IMMC 2020: Flash Sale

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Summary

When people go Black Friday shopping, they will almost always meet a huge crowd of people looking to take advantage of the lower prices offered by stores. Unfortunately, while people are shopping for goods, they tend to damage goods that were contested by multiple people or else just in people's way. We want to prevent this as much as possible in our store. This presents us with a pressing problem: how do we know what to do to minimize the damage?

The main thing we can get out of this model is that we will hopefully minimize the damage caused and therefore losses in revenue because of these events happening. The main purpose of our company is to earn a profit; the stampeding and destruction will only take away from our profit, so it must be our job to minimize this.

However, a question remains. How do we do our job? What way is there to predict the way customers act, and how will we act upon it? We thought of a lot of potential steps that we could take to ensure this minimum damage. Among these were graphical and economic analysis, which we thought had too many degrees of freedom to measure accurately. We had to think of bigger and better ways to go about this problem, so that the model is simple enough to understand yet accurate enough to actually make a difference.

What we ultimately decided on was a model that we thought was very easy to understand, and yet good enough to make a difference. At first we focused on statistical analysis of each good we were selling, and then turned our focus to a code oriented approach,simulating real patterns customers could potentially take while walking around the store. Combined with hotspots of the most frequently visited places and the specific demands for individual goods, our model is as close to complete as we think we could have gotten. Sure, nothing is perfect, and we are sure there are minor flaws in the model, but taken as a whole, we think our model is the best it can be, which can be seen through several ways.

The specific approach we used for each individual good, statistical analysis, revolves around taking the z scores and normalizing the data so that the measures of the different factors of demand are on the same level and weighted equally. We felt like we used all of the information we possibly could to come up with this standard, leaving no room for improvement and ensuring that we have taken all variables into account. This was all to gauge the demand of the goods from the people.

After we figured out a way to model demand, we had to figure out a way to predict how people in our store will move, and adjust accordingly so that the people are spread apart enough to not cause any destruction. Using a program called diffuser, we modeled the way people would walk given that the store has appeal all throughout the store. We assumed this because with our model for demand containing many elements, we have confidence that we can place our items in such a way around the store that there are equal amounts of human interaction everywhere.

Overall, this was the best and most simple model we could come up with, and we hope it is both informative and helpful for the company as a whole.

Introduction

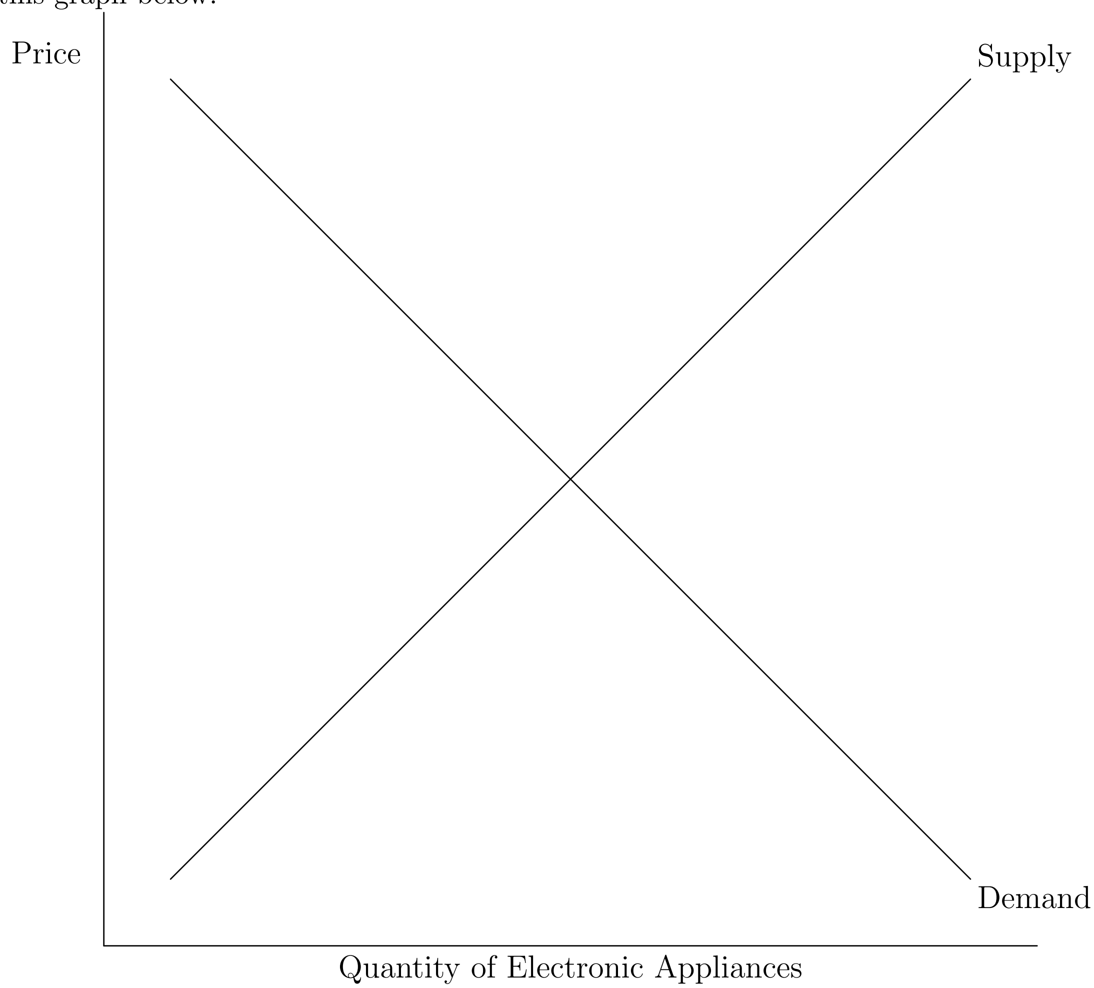
Consider this: it's almost Thanksgiving, and Black Friday is nearing the corner. A certain electronics company is trying to avoid the usual rush of people that fight for and destroy items. Because of this, a few of us are trying to find a way to help them and minimize losses from lost items due to damage. Using Keynesian Economics and statistical analysis, we came up with a model that will help mitigate the damage caused by the people in the store. There were many motivations behind this, and we will end with a letter to the manager of the store explaining our new layout. First, let's dive into the assumptions we made and the rationale behind them.

1 Assumptions

In order for our model to be understandable, while being relatively accurate, we had to make a few assumptions. The following assumptions will help make our reasoning easier to understand.

