



Figure 104: first scenario shoppers' densities graph for 2000 shoppers per day

Table 53: first scenario average shoppers' densities for 2000 shoppers per day

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 227 | 1758 | 12564 | 5204 | 8328 | 3133 |
| Average (Total shoppers/ simulation frame period) | 0.62 | 4.8 | 34.8 | 14.4 | 23 | 8.6 |

### 5.2.2 The fifth scenario results for 2000 shoppers per day:

#### 5.2.2.1 **Shoppers' social cost:**

Table 54 shows the revised cost with 2000 shoppers population during the day, the total social cost increased to 8257 pounds, the increase includes the time and cost for journey and congestion. The congestion cost equals to 36.5 pounds. The journey cost equals to 8220.5 pounds.

Table 54: fifth scenario social cost for 2000 shoppers per day

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 127:37:45 | 255:15:31 | 4:56:55 | 1883 | 36 | 1920 |
| Server Queue | 59:09:24 | 201:07:58 | 0:00:00 | 1484 | 0 | 1484 |
| Server Process | 263:00:12 | 657:30:29 | 0:00:00 | 4852 | 0 | 4852 |
| Total | 449:47:21 | 1113:53:57 | 4:56:55 | 8220 | 36 | 8257 |

### 5.2.2.2 **Average LOS (t) plan:**

The average LOS (t) plan in Figure 105 shows that LOS B started to appear in three zones, the 6th isle of average LOS (t) plan, the pre-prepared food area and fresh produce area. While the remaining areas has LOS A.

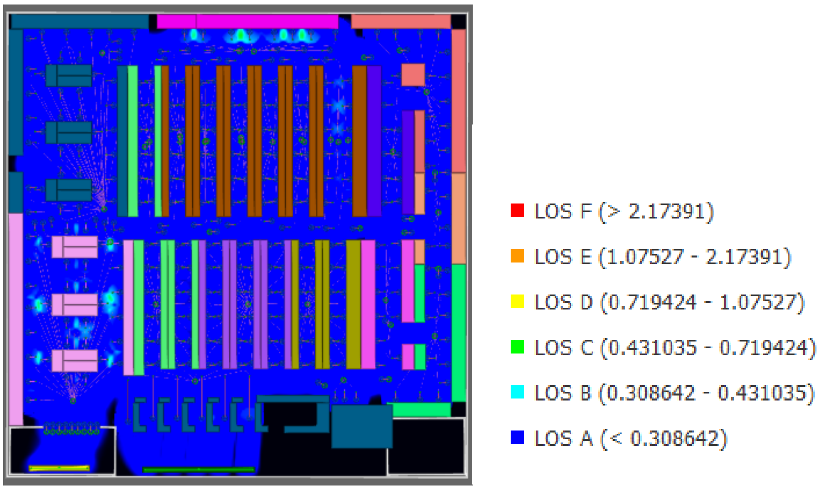



Figure 105: fifth scenario average LOS (t) map for 2000 shoppers per day

### 5.2.2.3 **Experienced LOS (t) plan**

The experienced LOS (t) plan, Figure 106, shows LOS C in the fresh produce, pre-prepared, seafood and the sixth isle of general items areas, while meat, frozen items, Japanese deli, western deli areas has LOS B, Household areas has LOS A. LOS D appeared in fresh produce and pre-prepared areas.

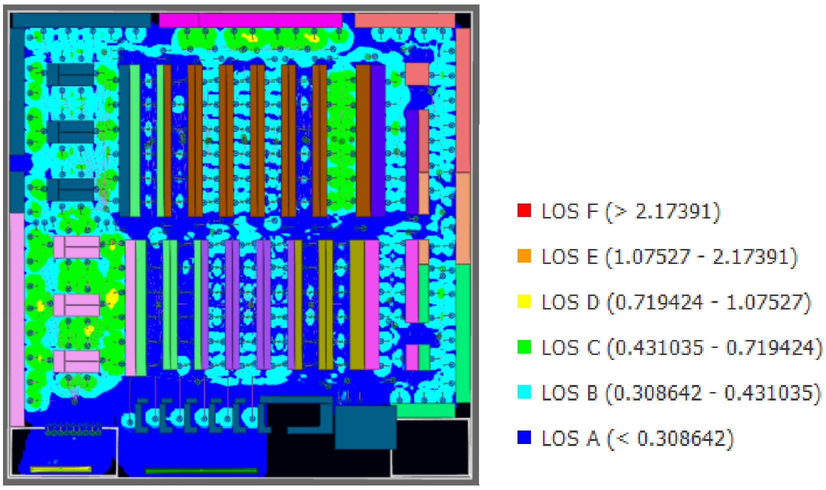



Figure 106: fifth scenario experienced LOS (t) map for 2000 shoppers per day

### 5.2.2.4 **Maximum LOS plan**

Figure 107 shows that the fresh produce, pre-prepared food and the sixth isle of general items areas reached the LOS F.

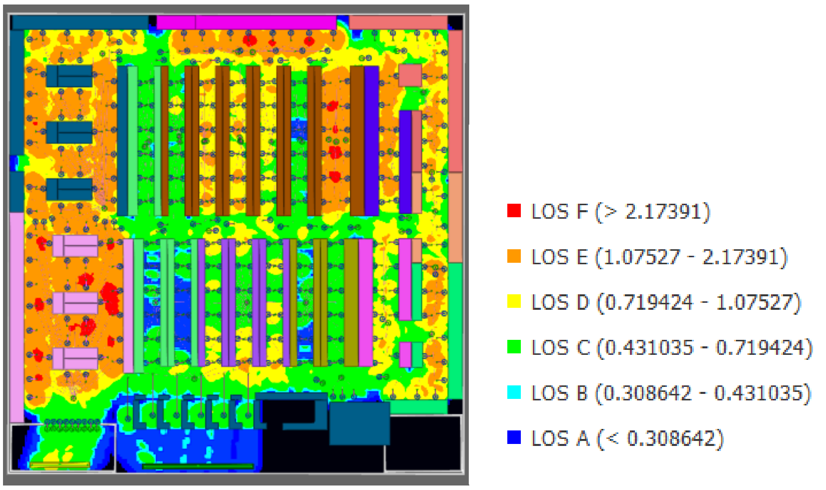



Figure 107: fifth scenario maximum LOS map for 2000 shoppers per day

### 5.2.2.5 **Shoppers' density graph:**

Figure 108 shows a lot of LOS F during the simulation, such as at 12:45 hours and 14:30 hours, while the dominant colour is LOS C. Table 55 shows that the average No. of Shopper fall into the LOS A are 1.3, while the average No. of shoppers fall into LOS F are 0.4 shoppers.

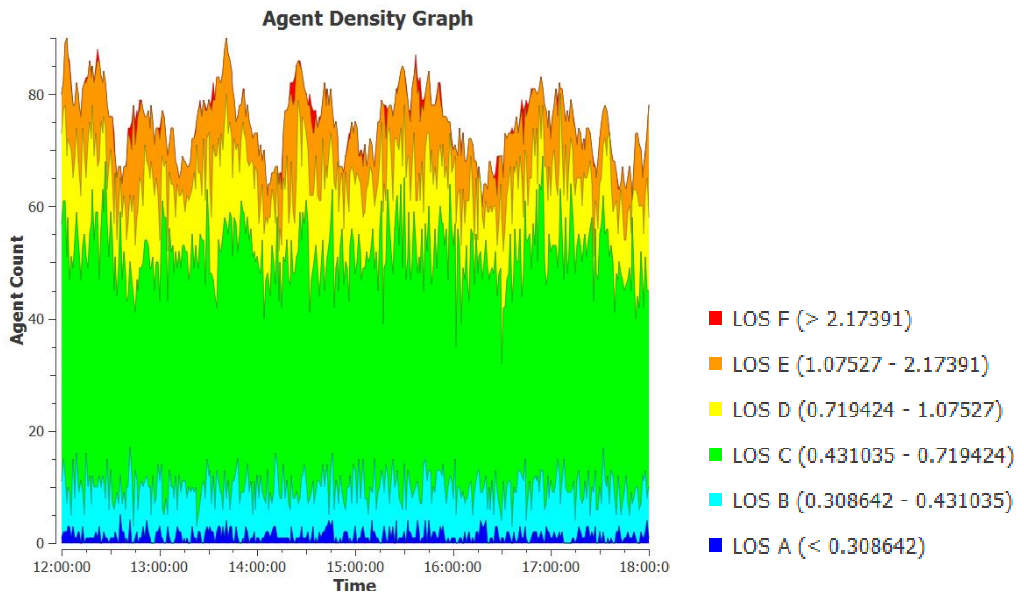



Figure 108: fifth scenario shoppers' densities graph for 2000 shoppers per day

Table 55: fifth scenario average shoppers' densities for 2000 shoppers per day

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 483 | 3047 | 15132 | 4800 | 3442 | 146 |
| Average (Total shoppers/ simulation frame period) | 1.33 | 8.44 | 41.91 | 13.29 | 9.53 | 0.4 |

### 5.2.3 The sixth scenario results for 2000 shoppers per day:

#### 5.2.3.1 **Shoppers' social cost:**

Table 56 shows that the total social cost of this scenario equals to 8211.6 pounds, which is lower than the previous case. The congestion cost reduced to 24.6 pounds and the journey cost became 8187 pounds.

Table 56: sixth scenario social cost for 2000 shoppers per day

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 123:33:06 | 247:06:12 | 3:20:24 | 1823 | 24 | 1848 |
| Server Queue | 60:13:53 | 204:47:14 | 0:00:00 | 1511 | 0 | 1511 |
| Server Process | 262:58:50 | 657:27:05 | 0:00:00 | 4851 | 0 | 4851 |
| Total | 446:45:49 | 1109:20:30 | 3:20:24 | 8186 | 24 | 8211 |

#### 5.2.3.2 **Average LOS (t) plan:**

The LOS B in Figure 109 reduced to the pre-prepared food area and a little at fresh produce area. While the remaining areas has LOS A.

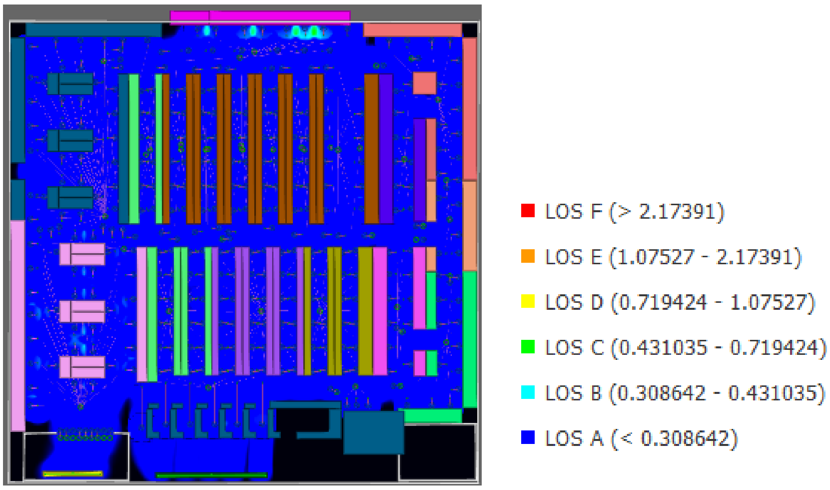



Figure 109: sixth scenario average LOS (t) map for 2000 shoppers per day

#### 5.2.3.3 **Experienced LOS (t) plan**

In Figure 110 LOS D appeared in pre-prepared food area only, while the sixth isle of general items, fresh produce and seafood areas had LOS C, the remaining areas ranged from LOS A to LOS B.

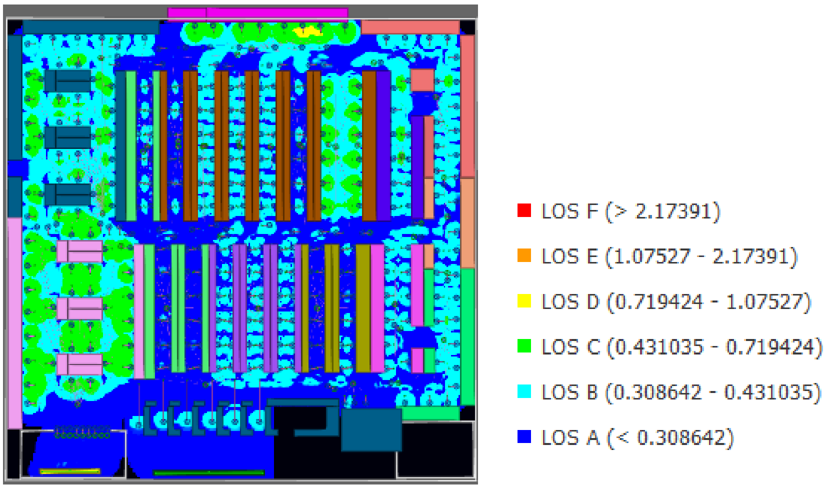



Figure 110: sixth scenario experienced LOS (t) map for 2000 shoppers per day

#### 5.2.3.4 **Maximum LOS plan**

The LOS F in Figure 111 appeared in fresh produce and pre-prepared food areas only, the seafood and sixth isle of general items, frozen items, meat and Japanese deli had LOS E. the remaining areas ranged from LOS A to LOS C.

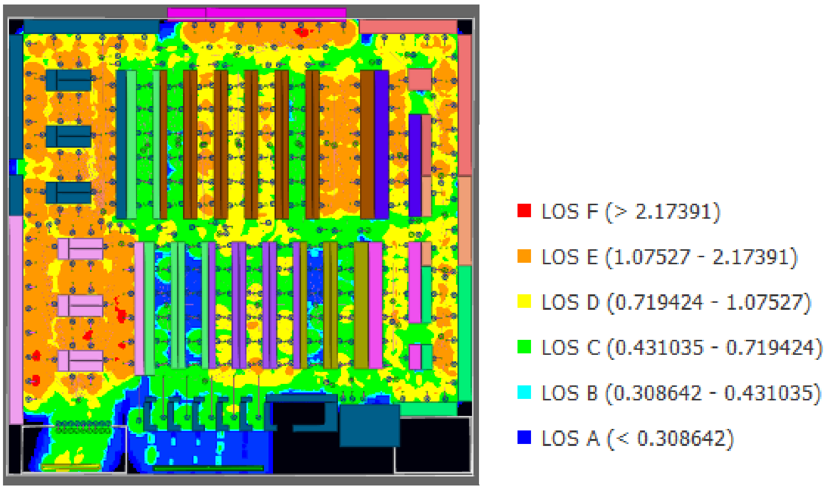



Figure 111: sixth scenario maximum LOS map for 2000 shoppers per day

### 5.2.3.5 **Shoppers' density graph:**

LOS F in Figure 112 is very minimal and it is mainly between 12:00 hours to 14:00 hours. Table 57 shows the LOS F is 0.14 while 2.26 average no. of shoppers falling in LOS A.

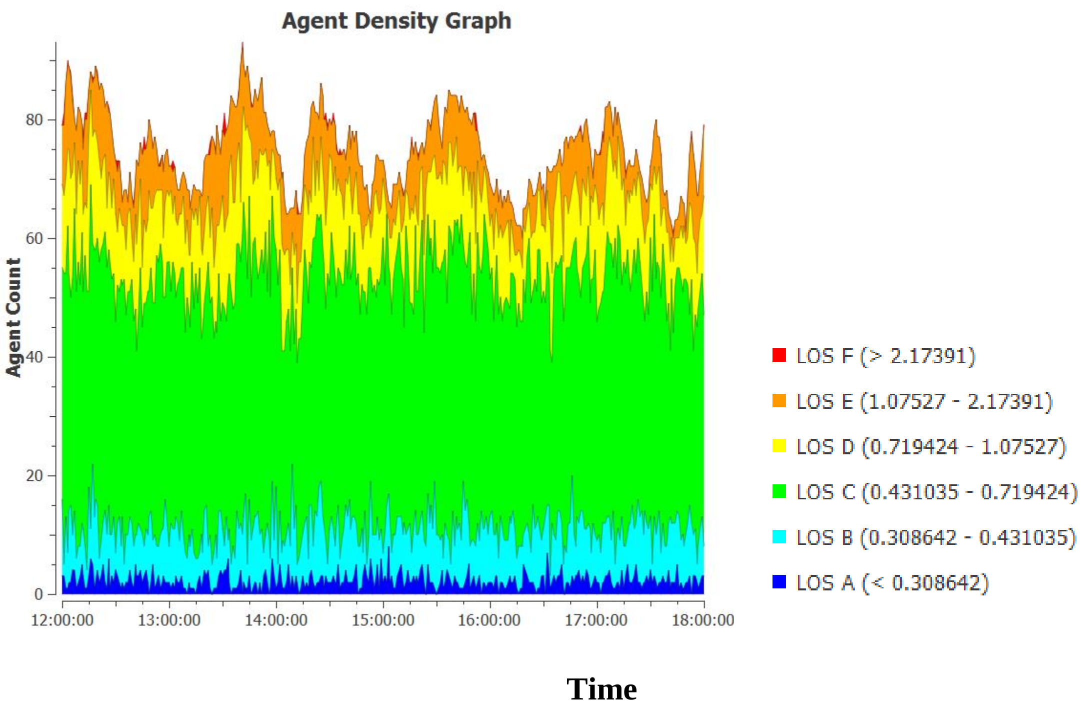



Figure 112: sixth scenario shoppers' densities graph for 2000 shoppers per day

Table 57: sixth scenario average shoppers' densities for 2000 shoppers per day

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 818 | 3121 | 15346 | 4607 | 2970 | 51 |
| Average (Total shoppers/ simulation frame period) | 2.26 | 8.64 | 42.5 | 12.76 | 8.22 | 0.14 |

### 5.2.4 The seventh scenario results for 2000 shoppers per day:

#### 5.2.4.1 Shoppers' social cost:

Table 58 shows that the total social cost for this scenario equals to 8130 pounds, the congestion cost equals to 15.8 pounds, while the journey cost equals to 8114 pounds.

Table 58: seventh scenario social cost for 2000 shoppers per day

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 121:12:30 | 242:25:00 | 2:08:19 | 1789 | 15 | 1804 |
| Server Queue | 58:34:31 | 199:09:21 | 0:00:00 | 1469 | 0 | 1469 |
| Server Process | 263:10:01 | 657:55:02 | 0:00:00 | 4855 | 0 | 4855 |
| Total | 442:57:02 | 1099:29:23 | 2:08:19 | 8114 | 15 | 8130 |

#### 5.2.4.2 Average LOS (t) plan:

The LOS B in Figure 113 almost disappeared from all areas, only small quantity remaining at the pre-prepared food area. All the other areas have LOS A.

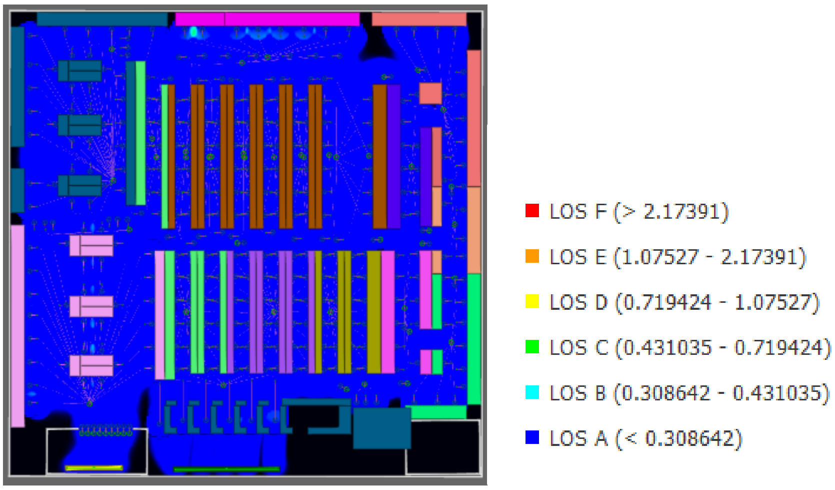



Figure 113: seventh scenario average LOS (t) map for 2000 shoppers per day

#### 5.2.4.3 **Experienced LOS (t) plan**

The LOS D in Figure 114 disappeared from all areas, however LOS C is available at fresh produce, seafood, pre-prepared and the sixth isle of general items areas.

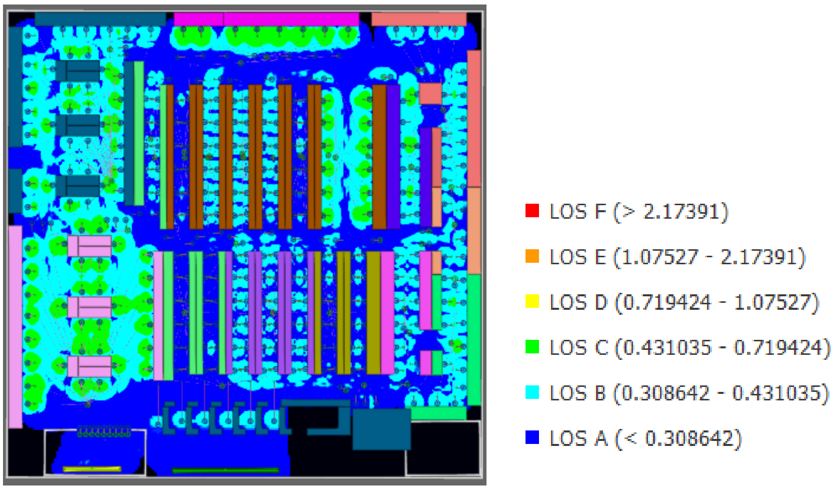



Figure 114: seventh scenario experienced LOS (t) map for 2000 shoppers per day

#### 5.2.4.4 **Maximum LOS plan**

The LOS F in Figure 115 is only available with small quantities at the fresh produce area, while other areas ranges from LOS A to LOS E.

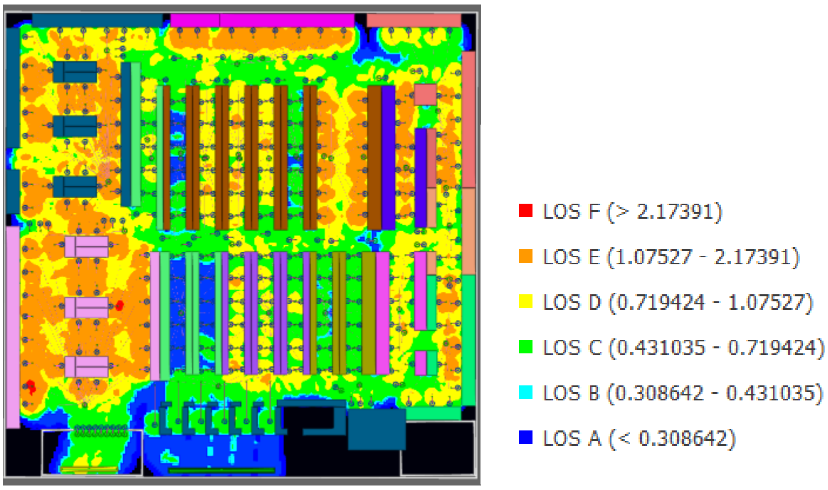



Figure 115: seventh scenario maximum LOS map for 2000 shoppers per day

### 5.2.4.5 **Shoppers' density graph:**

Figure 116 shows that LOS A is increasing, while fewer quantities of LOS F and E. Table 59 shows that LOS F became 0.08 average shoppers falling under LOS F, while LOS A became 4 shoppers on average.

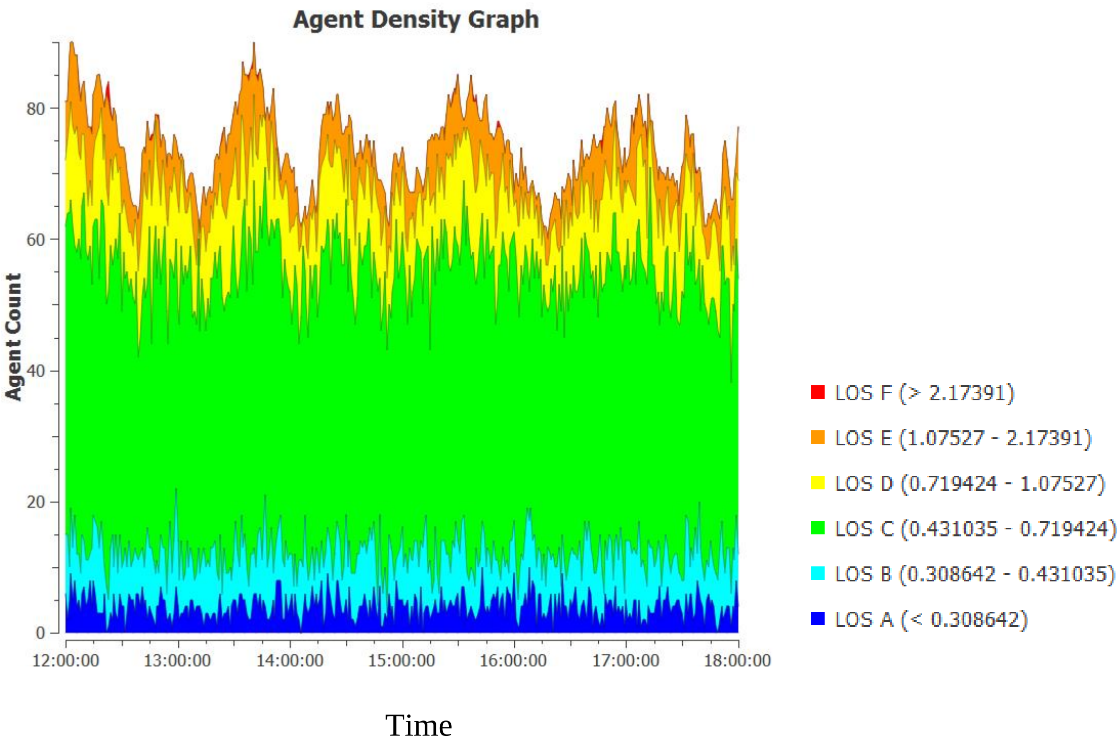



Figure 116: seventh scenario shoppers' densities graph for 2000 shoppers per day

Table 59: seventh scenario average shoppers’ densities for 2000 shoppers per day

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 1453 | 2873 | 15708 | 4190 | 2366 | 29 |
| Average (Total shoppers/ simulation frame period) | 4.02 | 7.95 | 43.51 | 11.6 | 6.5 | 0.08 |

### 5.2.5 The tenth scenario results for 2000 shoppers per day:

#### 5.2.5.1 **Shoppers’ social cost:**

Table 60 shows that the total social cost for this scenario equals to 8187 pounds, the congestion cost equals to 18.6 pounds, while the journey cost equals to 8168 pounds.

