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Simulating Alternative Models to Reduce Service and Wait Times in the United States Military Academy Mess Hall

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Abstract: For all meals in the COVID-19 environment, the United States Military Academy (USMA) feeds over 4,000 cadets using a buffet wing in the cadet mess hall. In the pre-COVID environment, lunch was served family style, while most other meals were buffet style. As a result of making all three meals buffet style, wait times have gone up significantly over the past year. Using queuing theory to construct a model of the mess hall in its current state showed that the average time a cadet spent in the buffet wing of the mess hall was 19.35 minutes per meal. Four different alternatives were constructed and compared to the current state using a discrete event simulation tool. The alternative selected for implementation in the mess hall reduced the average time a cadet spends in the buffet wing of the mess hall by approximately five minutes, while still allowing for all food items to be available to cadets.

Keywords: Queuing Theory, Simulation, Process Improvement, ProModel

1. Introduction

The Corps of Cadets at the United States Military Academy (USMA) is made up of over 4,000 cadets from all 50 states as well as international cadets from around the world. The mess hall serves these cadets during three predetermined mealtimes each day, with the exception of Sundays where a two-meal model is normally employed. In the pre-COVID-19 environment, lunch was the only mandatory meal for all cadets and the mess hall would serve all 4,000 cadets simultaneously with family style meals at assigned tables. In addition, about 1,200 fourth class cadets, or plebes, would have mandatory family style breakfast each morning using two wings of the mess hall while the remainder of the cadets would use the buffet lines in a separate portion of the mess hall. Considering health measures brought on by the COVID-19 pandemic, all mealtimes were changed to optional, using a buffet style system to serve the Corps of Cadets. This system was previously only used for dinner and breakfast for approximately 3,000 cadets each. With the pivot to feeding all 4,000 cadets three meals per day in two-hour windows, the mess hall has struggled with long queues forming and cadets have become frustrated with the amount of time it takes to get their meals. This research uses qqueuing theory and simulation models to better understand the complex system. Identifying potential bottlenecks, designing alternative solutions, and providing feedback to stakeholders can help alleviate these inefficiencies. The intent of this study is to reduce the long wait times for cadets in the mess hall without sacrificing the quality of the food being served.

2. Literature Review

Using queueing theory can help decrease wait times for customers in many different industries and is commonly seen in areas like healthcare. For example, in a study involving a hospital, the authors used financial and billing data instead of census data to construct a capacity planning tool to yield true hospital bed demand using queuing theory (Cochran and Roche, 2008). Fomundam and Herrmann (2007) discuss how different strategies such as priority queuing help to see what systems or alternatives can generate lower customer wait times, while minimizing doctor idle time. Queuing has also been used to develop a better understanding of a system and comparing how actual customer wait times relate to customer satisfaction in restaurants (Koh, et al., 2013). Little research has been conducted as it applies to buffet lines, but as this research will show, queuing theory and the use of models and simulation can have a positive impact on a system like USMA's mess hall. Bernhardsson (2019) believes that buffet lines are flawed and inefficient to serve groups of people. Bernhardsson (2019) constructed different models to demonstrate the inefficiency in buffet designs, however, this research will challenge his findings.

3. Model Development

The USMA mess hall is composed of three wings dedicated to seating and one wing dedicated to buffet lines. This project focuses exclusively on the wing that hosts the buffet lines, as seen in Figure 1.