1.1 Assumption 1: Sold out

Our first assumption is that the demand for each good is much higher than the quantity we supply them. The reasoning behind this is what we learned from using Keynesian economics. Take a look at this graph below:



The graph is a simplified supply and demand graph for the products in the store, with linear supply and demand curves. In the real world, the supply and demand curves aren't necessarily linear, but we simplified it because the graph is for the sake of visualization. When firms put these huge sales on items nationwide, they are practically creating a price ceiling on these items. As a result of the price ceiling, the company supplies at the quantity of the point where the supply curve meets the price ceiling. As seen by the figure, the price ceiling results in a higher quantity demanded than supplied, representing a shortage of goods. Due to this shortage, it means that items will basically be sold out. Using this basic fact, we are assuming that everything on sale will have sufficient amounts of interest to be sold out. This way, our model contains the least amount of variables possible, while being reasonably accurate.

1.2 Assumption 2: Spectators

Our second assumption is that everyone who shops and wants something can afford it. During these flash sales, the store typically opens earlier because if they don't, the people waiting outside would grow to too great a size, as the amount of people waiting outside typically grows the closer it is to morning. Thus, the people who initially enter the store clearly have an intent to buy at least one good, otherwise they wouldn't have had the motivation to wait so early in the morning for the opening of the store. This gets rid of the unknown variable of how many people just go to stand around and witness the opening of the store. These people who stand around impede the flow of human traffic and may lead to more collisions.

1.3 Assumption 3: Intentions

We assume that people who come to the sale have a list of items they're willing to buy and will buy them in the order of the goods they come across first. Put simply, people aren't targeting a single good and instead will go for the good on their list that they see first. The reasoning behind this is that people who target a single good will have to spend time going through the entire store in order to find that particular good. They'll pass goods that they still desire a lot in order to obtain the good that they want the most. However, in doing so, there is a good chance the product they want the most will run out. Then, when they turn back to target their second most wanted good, the time wasted looking for the first good has been used by others to buy out the person's second most wanted good. Then, they turn to their third most wanted good, so and so forth. Knowing this, we can conclude to due to the immense demand, if someone sees a good that they'll be happy buying, they'll buy it even if there may be other goods they'll rather buy.

1.4 Assumption 4: The Short Run

We will only be considering the short run when the demand is at its highest and there are still plenty of goods on the shelves. This is because in the long run, people would have completely scouted out the store to the point most goods would be gone as people leave to move on to other stores also on sale. After enough time has passed, the rush will have died out as people have gotten what they wanted or missed out on what they wanted. The only time we will be considering is the burst of energy after the store has opened and people are rushing through the store to get a chance at grabbing their desired product first.

1.5 Assumption 5: Rational

Additionally, we assume that every shopper is rational in their decision making. That is, they want to maximize their utility (happiness as a result of purchasing the good) given the budget that they have. This ensures that in general, people are drawn more strongly to attractive goods. This will be touched upon in a later section.

2 What causes goods to be damaged?

The last thing any business wants is to lose revenue due to destroyed in-store goods. For many firms, it can be a very frustrating and tedious process to deal with destroyed goods as well as attempting to minimize these losses. However, before trying minimize this type of revenue loss, it is important to understand why goods get destroyed in the first place.

To begin with, the first idea that comes to mind to many people is the classic enraged or careless consumer that acts recklessly and results in the destruction of goods. Unfortunately, the only way to change the amount of carelessness in a consumer is to change the type of goods that they are surrounded with, due to the fact that people are generally more careful and aware when they are surrounded with expensive items compared to when they are surrounded with cheaper items. For example, a customer is more likely to be careful around very expensive goods, such as electronic devices, jewelry, and expensive designer clothing. Other than this, it is virtually impossible to manipulate the carelessness in a person's behavior. However, it is possible to quantify the amount of anger in a customer's behavior because anger is tied to three things when it comes to shopping: stress, anxiety, commotion. Unfortunately, those three factors are the most prevalent in flash sales.

In addition, another reason why a particular good may be damaged is if the quantity demanded for that good is much larger than the quantity supplied, or in other words, if there is a shortage for that good. In rare cases, this may lead to customers getting into physical altercations, fighting for the right to purchase that good. This may result in the destruction of the good altogether, which leaves all parties unhappy. Furthermore, this cause ties back to the feeling of anger mentioned into the last paragraph; the commotion of many people trying to buy a rarely supplied good causes stress and anxiety in customers, leading to more reckless behavior. Unfortunately, flash sales result in very high demand for very lowly-supplied goods, making this type of scenario more prevalent.

Physically, goods can be damaged as a direct result of crowding and the lack of space. Due to a high population density in a certain area of the store, people can unintentionally or intentionally collide into others and damage the product if the person in the collision is holding a product. In order to minimize crowding, we can't limit the amount of people going into the store, so we can only try to make the crowd thinner, or make the population across the store as homogeneous as possible.

Another way goods can be damaged is through fighting or emotions. Depending on the good, there will be a certain amount of shoving and grabbing associated with the good. The higher the concentration of the commotion, or the most crowding around a good, the higher the chance goods get damaged in the struggle. As a result, potential damage caused by a certain good would need to be as equal as possible for every good. This idea of destruction based on the crowding and number of people going for a good will be touched upon in the next section.

3 Which goods are most popular?

In this section, we determined how exactly to rank each good based on popularity, which then translated into how much damage the goods cause. We thought that since a more popular good is likely to have many people going for it at once, it is also a component of destruction and damage caused. We decided to call this measure of destruction *mayhem*. Once we got to naming it, we had to define what it actually was.

3.1 An Economic Definition

At first we thought of an economic definition:

$$M = Q_d - Q_s, \tag{1}$$

Where M is mayhem, Q_d is quantity demanded, and Q_s is quantity supplied. Since we assumed that there was a price floor imposed by our store having a sale, this made sense, because the quantity demanded being more than the quantity supplied means that the difference in quantity demanded and quantity supplied is the number of people who wanted a good, but couldn't come away with it. We used economic analysis and coordinate geometry to try and figure out equilibrium levels, elasticity of demand, elasticity of supply, and the differences in the quantity demanded and the quantity supplied, but came away with nothing. This was due to the fact that the nature of the demand curve was impossible to determine using the information we were given, as this required more customer input. Assuming the demand curve to be linear and ignoring the strong possibility that it isn't would be unfair to the company and wouldn't be an accurate representation for the demand of certain goods. Thus, even though the economic idea of demand minus supply playing a part in mayhem holds true, we had to find another more mathematical and non-economic definition of mayhem in some way.

