Simulation and Analysis of the Hill Dining Center

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ABSTRACT

This project simulates the Hill Dining Center during peak hours. Currently, the large daily student volume into the cafeteria results in lengthy queues and long service times. Because we considered the current system operations optimal, we focused on providing recommendations for extreme scenarios, Stockwell and Thanksgiving, when arrival rates of students differs drastically from the norm. We examined how changing the number of serving stations affected average queue wait times. Our scenario simulation showed that this change does provide a significant impact on the average queue wait time. As all four scenario alternatives proved to be significant, we chose the alternatives that best provided a low cost to the housing office but still provided a high impact on average queue wait times in the Hill Dining Center. Thus we chose a serving station capacity of 4 for the Stockwell scenario and a capacity of 2 for the Thanksgiving scenario.

OVERVIEW

The Hill Dining Center is a university operated cafeteria that opened in fall 2008 and aimed to combine 3 previous dining halls. It contains multiple food stations with multiple servers that can accommodate between 1,200 and 1,800 students a day and seat up to 638 people at any given time. It is open continuously from 7:30 am to 8 pm for breakfast, lunch and dinner. The dining hall's large traffic is not only due to the need to service three residential buildings, but also due to its novelty in food quality and seating areas. Thus it attracts students not only from the Hill residential area, but also students that live both on and off campus. The major difference between the Hill dining facility and other on-campus cafeterias is the personalized service with made-to-order meals and the upscale dining atmosphere at the same price.

Typically, a student will come to the front door and hand his/her Michigan ID Card to an employee who will swipe the card and approve entrance into the dining facility. From then on, a student can pick up a tray and eating utensils and proceed to any venue of his/her choice. The layout of the dining halls discourages students to wait in line and all follow the same route through the dining hall while choosing food. Instead, the layout allows students to view the selection available at each venue and make an educated decision before joining the appropriate queue. This eliminates the need for students to wait unnecessarily in the queue for food items that they may not desire, hence increasing the efficiency of the system compared to previous dining halls.

By entering the dining hall, students are allowed to select food from as many venues as desired and there are no limitations on how many times they can visit any venue or the length of their stay at the dining hall. Once they exit the dining hall, they are no longer able to re-enter without paying for another meal.

Depending on the demand and type of food being served, food is either constantly replenished or made to order. The following shows a list of food/drink venues and their type of service:

Venue	**Type of service**
Marketplace Pizzeria	Self-Serve
Marketplace World Palate	Self-Serve
Marketplace Homestyles	Self-Serve
Marketplace Grill on the Hill	Self-Serve
Marketplace Just dessert	Self-Serve
Marketplace Salad Bar	Food to order
Marketplace Palmer Avenue Deli	Food to order
Marketplace Soup Station	Self-Serve
Fountain Drinks	Self-Serve

The length of the line for each venue will depend on the popularity of the food and if there is a need to wait until a meal is made to order. The University of Michigan hopes to implement similar dining hall facilities to replace individual cafeterias in other parts of its campus.

Therefore, the success of the Hill Dining Hall is integral consideration for future implementation.

In this project, we would like to provide recommendations to improve the efficiency of average wait time in queue for problematic venues. We defined problematic queues as those venues that experience high popularity and significantly long queues as a result.

CURRENT PROBLEM

Hill Dining Center operates continuously throughout the day and therefore copes with fluctuations in student traffic. Thus, most of the issues apparent in the dining center surface during high traffic times (5-8pm, Monday through Thursday). During this time frame, an increase in student volume affects how students enter and proceed throughout the dining hall. Lines to enter the cafeteria become excessively long, extending up to the entrance of the residence hall. Popular venues such as Homestyles and World Palate receive the largest amount of students, leading to lines often exceeding 20 people which leave Hill staff with very little resting time. The proximity of these two venues often causes lines to merge, and students fail to distinguish appropriate queue entrances. Although there is an upper deck for seating, it is often left closed, causing the lower level seating to become crowded as students search for seating.

