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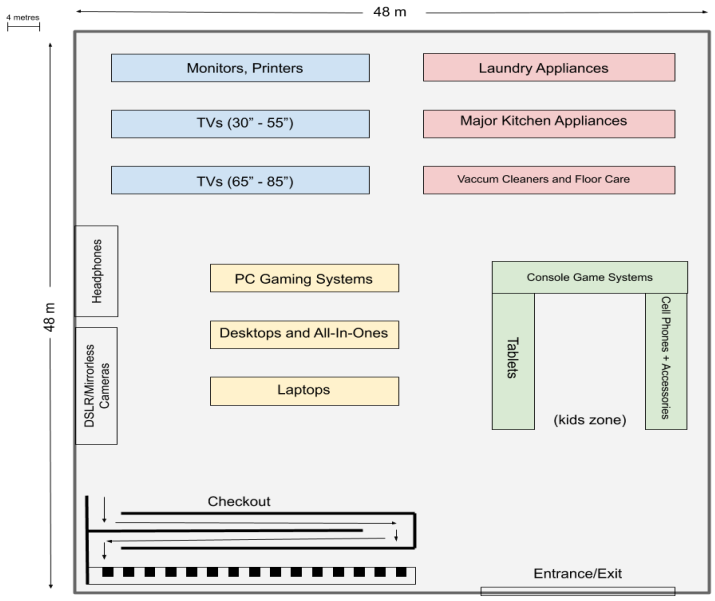
Letter to manager

Dear store manager,



Through our extensive research and mathematical modeling, we have come to the conclusion that an updated store layout as seen in the figure below will be greatly beneficial for the flash sale event.

We decided upon the layout of the various departments of the store by calculating the attractiveness of the departments. From research, we determined that the best layout of the store would be having the best deals at the back, 'worst' deals in the middle, and all other deals at the front of the store.

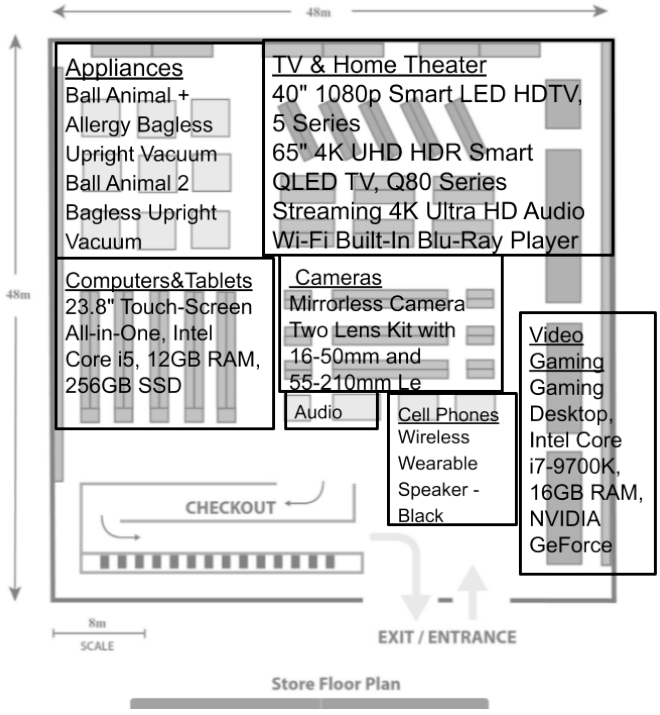
Our team calculated the attractiveness of products and placing them accordingly by considering the ratings and discounts of the various products and applying them to the department that they are found in. We also considered the quantity of products in the department. Using these three conditions, we placed the departments of the store in locations that will best enable customers to shop and select their desired items while reducing the risks of damage factors (such as fighting and dropping) through layout design. Our team believes it would be most beneficial to have a supervised area for children to stay while their parents or supervisors shop, with approximately four employees stationed in the area would be necessary to avoid damage to products.

In addition, a non-layout strategy which can improve the experience of customers and the retailer during the flash sale event is the use of a mobile application which can provide customers the ability to preview sale day store maps and the ability to create personal shopping lists. We believe that this will enable customers to plan their trip and avoid some frenzy created by sale-day stampedes.