3.2 A Statistical Definition

The next natural thing we came up with regarding mayhem was a statistical model. We used the data that was given to us to try to find components of demand that is a component to mayhem as well. First, we assumed that what we had with the sale values of the items was population data; that is, we assumed that these were the only things that we sell in our store. Once we assumed this, we could safely find the mean and the standard deviation of the three variables we thought was most important in determining the demand for a good. Then, we calculated the z scores of each good, and averaged them afterwards. In taking the z score, we assumed that these three determinants, percent remaining of the price of a good, the rating of a good, and the quantity available of a good, will have a normal distribution. We felt like this wasn't far off because of our big sample size. Here is the reasoning behind choosing these three variables.

3.2.1 Percent Remaining of the Price of a Good

We thought that the percent remaining of the price of a good was a good factor of demand because people look for things that are on sale. Something being on sale means that the customer, in their eyes, are getting a better deal, so this naturally has something to do with demand.

3.2.2 Rating of a Good

We thought that the rating of a good was a determining factor of demand because ratings represent the amount of satisfaction a customer gets form a good. In addition, other customers tend to look at people's opinions of a good, and choose to buy the good or not buy the good by gauging the general satisfaction.

3.2.3 Quantity Supplied

We thought that the quantity of the goods supplied at the store would have an effect on the mayhem created by the good. If there were a lot of one good, there will be less fighting and less shoving for that good because people are more sure that they'll be able to obtain that good. On the other hand, if there were only a small quantity of one good, the people who want that good know that the good may run out soon, so they are more inclined to to push and shove people out of the way to reach the good. The more pushing and shoving there is, the more mayhem there is and the higher chance that people holding goods in the vicinity will have their goods damaged. This idea is also supported by Equation 1, where if quantity supplied is increased, mayhem decreases and if quantity supplied is decreased mayhem increases. Thus, we can conclude that a lower quantity supplied translates to a higher mayhem.

3.3 The Process

We needed a way to normalize the values for the different measures so that they are weighted equally. First, we noted the enormous sample size that we had. We then realized that we could standardize them by using a z score, as a sampling distribution would make everything in terms of how many standard deviations away from the mean for each value there is. The way to calculate z score is:

$$S_z = \frac{x - \mu}{\sigma}, \tag{2}$$

where S_z is the z score, x is the sample value, μ is the mean of the data set, and σ is the standard deviation of the data set. Since one of our assumptions is that this is population data that we are given, we use the symbols μ and σ to indicate population values. We did this for the 3 values mentioned above, which resulted in a big table of values of z scores. To finally get a numerical value of demand, we defined demand as the average of the three z scores that we have calculated. Here are the values below:

(Table 1) Product Name	Demand Value
Wireless Bluetooth Headset - Black	-1.65942925076206
Sport Wireless Earbud Headphones	-1.55969051145861
70" 4K UHD HDR Smart LED TV, 6 Series	-1.54533893897046
Wireless Noise Cancelling Earbud Headphones - Graphite	-1.43303815333903
1.6cu ft Over-the-Range Microwave, Stainless Steel	-1.11148897431984
Mirrorless Camera with Lens	-1.0097193407339
10.1" Tablet, 32GB	-0.913917700883348
DSLR Two Lens Kit with EF-S 18-55mm IS II and EF 75-300m	-0.875307340440353
DSLR Two Lens Kit with AF-P DX NIKKOR 18-55mmf/3.5-5.6G VR	-0.846796732585582
32GB Console - Gray Joy-Con + 2 more items	-0.774280868735303
Mirrorless Camera with FE 28-70mm F3.5-5.6 OSS Lens	-0.74996285814303
65" 4K UHD HDR Smart QLED TV, Q80 Series	-0.72455785160787
DSLR Camera, Body Only, Black	-0.67531652428366
Wireless Earbud Headphones	-0.657061321615004
65" 4K UHD HDR Smart QLED TV, Q60 Series	-0.633840700429208
65" 4K UHD HDR Smart LED Roku TV, 4 Series	-0.631267624204737
App-Controlled Robot Vacuum	-0.60647951057222
28" LED 4K UHD Monitor, UE590 Series	-0.565721217953876
Gaming Desktop, Intel Core i7-9700K, 16GB RAM, NVIDIA GeForce	-0.565232440065164
DSLR Two Lens Kit with 18-55mm and 70-300mm Lenses, Black	-0.555569306387728
75" 4K UHD HDR Smart QLED TV, Q60 Series	-0.521052118048985
65" 4K UHD HDR Smart LED TV, NU6900 Series	-0.500410808035598