OBJECTIVES

The Housing Office wishes to expand this type of dining hall and replace the current individual cafeteria system at the University of Michigan campus. Successful implementation of this project under all conditions is extremely important. Therefore, our recommendations to the Dining Hall are of utmost significance in providing insight for the Housing Office.

While the Dining Hall has a few observable problems, the University of Michigan Housing Office does not feel that these issues need renovation or revision for the current student volume. However, the dining hall is not equipped to handle extreme student volume changes, and therefore the Housing Office would be willing to invest in additional resources to help address this issue. Due to this perspective, we must consider the dining hall's current operations optimal for the current student volume of 1200-1800 students per day.

Our main objective is to simulate the dining hall, both under the current situation and under extreme conditions. In both these situations, we want to minimize the time a student spends waiting in queues and offer recommendations to accommodate different arrival rates.

In order to accomplish our objectives, we will use arrival and service time data to accomplish the following:

1. Examine queue length
2. Find service station utilization for all locations
3. Obtain optimal number of service stations at problem venues
4. Determine number of people in the system at a given time
5. Investigate individual student venue preferences.

MODEL SCOPE

The purpose of this simulation initially is to demonstrate the flow of a large volume of students through the entire system during high traffic times. In order to accomplish this, we can model the behavior of any particular student and examine their trajectory, choice of venues and actions performed inside the dining hall. We will take into account variations in the process such as different student preferences, including the number of and particular food venues chosen along with time spent at each location. To make the student model applicable for peak periods in both our simulation and actual system, we examine interactions between large volumes of students that all intrinsically fit into our developed student model, hence following a similar behavior. For our model, we also take into account that there may be multiple serving stations at each food venue, depending on the size and popularity of the given venue.

Due to the complexity of the dining hall system, it is imperative to our project to simplify our model to incorporate the most important aspects of the system. The only venues we will examine are the Pizza station, World Palate, Homestyles, Grill on the Hill, Just Dessert and the Palmer Avenue Deli station. Additional locations will include the Entrance, Dining Area, and Dish Rack. We will only take into consideration the arrival, interarrival and service times for each of the locations mentioned above. While each venue offers a variety of meal options, the number or particular item(s) chosen by a student are not relevant to the optimization of the Hill Dining Center. Thus, we only take into account that when a student visits a particular venue, they obtain food and proceed to the next location, irrelevant of food amount. However, we take into consideration students preferences for the type and number of venues they wish to visit.

Because delays and inefficiencies usually occur during high traffic times, this is the primary concern of dining hall staff. Examining peak student volume during high traffic times will allow us to observe problems and accommodate to the Dining Hall's most strenuous situations.

MODEL LOGIC

A student's time in the dining hall is spent in two major areas: food service areas and dining areas. We assume that a student's trajectory will consist of collecting all the desired food for the evening and then sitting down to eat, followed by exiting the system. This implies that a student will not return to any food station area once they have entered the dining area. For example, students will not finish dinner and then go find dessert.

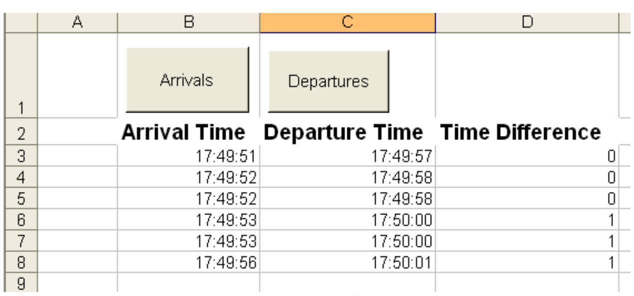
When calculating the amount of time spent in the system, we do not take into account how long it takes a student to pick up a tray and silverware. This is because there are multiple tray stations throughout the dining hall, making the time spent collecting these items almost negligible in comparison to visiting other locations.