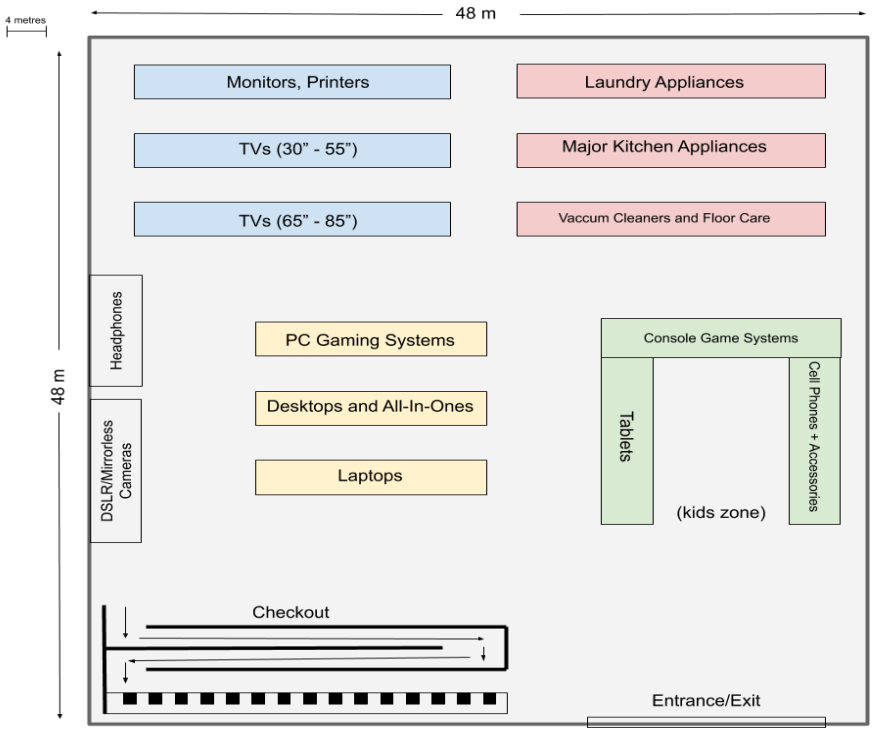
We hope that you will consider our solution to enhance your flash sale events.

Sincerely,
Team #2020038

Figure 1 with Items and Locations



Updated store layout



Problem and Analysis

Even with the decline in the market share of brick-and-mortar establishments due to online counterparts like Amazon impeding on their markets, flash sale and visiting a brick and mortar store in person has a certain appeal to it that continues to bring billions of people to the doors of retail stores multiple times every year. Now hundreds of people — with no rhyme or regard for their surroundings — rushing into a store to take advantage of the best deals available during flash sales presents a problem. During these flash sales, where indisputably anything could trigger a deadly stampede, how does a store guarantee the safety of both its shoppers and employees? Along with the obvious danger to humans, frenzied crowds of people are a genuine risk to the merchandise on shelves and the store's bottom line which is equally as important.

The problem in the questions above, wonderfully complicated and multi-faceted, forces us to quantify what good design really is. How do we know if a store's layout is objectively good? There are many relevant variables. For example, one factor our team had to consider was that a retail store's layout has to serve the store's purpose in two vastly different situations: a flash sale and a regular shopping day. During a flash sale, where the assumed primary goal is to get the customer to the product they wish to buy and out the door soon after; verses regular shopping days, where the primary goal is to keep the customers in the store by exposing them to all the products available, hopefully leading them to spend more than they expected. In order to produce an adequate store layout, one's analysis must account for both scenarios that a store will experience.

Assumptions

A problem such as the one presented for this year's Math Modeling Competition is, at first glance, quantitatively lengthy yet seems surprisingly simple. However, as one digs deeper into the parameters to set, controls to consider, and outliers to disregard, it becomes greatly apparent that an overall environment needs to be assumed for this problem to be solved in a perceptible and optimal way. These assumptions revolve around the average customer, store's history and current situation in an economical and personal aspect, and the reliability of customer feedback. Assumptions are required to solve the problem in an effective and efficient style, as they create a controlled set of circumstances for the math model to adhere to. The assumptions made by our team in order to accomplish our math model are outlined below:

Assumption 1: Reliability of customer ratings
In order to determine the placement of items in our math model, our team used the provided customer ratings of all merchandise for sale. It is not uncommon for customers to leave emotionally driven reviews on websites as a result of poor customer service or for comedic purposes that have nothing to do with the product being sold. Our team made the decision to assume that all ratings provided are an average of reliable customer evaluations made strictly about the product's performance, marketing, warranties, and any other related factors.