(Table 1 ctd) Product Name	Demand Model
50" 4K UHD HDR Smart LED Roku TV	-0.492769766383328
Bagless Cordless Pet Handheld/Stick Vacuum	-0.492001734151055
23.8" Touch-Screen All-in-One, AMD Ryzen 3-Series, 8GB Memory, 256GB	-0.449759524481103
55" 4K UHD HDR Smart LED Roku TV, 4 Series	-0.446948814785948
15.6" Gaming Laptop, Intel Core i7, 32GB RAM, NVIDIA GeForce RTX 2060, 5	-0.4455719324713
Wireless Wearable Speaker - Black	-0.439437517050027
Streaming Audio Blu-Ray Player	-0.431228903238013
55" 4K UHD HDR Smart LED TV, NU6900 Series	-0.430068625373572
75" 4K UHD HDR Smart QLED TV, Q70 Series	-0.385756986934403
Streaming Audio Wi-Fi Built-In Blu-Ray Player	-0.383342049721737
50" 4K UHD HDR Smart LED TV, NU6900 Series	-0.378910189881669
Gamer Master Gaming Desktop, AMD Ryzen 3 2300X, 8GB Memory	-0.353911158307966
15.6" Gaming Laptop, Intel Core i5, 8GB RAM, NVIDIA GeForce GTX 1650, 51	-0.338964698910027
3.8cu ft 12-Cycle Top-Loading Washer, White	-0.328999816666066
Wireless All-in-One Printer	-0.326706697505416
24" Front Control Tall Tub Built-In Dishwasher, Stainless Steel	-0.316428888247699
App-Controlled Robot Vacuum	-0.309116480826299
50" 4K UHD HDR Smart LED TV, 7 Series	-0.298274056728615
Gaming Desktop, Intel Core i5-9400F, 8GB RAM, NVIDIA GeForce G	-0.263349249634061
32" 720p Smart LED HDTV Roku TV, 3 Series	-0.256240591794778
65" 4K UHD HDR Smart QLED TV, Q70 Series	-0.2524587101348
65" 4K UHD HDR Smart LED TV, 7 Series	-0.252456091750288
11.4" Laptop, AMD A6 Series, 4GB Ram, AMD Radeon R4, 65GB e	-0.230013943824468
4.1cu ft 11-Cycle HE Top-Loading Washer, White	-0.221075263831196
12.3" Tablet, 64GB	-0.219900279202496
2-in-1 11.6" Touch-Screen Chromebook, Intel Celeron, 4GB RAM, 32GB	-0.192049546494218
23.8" Touch-Screen All-in-One, Intel Core i5, 12GB RAM, 256GB SSD	-0.191851856094504
13.5" 8GB RAM 256GB Solid State Drive	-0.173600380114651
DSLR Camera with 18-55mm IS STM Lens, Black	-0.160612674956095
65" 4K UHD HDR Smart LED TV, H6500F Series	-0.153902920989242
2-in-1 15.6" Touch-Screen Laptop, Intel Core i7, 12GB RAM, 512GB S	-0.152484548105023
15" 16GB RAM 256GB Solid State Drive	-0.151868300519679
17.3" Gaming Laptop, Intel Core i7, 16GB RAM, NVIDIA GeForce GTX 1660 T	-0.148636106162477
2-in-1 14" Touch-Screen Chromebook, Intel Core i3, 4GB RAM, 128GB	-0.134925906082487
Color Wireless All-in-One Printer	-0.124559876937074
1TB Fortnite Neo Versa Console Bundle - Jet Black	-0.120281291492787
1TB NBA 2K20 Bundle - Black	-0.10550467649105
65" 4K UHD HDR Smart LED TV, X900F Series	-0.0755841461723587
65" 4K UHD HDR Smart LED TV, X800G Series	-0.048807227912526
Wireless Color All-in-One Printer	-0.0427358983938247
55" 4K UHD HDR Smart OLED TV, A8G Series	-0.0426878603131119
27" Touch-Screen All-in-One, Intel Core i7, 12GB RAM, 256GB SSD	-0.0118609946803045
75" 4K UHD HDR Smart LED TV, NU6900 Series	-0.00925931160639408
5.1cu ft Freestanding Gas Range, Stainless Steel	-0.00113430470996945
43" 4K UHD HDR Smart LED TV, 6 Series	0.00458638002697387
65" 4K UHD HDR Smart OLED TV, A8G Series	0.0428438777728925
4.3cu ft 12-Cycle Top-Loading Washer, White	0.0443652965709902
1.6cu ft Over-the-Range Microwave, Black on Stainless	0.0729744376237157
26.2cu ft French Door Smart Wi-Fi Enabled Refrigerator, PrintProof, Black Stainless	0.0758491338664643
App-Controlled Self-Charging Robot Vacuum	0.0807012817153371
Intel Core i7 9700, 16GB RAM, NVIDIA GeForce GTX 1660 Ti,	0.0994477568769967
24" LED FHD Monitor, Black	0.102705317160077
14" Laptop, AMD A9 Series, 4GB Ram, AMD Radeon R5, 128GB SSD, WIndows	0.104358142213822
26.8cu ft French Door Refrigerator, Stainless Steel	0.114209468742514
2-in-1 11.6" Touch-Screen Laptop, Intel Pentium, 4GB RAM, 128GB	0.167493577386936
2-in-1 15.6" 4K Ultra HD Touch-Screen Laptop, Intel Core i7, 16GB	0.19955386682211
85" 4K UHD HDR Smart LED TV, X900F Series	0.202558541434367
7.3cu ft 8-Cycle Electric Dryer, White	0.210696346841307
15.6" Touch-Screen Laptop, Intel Core i3, 8GB Ram, 128GB SSD	0.218393920745899
24" Tall Tub Built-In Dishwasher, Monochromatic Stainless Steel	0.218847560628672
7.4cu ft 10-Cycle Smart Wi-Fi Enabled Electric Dryer, White	0.228333208538685
30" Combination Double Electric Convection Wall Oven with Built-In Microwave	0.235864524979344
17.3" Laptop, Intel Core i5, 8GB Memory, 256GB SSD, Jet Black, Maglia Pattern	0.253020648985275
Streaming 4K Ultra HD Hi-Res Audio Wi-Fi Built-In Blu-Ray Player	0.253034905041605
Wireless All-in-One Printer	0.258721723643987
2-in-1 12.2" Touch-Screen Chromebook, Intel Celeron, 4GB RAM, 32G	0.271624425476424
32" LED 720p Smart TV, H5500 Series	0.281147861454916
Mirrorless Camera Two Lens Kit with 16-50mm and 55-210mm Le	0.301066080729875
27" LED QHD G-Sync Monitor, Black	0.301464516694791
1TB Star Wars Jedi: Fallen Order Deluxe Edition Console Bundle	0.307969946549071
Wireless All-in-One Printer	0.322003871295241
5.0cu ft Freestanding Gas Range, Stainless Steel	0.347130414593213
55" 4K UHD HDR Smart LED TV, UK6090PUA Series	0.353258890080115
2-in-1 13.3" 8GB RAM 256GB Flash Memory	0.362812368861195
4.2cu ft 11-Cycle Top-Loading Washer, White on White	0.400385573707815
11.6" Chromebook, Intel Atom x5, 4GB Memory, 32GB eMMC Flash Memo	0.403968003465776
27.8cu ft 4 Door French Door Refrigerator, PrintProof, InstaView Door-in-Door, Stainless	0.404156991725219
75" 4K UHD HDR LED Smart TV, X800G Series	0.410282048610304
App-Controlled Self-Charging Robot Vacuum	0.440390991837286
2-in-1 11.6" Touch-Screen Chromebook, 4GB RAM, 32GB eMMC Flash Mem	0.444216327081338
55" 4K UHD HDR Smart LED TV, X800G Series	0.44489482003677
Ball Animal + Allergy Bagless Upright Vacuum	0.462790577498202
7.2cu ft 3-Cycle Electric Dryer, White	0.477087630880389
15.6" Touch-Screen Laptop, Intel Core i5, 8GB Ram, 256GB SSD	0.483567452299105
7.0cu ft 13-Cycle Electric Dryer, White	0.49039558505434
40" 1080p Smart LED HDTV, 5 Series	0.50130947978814
Desktop, Intel Core i7, 8GB RAM, 256GB SSD	0.508610260843531
Wireless All-in-One Instant Ink Ready Printer	0.509232723527419
31.5" IPS LED FHD Monitor	0.515319617704851
Gamer Master Gaming Desktop, AMD Ryzen 5 3600, 8GB Memory	0.515440164319266
2-in-1 14" Touch-Screen Laptop, Intel Core i5, 8GB RAM, 256GB S	0.525323347231795
32" LED QHD Monitor	0.528933199596919
Ball Animal 2 Bagless Upright Vacuum	0.57276780676141
20.7" LED FHD Monitor	0.588176099861056
2-in-1 11.6" 4GB RAM 32GB Flash Memory	0.60977488454076
30" Built-In Single Electric Wall Oven, Stainless Steel	0.622625356548758
2-in-1 14" Touch-Screen Chromebook, Intel Core i3, 8GB RAM, 64GB eMMC Fla	0.634011288413668
25.1cu ft Side-by-Side Refrigerator, Fingerprint Resistant, Stainless Steel	0.634807559496294