Table 60: tenth scenario social cost for 2000 shoppers per day

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 123:24:31 | 246:49:02 | 2:31:28 | 1821 | 18 | 1840 |
| Server Queue | 59:41:07 | 202:55:48 | 0:00:00 | 1497 | 0 | 1497 |
| Server Process | 262:50:03 | 657:05:09 | 0:00:00 | 4849 | 0 | 4849 |
| Total | 445:55:41 | 1106:49:59 | 2:31:28 | 8168 | 18 | 8187 |

#### 5.2.5.2 **Average LOS (t) plan:**

The LOS B in Figure 125 almost disappeared from all areas, also from the pre-prepared food area.

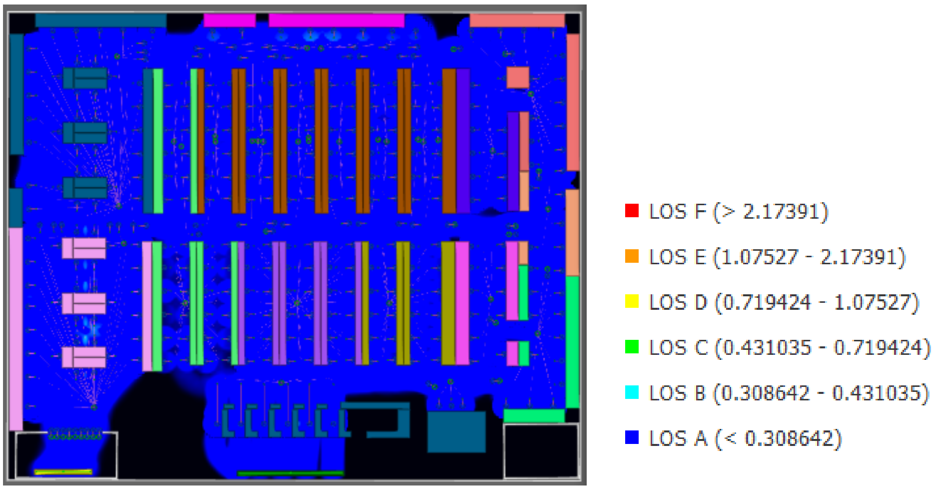



Figure 117: tenth scenario average LOS (t) map for 2000 shoppers per day

#### 5.2.5.3 **Experienced LOS (t) plan**

The LOS D in Figure 126 disappeared from all areas, however LOS C is available at fresh produce, seafood, pre-prepared and the sixth isle of general items areas.

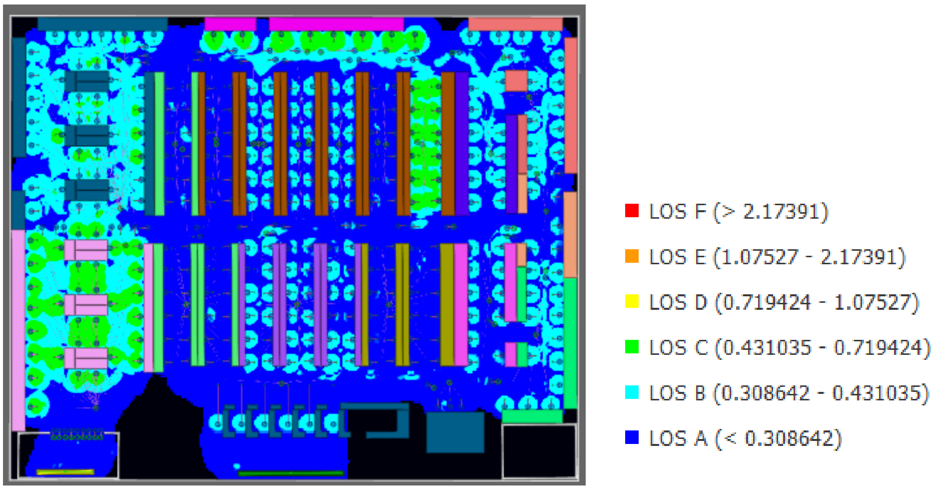



Figure 118: tenth scenario experienced LOS (t) map for 2000 shoppers per day

#### 5.2.5.4 **Maximum LOS plan**

The LOS F in Figure 123 is only available with small quantities at the fresh produce area, the pre-prepared food area and the sixth isle of general items, while other areas ranges from LOS A to LOS E.

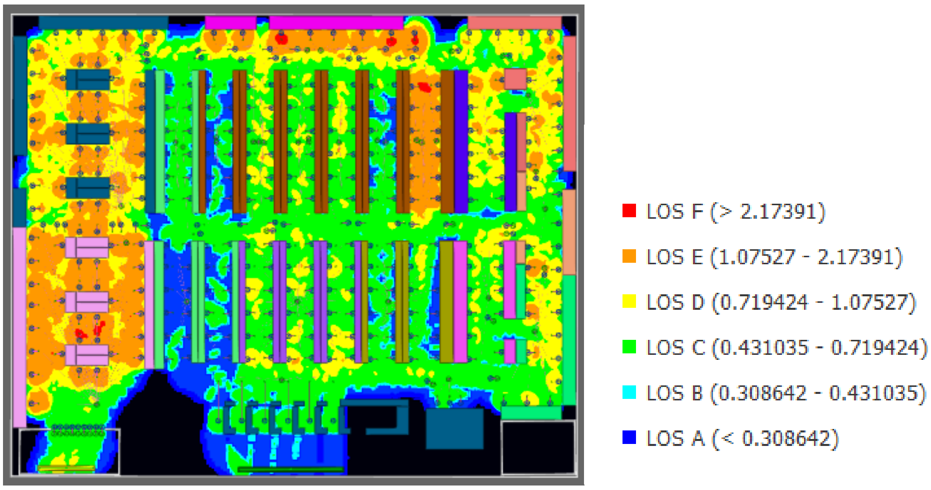



Figure 119: tenth scenario maximum LOS map for 2000 shoppers per day

5.2.5.5 **Shoppers' density graph:**

Figure 128 shows that LOS A is increasing, while fewer quantities of LOS F and E. Table 61 shows that LOS F became 0.16 average shoppers falling under LOS F, while LOS A became 4.5 shoppers on average.

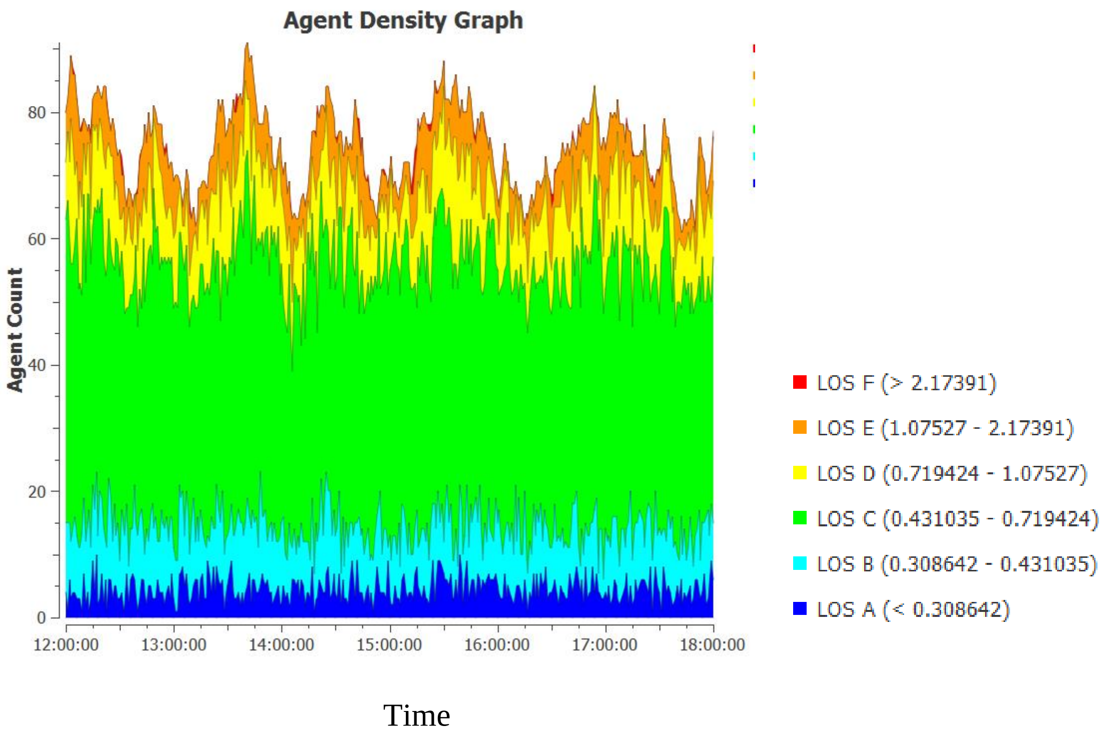



Figure 120: tenth scenario shoppers' densities graph for 2000 shoppers per day

Table 61: tenth scenario average shoppers' densities for 2000 shoppers per day

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 1631 | 3483 | 15151 | 4039 | 2459 | 58 |
| Average (Total shoppers/ simulation frame period) | 4.51 | 9.64 | 41.96 | 11.18 | 6.81 | 0.16 |

### 5.2.6 The eleventh scenario results for 2000 shoppers per day:

#### 5.2.6.1 Shoppers' social cost:

Table 62 shows that the total social cost for this scenario equals to 8203 pounds, the congestion cost equals to 14.7 pounds, while the journey cost equals to 8168 pounds.

Table 62: eleventh scenario social cost for 2000 shoppers per day

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 124:15:23 | 248:30:46 | 2:00:06 | 1834 | 14 | 1848 |
| Server Queue | 59:56:11 | 203:47:02 | 0:00:00 | 1503 | 0 | 1503 |
| Server Process | 262:53:30 | 657:13:45 | 0:00:00 | 4850 | 0 | 4850 |
| Total | 447:05:04 | 1109:31:33 | 2:00:06 | 8188 | 14 | 8203 |

#### 5.2.6.2 Average LOS (t) plan:

The LOS B in Figure 121 almost disappeared from all areas, all areas have LOS A.

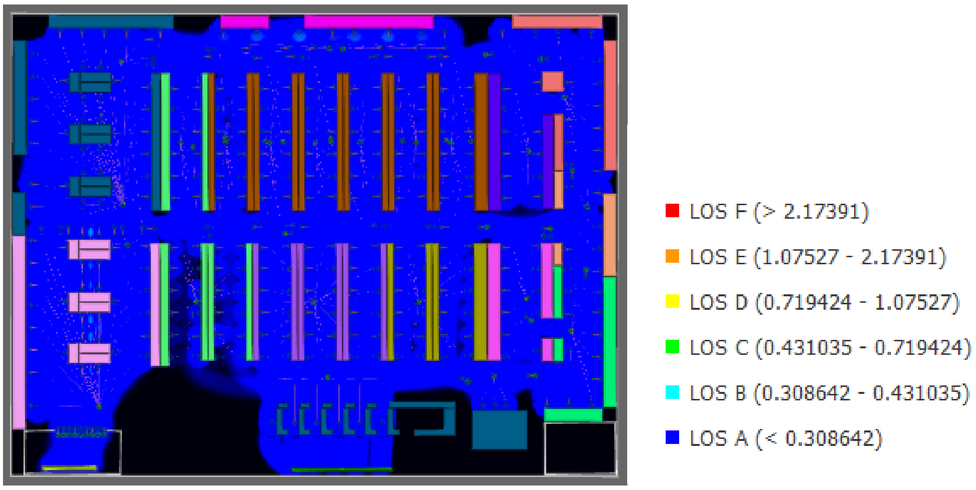



Figure 121: eleventh scenario average LOS (t) map for 2000 shoppers per day

### 5.2.6.3 **Experienced LOS (t) plan**

The LOS D in Figure 122 disappeared from all areas, however LOS C is available at fresh produce, pre-prepared and the sixth isle of general items areas.

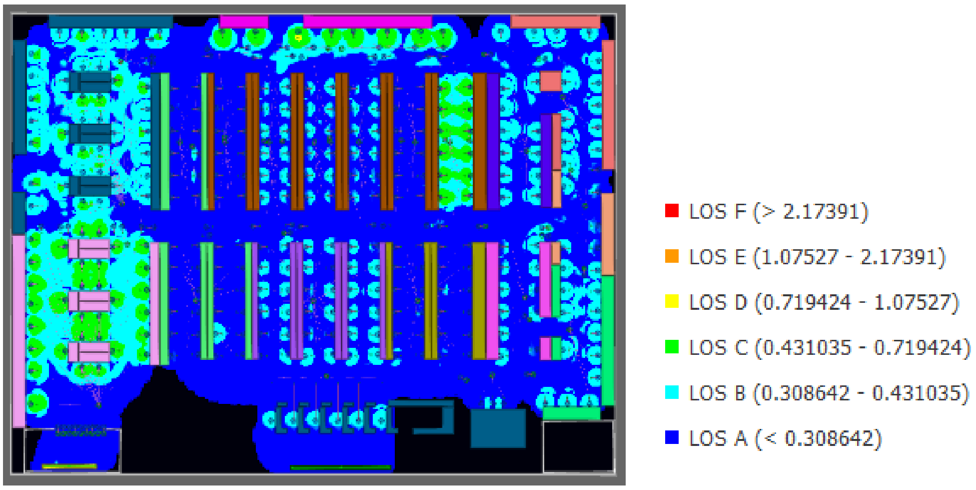



Figure 122: eleventh scenario experienced LOS (t) map for 2000 shoppers per day

### 5.2.6.4 **Maximum LOS plan**

The LOS F in Figure 123 is only available with small quantities at the fresh produce area, while other areas ranges from LOS A to LOS E.

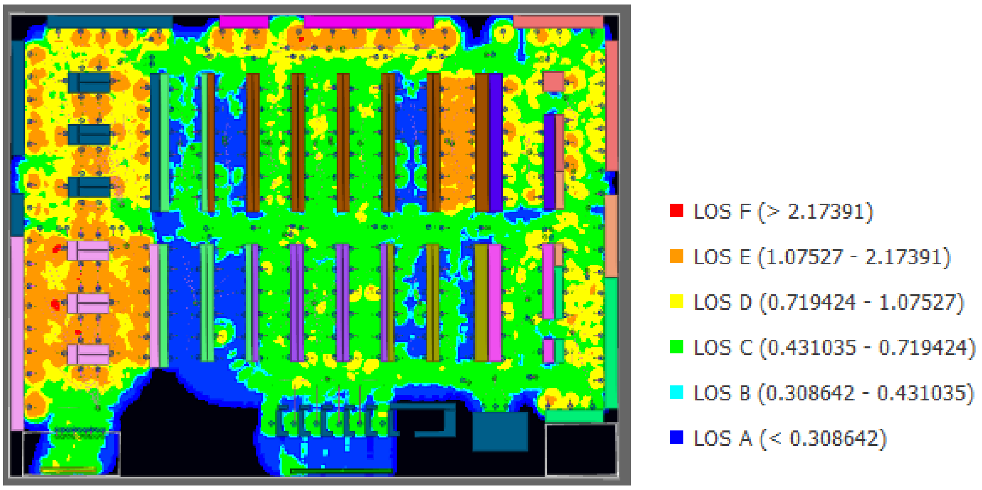



Figure 123: eleventh scenario maximum LOS map for 2000 shoppers per day

### 5.2.6.5 **Shoppers' density graph:**

Figure 124 shows that LOS A is increasing, while fewer quantities of LOS F and E. Table 63 shows that LOS F became 0.12 average shoppers falling under LOS F, while LOS A became 6.8 shoppers on average.

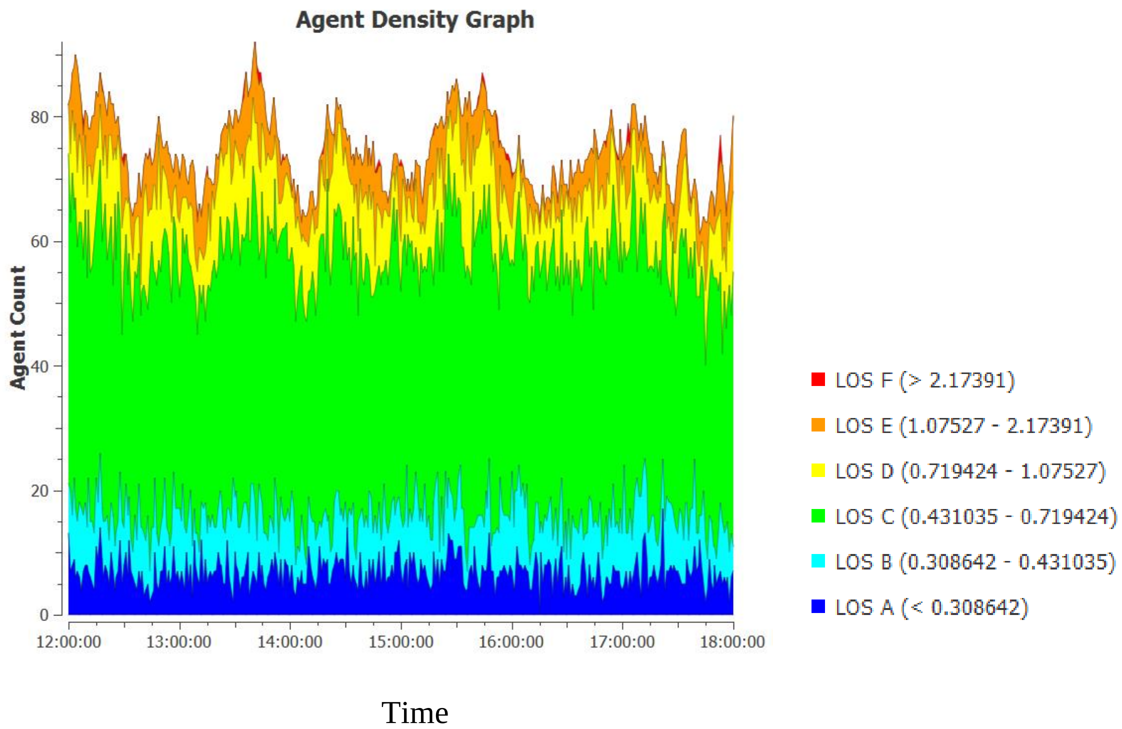



Figure 124: eleventh scenario shoppers' densities graph for 2000 shoppers per day

Table 63: eleventh scenario average shoppers' densities for 2000 shoppers per day

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 2482 | 3226 | 15188 | 3772 | 2176 | 44 |
| Average (Total shoppers/ simulation frame period) | 6.87 | 8.93 | 42.07 | 10.44 | 6.02 | 0.12 |

### 5.2.7 The fourteenth scenario results for 2000 shoppers per day:

#### 5.2.7.1 Shoppers' social cost:

Table 64 shows that the total social cost for this scenario equals to 8307 pounds, the congestion cost equals to 9.8 pounds, while the journey cost equals to 8297 pounds.

Table 64: fourteenth scenario social cost for 2000 shoppers per day

| | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|
| Walk | 131:24:35 | 262:49:10 | 1:19:52 | 1939 | 9 | 1949 |
| Server Queue | 59:57:04 | 203:50:03 | 0:00:00 | 1504 | 0 | 1504 |
| Server Process | 263:05:27 | 657:43:39 | 0:00:00 | 4854 | 0 | 4854 |
| Total | 454:27:07 | 1124:22:51 | 1:19:52 | 8297 | 9 | 8307 |

#### 5.2.7.2 Average LOS (t) plan:

The LOS B in Figure 125 almost disappeared totally from all areas.

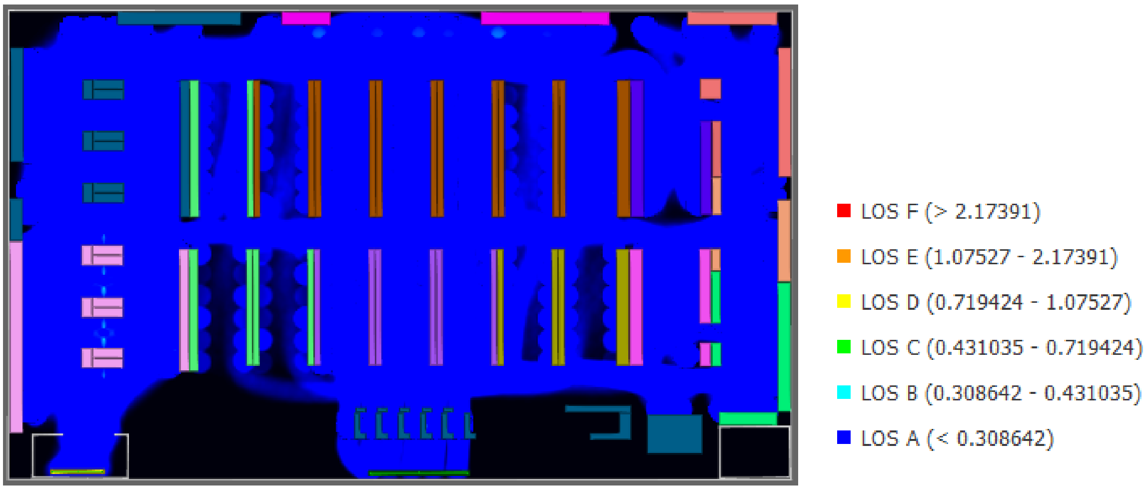



Figure 125: fourteenth scenario average LOS (t) map for 2000 shoppers per day

#### 5.2.7.3 **Experienced LOS (t) plan**

The LOS D in Figure 126 disappeared from all areas, however LOS C is available at fresh produce, pre-prepared and the sixth isle of general items areas.

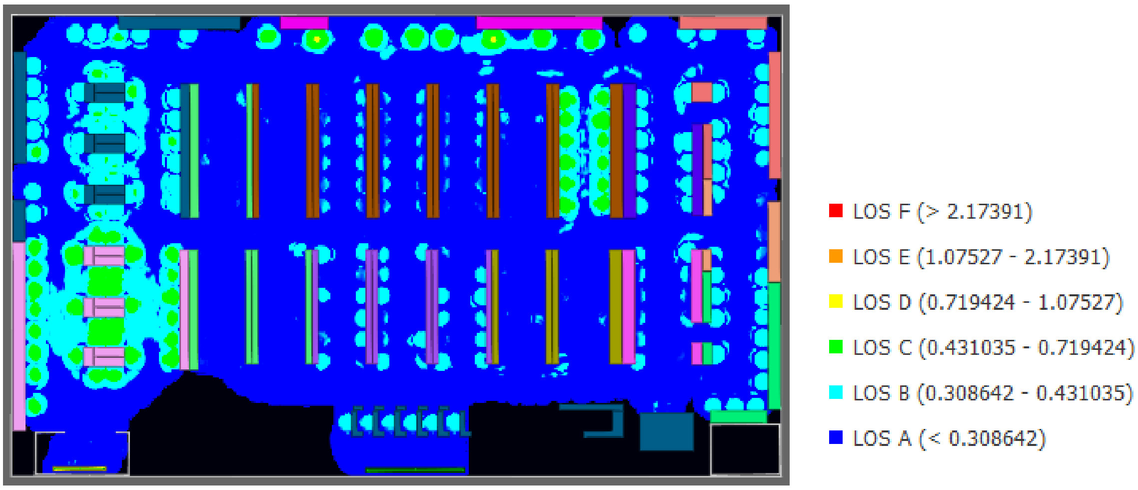



Figure 126: fourteenth scenario experienced LOS (t) map for 2000 shoppers per day

#### 5.2.7.4 **Maximum LOS plan**

The LOS F in Figure 127 disappeared from all areas.

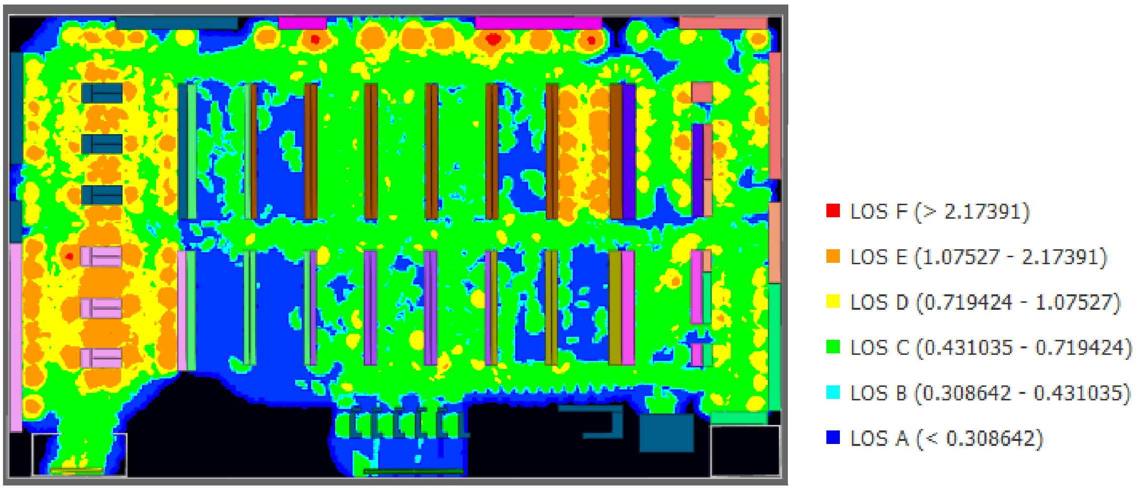



Figure 127: fourteenth scenario maximum LOS map for 2000 shoppers per day

#### 5.2.7.5 **Shoppers' density graph:**

Figure 128 shows that LOS A is increasing, while fewer quantities of LOS F and E. Table 65 shows that LOS F became 0.09 average shoppers falling under LOS F, while LOS A became 12.1 shoppers on average.