Assumption 2: Emotional reliance of customers
Human beings are each unique individuals with their own thoughts, opinions, and ideas. However, when performing a quantitative analysis, it is unrealistic to consider the reaction of each individual when developing a model. We determined the overall expected reaction from customers to be one of a rushed crowd with a maintained level of agitation. Though it may be difficult to describe, it is comparable to the typecasted role the media assigns to an American crowd during a Black Friday sale — the crowd is agitated, rushing to grab items, and is in a state of emotional overload during the time they are in the store.

Assumption 3: Renovations do not affect store's revenue or financial situation
Though this assumption is implied in the document detailing the problem, we feel it is important to make a clear distinction that this assumption still stands. Renovations made to the store using our mathematical model do not have a clear price listed and are not the main focus of the assigned problem. Hence, any costs to renovate are not outlined and will not be included for the sake of focusing on the problem at hand as much as possible.

Assumption 4: Excluded employee placement during the sale
On the day of the sale, as well other days the store is in business, the employees will need to be placed accordingly to control the mob of individuals aiming to get a desired item for an amazing deal. However, this is a factor our team feels is too far out of the perimeter of this problem, and therefore we have made the assumption that employees will either be working as per usual or will be placed accordingly by the manager after the renovations are complete. Due to this, the current assessment of the human traffic being dealt with is an uncontrolled, constantly flowing gathering of individuals. This assessment may be altered when the manager places their employees, hence is it not included as a factor.

Assumption 5: Customers have a set mentality when shopping
As aforementioned, each human being operates very differently from the next, especially in terms of emotions. In order to have a clean cut control to complete our quantitative analysis, we have made the assumption that all customers have a

homogenous mentality - “get what you can.” In this simulation, it is assumed that customers are not comparing deals (e.g. comparing washing machines to get a better price), rather are shopping in hopes of simply attaining as many items as possible and making their way to the cash register.

Through the establishment of the above assumptions, we are able to create a mathematical model that does not buckle under unprecedented demands placed upon it by human, financial, and technological factors.

Part A: The Event

Damage factors

Major damage factors that could result in the destruction of merchandise include dropping and fighting, which can be brought on in many different situations. The below outlined scenarios are what our team considers to be the major methods resulting in damage to merchandise. Damage can be a result of a mixing of two or more scenarios, or can be incited upon merchandise by one scenario alone.

Dropping and fighting are both a result of large crowds of shoppers. This stampede can cause trampling— a danger both for customers should they get trampled on, and for products that may end up destroyed. To reduce the impact of this risk factor, walking spaces better enabling the flow of customers will be considered in the updated floor plan. Tight, narrow walkways between aisles, particularly of desirable products, easily create opportunities for dropping, fighting, and stampedes—walkways must be redesigned to create open space and, as a result, avoid these damage factors.

In addition to adult shoppers, children often accompany their loved ones to sale events. They, too, may cause damage to products through dropping or fighting, and are particularly prone to dropping products due to their lower body mass and thus lower strength. Child-related damage of products can result from the careless or accidental actions of young individuals, which includes the dropping and fighting of adult customers already listed, but also includes child-associated behaviours such as excessive touching, salivation in the form of drooling, etc. These forms of damage pose a risk to both customers and products, as items on sale during this event are largely electronic with sensitive screens and wiring which, when broken, may harm the customer and/or render the product unusable/unsalable.

Available walking space between aisles

Larger items in stores require a great deal of room to maneuver in order to carry and not damage. Aisle space greatly impacts this, as it determines whether the item can even be carried out of the aisle by a customer without being dropped and virtually damaged. For example, most handheld smart devices and gadgets will not need a great deal of aisle space, as they can be carried in one's arms in and out of the aisle. On the contrary, an item such as a flatscreen TV requires a significantly greater amount of aisle space, as it cannot be easily held in one's hands and either needs to be wheeled out of an aisle or pushed out due to its size. Should this TV be placed in a narrow aisle, it will not only cause problems for the customer on an average sales day, furthermore this issue will escalate during a flash sale due to people rushing to attain an item.

Number of individuals in the store

Flash sales attract large crowds, which can leave more room for damaged merchandise. Damage occurs due to potential dropping, as large crowds can leave little to no room for customers to move freely among one another. Dropping items is a direct result, as customers may lose their grip on larger items.

Visibility

Visibility refers to the accessibility to items in stock. With limited visibility, customers will not have an idea as to what merchandise is no longer on the shelves and what merchandise is still there. Customers are likely to fight to get to the shelves should this be the case, causing potential damage to items through pushing and increasingly aggressive behaviours (e.g. Pushing that leads to snatching which leads to more extreme physical force).