Although we are aware that in real scenarios, students are free to browse for food, enter and leave the queue at any point, for our model we assume that once a student enters a queue, he or she will wait until service is completed. This means that students know what a venue offers before they make a committed decision to stand in line. Similarly, each station will follow a first in, first out queuing system.

Finally, there is no hierarchy in the system and all students are considered equal. Thus, if all students have the same priority, no student can interrupt the queue ahead of students already waiting.

DATA COLLECTION

Time Studies
We developed a Microsoft Excel® Macro, shown in Figure 1, which would be able to record instantaneous times categorized as arrivals or departures and also calculate the time difference between the two. The Macro allowed us to collect and record real time data instantly without having to manually input the time. This software was manipulated to record arrival, interarrival and service times for most of the locations examined.



	A	B	C	D
1		Arrivals	Departures	
2		Arrival Time	Departure Time	Time Difference
3		17:49:51	17:49:57	0
4		17:49:52	17:49:58	0
5		17:49:52	17:49:58	0
6		17:49:53	17:50:00	1
7		17:49:53	17:50:00	1
8		17:49:56	17:50:01	1
9				

Figure 1. Screenshot of Excel Macro

We estimated (rather than calculated) the service times for the pizza, entrance and dish rack locations because students consistently spent minimal time at these locations, thus complicating data collection.

Due to the large number of students present in the system, we decided that a minimum of 200 data points should be collected for each arrival, interarrival and service times at each location, to ensure a proper representation of system behavior. Two team members simultaneously collected data at the same venue to ensure that the service and arrival times represented the same time frame and set of students. Data was collected on Tuesdays and Thursdays from 5pm to 8pm, where at least one hour was devoted to collecting data at each venue. To support our findings, we used additional data provided by the Housing Office which allowed us to estimate the amount of people that enter the system at a given time.

Although the Housing Research office was aware of our study, students remained unaware of our time studies, which allowed us to prevent any bias or possibility of skewed data.

Student Surveys
To model the student routes and their venue preferences, we created a short questionnaire that would reflect how long a student spends eating, their top food venue preferences and how much time they would be willing to spend in a particular queue.

The questionnaire was created to approximate real behaviors actually observed in the dining hall. Asking students how much time they spend eating allowed us to calculate the service time of the dining area. We determined how many stations they usually visit and their top three venue preferences, allowing us to assign appropriate routing probabilities to students upon entering the dining hall facility. Finally, we asked students what would be the maximum queue length limit for them to reject a particular venue. This would allow us to establish routing rules and operation logic of an entity moving to and from each location in the system.

To ensure that we were captured accurate representations of the Dining Hall's student body habits and preferences, we only approached individuals or small groups of diners (less than three). This would prevent diners from exchanging ideas and presenting one collective group response. The surveys were conducted while students were in the dining area after they had collected their meals. This would ensure that our team was no influencing their responses and that interview students were in an environment where they could easily recollect their preferences.

Students were randomly selected for an interview, not biased to any specific gender, ethnic or age group. This ensured that we had a representative sample of the dining student body.

MODEL TRANSLATION

To create a viable ProModel design, we compiled all the arrival and service time data into StatFit to determine the appropriate discrete distributions, as shown in Figure 2 below. We selected the best distributions that fit within a 95% confidence interval. All of our service time data fit a uniform distribution while our arrival rate data fit Poisson and Geometric distributions. We then used these distributions in ProModel to model wait and arrival times.