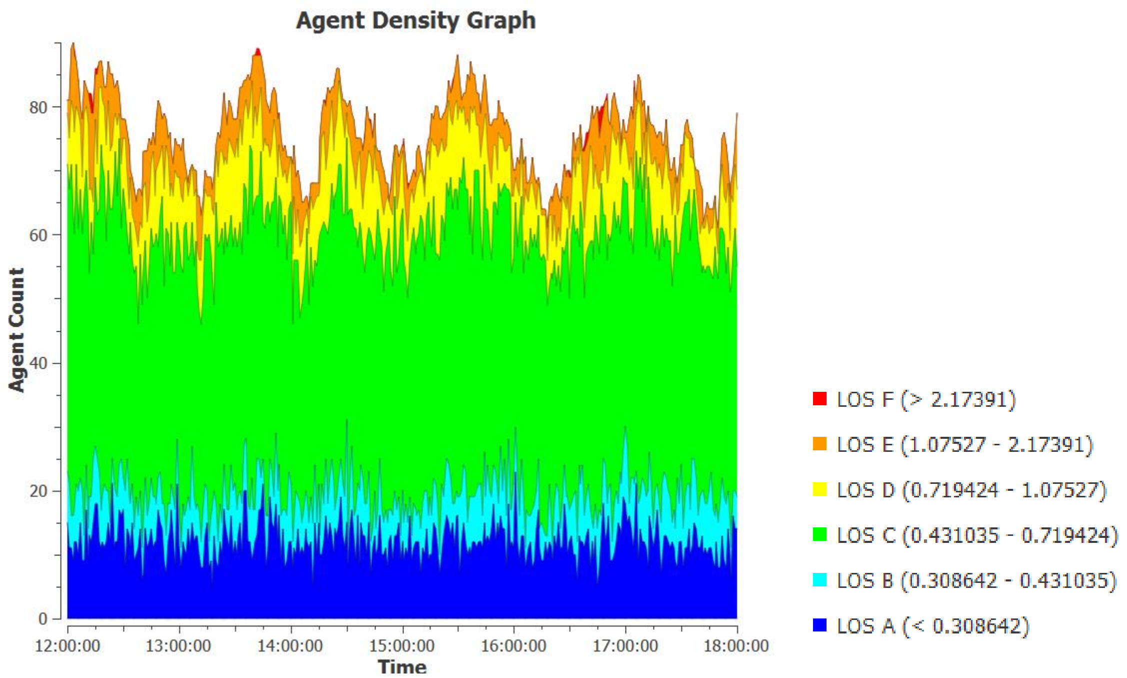



Figure 128: fourteenth scenario shoppers' densities graph for 2000 shoppers per day

Table 65: fourteenth scenario average shoppers' densities for 2000 shoppers per day

| | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|
| Total shoppers (every simulation frame) | 4380 | 2549 | 14926 | 3525 | 1923 | 34 |
| Average (Total shoppers/ simulation frame period) | 12.13 | 7.06 | 41.34 | 9.76 | 5.32 | 0.09 |

### 5.3 1000 shoppers per day results Summary:

The below section summarizes of all results scenarios from the social cost, average LOS (t), experienced LOS (t), maximum LOS maps and shoppers' density. The areas are arranged from the lowest to the highest.

#### 5.3.1 Costs Summary:

Table 66 combines all the fourteen scenarios together and compare the costs and times, including journey cost and time, congestion cost and time, and total social cost. Figure 129 converts the journey time in Table 66 to a graph, where the X-axis is the area and the Y-axis the journey time. Figure 130 converts the journey cost in Table 66 to a graph, the x-axis is the area and the y-axis the journey cost in pounds. Figure 131 converts congestion time into a graph, a-axis is the area, and the y-axis is the congestion time for each area. Figure 132 converts the congestion cost to a graph, where x-axis is the area, while y-axis is the congestion cost. Figure 134 shows the comparison between congestion costs and journey costs for the fourteen scenarios.

Table 66: scenarios cost summary for all agents during study period for 1000 shoppers per day

| scenario | Area | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|---|
| 1 | 1254.3 | 241:01:09 | 577:10:28 | 7:26:48 | 4259 | 54 | 4314 |
| 2 | 1394.9 | 226:31:34 | 547:37:40 | 1:53:17 | 4041 | 14 | 4055 |
| 3 | 1432.6 | 226:23:22 | 547:01:29 | 1:47:14 | 4037 | 13 | 4050 |
| 4 | 1432.6 | 225:16:13 | 545:03:31 | 0:54:14 | 4022 | 6 | 4029 |
| 5 | 1432.6 | 224:57:22 | 543:51:18 | 0:40:55 | 4013 | 5 | 4018 |
| 6 | 1485.5 | 225:13:48 | 545:46:36 | 0:33:42 | 4027 | 4 | 4031 |
| 7 | 1628 | 225:16:36 | 545:47:43 | 0:23:02 | 4027 | 2 | 4030 |
| 8 | 1663.2 | 224:58:11 | 544:14:56 | 0:35:09 | 4016 | 4 | 4020 |
| 9 | 1674.75 | 224:39:27 | 543:55:49 | 0:28:59 | 4014 | 3 | 4017 |
| 10 | 1960 | 225:45:58 | 547:01:48 | 0:22:52 | 4037 | 2 | 4039 |
| 11 | 2261.75 | 227:44:50 | 550:41:32 | 0:18:30 | 4064 | 2 | 4066 |
| 12 | 2550 | 228:43:30 | 552:24:27 | 0:16:15 | 4076 | 2 | 4078 |
| 13 | 2783.75 | 230:21:04 | 555:19:42 | 0:17:27 | 4098 | 2 | 4100 |
| 14 | 3017.5 | 232:31:37 | 560:04:25 | 0:12:26 | 4133 | 1 | 4134 |

Table 67: scenarios cost summary for one agent during study period for 1000 shoppers per day

| scenario | Area | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|---|
| 1 | 1254.3 | 0:26:23 | 1:03:12 | 0:00:49 | 7.77 | 0.0985 | 7.872 |
| 2 | 1394.9 | 0:24:48 | 0:59:58 | 0:00:12 | 7.37 | 0.0255 | 7.3996 |
| 3 | 1432.6 | 0:24:47 | 0:59:54 | 0:00:12 | 7.36 | 0.0237 | 7.3905 |
| 4 | 1432.6 | 0:24:40 | 0:59:41 | 0:00:06 | 7.33 | 0.0109 | 7.3521 |
| 5 | 1432.6 | 0:24:38 | 0:59:33 | 0:00:04 | 7.32 | 0.0091 | 7.3321 |
| 6 | 1485.5 | 0:24:40 | 0:59:45 | 0:00:04 | 7.34 | 0.0072 | 7.3558 |
| 7 | 1628 | 0:24:40 | 0:59:46 | 0:00:03 | 7.34 | 0.0036 | 7.3540 |
| 8 | 1663.2 | 0:24:38 | 0:59:35 | 0:00:04 | 7.32 | 0.0072 | 7.3357 |
| 9 | 1674.75 | 0:24:36 | 0:59:33 | 0:00:03 | 7.32 | 0.0054 | 7.3302 |
| 10 | 1960 | 0:24:43 | 0:59:54 | 0:00:03 | 7.36 | 0.0036 | 7.3704 |
| 11 | 2261.75 | 0:24:56 | 1:00:18 | 0:00:02 | 7.41 | 0.0036 | 7.4197 |
| 12 | 2550 | 0:25:03 | 1:00:29 | 0:00:02 | 7.43 | 0.0036 | 7.4416 |
| 13 | 2783.75 | 0:25:13 | 1:00:48 | 0:00:02 | 7.47 | 0.0036 | 7.4817 |
| 14 | 3017.5 | 0:25:28 | 1:01:19 | 0:00:01 | 7.54 | 0.0018 | 7.5437 |

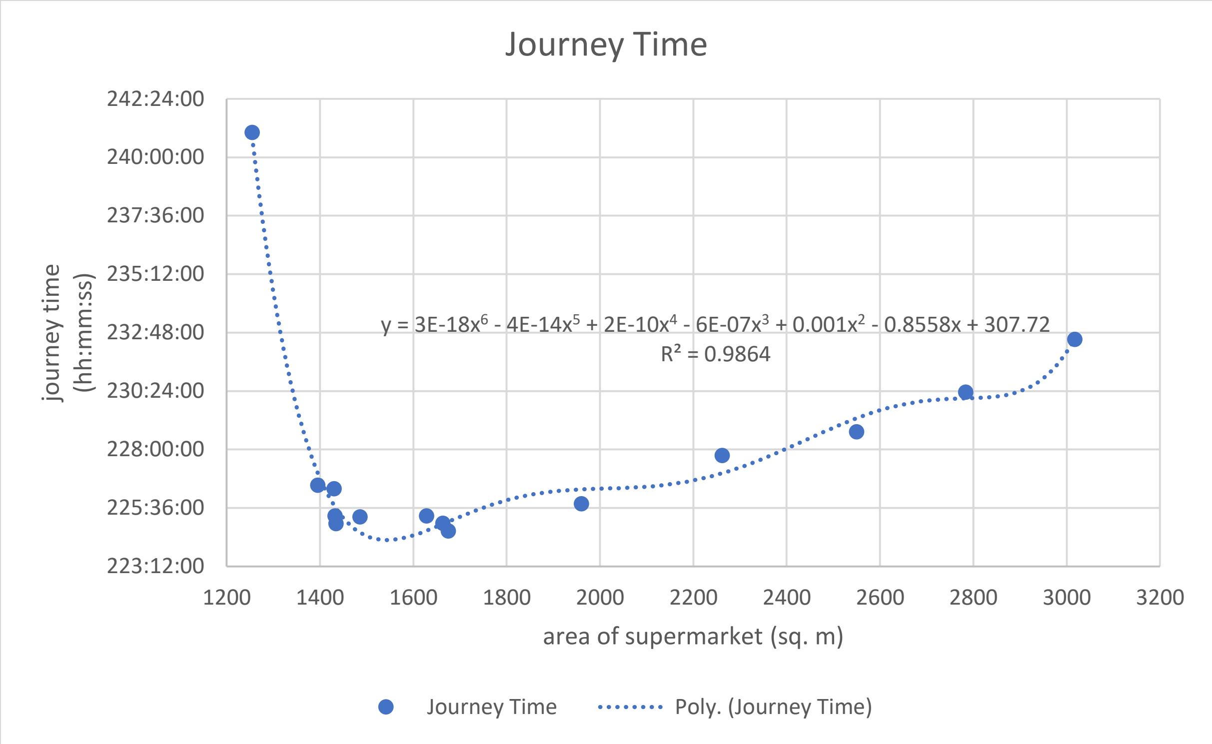



Figure 129: the fourteen scenarios' journey time summary for 1000 shoppers per day

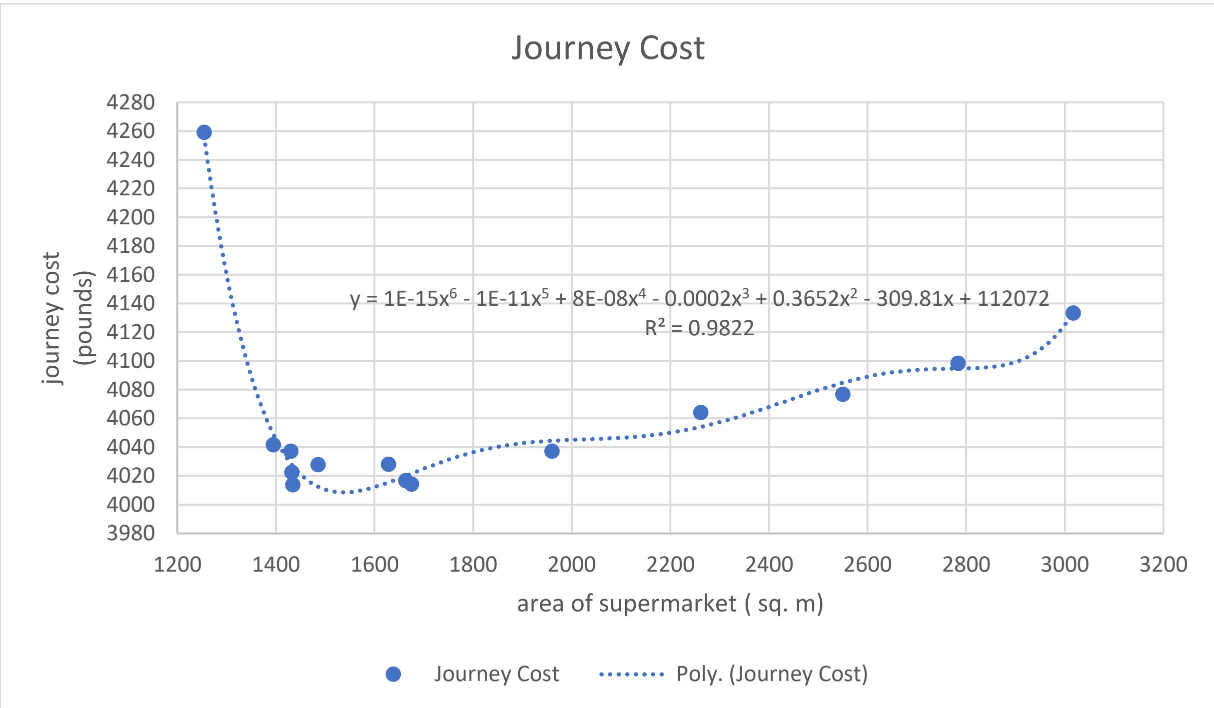



Figure 130: scenarios journey cost for 1000 shoppers per day

Table 68: Figure 130 trend line equation of 1000 shoppers' scenarios journey cost

| Area of the supermarket (sq.m) | Journey cost (pounds) |
|---|---|
| 1200 | 4400 |
| 1400 | 4050 |
| 1600 | 4015 |
| 1800 | 4040 |
| 2000 | 4040 |
| 2200 | 4050 |
| 2400 | 4070 |
| 2600 | 4090 |
| 2800 | 4100 |

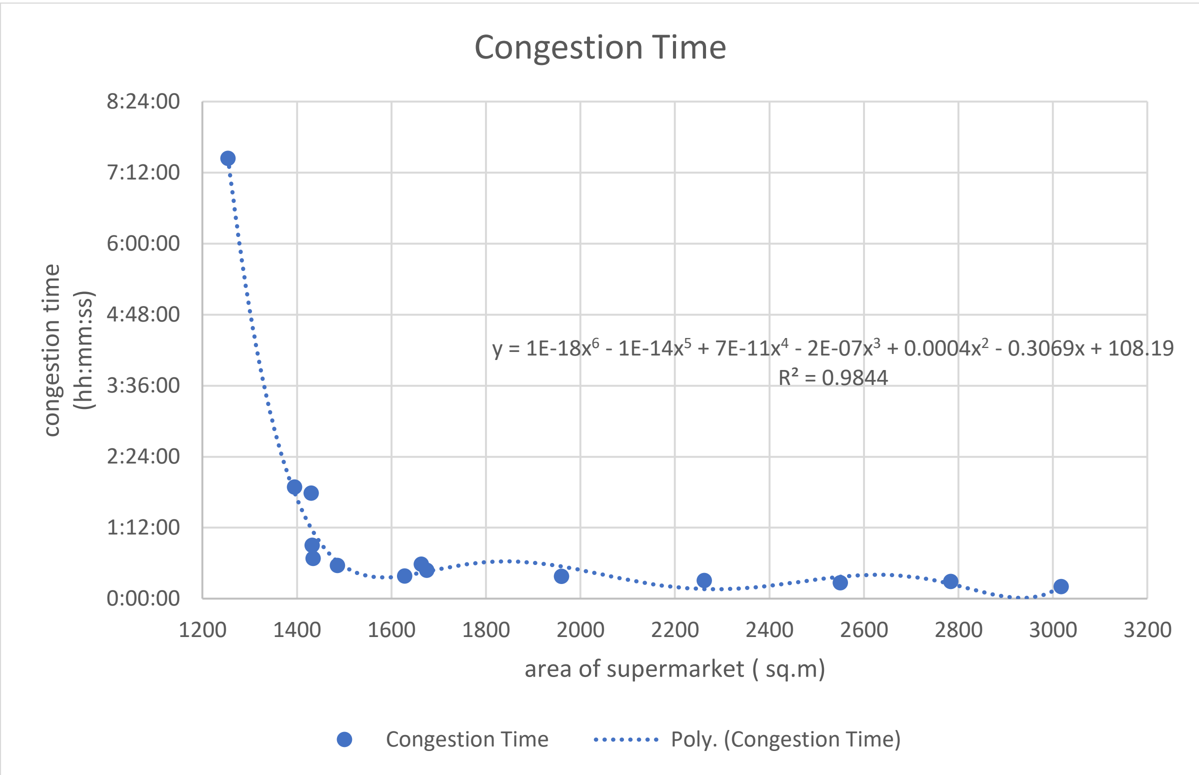



Figure 131: scenarios congestion time for 1000 shoppers per day

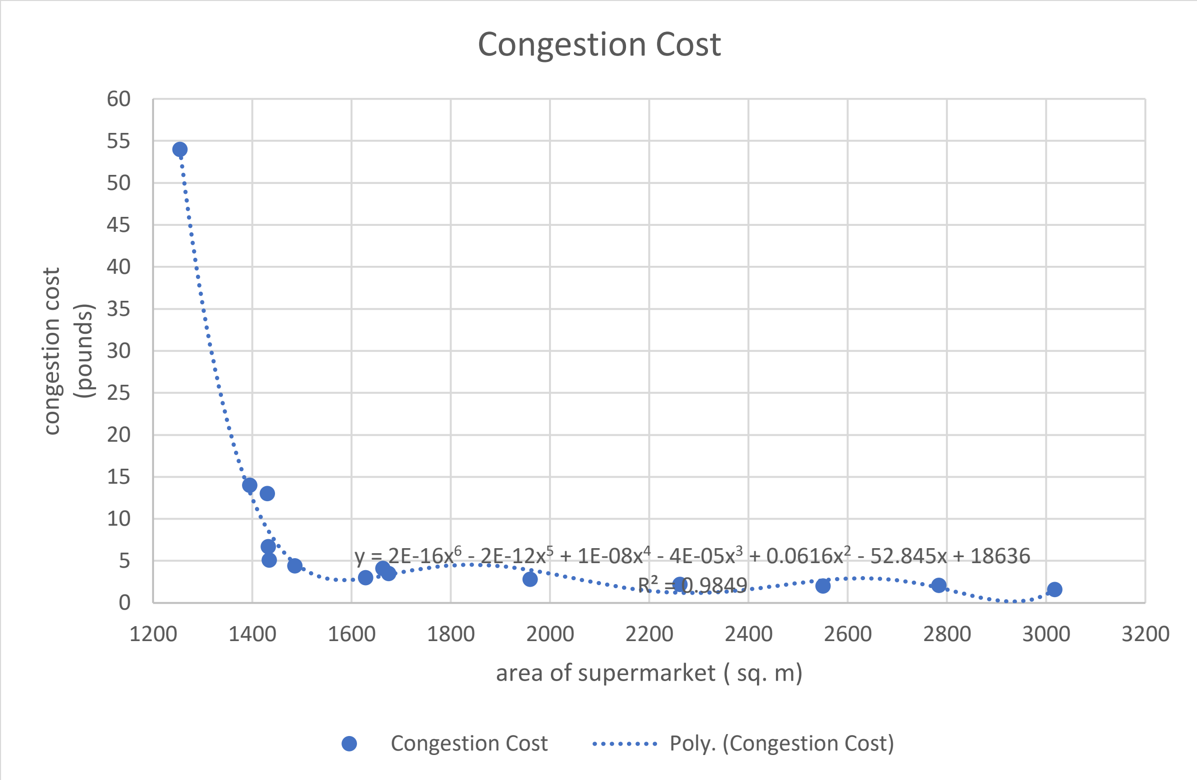



Figure 132: scenarios congestion cost for 1000 shoppers per day

Table 69: Figure 132 trendline equation of 1000 shoppers' scenarios congestion cost

| Area of the supermarket (sq.m) | congestion cost (pounds) |
|---|---|
| 1200 | 82 |
| 1400 | 12 |
| 1600 | 3 |
| 1800 | 5 |
| 2000 | 4 |
| 2200 | 2 |
| 2400 | 2 |
| 2600 | 3 |
| 2800 | 2 |

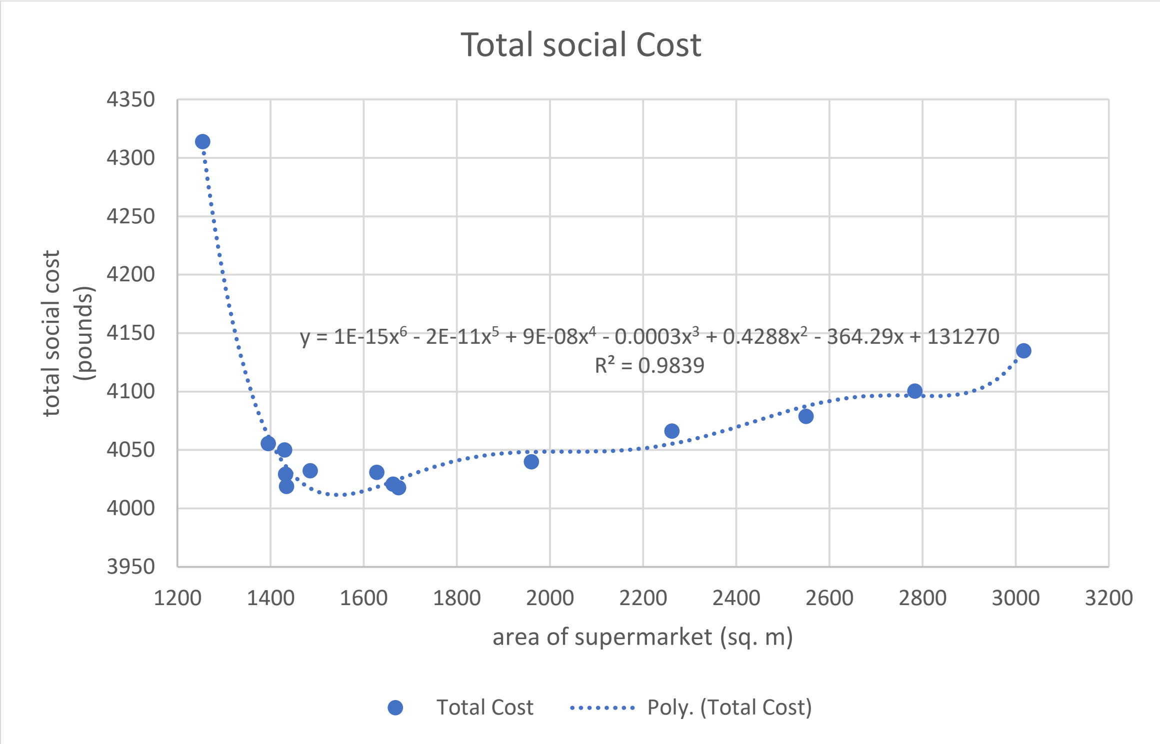



Figure 133: scenarios total cost for 1000 shoppers per day

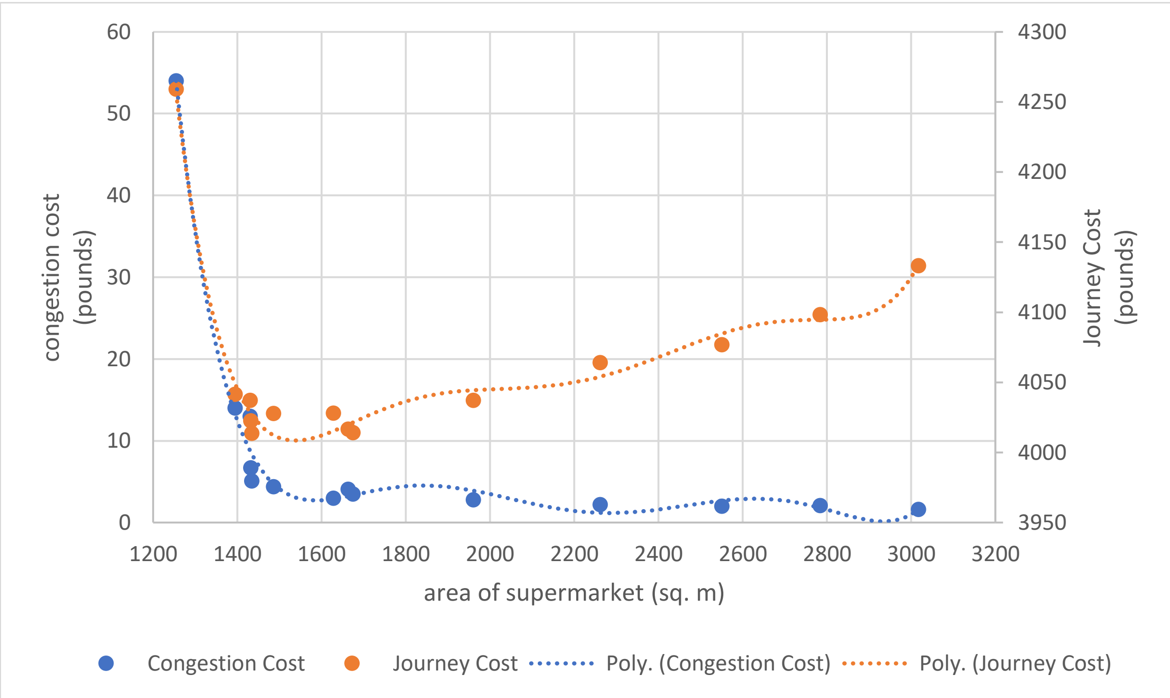



Figure 134: congestion vs. Journey costs for 1000 shoppers per day

### 5.3.2 LOS Summaries:

Table 70 summarizes all the average densities, falling in each LOS during the study period in the simulation, for the fourteen scenarios. Figure 135 reflects the values in Table 70.Figure 136 studies LOS C only, while Figure 137 studies LOS A, B, D, and E only. Figure 138 studies the average No. of shoppers falling in LOS F only. Figure 140 shows the comparison between LOS A and LOS F only.