Time spent in the store

Longer waits can cause customers to become increasingly impatient as time goes by, especially near the cash register. The urgency of wanting to leave with one's items not being met is a breeding ground to escalated emotions and aggressive behaviours as outlined above, especially for those who did not get their hand on as many items as they had wished, following the "get what you can" mentality. Increased emotions lead to fighting among customers, resulting in destruction of merchandise through physical force.

Most Popular Items

During flash sale events, there are always items that the majority of customers will find desirable. By determining which products these are, it will not only positively affect our decision making in regards to the layout of the store, but also in determining which products are at a greater risk to be damaged. Some of the products we identified as the most popular are ‘Gaming Desktop, Intel Core i5-9400F, 8GB RAM, NVIDIA GeForce G’, ‘75" 4K UHD HDR Smart QLED TV, Q70 Series’, ‘2-in-1 15.6" Touch-Screen Laptop, Intel Core i7, 12GB RAM, 512GB S’, ‘Wireless Wearable Speaker - Black’ and ‘27.8cu ft 4 Door French Door Refrigerator, PrintProof, InstaView Door-in-Door, Stainless’.

We came to these results using an ‘Attractiveness Score’ of our own creation based on the provided data that we processed using the coding language Python.

Attractiveness Score

The ‘Attractiveness Score’ consists of the sum of the rating score and discount score. The formulas for the rating and discount scores are as follows:

Rating score formula
Let x be the rating of the product and y be the weight of the product rating
$f(x,y) = y[5 \times (x - (x \bmod 1)) + 0.5 \times (x \bmod 1)]$

Discount score formula
Let x be the discount on the product and y be the weight of the discount
$f(x,y) = y(x/10)$

Studies have found that for every star rating, the attractiveness of a merchandise increases by a minimum of 5%. We applied this principle in our formula by multiplying the ones place (digit) in the rating of the product by 5. For example, if the rating was 4.7, we would multiply 4 by 5 giving us a product of 20. Since there are ten tenths of a rating (.1 ratings) between each star rating, we divided 5% by 10 giving us a 0.5% increase per .1 star rating. For example, if the rating was 4.2, we would multiply .2 by 0.5 giving a product of 0.1. Studies have shown that the attractiveness of a product steadily increases per .1 rating. But as the rating approaches 5 stars, the attractiveness decreases due to customers believing that the merchandise may be too good to be true and is possibly overrated. Thus, we assigned each rating a weight to better determine how significant the rating of the merchandise is. The weighting was derived from the percentage of merchandise with the same rating because, as shown in Figure A, the data showed similar results as

certain studies. The studies showed that merchandise with the same rating peaked at 4.7 but decreased as it neared 5 stars, since in recent times customers tend to be wary of perfect reviews, suspecting bots or paid marketing have diluted the veracity of reviews.

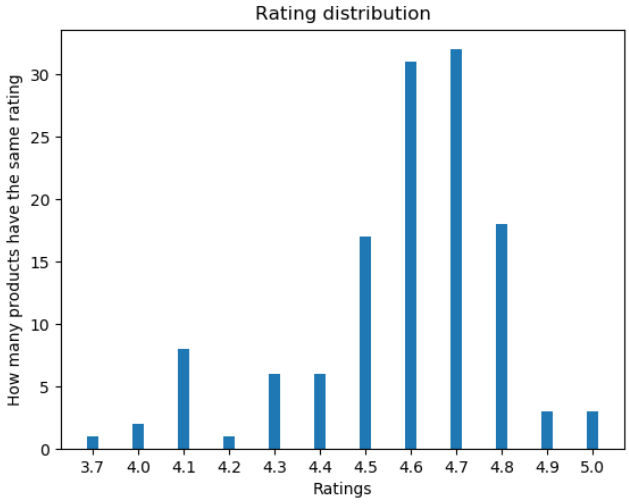


Figure A: Bar graph displaying the amount of products that share the same rating. Created with the coding language Python

Rating	Weight for the rating
3.7	0.0078125
4.0	0.015625
4.1	0.0625
4.2	0.0078125
4.3	0.046875
4.4	0.046875
4.5	0.1328125
4.6	0.2421875
4.7	0.25
4.8	0.140625
4.9	0.0234375
5.0	0.0234375

Figure B: Table displaying the weight of each rating. Created with the coding language Python

In terms of the discount score, we found that attractiveness based on the discount increased in a linear fashion due to the eagerness of customers wanting to buy a product increasingly as the discount on the product increased. So we divided the discount attractiveness into 10 groups (10% per group) and assigned a weighting that is the remainder of $1 - \textit{the rating score weighting}$. For example, if the weighting

on the rating score is 0.0234375, the weight of the discount score would be 1 - 0.0234375 which would give a weight of 0.9765625 for the discount score.