(Table 1 ctd) Product Name	Demand Model
Full-Frame Mirrorless Camera with 28-70mm Lens, Black	0.657281009585496
DSLR Camera, Body Only, Black	0.699042384062926
24.7cu ft French Door Refrigerator, Black Stainless Steel	0.727887154073185
3.8cu ft 12-Cycle Top-Loading Washer, White	0.739567339273787
6.3cu ft Slide-In Electric Range with ProBake Convection, Stainless Steel	0.743886506382368
11.6" Chromebook, Intel Atom x5, 2GB Ram, 16GB eMMC Flash Memory	0.755337546554652
Gamer Supreme Liquid Cool Gaming Desktop, AMD Ryzen 7 3700X	0.762186515461052
32" 720p LED HDTV	0.768387069163294
4K Ultra HD Blu-Ray Player	0.846120700934282
5.3cu ft Slide-In Electric Range, Stainless Steel	0.86774069415137
27" IPS LED FHD FreeSync Monitor, 27f	0.966645565930362
Streaming 4K Ultra HD Audio Wi-Fi Built-In Blu-Ray Player	0.994776078964732
Streaming 4K Ultra HD Hi-Res Audio Wi-Fi Built-In Blu-Ray Player	1.09214010604705
15.6" Gaming Laptop, AMD Ryzen 5, 8GB Ram, NVIDIA GeForce GTX 1050, 25	1.11501516878234

An important thing to note is that this data is sorted from the good that is the least demanded to the good that is the most demanded. Anyway, based on the data here, we grouped the different goods into all of its departments, which helped us determine which category of goods were most popular. We took the demand values of all the products and took the median of these values. The result is shown in the table below.

(Table 2) Department	Median demand
Appliances	0.2283332085
Computers and Tablets	0.2089738938
TV/Home	-0.2031795064
Video Gaming	-0.1486361062
Cameras	-0.6154429153
Cell Phones	-1.433038153

As shown from the data in **Table 2**, it is evident that in general, goods in certain departments are more demanded than goods in other departments. Appliances and Computer Tablets were the highest demanded departments, followed by Video Gaming, TV/Home, Cameras, and Cell Phones. One important note is that we did not include the Audio department because there were only two goods in that Department. **Table 2** shows that out of the 134 goods that are listed, one of the goods in the Audio department is ranked 133rd, and the other good in the Audio department is ranked 121st out of the 134 goods. Therefore, it can be concluded that the goods from the Audio department are not highly demanded.

4 Store Layout and Damage

In addition to the demand for the objects in the store, the way the store is laid out has an immense impact on how goods become damaged. Factors such as the width of corridors, the length of the shelves, the placement of goods, and the number of exit points someone has at any given point has to be considered and analyzed in order to best dampen the damage on goods without sacrificing too much efficiency. Later, we'll combine what we know about the demand for certain products and the elements discussed in the following sections to determine our suggested floor plan that minimizes crowding and risk of damaging products.

4.1 Placement of Goods

When imagining the placement of goods in a store, most people imagine that similar goods are grouped together. We concluded that this is optimal but why? At first we though if we spread similar goods farther apart from each other, it would lead to people diffusing throughout the store and decreasing the amount of crowding. However, placing goods too far away from each other so that they can't easily be located can have negative effects because it sets a false illusion that those goods are the only type of that good in the store. This apparent shortage of the good creates crowding as people are motivated to fight harder in order to obtain a TV. Thus, if goods are placed too far apart from each other, crowding can occur. Too close, and it encourages more crowding. Thus, a middle ground needs to be reached.

4.2 Maximum Distance to nearest path

The distance to the nearest exit is a factor in store layout that is important when considering how to arrange shelves. We now define a path as a corridor in the store that is more than 3 meters wide. A component of mayhem at a certain point is the minimum distance needed to get to the nearest path from the structure. The shorter the maximum distance to a path is, the faster a customer can leave with their desired goods and the easier we can avoid crowding in any area. A good way to do this is to maximize the number of walkways in the store that we can classify as "paths". Here are factors of paths that we need to consider in order to make the best choices.

4.3 Length of Shelves

For the most part, retail stores like ours operate with little to no risk of stampeding, which disincentivizes them from prioritising the factors we listed above, and instead makes them look at how they can display as many goods as possible. Goods are displayed on the outside of the shelves, which would be the perimeters of the shelves in the aerial view we are given. There is technically no maximum perimeter for an object with given area, as we can just infinitely stretch one of the shelves' dimensions and shrink the other. In a practical sense, the way to maximum available display area is to fill up as much space as possible with shelves, and make them as long as possible. This would maximise the efficiency for the retailer, but would also increase the maximum distance to nearest path, and greatly increase probability of goods and customers being damaged.

5 Trade-offs

Most of the layout features above decreases the likelihood of goods being damaged during a flash sale, and the remaining ones increase the store's efficiency, which is what we will use to refer to its ability to sell and display more goods. Retailers need to find a balance between all of these factors when designing their store layouts for each occasion, whether it be for Black Friday or a regular business day. In accordance to our prompt, we will be trying to minimize the possibility of a stampede, with much less concern about the layout's efficiency.

6 Case Studies

To get a better idea of the layout factors in action, we decided to examine the strengths and weaknesses of the original layout. We split the shelves into two different categories: peripheral shelves, which are the shelves attached to or very close to the walls, and integral shelves, which are near the middle.

6.1 Peripheral Shelves

6.1.1 Left and Top Walls

Comparing the shelves on the top and left walls, we can see that there is no benefit in pacing out shelves on the walls, as the created space will never be used for passage. The left wall shelf is superior to the top wall shelf in efficiency and has the same safety.

6.1.2 Right Wall

The right wall peripheral shelves include both the shelves lining the right wall and the shelves slightly to the left of them. The shelves lining the walls provide a great amount of display space, but the benefits are completely offset by the inclusion of shelves right next to them, creating a narrow corridor with only one side to escape from, and taking way the advantage that peripheral shelves have of being right next to a path.

6.2 Integral Shelves

6.2.1 Top Left Shelves

The square shelves in the top left corner of the store exemplifies the implementation that reduces the likelihood of a stampede, there are a myriad of ways to both enter and exit the area, along with very nearby exits to a main path. This would be the optimal location to display some of the less desirable goods out in the front of the store, as it will be the easiest section to diffuse through, but has the least efficiency.