Table 70: average No. of shoppers in each LOS for 1000 shoppers per day

| scenario | **Area** | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|---|
| 1 | 1254.3 | 0.4 | 3.1 | 23.6 | 5.6 | 6.5 | 0.7 |
| 2 | 1394.9 | 0.6 | 5.26 | 24.45 | 4.69 | 2.46 | 0.21 |
| 3 | 1432.6 | 0.92 | 5.09 | 24.59 | 4.57 | 2.32 | 0.16 |
| 4 | 1432.6 | 0.83 | 5.36 | 24.88 | 4.28 | 2.05 | 0.06 |
| 5 | 1432.6 | 0.82 | 5.43 | 25.26 | 4.1 | 1.78 | 0.019 |
| 6 | 1485.5 | 1.54 | 5.18 | 25.27 | 3.9 | 1.55 | 0.013 |
| 7 | 1628 | 2.48 | 4.98 | 25.15 | 3.5 | 1.37 | 0.01 |
| 8 | 1663.2 | 1.75 | 6.05 | 24.51 | 3.41 | 1.67 | 0.02 |
| 9 | 1674.75 | 1.83 | 6.06 | 24.57 | 3.45 | 1.49 | 0.00 |
| 10 | 1960 | 2.72 | 5.56 | 24.67 | 3.4 | 1.25 | 0.01 |
| 11 | 2261.75 | 3.98 | 5.26 | 24.47 | 2.98 | 1.15 | 0.01 |
| 12 | 2550 | 5.41 | 5.12 | 23.52 | 2.95 | 1.08 | 0 |
| 13 | 2783.75 | 5.75 | 5.27 | 23.38 | 2.8 | 1.11 | 0.02 |
| 14 | 3017.5 | 6.99 | 4.21 | 23.66 | 2.82 | 0.98 | 0 |

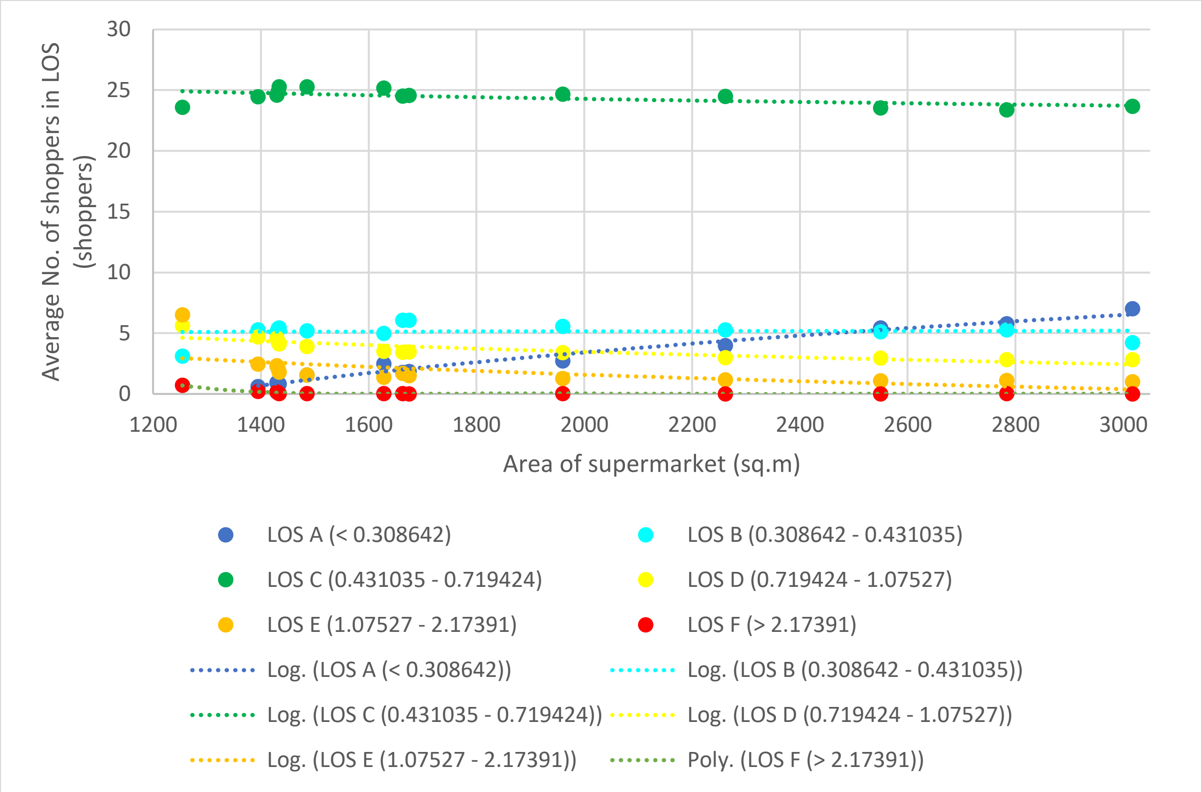



Figure 135: average No. of shoppers in each LOS vs. Area of supermarket for 1000 shoppers per day

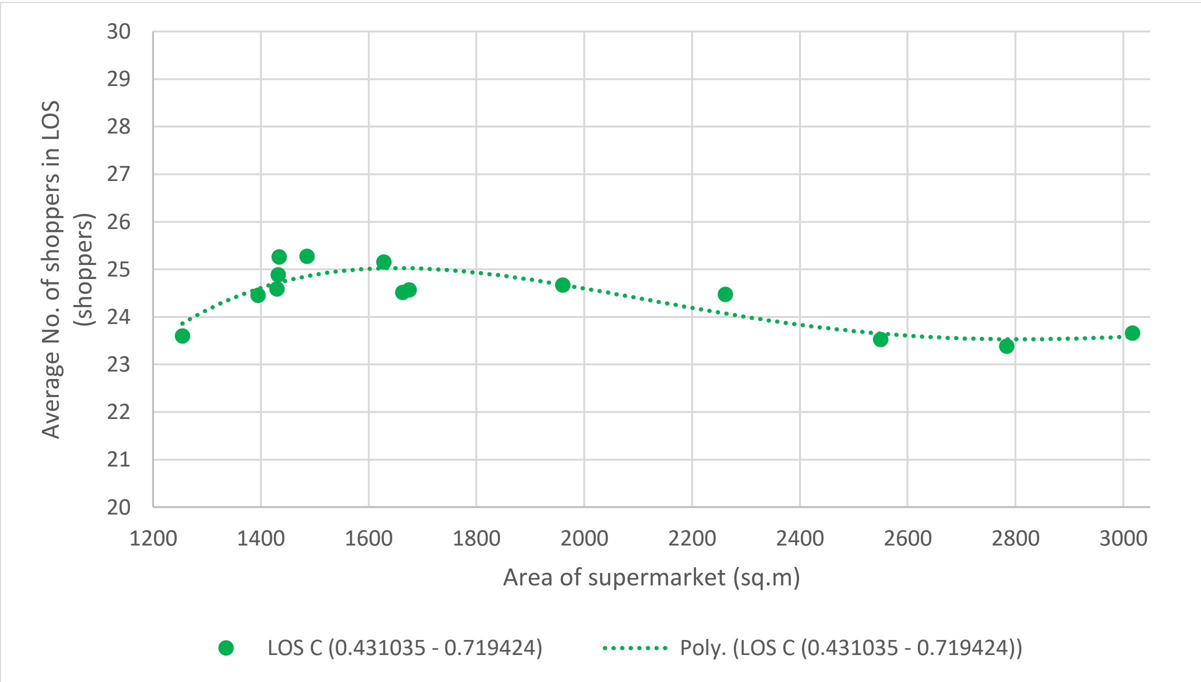



Figure 136: average No. of shoppers in LOS C vs. Area of supermarket for 1000 shoppers per day

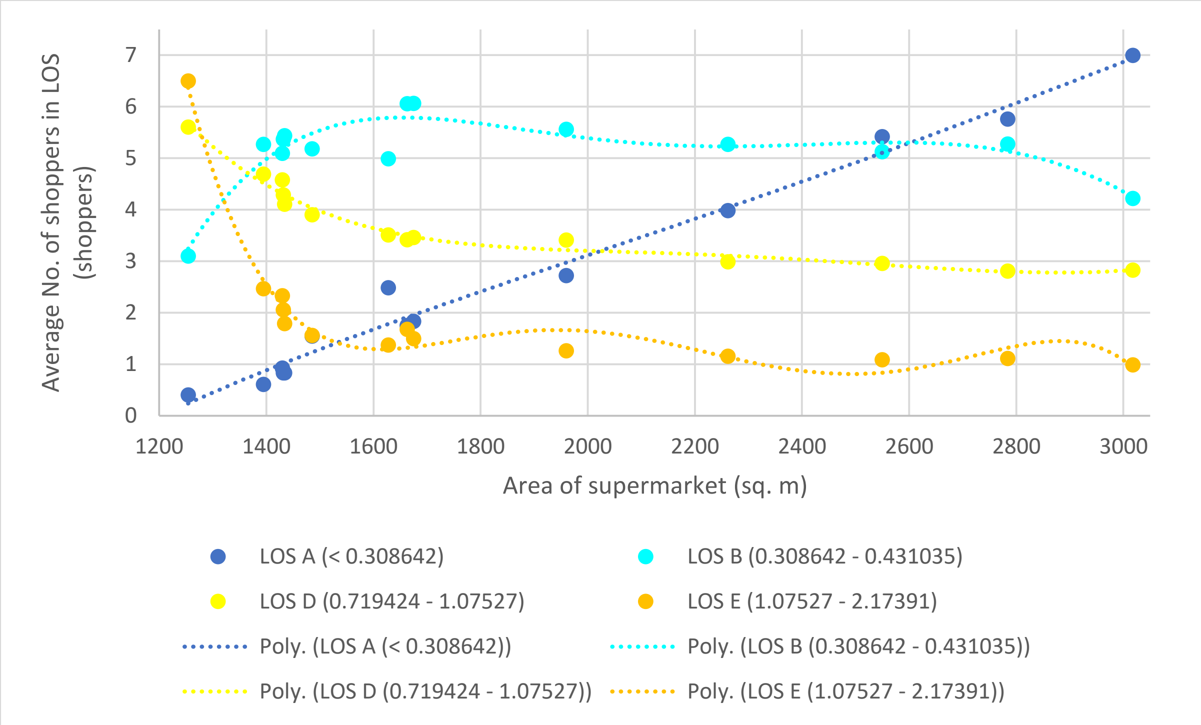



Figure 137: average No. of shoppers in LOS A, B, D, E and F vs. Area of supermarket for 1000 shoppers per day

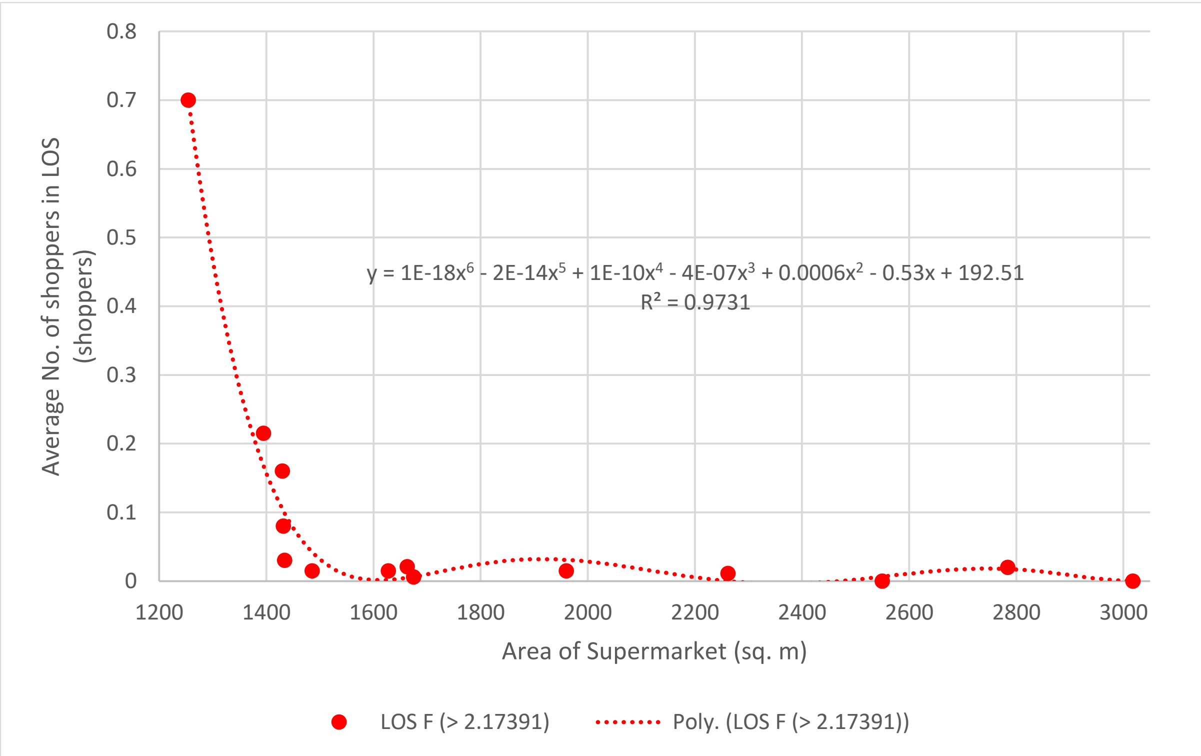



Figure 138: average No. of shoppers in LOS F vs. Area of supermarket for 1000 shoppers per day

Table 71: Figure 138 trendline equation of 1000 shoppers' scenarios of average no. of shoppers in LOS F

| Area of the supermarket (sq.m) | average No. of shoppers in LOS F (persons) |
|---|---|
| 1200 | 1.1 |
| 1400 | 0.16 |
| 1600 | 0 |
| 1800 | 0.01 |
| 2000 | 0.01 |
| 2200 | 0.0 |
| 2400 | 0.0 |
| 2600 | 0.01 |
| 2800 | 0.01 |

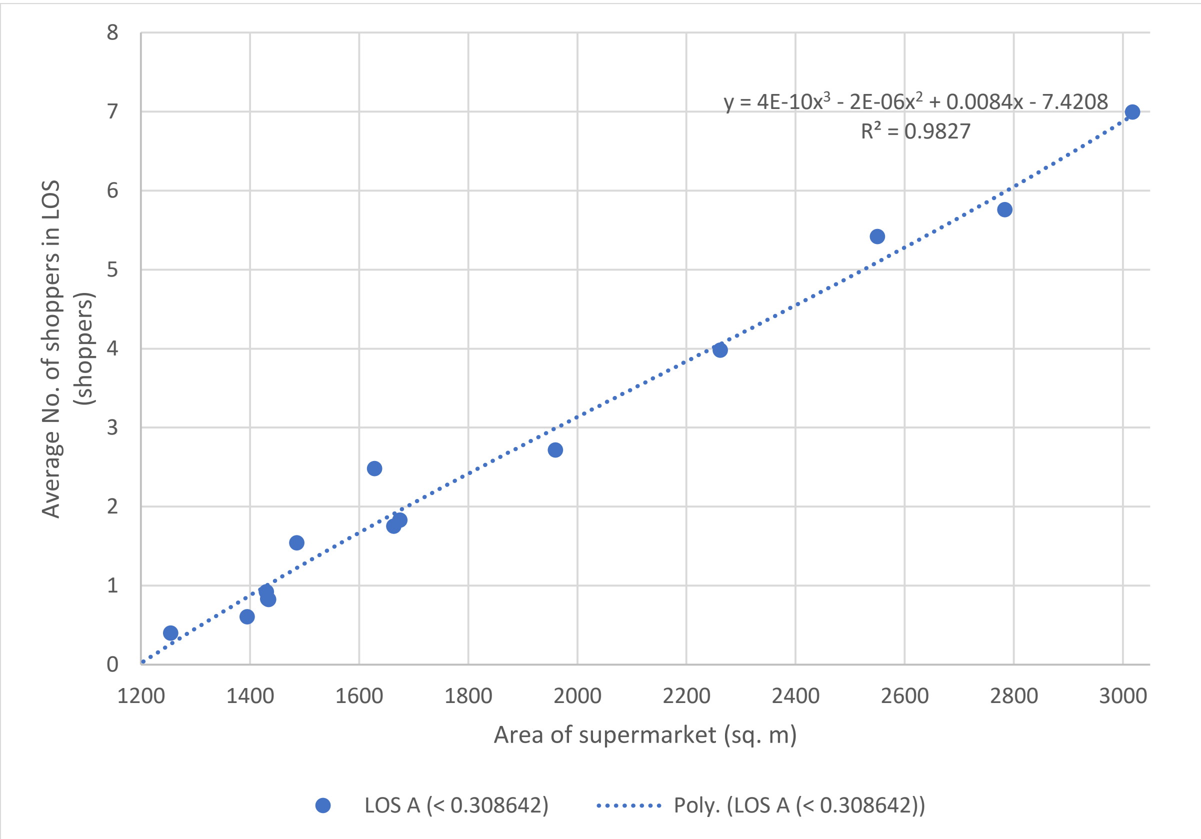



Figure 139: average no. of shoppers in LOS A for 1000 shoppers per day

Table 72: Figure 139 trendline equation of 1000 shoppers' scenarios of average no. of shoppers in LOS A

| Area of the supermarket (sq.m) | average No. of shoppers in LOS A (persons) |
|---|---|
| 1200 | 0 |
| 1400 | 0.9 |
| 1600 | 1.8 |
| 1800 | 2.2 |
| 2000 | 3.1 |
| 2200 | 3.9 |
| 2400 | 4.5 |
| 2600 | 5.2 |
| 2800 | 6.0 |

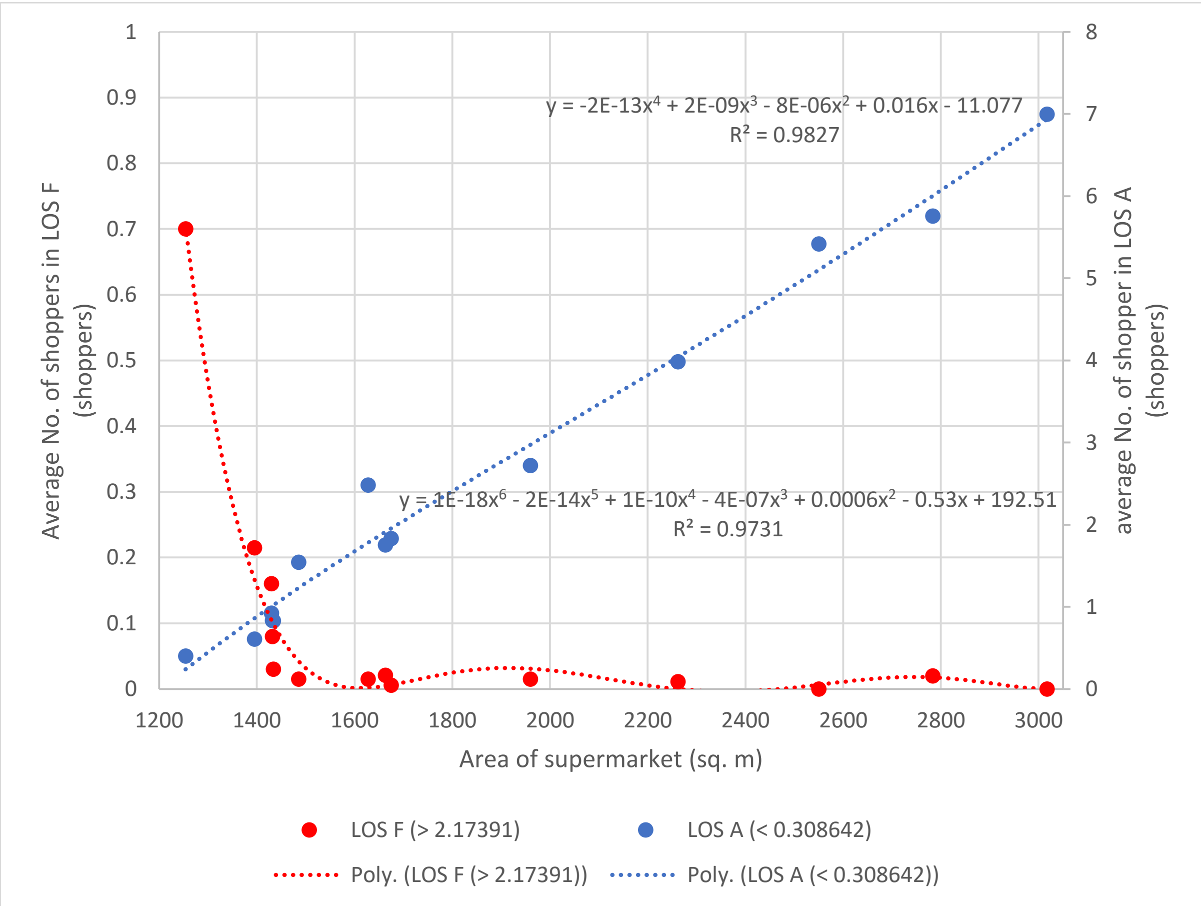



Figure 140: Average No. of shoppers in LOS A vs Average No. of shoppers in LOS F for 1000 shoppers per day

Table 73: Figure 140 trend line equation of 1000 shoppers' scenarios of average No. of shoppers in LOS A vs. average no. of shoppers in LOS F

| Area of the supermarket (sq.m) | average No. of shoppers in LOS A (persons) | average No. of shoppers in LOS F (persons) |
|---|---|---|
| 1200 | 0 | 1.1 |
| 1400 | 0.9 | 0.16 |
| 1600 | 1.8 | 0 |
| 1800 | 2.2 | 0.01 |
| 2000 | 3.1 | 0.01 |
| 2200 | 3.9 | 0.0 |
| 2400 | 4.5 | 0.0 |
| 2600 | 5.2 | 0.01 |
| 2800 | 6.0 | 0.01 |

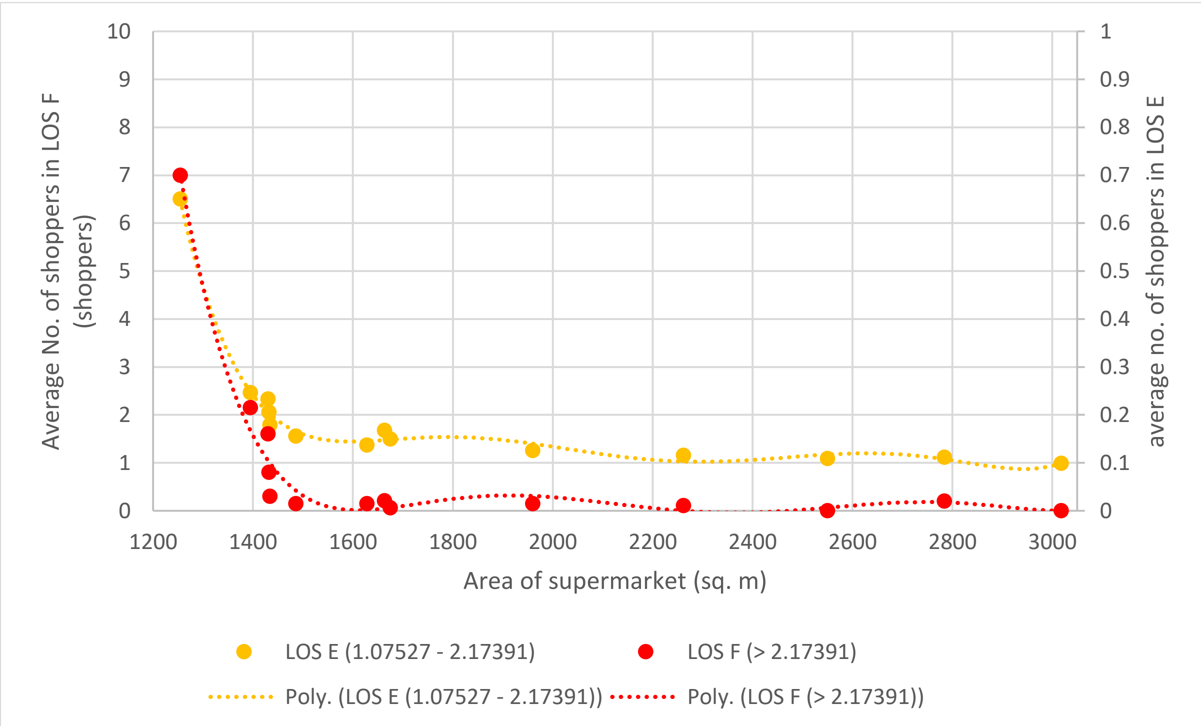
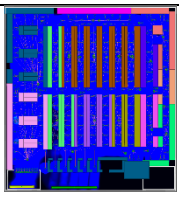
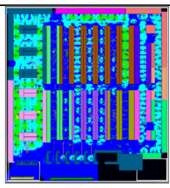
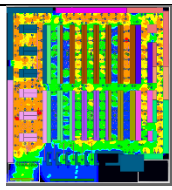
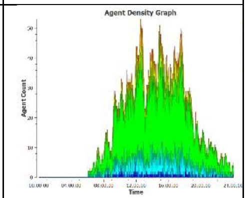
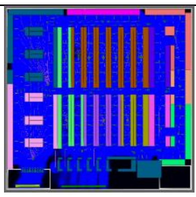
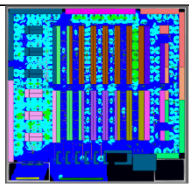
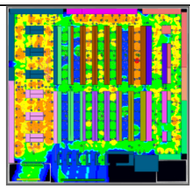
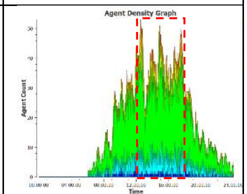
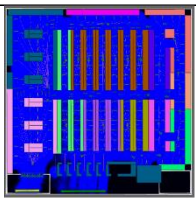
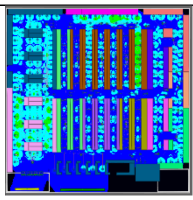
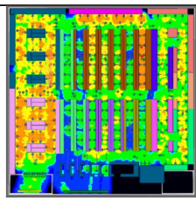
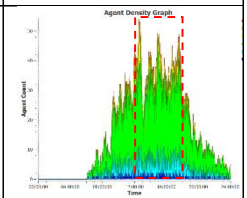
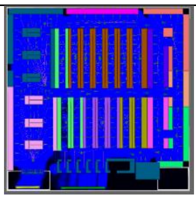
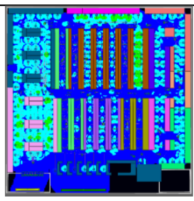
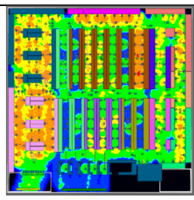
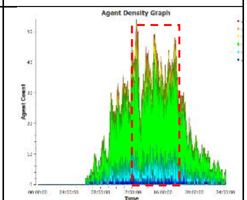
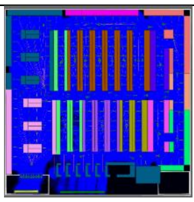
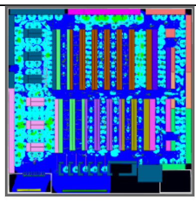
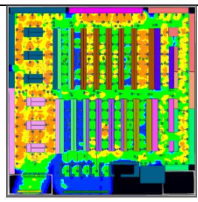
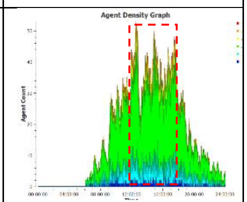
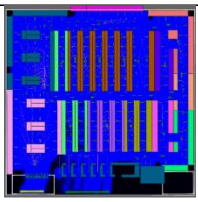
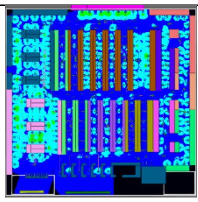
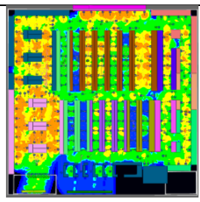
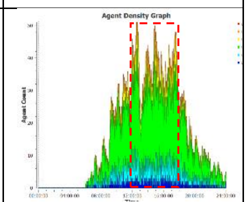



Figure 141: average no. of shoppers in LOS E and F for 1000 shoppers per day

### 5.3.3 Density Maps and graph summaries

Table 74 summarizes all the fourteen scenarios maps, i.e. average LOS (t), experienced LOS (t) map and maximum LOS maps; in addition to the graph density graphs. They are ordered from the lowest size to the highest.