Store Layout Factors

Children-related factors

As discussed previously, child-related damage to products is one that can both harm customers and damage items while also causing worry for their adult supervisors who are shopping. This is particularly true as children are more likely to be injured should a stampede trampling event occur, and even without such dangers, behaviours characteristic of children may damage products. Due to these potential impacts, a factor considered in the mathematical model for the creation of an adjusted store layout is methods to include an area that keeps children occupied during a flash sale event. From Apple stores' iPads and iPhones to IKEA's baby and kids room, retailers have developed various ways to improve shopping experiences for young 'customers.' While this feature has not yet been popularized for flash sale events, implementing a display area based on this idea could improve shopping experiences.

Utilizing the idea of a supervised 'kids zone' is a factor to consider when developing a store layout which will reduce product damage and improve customer experience. As all customers must arrive through the entrance, children must also go through this point. An area of play situated at the entrance location which includes models of products currently on sale, particularly entertainment items such as cell phones, computers, tablets, and gaming devices, provides benefits. First, some foot traffic—that of the children or youth—can be directed away from the main shopping path, which helps to ease stampede effects. This reduces the impact of damage factors such as dropping, fighting, and children-related damage, as fewer people in aisles and walkways overall means a lower likelihood of carelessness, accidents, and damage. In addition, when having items which are on sale be used as an interactive piece of the play area, children are exposed to some products which may lead to a purchase—the interest of a parent's child may enable the parent to consider a product previously not on the family's wish list. Not only so, a 'kids zone' rather than displays throughout the store will make the activity of children centralized: this reduces chances of children getting lost among all the foot traffic, lowering the risk of trampling. Benefits from including a main area for children include safety for customers, a degree of damage prevention for products, and a potential of customers purchasing items beyond previously intended due to their children. To ensure the safety of children and to prevent damage of products on display, the 'kids zone' will be supervised by staff members.

However, the idea of a ‘kids zone’ also has drawbacks. Checking children in and out of the play area takes time, which is especially precious on a day of flash sale events. In order to compensate for this, the area will be located between the entrance and exit (see Figure 1 below) and extend outside, so parents, guardians, and their children will be able to easily access the area both when entering and exiting the store. Keeping the checkout lines near this play area means that while waiting, parents are able to check out their children from the ‘kids zone’ as well, which then provides opportunity for customers to make additional purchases from the displays lining the checkout section as this is when children might declare their desire for some product with which they have just interacted.

Figure 1: sample play area layout

Overall, the play area located at the entry point serves as a sort of filter that diverts the foot traffic of children away from the main crowd, reducing risks of dropping, fighting, and children-related damage to products. This play area, by being separate from the crowd, will also increase safety for children, whose size and strength make them more likely to suffer during a stampede. The drawbacks of potentially slowing down the shopping process is negated by the placement of the area, which ensures that the area is accessible by parents and guardians picking up the children both when entering and exiting the store and waiting in line at checkout.

Location and placement

The location and placement of aisles, displays, checkout, and children's play areas are all significant in reducing the impact of various damage factors. In addition to the factors previously discussed, the placement of products is also significant. The departments that items on sale belong to vary in number of products, price, customer satisfaction rating, and therefore have different levels of attractiveness to shoppers. In order to create a new floor plan, this scale of attractiveness must be modeled to determine the best placement of various products and departments.