Venues	Arrival Rate	Service Time
Entrance	Poisson(7.21)	U(2,1)
Pizzeria	Poisson(6.98)	U(7,4)
Homestyles	Geometric(.074)	U(34,15)
World Palate	Geometric(.124)	U(31,11)
Grill	Geometric(.117)	U(10,8)
Deli	Geometric(.063)	U(54,42)
Dessert	Geometric(.0886)	U(10,5)
Dish Rack	Geometric(.153)	U(3,1)

Figure 2. Arrival and Service Time Distributions

Our student survey results allowed us to find venue preferences and the time students spent in the system. In order to find venue preferences, we calculated the popularity of each venue according to the percentage of students who listed it as a top 3 venue preference. For example, 47% of students would be willing to stand in line for pizza. Next, assuming a student wants a particular venue item, we determined the maximum queue length at which they would be willing to enter and stand in line for. From our survey data, we determined the percentage of students who would: 1) not enter at all if there is anyone present, 2) wait if there are less than 3 students, 3) less than 6, 4) less than 10, or 5) greater than or equal to 10 students. We then created a cumulative density function (cdf) distribution using these percentages, setting the probability to 100% for the case where a student wants to enter a particular venue and there are less than 3 students in line.

Our survey data indicated that students differ in the number of venues that they visit. Based upon our collected data, we calculated probabilities of how many students visit only 1 venue, 2 venues and up to 6 venues. For example, we found that a majority of students (38.75%) visit 3 venues during their time in the dining hall. However, this varies depending on the individual's preferences.

These probabilities were used in combination with the service and arrival times to create a routing pattern implemented in our ProModel simulation, as shown in Figure 3. As soon as a student enters into the dining hall, he or she is assigned an attribute number of 1-6. This value indicates the number of venues this particular student will visit. The probability of being assigned a particular attribute number is based on the calculations described previously to determine the number of venues visited. This means a student cannot visit more than 6 food venues, but these do not need to be unique venues. For example, a student with an attribute of 6 can visit six venues in any combination, including visiting the same venue six times.

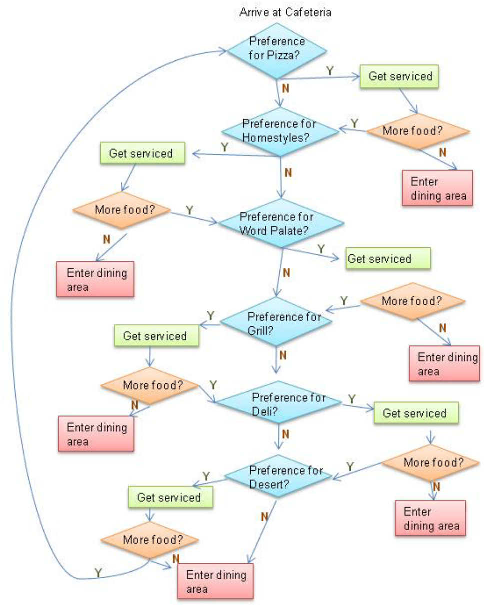


Figure 3. Arrival event flow diagram

Once a student is assigned an attribute, he or she then proceeds to the first venue, the pizzeria (Figure 3). The student arrives at a "decision location," which is a location situated before the queue location. At this location, the student must go through two "if-statement" loops before they can even enter the queue to stand in line for the venue. The first "if" statement determines whether or not the student want the venue item, and the second "if" statement determines whether or not the student is willing to stand in line, depending on the current queue length. As shown in Figure 3, upon entrance to the dining hall, the student first decides if they would like pizza or not, which is dependent on the probabilities as calculated from the survey data. For example, only 47% of students arriving in front of the pizzeria will actually want or prefer pizza (Figure 3). However, of the students who want pizza, not all will enter the queue. The next "if" statement route examines the number of people who are already in the queue for the pizzeria. The student will decide whether or not they want to enter the queue based upon the current queue length, as determined by the probabilities calculated from the survey data. Therefore, if a student decides that they do indeed desire pizza, and there are less than three people in line, there is a 100% probability they will enter (determined by the cdf described earlier). However, as the number of people already in line increases, the probability that a student will enter and wait in the queue diminishes. Consequently, few people are willing to stand in the pizzeria line if the queue is long, even if they wanted pizza initially.