Table 74: average LOS (t), experienced LOS (t), maximum LOS and density graph summary for 1000 shoppers per day

| scenario | Average LOS (t) map | Experience LOS(t) map | Maximum LOS map | Density graph |
|---|---|---|---|---|
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |
| 4 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |

| | | | | |
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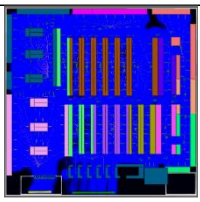
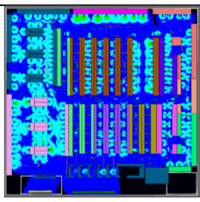
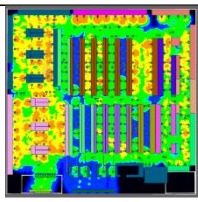
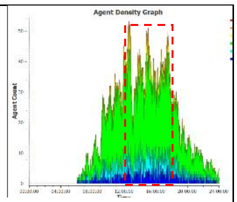
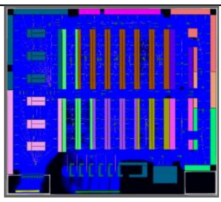
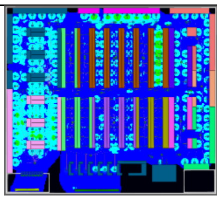
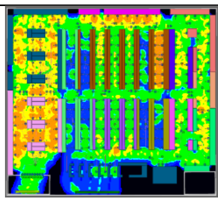
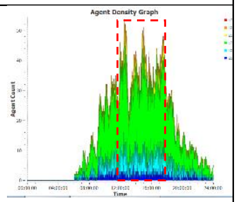
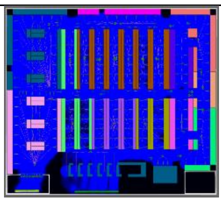
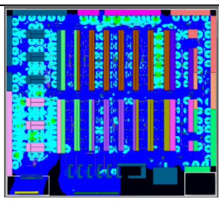
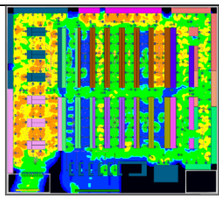
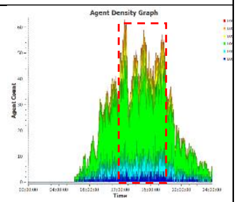
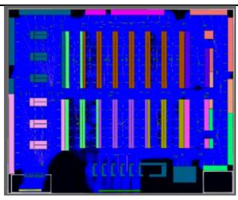
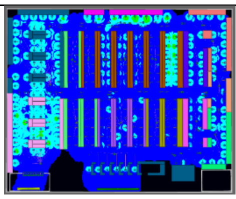
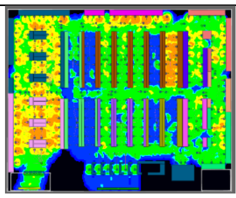
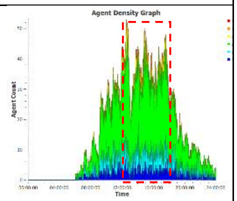
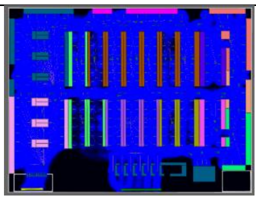
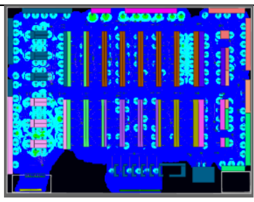
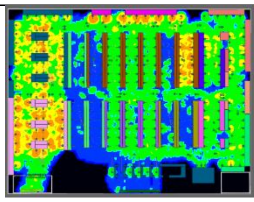
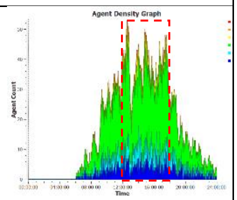
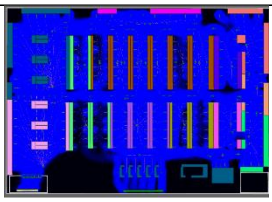
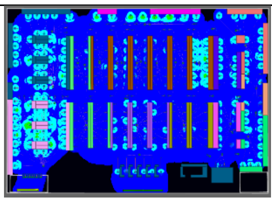
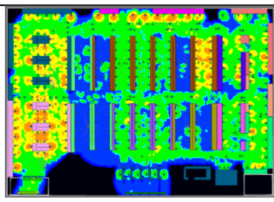
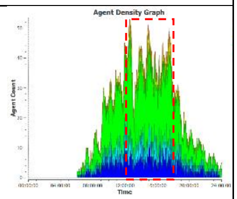
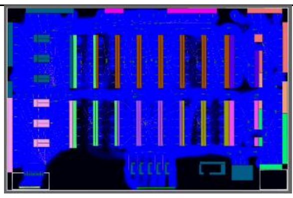
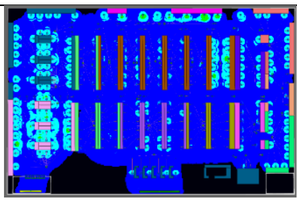
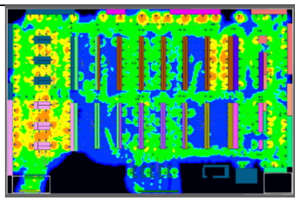
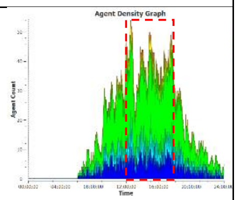
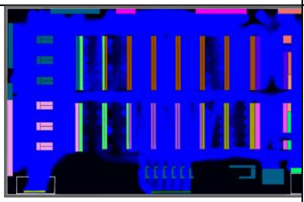
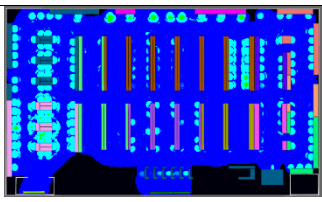
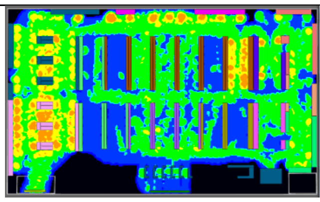
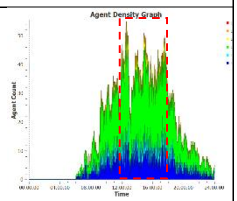
| 7 |  |  |  |   |
| 8 |  |  |  |   |
| 9 |  |  |  |   |
| 10 |  |  |  |   |
| 11 |  |  |  |   |
| 12 |  |  |  |   |
| 13 |  |  |  |   |
| 14 |  |  |  |   |

### 5.4 2000 shoppers per day results summary:

The following section shows the summary of the revised fifth, sixth and eighth scenarios results, it includes social costs, densities, and maps summaries.

#### 5.4.1 Costs Summary:

Table 75 summarizes the cost of revised scenarios with 2000 shoppers per day, the table includes journey times along with areas arranged from lowest to highest. Figure 142 reflects the journey time in Table 75 for the revised scenarios, while Figure 143 shows the journey cost.  Figure 144 and Figure 145 shows the congestion time and cost. Figure 146 shows the revised total social cost for the three revised scenarios.

Table 75: scenarios cost summary for all agents during study period for 2000 shoppers per day.

| scenario | **Area (sq. m)** | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|---|
| R1 | 1254.3 | 518:57:07 | 1258:12:03 | 43:15:13 | 9285 | 319 | 9604 |
| R5 | 1394.9 | 449:47:21 | 1113:53:57 | 4:56:55 | 8220 | 36 | 8257 |
| R6 | 1432.6 | 446:45:49 | 1109:20:30 | 3:20:24 | 8186 | 24 | 8211 |
| R7 | 1432.6 | 442:57:02 | 1099:29:23 | 2:08:19 | 8114 | 15 | 8130 |
| R10 | 1960 | 445:55:41 | 1106:49:59 | 2:31:28 | 8168 | 18 | 8187 |
| R11 | 2261.75 | 447:05:04 | 1109:31:33 | 2:00:06 | 8188 | 14 | 8203 |
| R14 | 3017.5 | 454:27:07 | 1124:22:51 | 1:19:52 | 8297 | 9 | 8307 |

Table 76: scenarios cost summary for one agent during study period for 2000 shoppers per day

| scenario | **Area (sq. m)** | Sum of Journey Time (hour: minute: second) | Generalized Journey Time (hour: minute: second) | Sum of Congestion Time (hour: minute: second) | Journey Cost (Pounds) | Congestion Cost (Pounds) | Total social Cost (Pounds) |
|---|---|---|---|---|---|---|---|
| R1 | 1254.3 | 0:56:49 | 2:17:46 | 0:04:44 | 17 | 0.582 | 17.52 |
| R5 | 1394.9 | 0:49:15 | 2:01:58 | 0:00:33 | 15 | 0.065 | 15.06 |
| R6 | 1432.6 | 0:48:55 | 2:01:28 | 0:00:22 | 14.93 | 0.043 | 14.98 |
| R7 | 1432.6 | 0:48:30 | 2:00:23 | 0:00:14 | 14.80 | 0.027 | 14.83 |
| R10 | 1432.6 | 0:48:49 | 2:01:11 | 0:00:17 | 14.90 | 0.032 | 14.93 |
| R11 | 1485.5 | 0:48:57 | 2:01:29 | 0:00:13 | 14.94 | 0.025 | 14.96 |
| R14 | 1628 | 0:49:45 | 2:03:06 | 0:00:09 | 15.14 | 0.016 | 15.15 |

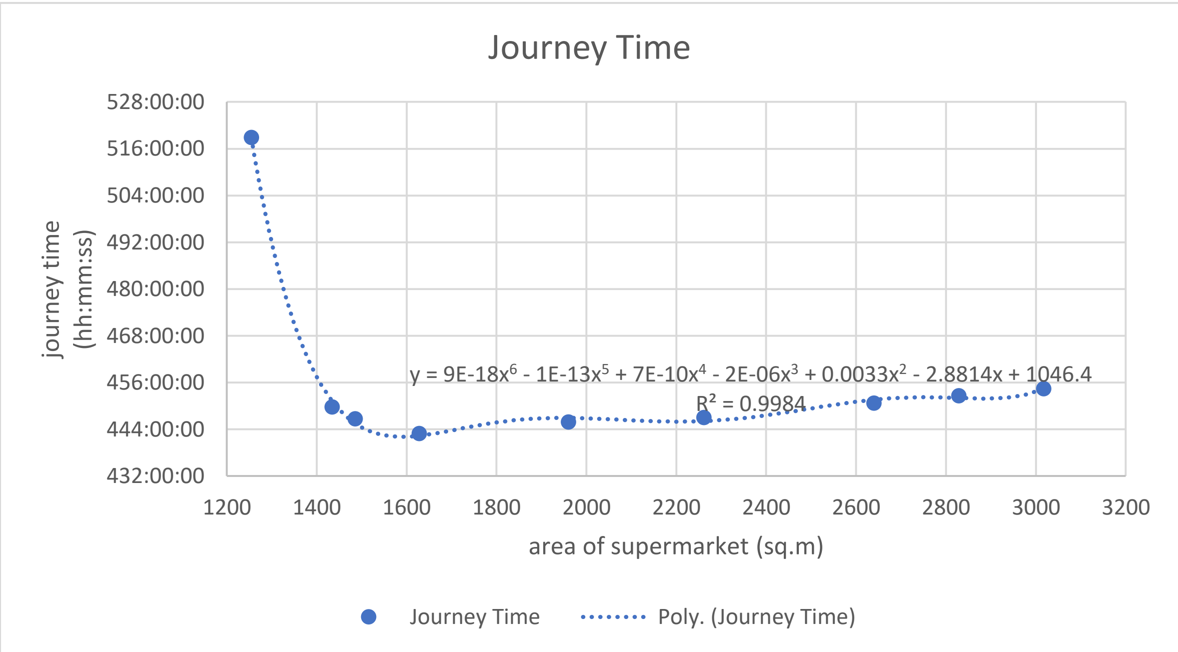



Figure 142: scenarios journey time summary vs. area of supermarket for 2000 shoppers per day

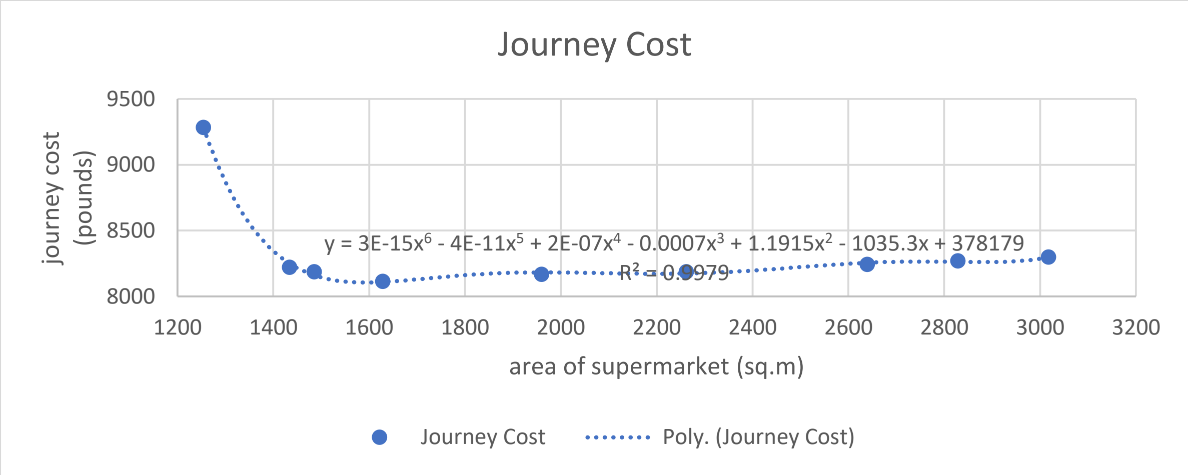



Figure 143: scenarios journey cost summary vs. area of supermarket for 2000 shoppers per day

Table 77: Figure 143 equation schedule

| Area of the supermarket (sq.m) | Journey cost (pounds) |
|---|---|
| 1200 | 10000 |
| 1400 | 8350 |
| 1600 | 8100 |
| 1800 | 8200 |
| 2000 | 8200 |
| 2200 | 8200 |
| 2400 | 8200 |
| 2600 | 8250 |
| 2800 | 8270 |

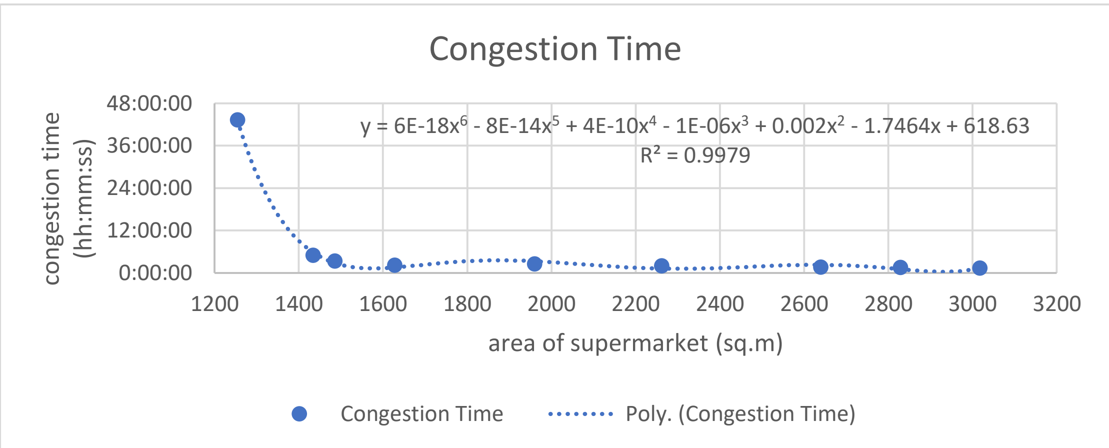



Figure 144: scenarios congestion time summary vs. area of super market for 2000 shoppers per day

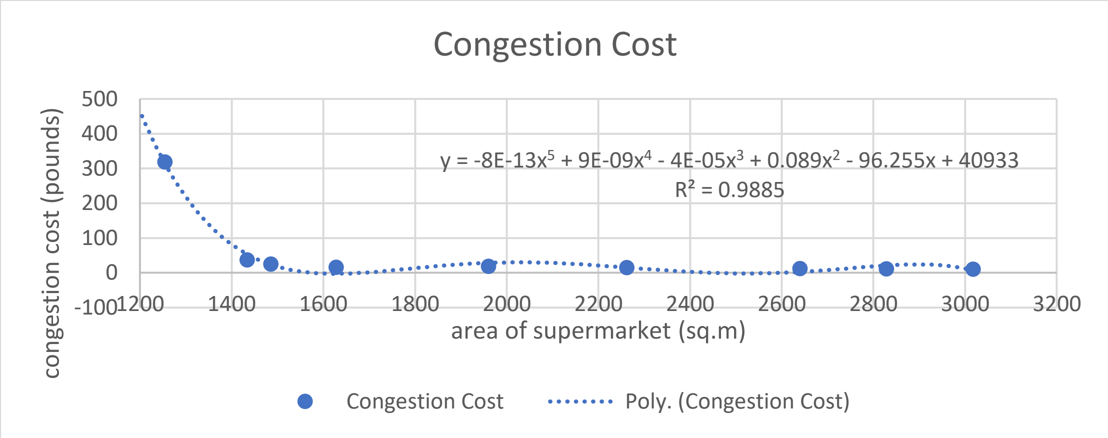



Figure 145: scenarios congestion cost summary vs area of supermarket for 2000 shoppers per day

Table 78: Figure 145 congestion cost equation

| Area of the supermarket (sq.m) | congestion cost (pounds) |
|---|---|
| 1200 | 450 |
| 1400 | 90 |
| 1600 | 0 |
| 1800 | 10 |
| 2000 | 40 |
| 2200 | 35 |
| 2400 | 0 |
| 2600 | 0 |
| 2800 | 10 |

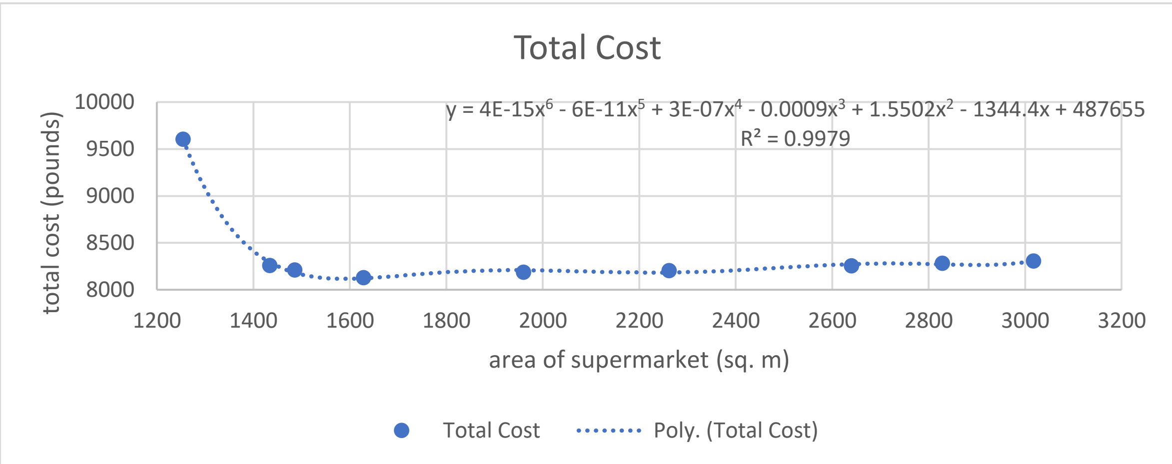



Figure 146: scenarios total cost summary vs area of supermarket for 2000 shoppers per day

### 5.4.2 LOS Summary:

Table 79 shows the revised average No. of shoppers falling under each LOS for the revised scenarios arranged by area from lowest to highest. From Figure 147 to Figure 151 the revised average No. of shoppers in each LOS vs. Area are shown in graphs reflecting Table 79.

Table 79: revised scenarios average No. of shoppers in each LOS for 2000 shoppers per day

| scenario | Area (sq. m) | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|---|
| R1 | 1254.3 | 0.62 | 4.8 | 34.8 | 14.4 | 23 | 8.6 |
| R5 | 1394.9 | 1.33 | 8.44 | 41.91 | 13.29 | 9.53 | 0.4 |
| R6 | 1432.6 | 2.26 | 8.64 | 42.5 | 12.76 | 8.22 | 0.14 |
| R7 | 1432.6 | 4.02 | 7.95 | 43.51 | 11.60 | 6.55 | 0.08 |
| R10 | 1960 | 4.51 | 9.64 | 41.96 | 11.18 | 6.81 | 0.16 |
| R11 | 2261.7 | 6.87 | 8.93 | 42.07 | 10.44 | 6.027 | 0.12 |
| R14 | 3017.5 | 12.13 | 7.06 | 41.34 | 9.76 | 5.32 | 0.09 |

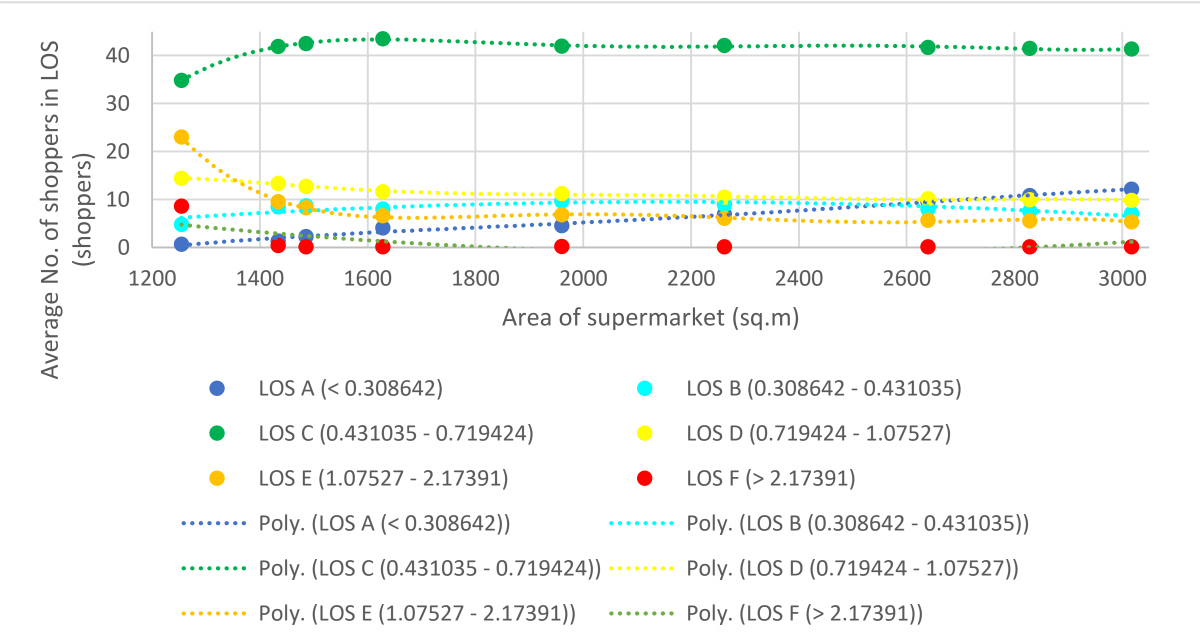



Figure 147: average No. of shoppers in each LOS vs. Area of supermarket for 2000 shoppers per day

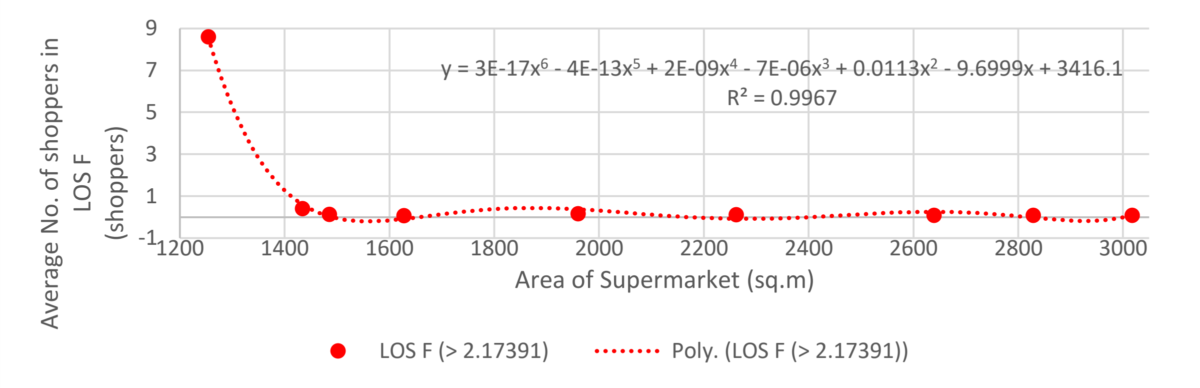



Figure 148: average No. of shoppers in LOS F vs. Area of supermarket for 2000 shoppers per day