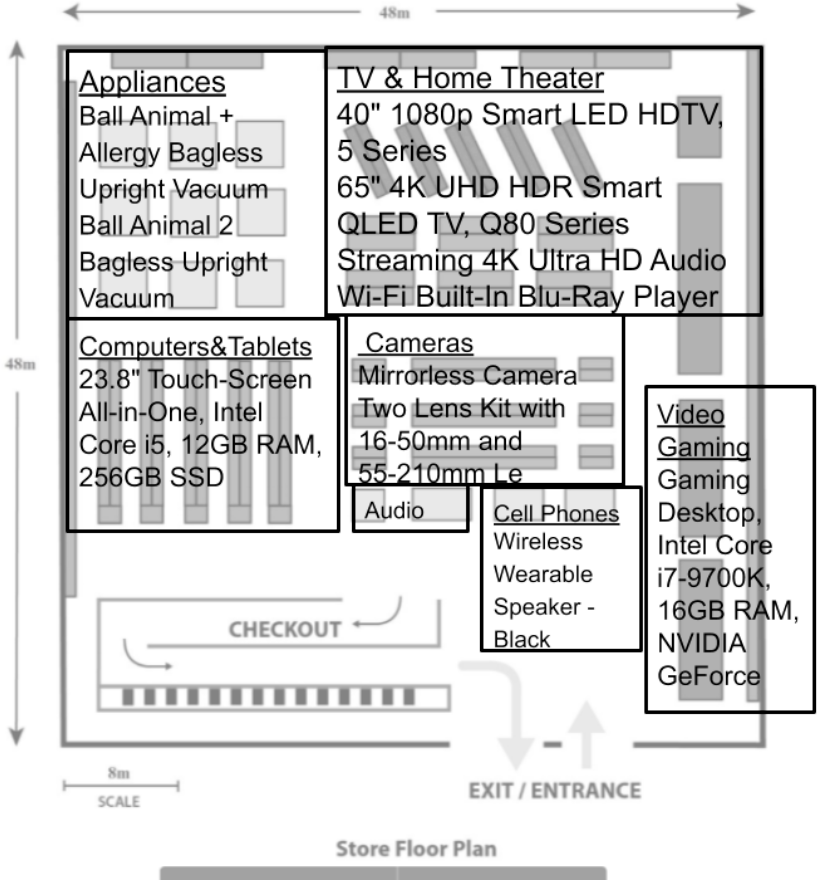
Through research of existing layouts of stores such as Costco, the team has determined that placing products in three scale tiers at different locations in the store is the best strategy. This optimal organization involves placing the second-most attractive tier of products closest to the entrance, the least attractive tier in the middle, and the most attractive tier of products furthest from the entrance. This organization encourages customers to walk through the entire store, spreading out foot traffic which reduces the likelihood of one area being the most crowded and thus lowers the risks of damage factors that center around the formation of a stampede. With a lower likelihood of stampedes, damage factors naturally also decline in their impact. Mathematically modeling this situation, the walk-through approach increases the area that customers access during their visit. Given a constant number of customers, if the customers must traverse a greater distance and therefore be spread out over a larger area, the store will have a lower customer density, which allows better flow in, out, and through the store. This reduced density enables faster trips through the store and a lower risk of damage factors, as most product damage is a direct result of the crowding of customers due to high density.

When determining where each department would be located we considered both the average rating of the department as well as the size (as shown in Figure C). We know that departments with higher average attractiveness scores would draw larger crowds in general, (ex TV and Home Theater;) while departments with smaller attractiveness scores would not. So anti-incident measures would primarily be concentrated in these areas. According to general sale trends TV/Home Theater, Computers and Tablets, and Video Games are the most popular items bought on Black Friday and other such flash sales while Cameras and Appliances come in second. This also correlates with our data, where the average attractiveness rating in those high traffic departments is higher. This means that just by volume these departments are at the highest risk of an incident (dropping, fighting) occurring. We started by spacing the highest volume departments out.

Department	Number of products	Average rating
Appliances	31	4.5
Audio	2	4.3
Cameras	10	4.8
Cell Phones	3	4.3
Computers&Tablets	40	4.5
TV&Home Theater	35	4.6
Video Gaming	13	4.7

Figure C: Table displaying how many products are in each department alongwith the average rating of the department. Created with the coding language Python