If the student decides that they are willing to stand in line after both "if-statements," he or she will now enter the queue. As soon as a student enters a queue, he commits himself to waiting however long it takes for him to reach the venue location and get serviced. The student will not switch to a different venue queue, or leave without getting serviced. Once a student has been serviced at the venue, the attribute number originally assigned decreases by one. Once this number reaches zero, the student bypasses all other venues and is automatically redirected to the seating area and cannot visit any more food venues.

At the pizzeria decision location, if the student decides that they do not desire pizza and/or are not willing to wait in line for it, they move to the decision location for the next venue, Homestyles (Figure 3). Here, the entire process is repeated, where the student decides whether they desire the item, and if so, whether they will stand in line based on current queue length. The student will continue this progression from venue to venue, all the way to desserts. If their attribute number has still not reached zero by the time they proceed past desserts, they will return to the pizzeria and continue through all the venues until they finally do reach zero, and proceed to the seating area. After a student finishes eating in the seating area, they follow a specific path- seating to disk rack to exit (Figure 5).

SIMULATION DESIGN

We modeled our simulation with a run time of 1 hour. This was replicated 125 times to provide us with accurate output data. We also ran our simulation using batch means of 5 minutes to help us determine whether or not there was initialization bias. We used batch means to determine if there was a warm up period, which we found to be approximately 5 minutes.

To model the different scenarios, we inserted macros in place of values within our ProModel code. This was used to see how varying the server capacity affected the total time spent in the system and if there were any failed arrivals. We created four different scenarios for varying server capacity, which will be discussed in the *Modeling Scenarios* section.

VERIFICATION

Verification of our model included an analysis and comparison of the real and simulated system, an analysis of ProModel code by all group members, debugging the computerized code to ensure that it runs properly, and comparing output to predicted results.

Figure 4 and Figure 5 show diagrams of the real and simulated system, respectively. Here, the figures show the complexity of the system at the Hill Dining Center, as students can go to any venue of their choice in any particular order upon entering the cafeteria. This complexity was considerably extraneous to simulate in ProModel, and we therefore designed a simpler version of the Hill Dining Hall system, shown in Figure 4. Here, the main flow is preserved, as students can go to any venue of their preference, yet a particular logic and path is enforced so the center can be simulated and replicated correctly.

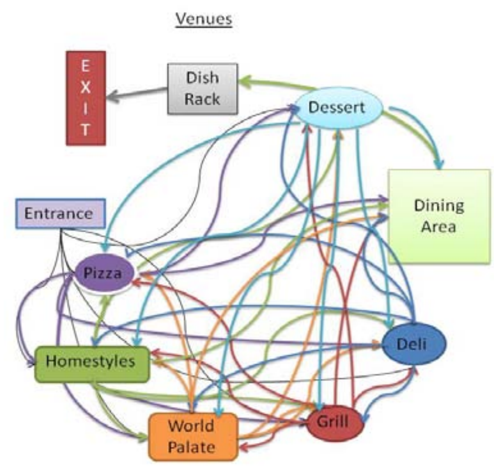


Figure 4: Diagram of Real System

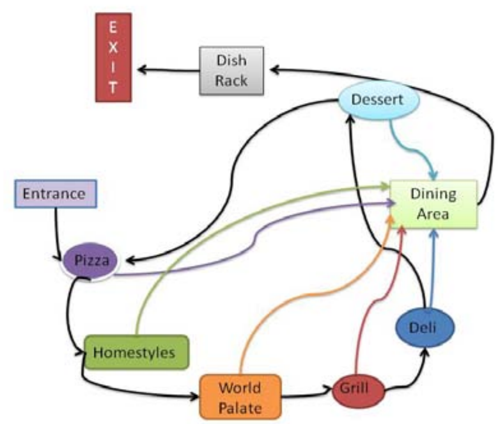


Figure 5: Diagram of Modeled System

Upon successful completion of the simulation, we analyzed the output to determine if it was logical in relation to the expected results. For example, we expected that the Pizzeria, Homestyles and World Palate would have a much higher throughput volume than the

Desserts station, and found our simulation to show similar trends. We also compared the ProModel resulting queue lengths at problem queues based upon our arrival and service data to observed queue lengths at these venues. We did hypothesis testing between observed and simulated queue length for our six food venues, and we failed to reject our null hypothesis (no difference between observed and simulated queue length) for each venue except for Just Desserts, at a 90% confidence level. This may be accounted for by the inconsistency in students approaching the dessert venue and observing desserts at the end of the high traffic period, skewing observed queue length data.