Table 80: Figure 148 average no of shoppers in LOS F equation

| Area of the supermarket (sq.m) | average No. of shoppers in LOS F (persons) |
|---|---|
| 1200 | 13.5 |
| 1400 | 1 |
| 1600 | 0 |
| 1800 | 0.5 |
| 2000 | 0.4 |
| 2200 | 0 |
| 2400 | 0 |
| 2600 | 0.3 |
| 2800 | 0 |

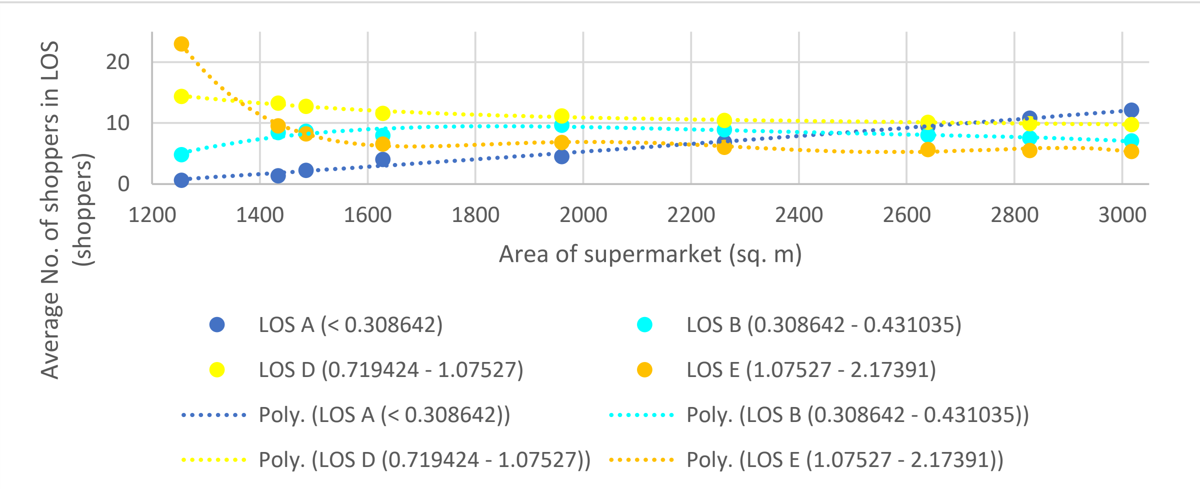



Figure 149: average No. of shoppers in LOS A, B, D and E Vs. Area of supermarket for 2000 shoppers per day

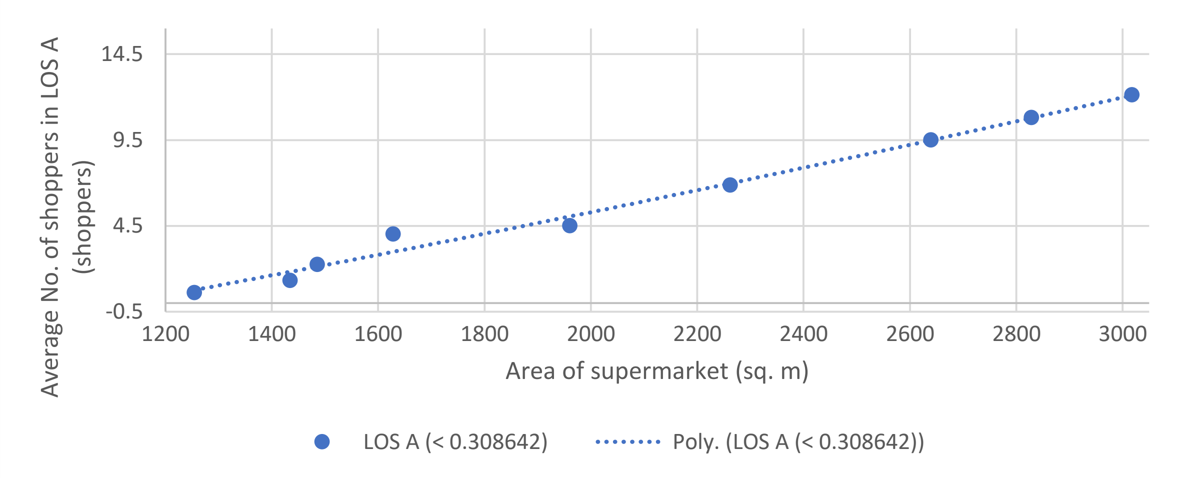



Figure 150: average No. of shoppers in LOS A Vs. Area of supermarket for 2000 shoppers per day

Table 81: Figure 150 average no. of shoppers in LOS A equation

| Area of the supermarket (sq.m) | average No. of shoppers in LOS A (persons) |
|---|---|
| 1200 | 0 |
| 1400 | 1.5 |
| 1600 | 3.0 |
| 1800 | 4.0 |
| 2000 | 5.3 |
| 2200 | 6.5 |
| 2400 | 8.0 |
| 2600 | 9.0 |
| 2800 | 10.5 |

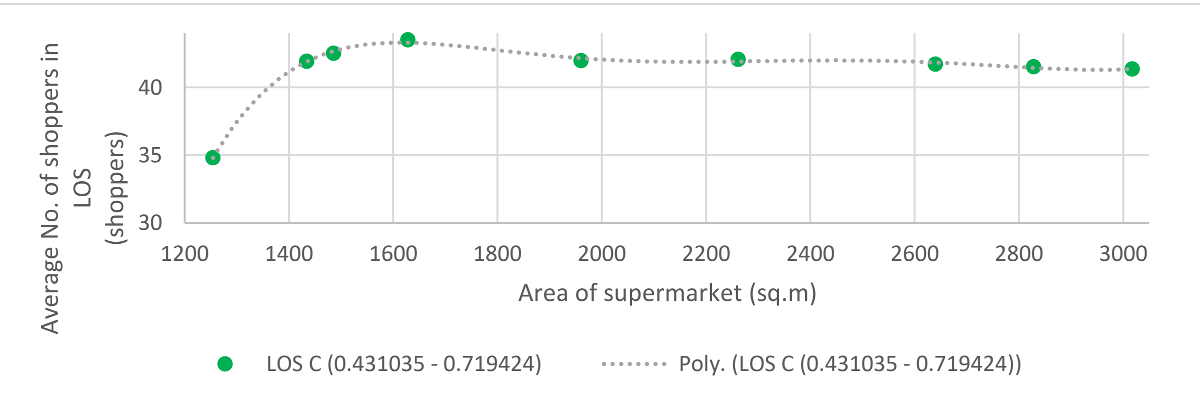



Figure 151: average No. of shoppers in LOS C vs. Area of supermarket for 2000 shoppers per day

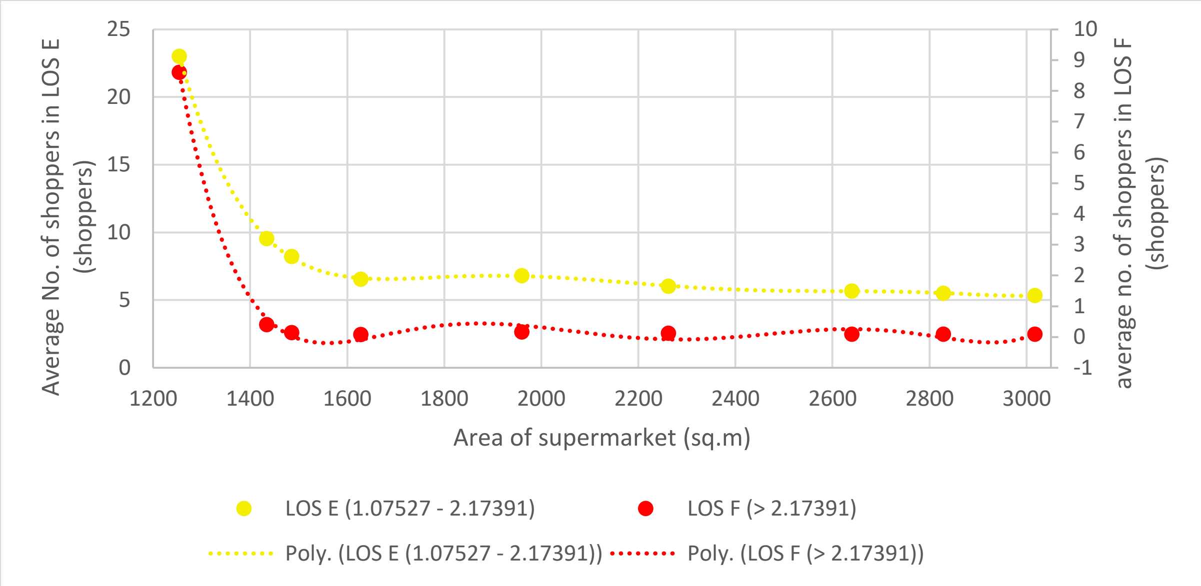



Figure 152: 2000 shoppers per day comparison between average no. of shoppers in LOS F vs. average no. of shoppers in LOS E

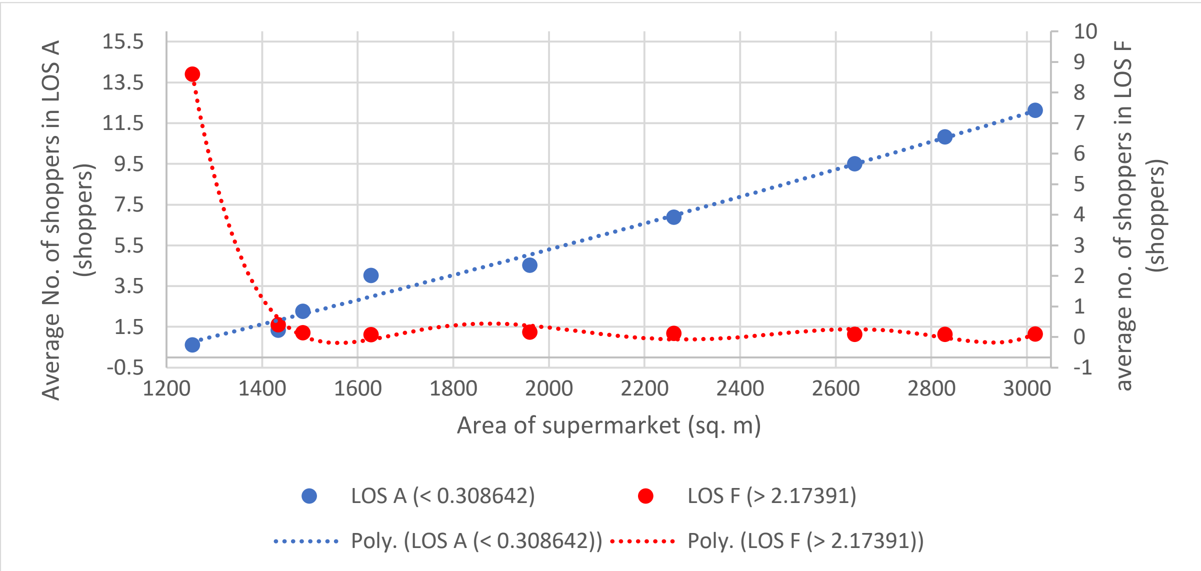
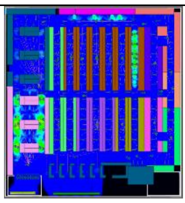
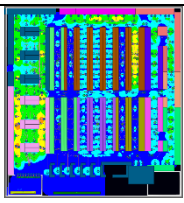
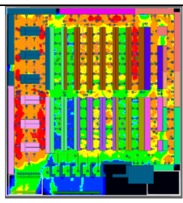
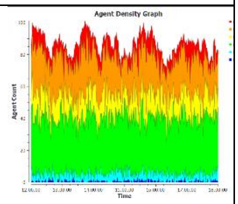
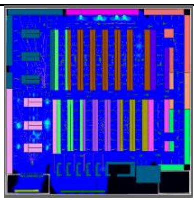
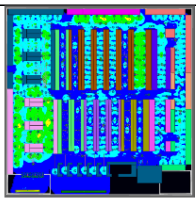
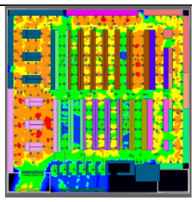
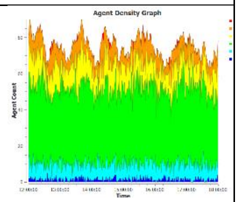
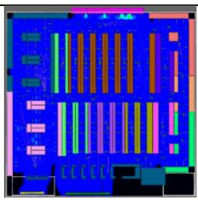
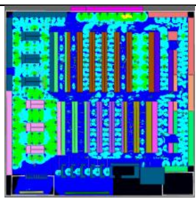
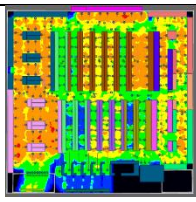
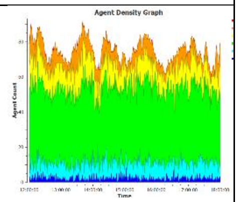
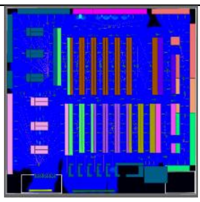
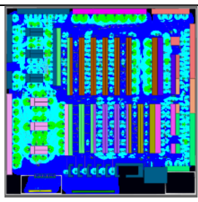
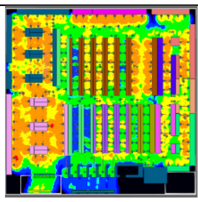
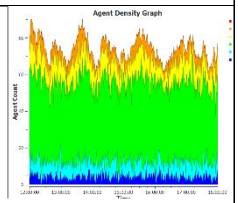
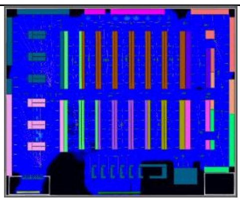
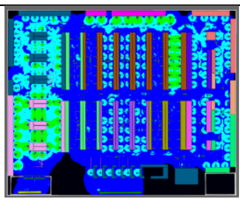
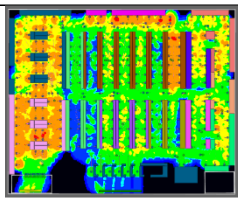
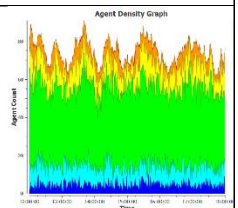
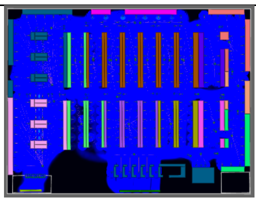
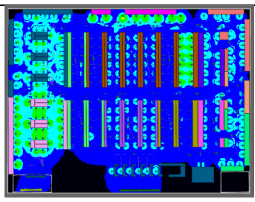
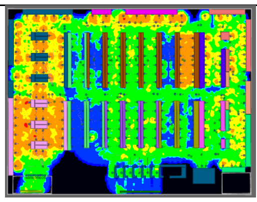
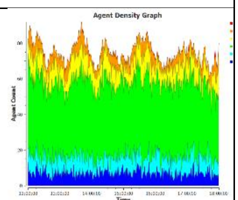
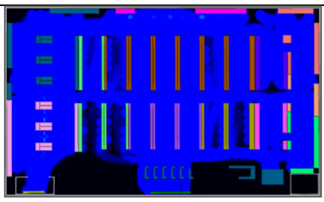
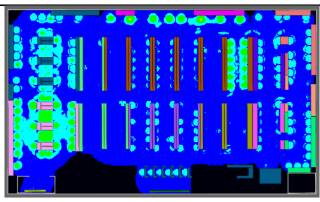
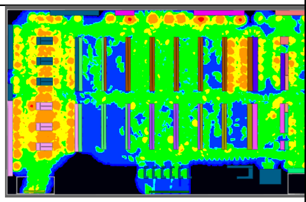
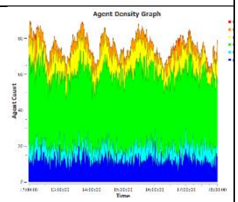



Figure 153: 2000 shoppers per day comparison between average no. of shoppers in LOS F vs. average no. of shoppers in LOS A

### 5.4.3 Density Maps and graph summaries

Table 82 summarizes all the revised three scenarios maps, i.e. average LOS (t), experienced LOS (t) map and maximum LOS maps; in addition to the graph density graphs. They are ordered from the lowest size to the highest.

Table 82: average LOS (t), experienced LOS (t), maximum LOS and density graph summary for 2000 shoppers per day scenarios

| scenario | Average LOS (t) map | Experience density map | Maximum LOS map | Density graph |
|---|---|---|---|---|
| 1 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |
| 7 |  |  |  |  |
| 10 |  |  |  |  |
| 11 |  |  |  |  |
| 14 |  |  |  |  |

# Chapter 6:

# Discussion

# Chapter 6 Discussion:

## 6.1 1000 shoppers' Results discussion

This section discusses the first set of results, which is the 1000 shoppers per day results, reflecting the normal supermarket days, we started by the total social cost, then journey and congestions costs, after that, we discussed the densities and the average no. of people in LOS, and finally the average, experience and maximum LOS maps.

While increasing the areas, the total social costs dropped in the first five scenarios from 4314 pounds, which is the highest point the total social cost reached, to 4018 pounds, in the sixth scenario, which is the lowest point it reached, the cost increased slightly to 4031 pounds and went back up in the seventh scenario to 4030 pounds. In the eighth scenario, it dropped again and continued till the ninth scenario, were it reached o 4017 pounds. In the tenth scenario it went up and continued going up till the fourteenth scenario, where it reached to 4134 pounds, and this was the second highest point the total social cost reached. The reason behind the shape of this curve, shown in Figure 133, is because the total social cost is affected by the journey and the congestion costs, however, the journey costs has the higher values when compared with congestion costs, hence these higher values control the shape of the total social cost. The journey cost is 98 percent of the total social cost, while the congestion cost occupies 2 percent from the total social cost. The higher journey cost is due to the weight of walking, queuing and waiting, since they have higher weights when compared with the congestion, in addition the congestion time is only part of the journey time, i.e. the congestion time ranges from 1 second to 1 minute, while the journey ranges from 30 minutes to 1 hour. The areas that has lowest total social cost ranges from 1450 square meters to 1650 square meters.

The journey cost started at 4259 pounds, and it started to decrease while increasing the area, till it reached 4013 pounds at the fifth scenario, after that the journey cost increased till it reached 4133 pounds. The reason behind these slops are the following: (1) when we started to increase the area, the journey time and cost reduced, since the new dimensions made it easier to the shoppers to flow freely in the space, so the time from entering to existing got reduced; (2) while at one point, which is the point of the sixth scenario, an additional increase in the area made the shoppers spent more time walking from one zone to another, and the total time for the journey increased, hence the journey cost increased.

We had two types of scenarios, the ones that we increased the critical isles dimensions only and the other we increased in all isles' dimensions. The first type includes the first seven scenarios, the remaining seventh scenarios follow the second type. However, the major effectiveness in reducing crowding levels was in the first seventh scenarios. When we started increasing the areas, the congestion cost reduced dramatically, from 45 pounds in the first scenario to 2 pounds in the seventh scenario, after that, congestion cost continued to decrease slightly till it reached 1 pounds in the fourteenth scenario. The reason behind this curve, shown in Figure 132, is that in the first scenarios, any increase in the critical areas affected the congestion heavily, while after the seventh scenario, the effect was very minimal, because the shoppers moved smoothly in the seventh scenario and removed almost all the congestion and obstacles. Worth mentioning, the seventh scenario had the maximum increased in the widths of critical areas only, which are the fresh produce, pre-prepared food and the sixth isle of general items, while keeping the remaining areas with the remaining areas at 1.3 meters width.

Figure 154 shows the reduction, in both congestion cost and in journey cost, in the first scenarios. Hence, we are prioritizing the congestion cost over the journey cost, since the congestion affects the human comfort while for journey time, the shoppers already planned the visit to the supermarket and they know that it will take time, hence, reference to the literature review Bennett (1998), if the shoppers is expecting something, the feeling of discomfort will be less, i.e. if they are expecting to take 30 minutes for shopping journey, they will be comfortable, but if they are not expecting crowding, and it was crowded the feeling of discomfort will be duplicated. On the other hand, the journey cost has the higher percentage of the total social cost. However, we need the optimal area that shares the lowest congestion and journey costs, which is the area that ranges between 1450 square meters to 1650 square meters.

We divided Figure 154 into three zones , the first zone, shown in red, is the sudden drop in congestion and journey time & costs, and where the congestion cost dropped 85 percent, as shown in Table 83, the second zone is the optimal area zone, shown in green, this zone has the lowest congestion and journey time & costs, the third zone is the needless increase zone, shown in yellow colour, where the increase in area has a minimal influence on the decrease in congestion time and costs, while increasing the  journey time and cost. Table 83 shows that an increase on 16 percent in area of supermarket will result in 85 percent reduction in congestion, while an increase of 33 percent in area will result in 96 percent reduction in congestion cost, these are the optimal increase in the area of supermarket.

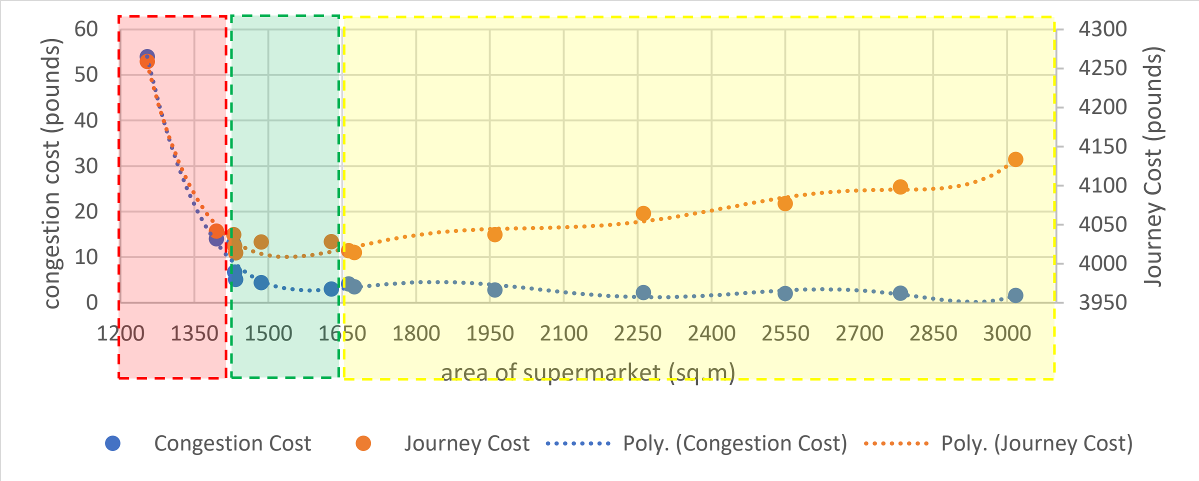



Figure 154: congestion vs. journey cost down areas for 1000 shoppers per day simulation.

Table 83: percentage of decrease in congestion cost compared to percentage of increase in area for 1000 shoppers per day

| Area of the supermarket (sq.m) | congestion cost (pounds) | Percentage of decrease in average congestion cost (%) | Percentage of increase in area of supermarket (%) |
|---|---|---|---|
| 1200 | 82 | 0 | 0 |
| **1400** | **12** | **-85** | **16** |
| **1600** | **3** | **-96** | **33** |
| 1800 | 5 | -93 | 50 |
| 2000 | 4 | -95 | 66 |
| 2200 | 2 | -97 | 83 |
| 2400 | 2 | -97 | 100 |
| 2600 | 3 | -96 | 116 |
| 2800 | 2 | -97 | 133 |

Table 70 and Figure 140 show that the average no. of shoppers falling under LOS A had constant increase from the first scenario, where it was 0.4 shoppers on average, then they increased to reach to 7 shoppers on average, as shown in Figure 139, which is 1649 percent increase; on the other hand, the average no. of shoppers in LOS F, which the worst in density level, is reducing, where it got reduced from 0.7 to almost zero shoppers, i.e. it is 100 percent decrease. The average no. of shoppers in LOS B and had 19 percent reduce, from 3.1 to 4.2 shoppers on average. Average no. of shoppers in LOS C almost remained the same on 23.6

shoppers on average. Average no. of shoppers in LOS D had 49 percent decrease, from 5.6 to 2.8 shoppers on average. Average no. of shoppers in LOS E had 84 percent decrease, from 6.5 to 1 shopper on average. Table 84 shows the percentages of increase or decrease in average no. of shoppers in each LOS. The reduce in the no. of shoppers on average in LOS E and F shows the enhancement in densities, crowding levels and overlapping in personal spaces, when compared between lower areas and higher areas. The average no. of shoppers in LOS F curve went through three sections, shown in Figure 155, the first section is the heavy drop section, where the value dropped from 0.7 to almost zero, however, in the second, the results remained at zero, and in the third section the value fluctuated between 0 and 0.02 shoppers on average. The sudden drop happened when we increased the area of the main three crowded areas (fresh produce, pre-prepared food and the sixth isle of general items areas), however, when we started to over increase, it did not affect the average no. of people in LOS F. the fluctuation happened because in the last seven scenarios, we are not only focusing on the critical zones, but increasing all isles at once, hence despite the increase but it is not 100 percent efficient.

Table 85 shows that an increase in 16 percent in area of supermarket will result in 85 percent reduction in the average no. of shoppers in LOS F. while an increase of 33 percent in area will result in 100 percent of reduction in average no. of shopper in LOS F. while after the 33 percent increase, which is considered the perfect point and the optimal area, the average no. of people in LOS F starts to fluctuate between zero and 0.01.