Figure one with Items and Locations Explanation

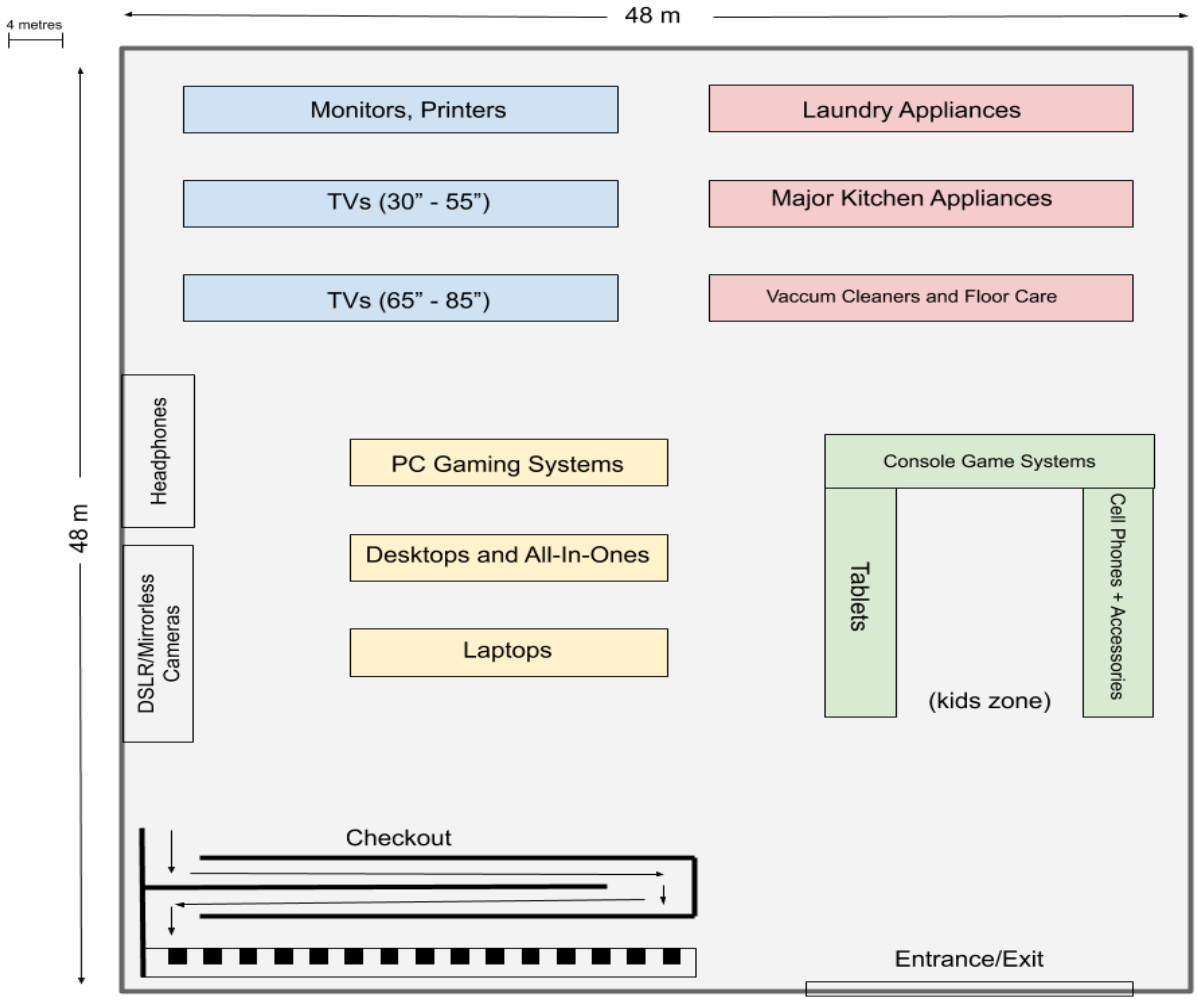


Our team decided on the layout of Figure 1 considering the size and popularity of the departments of the store. The Appliances, Computers & Tablets and the TV & Home Theater departments have the most products, and thus are the largest departments, as well as being some of the most popular departments in the store which is why they were given more space than the other departments. Televisions are some of the largest items in the store which is why the TV & Home Theater department was given the most space. The Audio and Cell Phones departments have the least amount of products which is why they were given the smallest amount of space. The Video Games department was moved to the side because our team wishes to implement a supervised area for children that would be placed in close proximity to the entrance of the store and video games tend to appeal to children. Thus we decided to place the Video Games department near where we would like our children’s area to be located.

The popular products of the departments were determined using our team's aforementioned attractiveness scoring system. The Appliances department in particular has many products that although would be considered popular, are quite large in size, such as refrigerators and electric dryers. This makes it unlikely that many shoppers will be willing to purchase those products and thus were not listed as products that would be on display.

Note: there are many products in the store that would be popular however there is not enough space to list them all on Figure 1 so we chose only a few to list.

Updated store layout and Explanation



All the reasoning that we used for Figure 1 were also considered in our own redesign, the high traffic departments were well spaced apart based on their attractiveness ratings.

Going furthur we determined that TV's and computers are the highest drop risks due to their size. If an individual is carrying a large TV, they might bump into someone, be unable to correct their balance due to the abnormally large item, resulting in both the customer and the TV falling to the ground and the TV being damaged. A heavy PC presents a similar problem. In the original design there was an abundance of thin, single or dual person aisles that would be a nightmare to traverse carrying a heavy object. Our team's solution in the custom layout involved creating large hallways with lots of legroom to allow for easier travel from the product shelves to the cashiers.