Finally, we performed debugging of the computerized ProModel code to ensure that it ran properly, done first by the programming group and followed by non-programming group members. The debugging process was helpful in making sure that each individual step of the model worked as desired. The trace function was utilized for each scenario during the simulation. The trace text file also helped verify that the routing and processing followed the appropriate specifications. For example, after visiting each food station, all students should proceed to the dining area, disk rack and exit. Thus, in an 8 hour period, the number of exiting students should be slightly lower than the amount of entering students (to account for students still eating in the system at the time of termination.) Similarly, the percent utilization also played a key component in verification that the model properly routed entities from location to location without any gridlocks or errors.

VALIDATION

To validate our ProModel code, we modeled the simulation with the current settings and compared the output analysis to historical data given to us by dining hall staff. The dining hall estimated that a given student spends approximately 45 minutes within the dining hall. Our ProModel system gave an estimated time of 39 minutes. This was verified by hypothesis testing at a 90% confidence level. We performed additional hypothesis testing on the average wait time in queue for both World Palate and Homestyles venues in order to determine how well our model simulates the real system. Figure 6 shows our hypothesis testing results. Comparing the model with historical data shows that there is no significant difference in average queue wait time values.

	Average	$t_{\alpha/2,n-1}$	Reject/Fail to
Original HomeStyles	1.79	2.132	Fail to reject
Original World Palate	1.9	1.943	Fail to reject

Figure 6: Hypothesis testing results for Average wait time in queue

The confirmation of validity from this hypothesis testing will allow us to accurately determine what will happen in the real situation when making modifications to our modeled system. For example, we changed the arrival rate into the dining hall by increasing the number of students in queue. This caused failed arrivals as the dining center did not have the capacity to accommodate an increased volume of students, which helped verify our code.
We also noticed that in our earlier models, the number of students who visited the Dessert venue was very small (less than 5). This did not comply with our observations and therefore we had to modify our code to ensure that each venue was properly utilized. This is why it is important to have both observational and historical data to help confirm the validity of the program.

In order to accurately validate our model, we used the following techniques:

- Created of arrival event flow diagrams (Figure 3)
- Changed the number of entities in the system to one
- Ran simulation at slower speed
- Implemented local variables

First, the creation of the arrival event flow diagrams also allowed us to compare our model to the real system. We compared the event flow diagram with our process and routing code in ProModel to ensure that entities were moving according to real system design.

Next, we visually examined the animation by changing the number of entities within the system to one and running the simulation at a slower speed. This allowed us to visually validate the movement of our entity through the system. We repeated this process a few times to account for the different preferences and attributes assigned to entities.

Finally, we implemented local variables at each location to notify us when an entity visited each location. This allowed us to eliminate any errors, possibly missed during visual validation.

MODELLING SCENARIOS

We modeled two different scenarios that the Hill Dining Center would most likely experience, and thus accommodate for. The first scenario we modeled was the reopening of Stockwell Residence Hall in Fall 2009, which would increase the hourly number of incoming students to the cafeteria from 500 to approximately 700. With this scenario, we modeled two possible alternatives that would bring productivity back to the current optimum: increasing the number of serving stations at both Homestyles and World Palate from 3 to 4, and again from 3 to 5. We believe that this predicted increase in student arrival rate will not require the cafeteria to increase serving station capacity to more than 5.