Table 84: percentage of increase or decrease in average No. of shoppers for 1000 shoppers per day scenarios

| scenario | Area | LOS A (< 0.308642) | LOS B (0.308642 - 0.431035) | LOS C (0.431035 - 0.719424) | LOS D (0.719424 - 1.07527) | LOS E (1.07527 - 2.17391) | LOS F (> 2.17391) |
|---|---|---|---|---|---|---|---|
| 1 | 1254.3 | 0.4 | 3.1 | 23.6 | 5.6 | 6.5 | 0.7 |
| 14 | 3017.5 | 7 | 4.21 | 23.66 | 2.82 | 1 | 0 |
| Increase/ decrease % | 140 | 1649 | 36 | 0.26 | -49 | -84 | -100 |

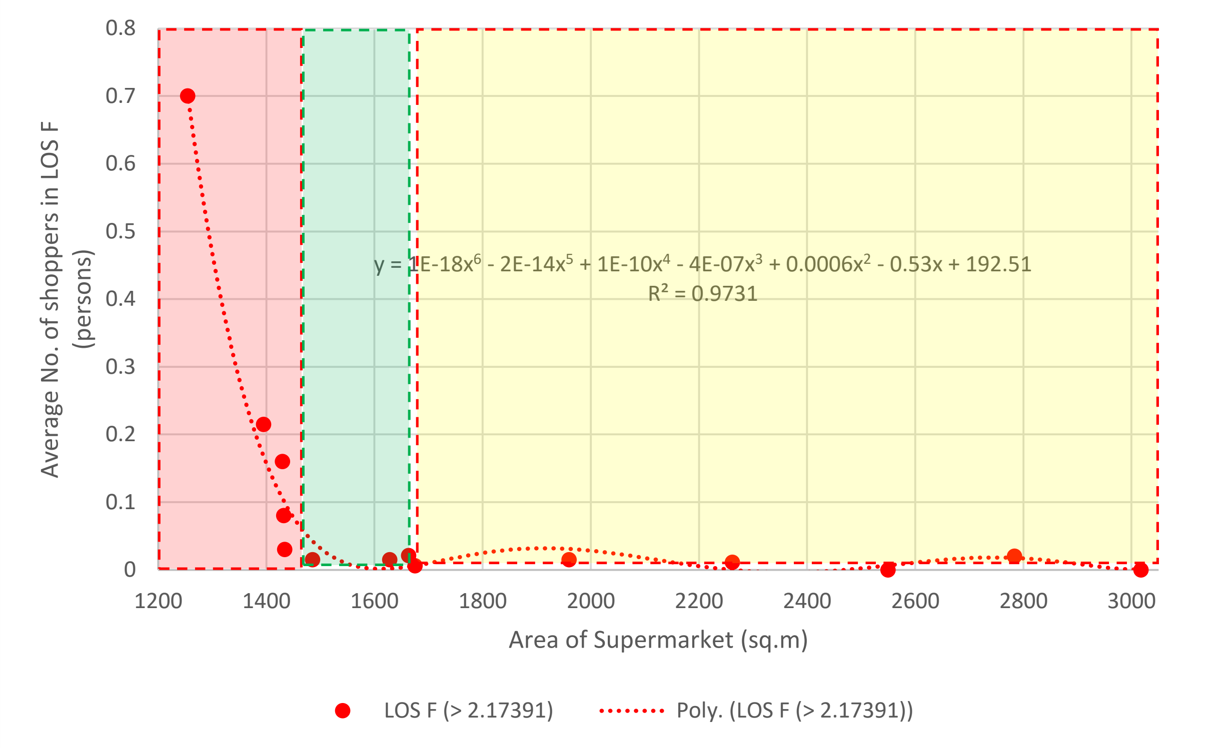



Figure 155: the average no. of shoppers in LOS F for 1000 shoppers' simulation, two sections

Table 85: percentage of decrease in average no. of shoppers in LOS F and percentage of increase in area of supermarket for 1000 shoppers per day.

| Area of the supermarket (sq.m) | average No. of shoppers in LOS F (persons) | Percentage of decrease in average No. of shoppers in LOS F (%) | Percentage of increase in area of supermarket (%) |
|---|---|---|---|
| 1200 | 1.1 | 0 | 0 |
| **1400** | **0.16** | **-85** | **16** |
| **1600** | **0.00** | **-100** | **33** |
| 1800 | 0.01 | -99 | 50 |
| 2000 | 0.01 | -99 | 66 |
| 2200 | 0.00 | -100 | 83 |
| 2400 | 0.00 | -100 | 100 |
| 2600 | 0.01 | -99 | 116 |
| 2800 | 0.01 | -99 | 133 |

The average LOS (t) maps remained at LOS A for the fourteen scenarios, however the black areas increased during the increase in supermarket areas, especially in the household items area, because these areas have lesser visits when compared with other areas, such as the fresh produce areas, the increase in these areas has negative effect, since the increase will result in higher energy consumption. The maximum LOS maps in Table 74 shows the LOS E and F, which have the critical densities and crowding levels is decreasing when the area, i.e. space dimensions, is increasing. On the other hand, the LOS A is increasing. In the first three scenarios, LOS F was appearing, however, in fifth scenario, it disappeared, the reason behind the increase in LOS A levels and the decrease in LOS F levels is due to the lesser overlapping in personal spaces. The experienced LOS (t) maps highlights the crowded areas, the LOS in the maps ranged from LOS A to LOS C. The LOS C in the experienced LOS (t) maps was mainly in three areas, the fresh produce, pre-prepared food and the sixth isle in the general items' areas, the areas are highlighted in red in Figure 156, since those areas have the higher visits by shoppers, however, when we increased the area of the supermarket the LOS C reduced to LOS B and A, which means the following: lesser overlapping in personal spaces, lesser densities at these areas, more human comfort, lesser crowding and smooth flow of shoppers. In the density graph, shown in Table 86, it is clearly noticeable that the LOS A is increased.

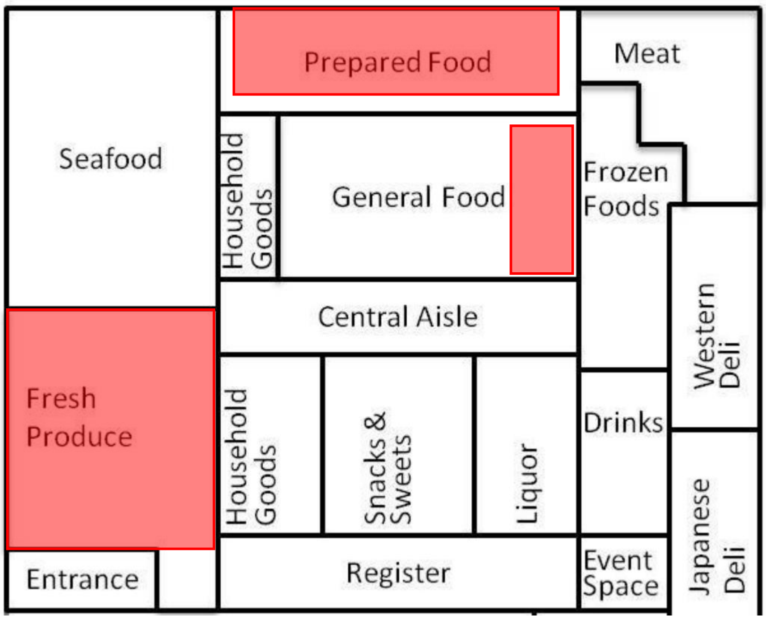
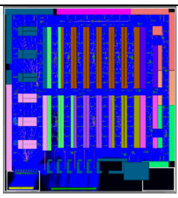
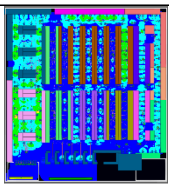
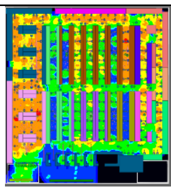
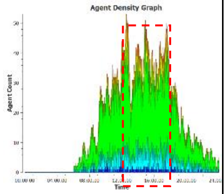
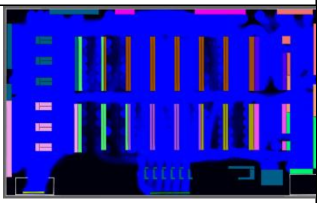
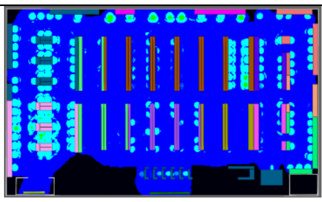
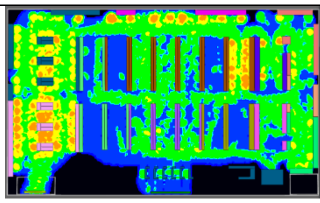
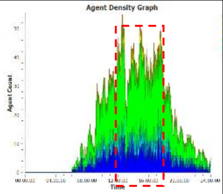



Figure 156: critical crowded areas in the supermarket

Table 86: first and fourteenth scenarios maps and graphs comparison

| scenario | Average LOS (t) map | Experience density map | Maximum LOS map | Density graph |
|---|---|---|---|---|
| 1 |  |  |  |  |
| 14 |  |  |  |  |

### 6.2 2000 shoppers' Results discussion:

In this section, we discuss the second set of results, where the total no. of shopper increased to 2000 per day to reflect the case of an event, such as a festival, or a weekend scenario, and to study the section between the sudden drop in crowding, densities and congestion time and cost, and the section of decrease in them. When we increased the no. of shopper the differences in results between the scenarios became bigger, as shown from Figure 159 to Figure 163.

The total social cost started at 9604 pounds for all agents per the 6 hours of the study period, however, this is the highest point the total social cost reached, and then suddenly dropped with the increase in area of supermarket to 8257 pounds for all agents per the 6 hours of the study period; then continued to decrease till it reach 8130 pounds for all agents per the 6 hours of the study period at the revised seventh scenario, which is the lowest point the total social cost reached; after that, the total social cost continued to rise till it reached 8307 pounds for all agents per the 6 hours of the study period, which is the second highest point the total social cost reached. Similar to the first set of results, the total social cost is mainly affected by the journey cost rather than the congestion cost, since the journey cost occupies 97 percent from the total social cost, while the congestion cost occupies the remaining 3 percent. The optimal result of the total social cost was at 1600 square meters, where the total cost was 8100 pounds for all shoppers per the 6 hours of the study period. Hence the optimal range was from 1500 square meters to 1700 square meters. And this area is lesser than any carrefour supermarket area, since carrefour sales area ranges from 2400 – 23,000 square meters ("Carrefour Group" 2019). On the other hand, the typical supermarket isles width ranges from 1.8 meters to 2.4 meters, however, our finding showed that some areas can have lower dimensions, while other areas can have higher dimensions than the typical isle width, such as 1.3 meters in uncrowded isles and 3.9 meters in crowded ones. In the previous set of scenarios (the 1000 shoppers) the range was from 1450 square metres to 1650 square meters. And this is logical since the increase in population require an increase in area, and the optimal area for 2000 shoppers per day is more than the optimal area for 1000 shoppers per day. We divided Figure 157 into three zones, the sudden decrease in congestion and journey costs zone, the optimal zone and the unnecessary increase in area of supermarket zone. Similar to 1000 shoppers per day scenarios, when the increase was in the fresh produce, pre-prepared food area and the 6th isle of general items, the reduction in congestion cost and LOS F levels was effective. However, when we increased all the isles, that resulted in increasing the journey time and cost.

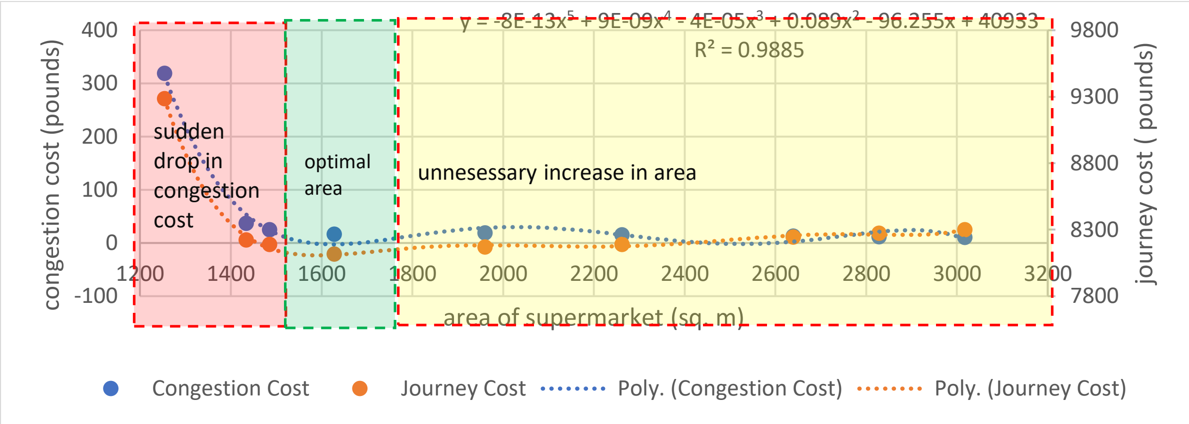



Figure 157: 2000 shoppers' scenarios congestion and journey costs summary

We can notice also that the best result is the revised seventh scenario, where it has the lowest journey cost, congestion cost, total social cost and average no. of people in LOS F, when compared with the other revised scenarios. However, in the first set of results the differences between the fifth, sixth and seventh scenarios were small, in this set of results the difference increased. In addition, the seventh scenario had the lowest average no. of shoppers in LOS F in the first and second sets of results. Scenario no. 5 had the lowest total cost in results 1, but in results 2, the seventh scenario is the lowest and the same is for the journey cost.

We called the seventh scenario: the balance point, since any increase in area after this point will have a very minimal reduction in crowding and it increases the energy consumption; on the other hand, any reduction in area below this point, will heavily affect the crowding levels, while very minimal effect on energy consumption. In addition, the journey cost will increase after this point, while below it, the journey cost will decrease. This is the best scenario because of the sudden drop in congestion cost, LOS F and journey cost, which results as we increased the critical areas.

Table 87 shows that an increase on 16 percent in area will result in 80 percent reduction in congestion, while an increase of 33 percent in area will result in 100 percent reduction in congestion cost. Which means a small increase in area has a significant reduction in congestion time and cost, while bigger increases have minimal effect, which is above 33 percent increase. At 2400 square meters, the reduction in congestion cost became 100 percent, where at 2200 it was 92, this decrease is due to the increase in the critical zones' dimensions (fresh produce, pre-prepared food area and the sixth isle of general items), where they exceeded the dimensions in the seventh scenario.

Table 87: percentage of decrease in congestion cost compared to percentage of increase in area for 2000 shoppers per day.

| Area of the supermarket (sq.m) | congestion cost (pounds) | Percentage of decrease in average congestion cost (%) | Percentage of increase in area of supermarket (%) |
|---|---|---|---|
| 1200 | 450 | 0 | 0 |
| **1400** | 90 | -80 | **16** |
| **1600** | 0 | -100 | **33** |
| 1800 | 10 | -97 | 50 |
| 2000 | 40 | -91 | 66 |
| 2200 | 35 | -92 | 83 |
| 2400 | 0 | -100 | 100 |
| 2600 | 0 | -100 | 116 |
| 2800 | 10 | -97 | 133 |

Figure 158 shows the average no. of shoppers falling under LOS F, it shows a sudden drop from 1200 to 1450 square meters, then it moves to the optimal range areas, from 1450 to 1650 square meters, while after this period the average no of shoppers in LOS F is constant between 0 to 0.01 shoppers on average. The green area is the optimal zone.

Table 88 shows that an increase in 16 percent in area of supermarket will result in 92 percent reduction in the average no. of shoppers in LOS F. while an increase of 33 percent in area will result in 100 percent of reduction in average no. of shopper in LOS F. while any increase after this point will result in constant reduction between 96 to 100 percent, which means that after 33 percent increase in area, almost no shopper fall under LOS F and the human comfort increase dramatically, since the overlapping in personal spaces is very minimal when compared with lesser areas.

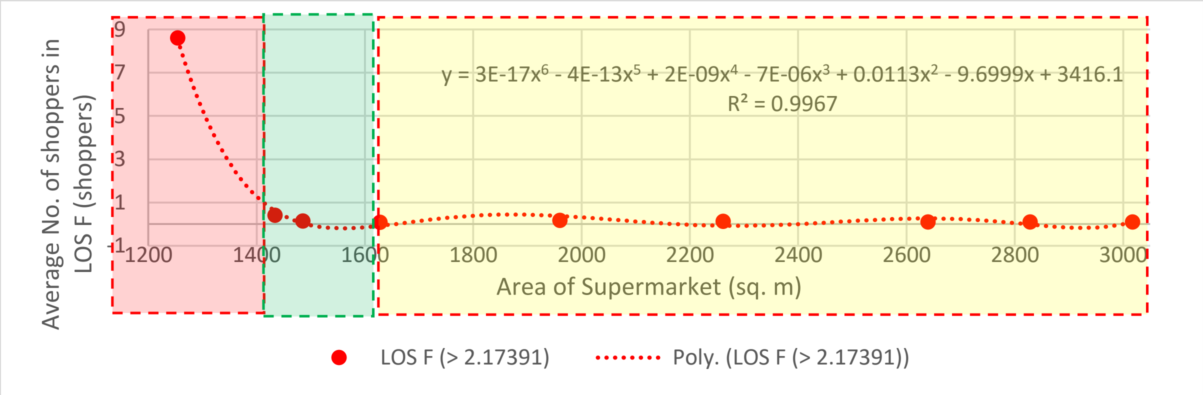



Figure 158: 2000 shoppers' average No. of shoppers in LOS F vs. Area of the supermarket

Table 88: percentage of decrease in average no. of shoppers in LOS F and percentage of increase in area of supermarket for 2000 shoppers per day.

| Area of the supermarket (sq.m) | average No. of shoppers in LOS F (persons) | Percentage of decrease in average No. of shoppers in LOS F (%) | Percentage of increase in area of supermarket (%) |
|---|---|---|---|
| 1200 | 13.5 | 0 | 0 |
| **1400** | 1 | -92 | **16** |
| **1600** | 0 | -100 | **33** |
| 1800 | 0.5 | -96 | 50 |
| 2000 | 0.4 | -97 | 66 |
| 2200 | 0 | -100 | 83 |
| 2400 | 0 | -100 | 100 |
| 2600 | 0.3 | -97 | 116 |
| 2800 | 0 | -100 | 133 |

### 6.3 1000 & 2000 shoppers per day comparison

The average percentage in Table 89 and Table 90 is calculated by giving the percentage of 2000 shoppers scenarios a weight of two, because the number of shoppers is double the 1000 shoppers' scenarios, and giving a weight of 6 to the percentage of 1000 shoppers scenarios, since this percentage is for 6 days a week, while the 2000 shoppers percentage is only for the weekend. Since an increase of 16 percent in the area of the supermarket resulted in 86 percent reduction in the average no. of shoppers falling under LOS F and 83 average percent reduction in congestion cost, as shown in Table 89 and Table 90, thus, the 1400 square meter area of supermarket, which is the 16 percent increase, is the optimal area. Since after this point the improvement is very minimal, and the congestion cost and average no. of people in LOS F is constant. Figure 159, Figure 160, Figure 161 and Figure 162, all these figures shares one thing, which is the optimal area of the supermarket ranges from 1450 to 1650 square meters, this range is the lowest among, congestion cost, journey cost and the average no. of shoppers in LOS F. these figures also show the same shape of curves in the situation of 1000 or 2000 shoppers per day, the only difference is the values, where 2000 shoppers per day had larger values. Figure 163 shows that LOS A which is the opposite of LOS F is increasing with the increase in area, the constant increase is because every increase in area gives the shopper an additional space hence better LOS.

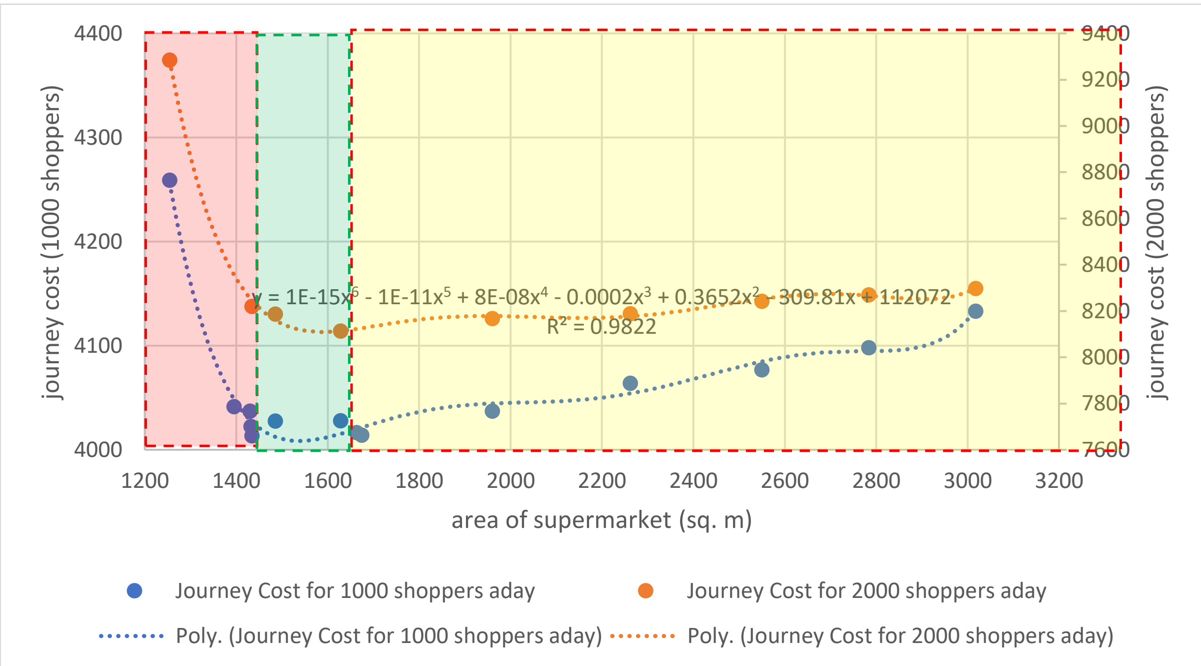



Figure 159: journey cost for 1000 shoppers' results vs for 2000 shoppers' results

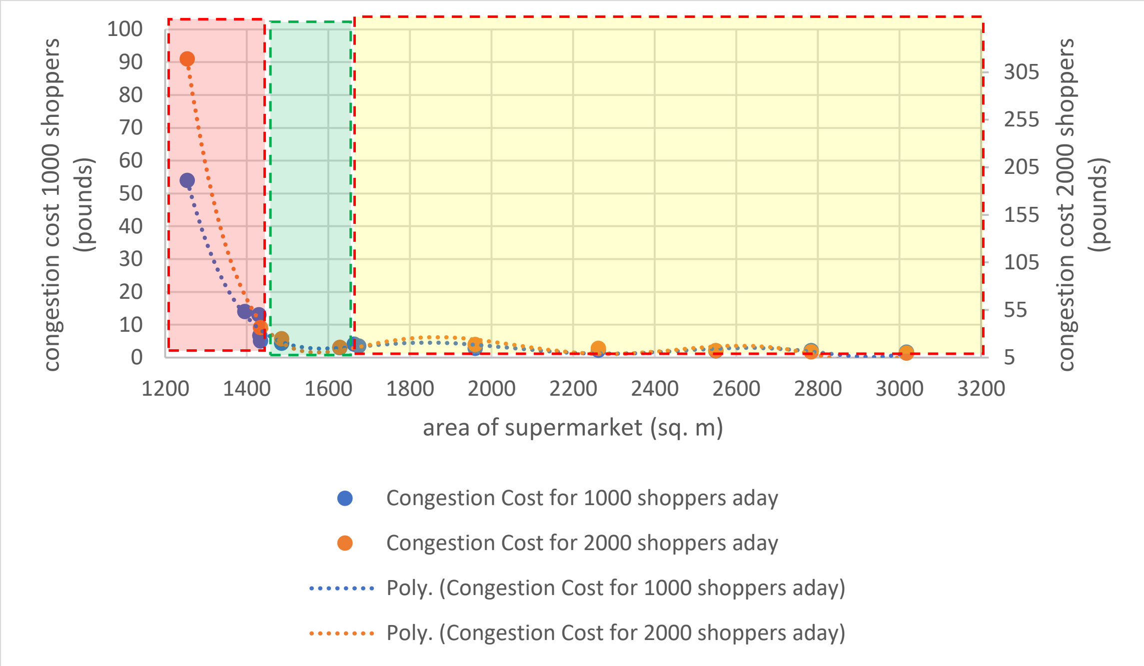



Figure 160: congestion cost for 1000 shoppers' results vs for 2000 shoppers' results

Table 89: comparison between 1000 and 2000 shoppers per day for the decrease in congestion cost while increasing the area

| Area of the supermarket (sq.m) | Percentage of increase in area of supermarket (%) | Percentage of decrease in average congestion cost for 1000 shoppers per day (%) | Percentage of decrease in average congestion cost for 2000 shoppers per day (%) | **Average percentage** |
|---|---|---|---|---|
| 1200 | 0 | 0 | 0 | 0 |
| **1400** | **16** | -85 | -80 | -83.75 |
| **1600** | **33** | -96 | -100 | -97 |
| 1800 | 50 | -93 | -97 | -94 |
| 2000 | 66 | -95 | -91 | -94 |
| 2200 | 83 | -97 | -92 | -95.75 |
| 2400 | 100 | -97 | -100 | -97.75 |
| 2600 | 116 | -96 | -100 | -97 |
| 2800 | 133 | -97 | -97 | -97 |

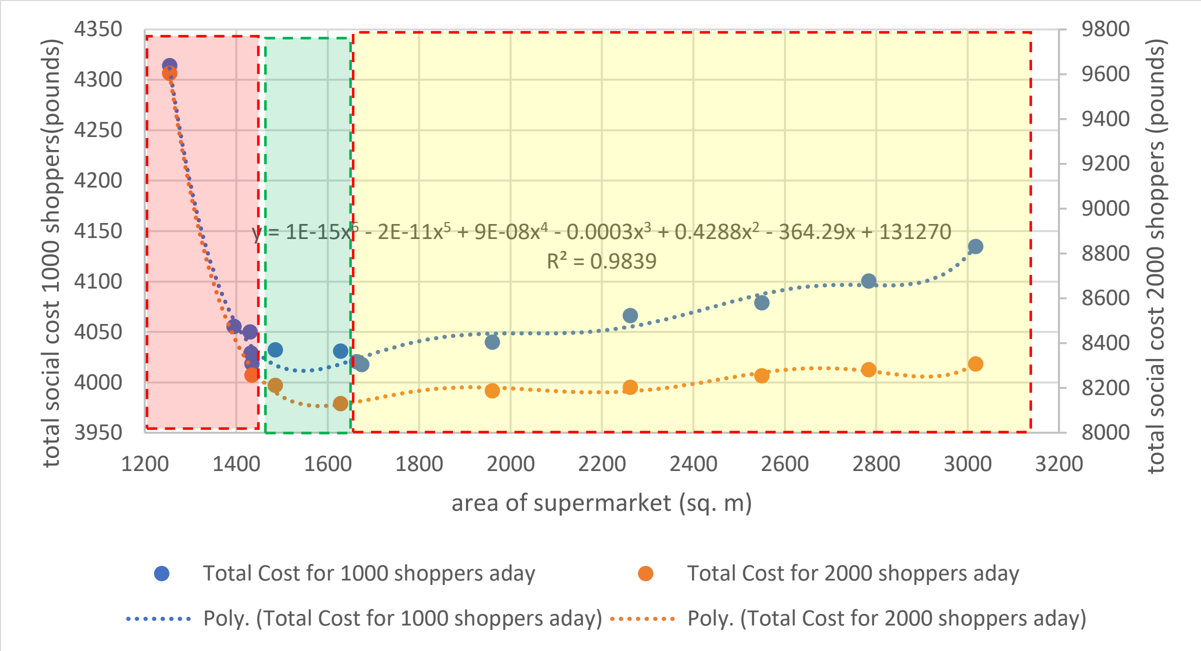



Figure 161: total social cost for 1000 shoppers' results vs for 2000 shoppers' results