6.2.2 Bottom Left Shelves

If the top left shelves represented one end of the safety-efficiency spectrum, then these shelves on the bottom left represent the exact opposite end. These long shelves can display a lot more products for every unit of area, but are tightly packed together, with no easily accessible exit. If a stampede were to happen, this would be the most likely place. With crowds able to flood in from both sides, customers in the middle won't be able to escape even if they already picked up their goods. The risk of goods being damaged here is at a peak, with people leaning against both sides of the shelves due to the narrowness of the corridors, and possibly crushing goods that customers moving towards the checkout line were holding.

6.2.3 The Right Shelves

Both of the shelves on the right employ a healthy combination of both efficiency and safety. The top shelves focus more on safety, and the bottom ones focus more on efficiency. The combination of both angled and straight shelves in the top section create ample space for customers to gather without damaging the goods, while still providing a fair amount of display space, which we considered for our design. The bottom shelves just essentially the two left shelves combined, and does pretty well in both categories, but does neither too well and ends up having too many corridors that are too narrow to be easily navigable.

7 Takeaways

The design of Integral shelves have to vary according to the goods they carry and their position in the store. Integral shelves need to be more spaced out near the front due the larger concentration of people, and as we move further radially from the entrance, we can start lengthening them to add some efficiency so that we can display all our goods. Since peripheral shelves are almost always accessed from only one of their sides, we won't need to consider many of the safety variables, since there are no corridors to speak of and you are already on the main path when accessing them, so it would be best to just make them span the entire length of the walls. A good way to additionally mitigate the mayhem for more desirable goods is to provide plenty of walking space around the shelves, even better if we are able to create paths all around them.

8 Our Model

We had to find a way to quantify mayhem. We thought of a few potential ways, like using a computer generated model of our layout and keeping track of the number of times people collided. However, we determined that there were too many unknown variables to make a good model there, so we had to view this problem in a new way. To gain some inspiration, we watched a few videos of Black Friday shoppers crowding various stores. What we saw helped us develop our model. We witnessed how people tended to grab and fight for the same items, and realized that there simply wasn't enough of everything to satisfy the wants of the shoppers. After reviewing the store layout factors, factors of demand, and the effect of crowding, we determined that the mayhem of a good is composed of the number of people surrounding the good and how badly people desire the good. Fortunately, the demand part of the model is already taken care of by the statistical analysis. However, the demand isn't the only component of mayhem. so the remaining part of the model will only need to deal with the natural diffusion of customers and how they would move through a store disregarding the demand for certain items.

8.1 Population Density

Imagine a mass of people entering a store from a single entrance and diffusing through the store from high to low concentration almost like a gas would when released in a room. Take the point of view of a camera high up looking down at the people in the store. Because of Assumption 3, over time as people move through the store, more people branch off as they see something on their list. As a result, a smaller percentage of the population will be able to reach the parts of the store farthest away from the entrance. This ties into the idea of demand, because in order to reduce crowding, we want a smaller percent of the population to be able to see the most demanded goods. That way, we balance a large demand for the good by reducing the amount of people able to reach the good. To prove this, we made a computer science model to show the natural diffusion of people.

8.2 Coding

We wrote a program that generated a particle and that particle would move around in random directions until it hit a surface, such as the edge of the building. Every time it moved, it would make the pixel it came from darker by one unit, with 255 units representing white and 0 units representing black. For example, after the particle moved to an adjacent pixel, if the pixel it came from had a brightness of 243, it would darken and then have a brightness of 242. Therefore, the lower the brightness at a certain point, the more traveled across that point is. The particles represent people, and how people would naturally diffuse through the store. All particles start in the center of the map, and we only considered a quadrant of the map to represent the store. Thus, when only a quadrant of the map is taken in consideration, it represents all particles starting at a point on the vertex of the square and moving through the store. In our program, we unleashed 1000 particles because it was enough particles to represent masses of people, but not too many that it paints the entire map black. The final step came in normalizing the values of brightness from a scale of 0 to 255. Basically, it takes the range of values in the map and scales to the range of 0 to 255. With this all in mind, the image below is produced.

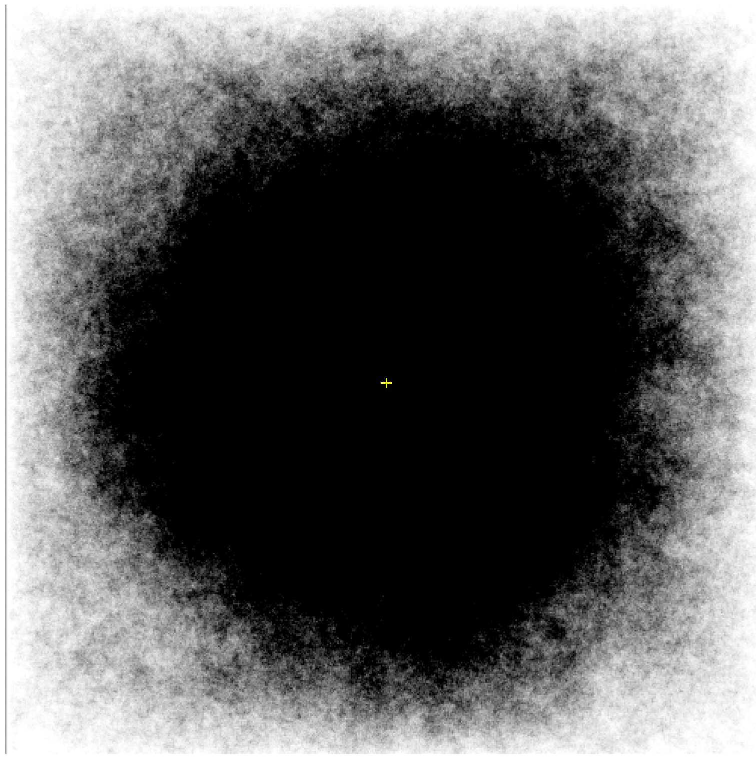


Figure 1: Image produced by the code

8.3 Analysis

Since every quadrant is nearly identical, we can choose the upper left quadrant without loss of generality. In the future, we will refer to the point all particles start at as the origin. With the dark spots representing a higher percent of the population walking there, we can see that the area least traveled is the area in the very back of the store the farthest away from the entrance. In addition, we can see that the population density decreases radially from the origin. In our program, we coded a section that would output the brightness at select distances away from the origin, and we made a graph of it with distance on the x-axis and brightness on the y-axis. The following table displays the values:

D from Origin	Brightness
0	0
50	97
100	172
150	203
200	245

Upon graphing this using a calculator, we found that the R value was 0.9744443668. This means that the graph is basically linear and that there is a linear relationship between the distance to the origin and the population density. As the distance from the origin increases, brightness increases and the population density decreases. This result can quantitatively prove that people naturally branch off as they progress through the store which leaves less people at the back of the store. Since this is in the short run (Assumption 4) the entire store won't be black, as it takes time for people to be able to fully diffuse through the store. The program simply gives a quantitative way to view the initial spreading of the people as a linear relationship to distance. With this in mind, we can write our equation:

$$M = D * Pd, \tag{3}$$

Where M is mayhem, D is demand for the good calculated from the statistical analysis, and Pd being the population density as modeled by the program. Since our method discussed earlier in the paper to prevent damage to goods consists of distributing the mayhem out as thin as possible throughout the store, we need to make mayhem as equal as possible at every point in the store. Thus, we need to make demand times population density as even as possible, so goods with high demand should be placed farthest from the entrance in order to do so. We mentioned the floor plan characteristic of goods being placed by departments with the goods being spaced apart slightly so that crowding can be smaller. This can be applied to our model, as we were able to statistically identify which departments had the most demand, thereby placing goods within each department slightly apart to comply with factors. With regards to the cash register, the cash register should be placed as close as possible to the exit in order for people to quickly be able to exit upon obtaining their good. Using the model and the statistical data, the next section will go in depth on how our principles can be applied to the floor layout given to us.

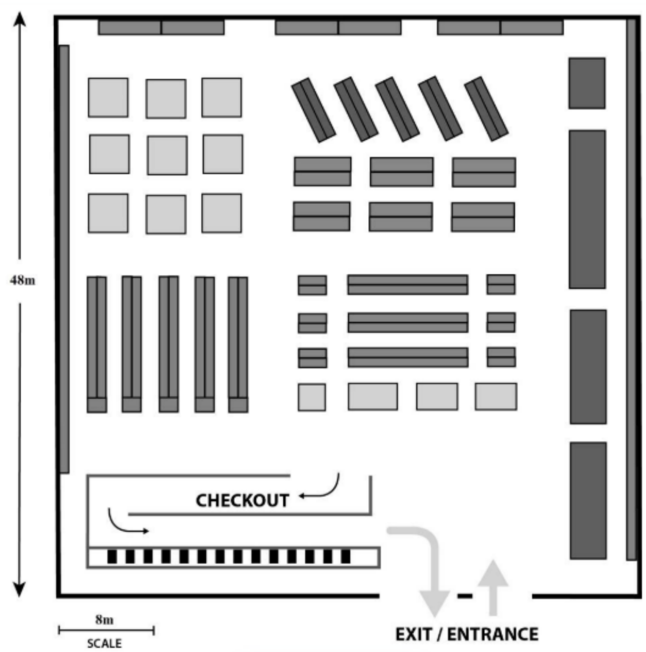


Figure 2: 1st Layout

9 Assignment of Goods on the First Layout

For the sake of simplicity, the north wall is the wall closest to the upper part of the page, the east wall is the wall closest to the right side of the page, etc.

When assigning the goods, our first thought was to avoid placing the highest demanded goods at the entrance of the store to avoid clustering at the entrance. Therefore, we decided to place the goods with the lowest demand at the entrance of the store to minimize clustering at the entrance.

Specifically, we placed the goods of the Cell Phones Department on the two bottom right shelves on the east wall of the store. Then, we placed the Audio goods in the first row of shelves parallel to the horizontal axis that customers will first see when walking into the store.

Now that we placed the goods with lower demand, we can now focus on goods with mediocre demand. Our next priority was to spread out the clustering of people as much as possible, so we decided to put the departments of goods with mediocre demands, which are TV/home, Video Gaming, and Cameras, at the first quadrant, the remainder of the fourth quadrant, and the entire third quadrant of the store. To make it easier to visualize, the origin of "coordinate axis" that we are referring to here is located where the four corners of the rectangular-looking groups of shelves meet up at a point slightly northwest to the exact center of the store. However, we avoided placing mediocre goods on the top three shelves on the north wall along the store. More specifically, we placed the goods of the TV/Home department along the west side of the wall to minimize the commotion, due to the fact that the TV's more costly to businesses when destroyed and are less fragile. Since there are so many varieties of TV's, the third quadrant was also going to be filled with same department. In the remainder of the fourth quadrant, we placed the goods of the Cameras department in order to further minimize clustering at the beginning of the store. Furthermore, we put the Video Gaming department in the first quadrant of the store, and along the top two shelves of the east wall.

Lastly, we placed the most demanded departments of goods in the second quadrant of the store and on the top shelves at the north wall of the store. Specifically, the Computers and Laptops were placed in the three-by-three square composed of small, square shelves, and the Appliances were placed along north wall of the store.

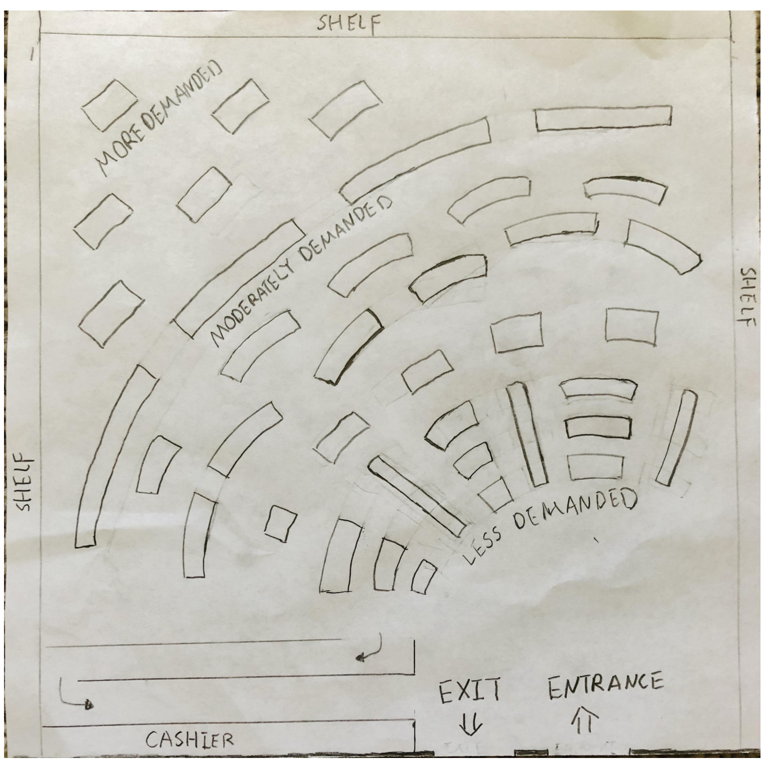


Figure 3: Our Recommended Store Layout

10 Recommended Store Layout

Using what we learned from our model and analysis, we have come up with a store layout that best satisfies the principles introduced in our paper. We concluded from our model that the likelihood a person will walk to a location decreases proportionally to its radial distance from their starting point. Many of the elements in our design employ a semi-circular design, to make sure goods that are equally desirable don't attract more customers just because of their placement. We will place the less desirable departments such Cell Phones in the front of the store, to reduce the probability of early congestion, and place the most demanded departments, like appliances in the very back, on the shelves with paths on all sides. The mayhem all around the store would be equalized this way, with any good's desirability being offset by the distance customers have to walk to reach them. In addition to that, we redistributed some of the excessive space in paths to space each individual shelf out more.