The second scenario we modeled dealt with the decrease in student arrivals to due to the Thanksgiving Holiday. Due to students leaving to go home during the holiday, we predicted that the rate of arrivals will decrease from 500 to approximately 250. We provided two alternatives for this scenario, decreasing the capacity from 3 serving stations to 2, and again from 3 to 1, for both Homestyles and World Palate. Again, we only focus on these specific venues, as these are most easily affected (in both queue length and service time) by drastic changes in the system.

The goal for each of these scenario alternatives was to determine the optimal number of serving stations for each circumstance. Therefore, for the Thanksgiving model, we wanted to minimize the number of serving stations present so that each station would be maximally utilized, while still keeping the time a student spends in the system similar to our original model. For the Stockwell model, we wanted to provide additional serving stations for students to ensure that the total service time for a student would still remain minimal. These scenarios in ProModel provide us with recommendations to present to the Housing Office regarding further improvement at the Hill Dining Center and for future projects.

REPLICATION ANALYSIS

We performed replication analysis on each scenario alternative for both the World Palate and Homestyles venue. Our aim was to find out how many runs were necessary in order to obtain an accurate average queue wait time at a 90% confidence level, based on the standard deviation from our initial replications. We began our calculations initially with 4 replications and a standard error of 0.1. After calculating the minimum number of replications needed, we performed additional analysis to estimate the optimal number, using our minimum value as a starting point.

For example, for the Stockwell Scenario (Alternative with capacity of 4) in World Palate, we began with 4 replications and a standard error of 0.1. Our mean was 1.78 and the variance was 0.0256. Using replication calculations, we found that the minimum number of replications necessary was 7. After additional calculations, the optimal number of replications resulted in 9. With this new information, we ran the model again, using the appropriate number of replications for each scenario alternative.

Figure 7 shows a summary table of our replication analysis results for the optimal number of replications. The large difference in optimal number of replications is largely influenced by a large standard deviation in the queue wait time of each alternative. Furthermore, we believe that the large standard deviation in the Stockwell scenario is related to the inadequate number of serving stations in comparison to the increase arrival rate. Thus, as the number of serving stations increases, queue wait times are reduced, allowing for more consistency in the system, demonstrated by a reduced standard deviation.

	HomeStyles	World Palate
Original	5	7
Stockwell	53	454
Stockwell (Cap 4)	2	179
Stockwell (Cap 5)	2	4
Thanksgiving	2	2
Thanksgiving (Cap 1)	17	46
Thanksgiving (Cap 2)	8	2

Figure 7: Optimal number of replications needed for each scenario

OUTPUT ANALYSIS

We wanted to investigate if changing the serving station capacity in any of the scenarios would provide a significant impact on the average queue wait time for both the World Palate and the Homestyles venues. To do this, we performed pairwise t calculations, comparing each scenario alternative with the original (current) scenario.

Figure 8 and 9 below shows the 90% confidence intervals found for each scenario alternative for HomeStyles and World Palate. We determined whether or not a scenario was significant based on if the 90% confidence interval encompassed zero as a value. The range of these confidence intervals demonstrates that each scenario alternative provides a significant impact on the average queue wait time.

Scenario	Capacity 4	Capacity 5
Stockwell	(0.9321, 1.0587)	(1.4607, 1.59256)
Scenario	**Capacity 1**	**Capacity 2**
Thanksgiving	(-5.0934, -4.9426)	(-0.513, -0.4237)

Figure 8: Pairwise t Comparisons between scenarios and current system for the Homestyles venue

Scenario	Capacity 4	Capacity 5
Stockwell	(5.93296, 6.4353)	(7.7987, 8.2274)
Scenario	**Capacity 1**	**Capacity 2**
Thanksgiving	(-4.9889, -4.62913)	(-0.1102, -0.0895)

Figure 9: Pairwise t comparison of scenario alternatives and current system for the World Palate venue

As all scenario alternatives were found significant with respect to the current system, we proceeded to compare the scenarios alternatives against each other. Hence, we performed another pairwise t test to compare the Stockwell scenarios with capacity 4 and 5 and the Thanksgiving scenario with capacity 1 and 2. The results of these tests, displayed in Figure 10, showed that there is, in fact, an additional impact between the two alternatives.