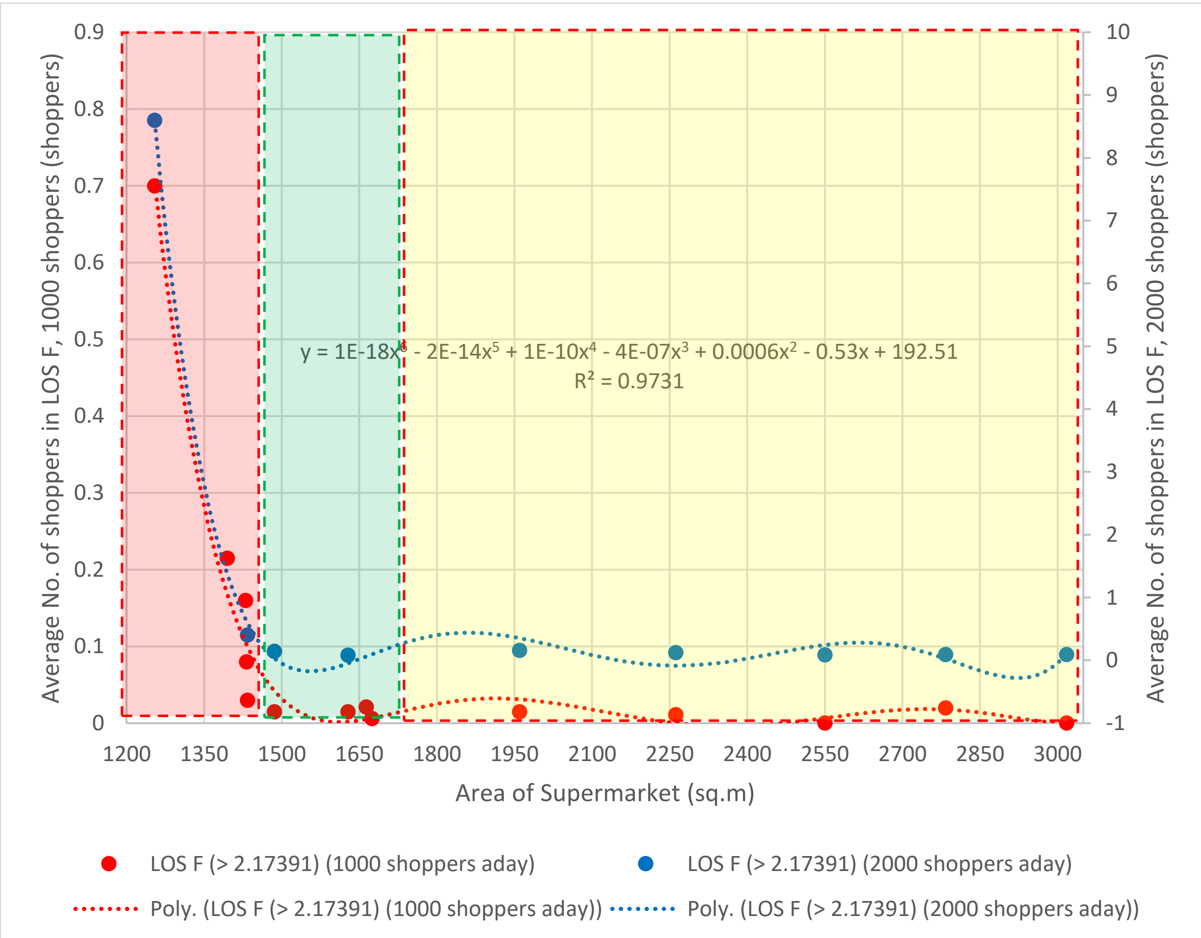



Figure 162: average no. of shoppers in LOS F results 1 vs results 2

Table 90: comparison between 1000 and 2000 shoppers per day for the decrease in average no. of shoppers while increasing the area

| Area of the supermarket (sq.m) | Percentage of increase in area of supermarket (%) | percentage of decrease in average No. of shoppers in LOS F (%) for 1000 shoppers per day | percentage of decrease in average No. of shoppers in LOS F (%) for 2000 shoppers per day | average percentage |
|---|---|---|---|---|
| 1200 | 0 | 0 | 0 | 0 |
| **1400** | **16** | **-85** | **-92** | -86.75 |
| **1600** | **33** | **-100** | **-100** | -100 |
| 1800 | 50 | -99 | -96 | -98.25 |
| 2000 | 66 | -99 | -97 | -98.5 |
| 2200 | 83 | -100 | -100 | -100 |
| 2400 | 100 | -100 | -100 | -100 |
| 2600 | 116 | -99 | -97 | -98.5 |
| 2800 | 133 | -99 | -100 | -99.25 |

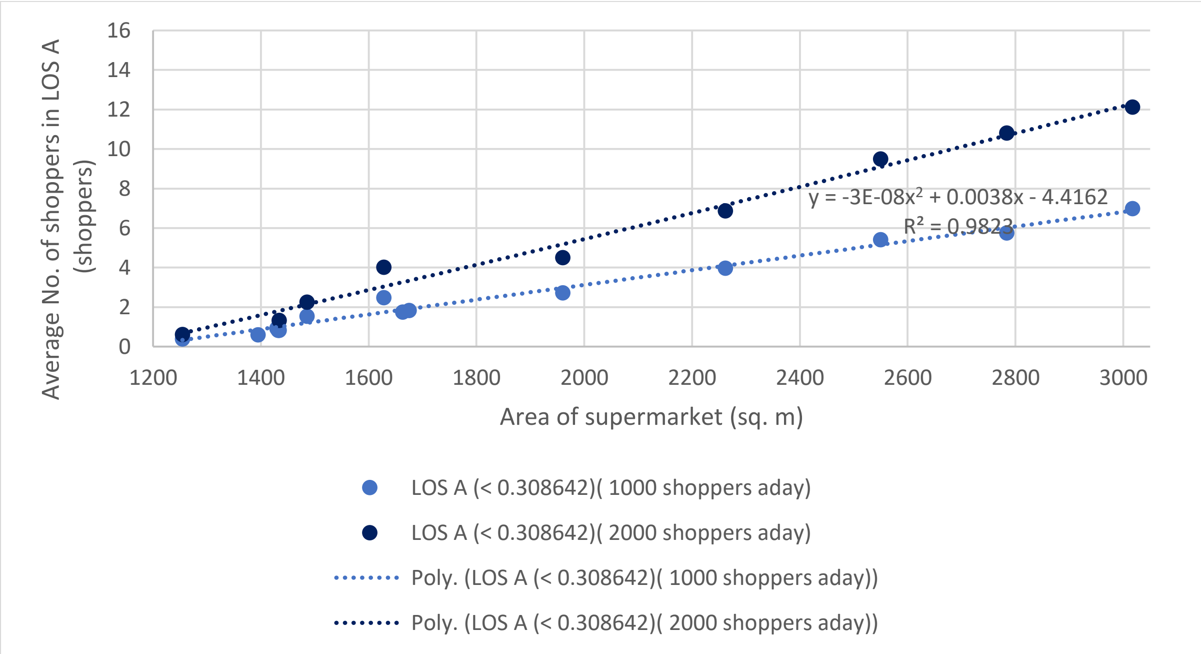



Figure 163: average no. of shoppers in LOS A results 1000 shoppers per day vs results 2000 shoppers per day

Aylott & Mitchell (1998), Lee, Kim & Li (2011) Machleit, Eroglu & Powell Mantel (2000) and Verma & Singh (2018) results showed that the supermarket is affected by the layout but did not show method of measuring it. However, in our research we showed how it can be measured using the simulation methodology. On the other hand, they did not show the optimal size of the supermarket and isles widths, but our finding showed the optimal size where it increased the human comfort and reduced the crowding levels.

# Chapter 7:

# Conclusion:

# Chapter 7 Conclusion

## 7.1 Summary

We defined crowding as an undesirable situation that a lot of people suffer from it. It is the situation where the shoppers feel that the supermarket is overloaded with people at certain times. The shoppers dislike the situation because of the following: the noise pollution, the delays in buying the planned items, fear from disease infections, the feeling of disorganization. Crowded supermarkets force the people to avoid the peak time, rather than choosing the suitable time for customers. For some people, who have diseases such as breathing Asthma or depression, it is not advisable for them to go through crowded areas. In addition, the crowded supermarkets encourage the customers to shop faster, to avoid the situation. Then previous studies to the crowding and human comfort in the supermarkets were studied, and the factors affecting the human comfort in supermarket were listed, such as shoppers' densities, including the crowding evaluation. We studied the personal space dimensions as well, in addition to studying the supermarkets layouts and how are they designed. Then, different approaches were examined to select the best suitable methodology for our study, were we used the simulation approach, since it gives the flexibility to test different scenarios, when compared to the observation or survey methodologies. We selected the appropriate software, which is mass-motion, through a comparison between different software such as mass motion and sim-walk. The model was set up according the logic of shopping in supermarkets were followed. In addition, we defined the measures of crowding, including level of service, social costs, including congestion cost and journey cost and LOS maps, i.e. average LOS (t), Experienced LOS (t) and maximum LOS maps. We focused on the level of service and social costs as measures of the crowding, because, we could convert them to numbers that we could study, quantitate and compare, while the maps were used to locate the areas of crowding. Then we created several options, with different isles dimensions, took the results for each one of them and discussed them in chapter 6. The options were arranged from smallest possible dimensions to the largest, the first seven scenarios, we increased the critical zones only, such as fresh produce, pre-prepared food area and the sixth isle of general items; while the last seven scenarios, the increase was in all isles at once.

## 7.2 Findings

The results showed that the size of the supermarket affects the crowding and energy consumption, the increase in supermarket size causes a reduction in crowding and congestion, since the shoppers are moving freely and the overlapping in shoppers' personal spaces is fewer, however, the reduction is rapid until it reaches a certain point, which is at 1450 square meters in the case of 1000 shopper per day and 1500 square meters in the case of 2000 shoppers per day, after this point, the crowding levels stabilize. On the other hand, increasing the supermarket size increase the energy consumption and the usage of materials.

Two sets of scenarios were tested, one with 1000 shoppers per day and the other with 2000 shoppers per day. In the discussion, it was shown that 16 percent increase in the area of supermarket over the smallest size the supermarket can reach (1200 square meters), is the optimal increase from the human comfort perspectives. The optimal area is 1450 square meters, where it reduced the crowding by 87 percent and the congestion cost by 83 percent relative to 1200 square meters, and this is considered the beginning of the optimal area, which ends at 1650 square meters, after this point the change in crowding and congestion is very minimal, hence the increase in area of supermarket is unnecessary beyond 1650 square meters. In addition, the increase in the supermarket is not only unnecessary but also cause an increase in journey cost, since the movement is smooth and the distances between the zones inside the supermarket is large causing an increase in journey time and cost. we have found that the increase in the critical zones, i.e. the fresh produce, pre-prepared zone and the sixth isle of general items, had the major cause in the reduction of congestion cost, journey cost, higher LOS, such as LOS E and F. We learnt how to find the optimal area of the supermarket or any other space with minimal effect on environment and human comfort.

### 7.3 Design implications

The traditional way of designing the supermarket, as shown in the literature review chapter, was by following the standard space dimensions; by maximizing the sales by exposing the shoppers to the maximum number of items and increasing the time spent in the supermarket by providing a comfortable environment, such as putting music; or by designing the customers journey in the supermarket, such as the location of breakfast items, i.e. milk and cornflakes, together, so the customer can find all the needed items at one place.

Our research proposes a useful way to design the supermarkets and increase the comfort levels for the shoppers, by decreasing the crowding levels and congestion areas, this is done by defining the needed width for isles and the space for circulation, depending on the human logic in shopping in the supermarket. A set of options of the space, i.e. the supermarket is proposed, including the minimal area the supermarket can reach and the maximum area, then tested by agent-based modelling and simulations, while evaluating the crowding levels and congestion areas. Our study showed that it is more efficient to increase the area of the crowded zones in the supermarket only, while reducing the sizes of uncrowded isles. Our research finding shows that the uncrowded isles can be 1.3 meters width, but the crowded isles, such as the fresh produce, pre-prepared food area and the sixth isle in the general items, should be larger with minimum 2.7 times the uncrowded zones, i.e. they should have a width of 3.6 meters, as shown in the seventh scenario.

### 7.4 Sustainability implications

Increasing the area of the supermarket means increasing the materials used, such as floor tiling, concrete, walls and structure elements. It also means increasing the energy consumption, for many reasons, first, the volume is larger, hence the cooling loads are greater, secondly the lighting requirement is more, since it needs to cover all the additional areas, to avoid any low lux levels. The maintenance costs will increase because of the larger number of machines such as additional AC units, including AHU, compressors, pipes; additional lighting, which needs to be changed and maintained regularly; in addition to cleaning; and testing of electrical items, such as the electrical panels, wires and switches; maintenance cost includes also civil items, such re-painting the store or changing the tiles.

Our research proposes a useful methodology to define the optimal area of the supermarket or any other space functions such as shopping mall, terminal or airports, avoiding unnecessary increase in area, at the same time preventing human congestion and crowding effects on humans, this will result in avoiding unnecessary increase in energy consumption, material usage, operational or maintenance costs. Optimizing the space dimensions, i.e. the supermarket area, will result, in optimal energy consumption, maintenance costs, material usage, and operational costs; hence enhancing the energy consumption in interior spaces and lowering the effect on global warming without affecting the human comfort.

### 7.5 Operational implication

As shown in the introduction section, the operators tend to create crowded conditions, Chen, Lee & Yab (2018), show that shoppers tend to buy more in crowded conditions, in addition of increasing the journey time, since the more time shoppers spend in the supermarket, the more they buy. They stated all that crowded conditions attract customers, because it gives the feeling that the supermarket has discounts and offers. Our research gives an overview of the whole range of areas and the associated journey time, crowding levels and costs in order to choose the suitable area of supermarket, where they can compare the amount of sales to the costs it implies with it.

### 7.6 Recommendations for future research

The future works can study energy consumptions, material used, maintenance cost, operational cost in supermarkets vs. The increase in the area of supermarket. The process, which is used in our research, of creating options and evaluating them, according to level of service, congestion and journey costs, can be used/ automated in a generative design approach, where a set of layouts are created by defining a set of parameters, then evaluated, and the process includes choosing the optimal areas according lower environmental effect, higher human comfort and lower crowding levels. In this research we studied the shoppers' movement only, however, future research can study other movements and their effect on crowding and human comfort, such as the staff movement. In our research, we studied the isles width variable effect on crowding, however future research can study other design variables, such as the distribution of isles, i.e. vertical horizontal or angled, or the locations of items and racetrack circulation. We did not study the effect of carts on crowding, however, carts can affect the crowding levels and human comfort in supermarket, which can be studied as well. Different spaces and different space functions can use the same methodology to generate layout options and evaluate them according to environmental and human comfort impact, such as airports, shopping malls, terminals and exhibitions. The future studies can show the optimal point from sales perspective, where the crowding reach a level that attracts shoppers without affecting human comfort and overlapping in personal spaces.

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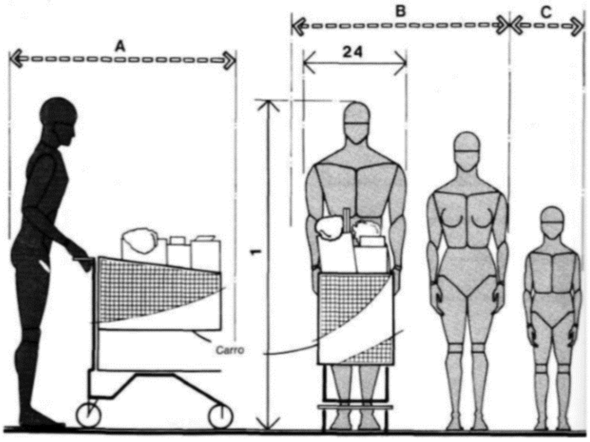
# Appendix

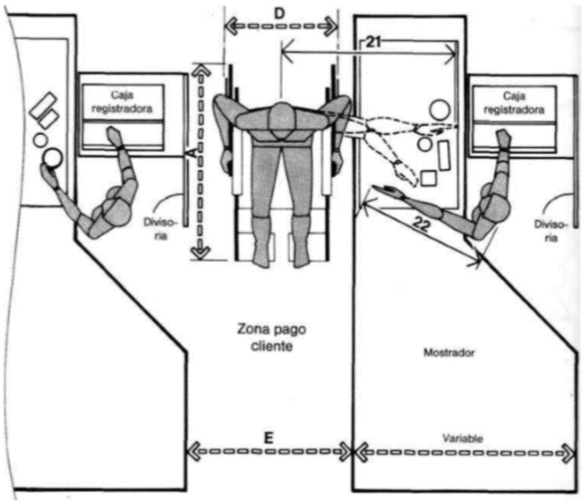
## 4.2 TIENDAS DE ALIMENTACIÓN

El dibujo superior izquierdo representa la holgura total de 106,7 cm (42 pulgadas) que precisa un comprador y su carro, y en el derecho vemos a una pareja de frente, cuya holgura es de 152,4 cm (60 pulgadas), incrementada en 45,7 cm (18 pulgadas) cuando va acompañada de un niño/a. La medida antropométrica base de la estimación es la máxima anchura corporal.

El dibujo inferior es un ejemplo de caja de cobro con su holgura que, incluso para acomodar a personas en silla de ruedas, se establece en 91,4 cm (36 pulgadas). La dimensión en planta de una silla de ruedas es de 63,5 x 106,7 cm (25 x 42 pulgadas).




HOLGURAS PARA CLIENTES




ZONA DE PAGO/HOLGURA PARA SILLA DE RUEDAS

| | pulg. | cm |
|---|---|---|
| A | 42 | 106,7 |
| B | 60 | 152,4 |
| C | 18 | 45,7 |
| D | 25 | 63,5 |
| E | 36 min. | 91,4 min. |

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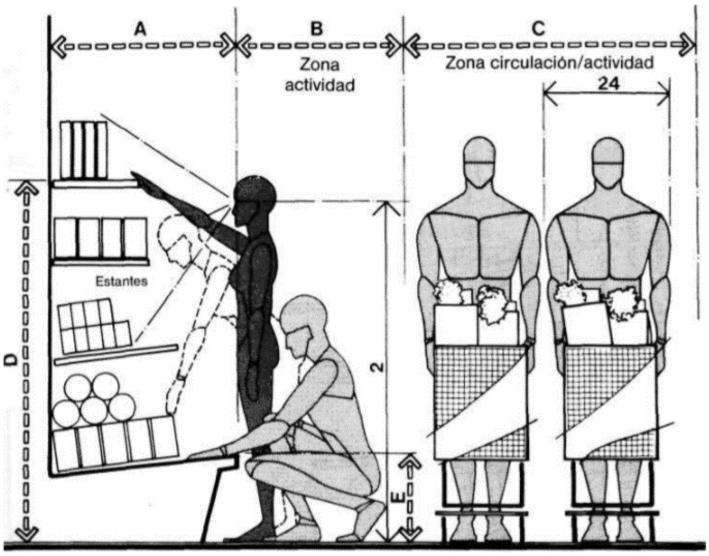
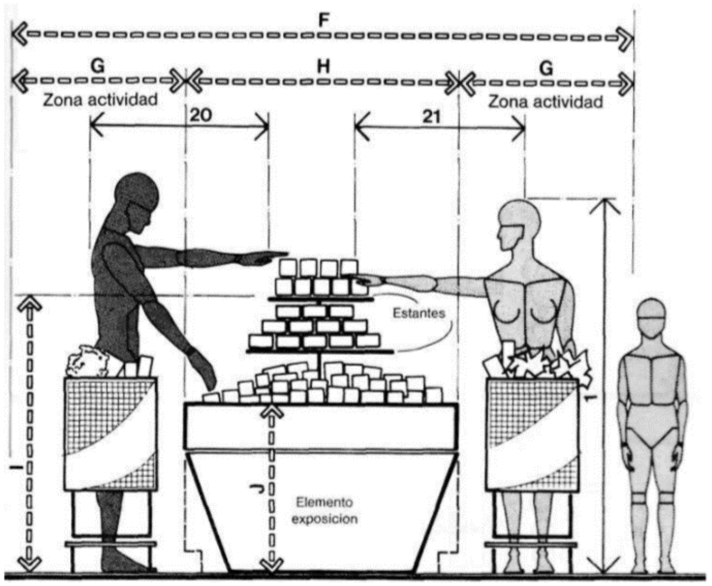



**ESTANTERÍA ESPECIAL DE EXPOSICIÓN/CIRCULACIÓN**

# 4.2 TIENDAS DE ALIMENTACIÓN

El dibujo superior ilustra las holguras relativas a la exposición de productos alimenticios por el sistema de estanterías. La persona arrodillada se desenvolverá cómodamente en una holgura mínima de 91,4 cm (36 pulgadas) que, suplementada en 152,4 cm (60 pulgadas), da paso a dos compradores de frente.

El dibujo inferior informa sobre las holguras que exige una organización en isla a la que se le asigna un espacio perimetral de 76,2 cm (30 pulgadas), apto para cualquier actividad por parte de los compradores. Las dimensiones clave, en este caso, son la máxima anchura corporal y ancho del carro; ambas quedan englobadas en esta última medida, si bien se destina únicamente para la zona de actividad, ya que, como puede verse en el dibujo, la circulación se segrega de la misma.

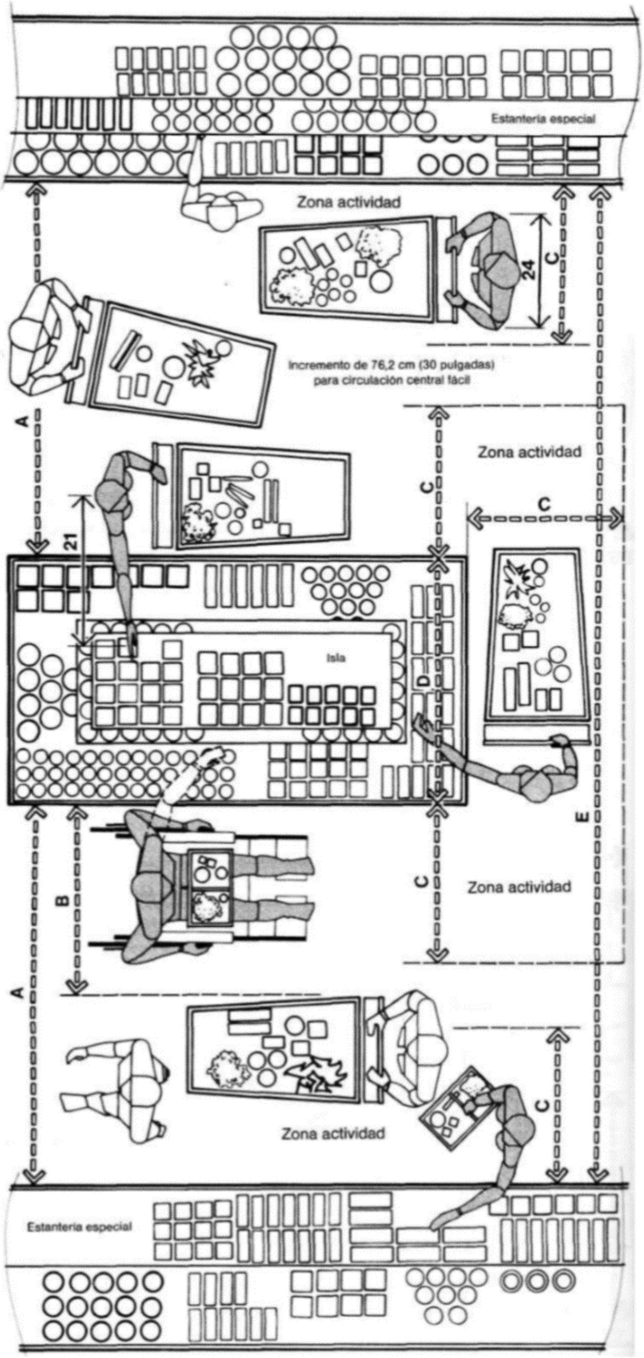



**ELEMENTO DE EXPOSICIÓN EN ISLA**

| | pulg. | cm |
|---|---|---|
| A | 32 | 81,3 |
| B | 36 max. | 91,4 max. |
| C | 60 | 152,4 |
| D | 63 max. | 160,0 max. |
| E | 15 max. | 38,1 max. |
| F | 108 | 274,3 |
| G | 30 | 76,2 |
| H | 48 | 121,9 |
| I | 48 max. | 121,9 max. |
| J | 30–32 | 76,2–81,3 |

# 4.2 TIENDAS DE ALIMENTACIÓN

La exhaustiva representación gráfica de esta página no hace más que reunir facetas del tema expuestas aisladamente en los dibujos de las anteriores. También proporciona información acerca de las holguras mínimas exigibles entre éstas y las estanterías. Se entiende que la holgura mínima que debe separar los componentes de exposición de alimentos ha de ser de 189,9 cm (72 pulgadas), capaz para acomodar, a ambos lados, un comprador y su carro, pero mermando considerablemente la posibilidad de paso de un tercer comprador, a no ser que uno de los dos primeros se aparte. Esta molestia se solventa agregando a la holgura mínima 76,3 cm (30 pulgadas) adicionales, por lo que la total queda en 259 cm (102 pulgadas).




HOLGURAS EN PASILLOS

| | pulg. | cm |
|---|---|---|
| A | 72 min. | 182,9 min. |
| B | 36 | 91,4 |
| C | 30 min. | 76,2 min. |
| D | 48 | 121,9 |
| E | 192 | 487,7 |