As for the fighting risk, whether customers will start a conflict over a product is linked directly to how good of a deal the product has, or as explained before, its attractiveness score. The products with the highest attractive scores (such as, Gaming Desktop, Intel Core i5-9400F, 8GB RAM, NVIDIA GeForce G gaming station. The '75" 4K UHD HDR Smart QLED TV, Q70 Series' TV and the, '2-in-1 15.6" Touch-Screen Laptop, Intel Core i7, 12GB RAM, 512GB S') are the ones that most fights will start over. Fighting is a notably problematic issue due to the complexity of humans, and our propensity to fight over much of nothing. Placing security guards at particularly high density locations in the store would prove helpful; so would having a hard rule that anyone caught fighting would be told to leave the store, unable to shop at the store during the sale in question. These solutions are unrelated to the layout of the store itself and hence, out of our purview. Instead we took measures that should reduce our incident rate. Quite a lot of human behavior is based on triggers (Gladwell, 2020) humans will only take to certain extremes (e.g. starting a fight) if a trigger is there. We believe that the trigger for a customer to start fighting over an item in this flash sale example is seeing another customer with the product that they want. The problem here is visibility so we recommend that the shelves are sorted by attractiveness score, with the most attractive products being placed at the end of the aisles to allow the buyer to leave the siteline of other customers as fast as possible.

We also added a kids zone to occupy children; the reasoning for this has been discussed earlier.

Additional discussion

Beyond previously stated considerations regarding the layout, there are other factors that will make a flash sale event successful, safe, and profitable. Information discussed in this section will be included as a part of the letter to the store manager detailing the store layout and additional strategies for a successful flash sale event.

As an additional consideration, it can be seen from similar tactics by retailers such as Walmart and Target that mobile applications containing maps of flash sale store layouts available prior to the day of the event are effective. The figure is a sample mobile application that can be used by the retailer and store manager to provide a planning tool for customers prior to the flash sale event. Being able to plan and tailor a personal shopping list or guide using the app will enable customers to move through the store efficiently and shop with a purpose—this reduces some of the panic and frenzy induced when customers scramble to search for a desired item rather than directly going to the location of the product.

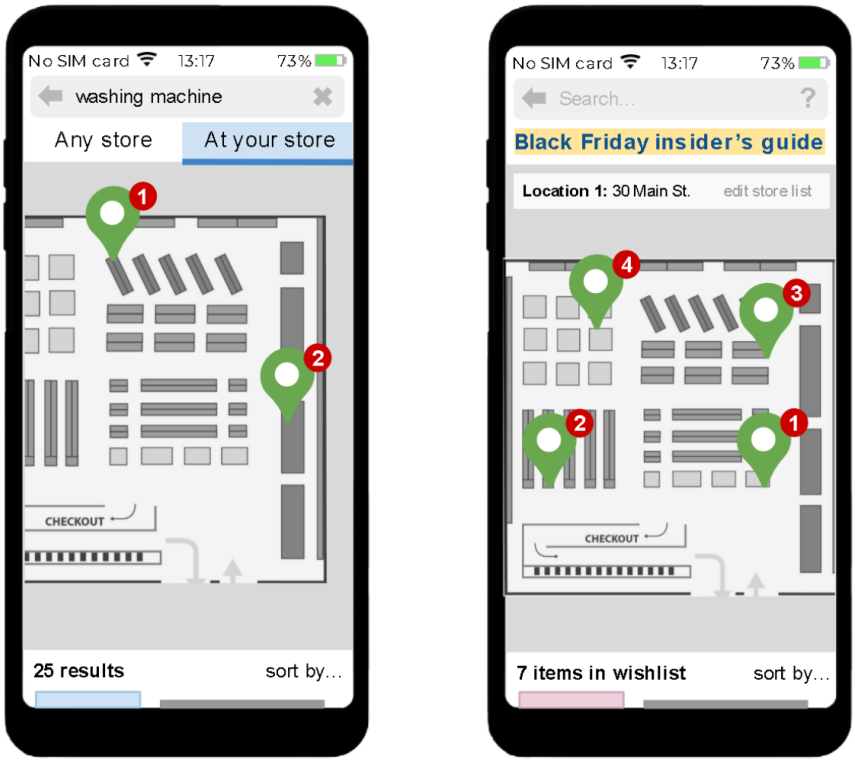


Figure: product-searching abilities (left) and personal shopping list functions (right) are some features that should be available in a mobile application for the store/retailer.

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