	Homestyles	World Palate
Stockwell Alternatives	(0.5136, 0.5487)	(1.6942, 1.9637)
Thanksgiving Alternatives	(4.4648, 4.6341)	(4.5274, 4.8907)

Figure 10: Pairwise t comparison of scenario alternatives

The pairwise t test ranges shown above only allow us to determine which scenarios provide a significant difference in comparison to the original scenario. Since all alternatives have shown to be significant, our recommendations will be based on an analysis between average queue wait times and the costs associates to implementing each scenario alternative.

RECOMMENDATIONS

We defined a solution to be optimal if the alternative provides both a significant decrease in average queue wait time and can be realistically implemented by the Hill Dining Center. This realistic implementation depends on both spacing and financial considerations.

After a careful comparison (Figure 11) of the significant alternatives for the Stockwell scenario, we would like to recommend to the Hill Dining Center to increase the serving station capacity from three to four for both the World Palate and Homestyles venue for when the Stockwell Residence Hall reopens. We felt that although there is a significant decrease in average queue wait time due to a serving capacity of 4 and 5 we still recommend choosing 4 stations. The addition of another serving station in the capacity 5 alternative only reduces time spent waiting in queue by a maximum of 1.82 minutes. While this is a significant change, we feel that it does not justify the incurring high implementation costs necessary to remodel the venues to create additional spacing. By increasing the capacity to four, the average queue wait times will still be significantly reduced without incurring substantial costs, while keeping with the hall's physical space limitations.

	HomeStyles	World Palate
Original	2.50	8.87
Capacity 4	1.50	2.62
Capacity 5	0.96	0.80
l(Capacity 4 - Capacity 5)l	0.54	1.82

Figure 11: Average queue wait times for the Stockwell Scenario (mins).

Figure 12 shows the average queue waiting times for the Thanksgiving scenario. Here it is apparent that decreasing the capacity to one serving station increases the amount of time a student spends waiting much more significantly than alternative two. Although it appears that maintaining the current capacity of 3 serving stations to be optimal, the serving stations are not being fully utilized, leading to wasted resources. This is why there is an increase in the average queue wait time for both capacity 1 and capacity 2 alternatives.

We believe that the capacity 2 alternative provides a better solution for the Thanksgiving scenario. By decreasing the capacity to two serving stations, we minimize the increase in average queue wait time (by .47 mins) while fully utilizing the available resources.

	HomeStyles	World Palate
Original	0.13	0.13
Capacity 1	5.15	4.94
Capacity 2	0.60	0.23
l(Capacity 1 - Capacity 2)l	4.55	4.71

Figure 12: Average queue wait times for Thanksgiving Scenario (mins).

OTHER SUGGESTIONS

During our on-site visits to the dining center, we noticed that it would benefit students if there were clear signs indicating where serving stations are located. This would allow venues to form multiple queues and consequently decrease the average queue wait time additionally. This would also solve our initial observed problem where students could not find the beginning of the queue for their desired venue.

If the Hill Dining Center has plans for future renovations, we suggest that popular venues be separated, instead of being placed adjacent to one another. Moreover, venues should be designed so that students can serve themselves on both sides (Figure 13). This would allow students to immediately find queue entrances, eliminating any confusions and wasted time waiting. The proposed layout shown below eliminates the FIFO system currently applied. This system also necessitates that venues become independent hubs, and dining hall staff must monitor food levels and replenish accordingly. However, these modular venues are not directly connected to the kitchen, which may increase the distance traveled by dining staff to replenish food stations.

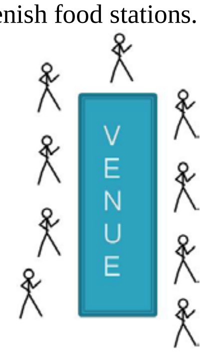


Figure 13: Diagram of suggested venue layout

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