While our design may have slightly less total display space than the original design, almost every single one of our corridors qualifies as a passage, which essentially eliminates the possibility of people getting stuck between shelves. Unlike the old layout, our new design accepts that there will be goods that will inevitably be fought for, and adds plenty of "fighting space" around them, so that the people that want them can take them from all directions comfortably, and leave with them right after, minimizing the damage done. All in all, what the original layout lacked in safety, we made up for in the new design by sacrificing bits of efficiency which, considering the tremendous increase in demand during flash sales, we will not need.

11 Letter to Manager

Dear Store Manager,

We hope you are more than excited for your store's Flash Sale to commence. We were able to analyze your store layout before coming up with ours, and we want to commend your design for being very efficient for everyday operation. However, we believe we can offer a better design specifically for the Flash Sale. We believe that you should consider implementing our design because it minimizes the destruction of goods during the Flash Sale and it prevents massive clusters of consumers in certain areas of the store.

To begin with, our store design minimizes the destruction of goods that will occur during the Flash Sale. In our analysis, we initially identified what factors contribute to destroyed goods, and we created a variable called "Mayhem", that measured how prone certain goods are to being destroyed. Using our newly created variable, we used the factors mentioned above as components of the variable, and we based our store design around this variable to minimize it. For instance, one factor that contributes to "Mayhem" is the difference between the quantity demanded and the quantity supplied of a good. We were able to calculate how demanded goods were with respect to one another, which played a major role in our layout design.

In addition, our layout prevents clustering throughout the store. The circular shape of the shelves make it so that the radial decrease in population density as a function of distance can best fit the natural diffusion of people across the store. In our statistical analysis, we used used Z-scores to fully and accurately determine which departments are the most demanded given the data provided to us. We used this coupled with thought out layout plans in order to come up with a way to distribute the departments based on the demand for the departments. Then, regarding the model, we used computer science to be able to code the diffusion of people throughout the store. This diffusion pattern opened our eyes to new possibilities, as we could then use aspects of both to come up the fact the departments can be placed throughout the store based on the two components: Demand and population density. We even managed to make our computer program more quantitative by actually plotting certain data points to determine a linear relationship between distance and population density. All these attributes for minimizing damage to goods are compiled in our store layout, as mayhem is neatly spread out across the store as evenly as we could make it.

In conclusion, we hope you will consider our store layout as we are sure it will reduce mayhem in your store and help you business out as a whole.

Sincerely, Team 10147

12 Appendix

```java
package picturelab;

import java.awt.Color;
import java.util.*;

/**
 * Diffusion Limited Aggregation
 * @author
 */
public class Diffuser extends Picture
{
    //Opening these data fields to be public,
    //since they are picture specific, and poses
    //no danger to the integrity of the program
    public Color particle = Color.yellow;

    /**
     * Constructs a blank picture of a given size
     * @param width  width of the picture
     * @param height height of the picture
     */
    public Diffuser(int width, int height)
    {
        super(width, height);
    }

    /**
     * Constructs a picture from a file
     * @param fileName file name of the starting picture
     */
    public Diffuser(String fileName)
    {
        // let the parent class handle this fileName
        super(fileName);
    }
```

```java
/**
 * Gets the set of neighboring pixels to a specific pixel
 * @param r row number of the pixel
 * @param c column number of the pixel
 * @return an array list of neighboring pixels.
 */
private ArrayList<Pixel> getNeighbors(int r, int c)
{
    ArrayList<Pixel> pixels = new ArrayList<Pixel>();
    if(r != getHeight() - 1)
        pixels.add(getPixel(r + 1, c));
    if(c != getWidth() - 1)
        pixels.add(getPixel(r, c + 1));
    if(r != 0)
        pixels.add(getPixel(r - 1, c));
    if(c != 0)
        pixels.add(getPixel(r, c - 1));
    return pixels;
}

/**
 * Diffuses "particles" within our boundary, starting in middle
 * @param particles the number of particles used.
 */
public void runDiffusion(int particles)
{
    int i = 0;
    while(i < particles)
    {
        Pixel pix1 = getPixel(500, 500);
        while(!pix1.getColor().equals(particle))
        {
            if(pix1.getColor() != Color.BLACK)
            {
                pix1.setRed(pix1.getRed() - 1);
                pix1.setGreen(pix1.getGreen() - 1);
                pix1.setBlue(pix1.getBlue() - 1);
            }
            pix1 = randomWalk(pix1);
        }
        ++i;
    }
}
```

```java
    public Pixel randomWalk(Pixel pix)
    {
        ArrayList<Pixel> pixels = getNeighbors(pix.getRow(), pix.getCol());
        int random = (int)(Math.random() * pixels.size());
        return pixels.get(random);
    }

    public static void main(String[] args)
    {
        Diffuser pic = new Diffuser(1100, 1100);
        int l = 1000;
        int w = 1000;
        for(int i = 0; i < l; ++i)
        {
            pic.getPixel(0, i).setColor(pic.particle);
        }
        for(int i = 0; i < w; ++i)
        {
            pic.getPixel(i, 0).setColor(pic.particle);
        }
        for(int i = 0; i < l; ++i)
        {
            pic.getPixel(l, i).setColor(pic.particle);
        }
        for(int i = 0; i < w; ++i)
        {
            pic.getPixel(i, w).setColor(pic.particle);
        }
        pic.runDiffusion(1000);
        pic.normalize(0, 255);
        System.out.println();
        System.out.println("500: " + pic.getPixel(500, 500).getRed());
        System.out.println("450: " + pic.getPixel(450, 450).getRed());
        System.out.println("400: " + pic.getPixel(400, 400).getRed());
        System.out.println("350: " + pic.getPixel(350, 350).getRed());
        System.out.println("300: " + pic.getPixel(300, 300).getRed());
        System.out.println("250: " + pic.getPixel(250, 250).getRed());
        System.out.println("200: " + pic.getPixel(200, 200).getRed());
        System.out.println("150: " + pic.getPixel(150, 150).getRed());
        System.out.println("100: " + pic.getPixel(100, 100).getRed());
        System.out.println("50: " + pic.getPixel(50, 50).getRed());
        pic.write("diffuseCircle.jpg");
        pic.explore();
    }
}
```