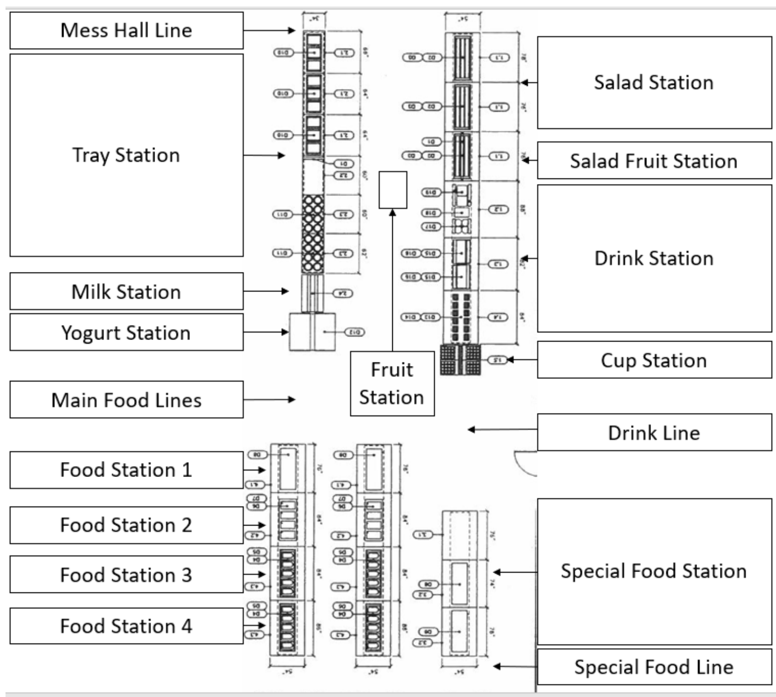

Figure 1. Mess Hall Buffet Wing Layout

The main components of the model are entities, locations, queues, and routes. To construct the model, an entity flow diagram was created to understand where data needed to be collected. Figure 2 shows the entity flow diagram and demonstrates the traditional route that cadets take in the buffet wing. Multiple data collection periods were conducted to capture service times and the frequency that locations were used. Service time data was collected by measuring the time it took for cadets to get through the various locations in the buffet (in seconds), while the percent usage of stations was determined by the number of cadets who entered and exited each location in the system. By measuring both service time and usage, the model can accurately capture the time it takes for cadets to navigate each station as well as the likelihood they will stop at a certain station. By building the model in the software ProModel, alternative models could be easily created. With the data collected and the model constructed, researchers ran multiple iterations of the status quo to ensure the simulation was accurately reflecting the current status of the buffet operations.

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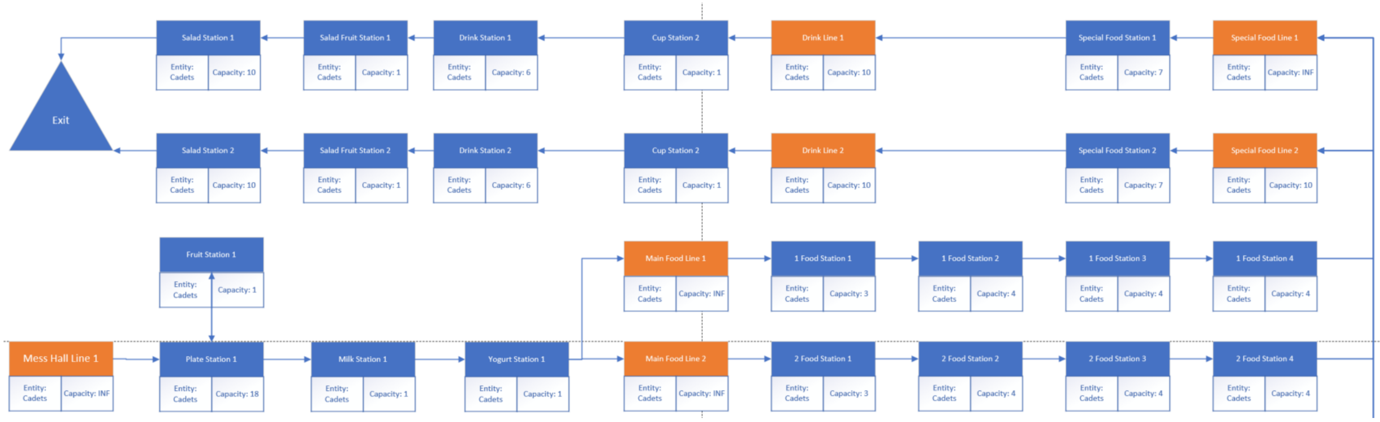

Figure 2. Entity Flow Diagram

3.1 Baseline Overview of the System

Upon entering the mess hall, cadets have the option of choosing one of four relatively similar lines to navigate through the system to select their food and drinks. While the buffet wing has multiple locations that make up the system, many of these locations were aggregated together to reduce system complexity and allow for data collection to be handled within the scope of this project. For example, a warming station with three trays of food was combined into one location in the model. Based on observations, this aggregation does not have an impact on the model's overall accuracy. The aggregated locations include the plate stations, the food stations, the special food station, the drink stations, and the salad station. The plate station is composed of individual locations to retrieve trays, plates, utensils, and napkins. The food stations are divided into four sub stations that combine four food containers each. The special food station, made up of two areas to retrieve desserts, is combined into one location. The drink station is composed of multiple locations to retrieve water or flavored beverages. Lastly, the salad station, is composed of multiple serving bowls that have various salad items. Because cadets pass through or use the individual stations, the average time it takes for a cadet to get through the combined location is accurate enough to provide feedback on how the system is currently operating and how it will operate if changed. Another assumption made was that cadets would not significantly deviate from the normal routes in the buffet shown in figure 2. The normal route assumes that cadets will use all stations in the buffet wing. While every cadet acts differently in the real world, it is infeasible to model how every single user going through the system would act. Therefore, based on observations of cadet behavior, it is assumed that all cadets follow a traditional path, with uncertainty accounted for by the model assigning probabilities that cadets take alternative routes by skipping some locations, as observed during data collection.

In the current COVID-19 environment, increased cleaning operations are occurring to prevent the spread of the virus. These efforts range from mess hall staff cleaning individual areas to shutting down entire lines for brief periods of time. To best replicate the current cleaning protocols, the model requires each line to be closed for five minutes every hour, redistributing the individuals in those lines to another line for that short period of time. From there, ten minutes later, another two lines would be cleaned, until all eight lines have been cleaned over the course of an hour. The final assumption pertained to the number of cadets that arrive at the mess hall and how often they arrive. This would allow the construction of a baseline model for comparison against the alternative models, as well as understanding how the mess hall can handle different arrival rates. It was assumed that 10 cadets would show up every minute to the mess hall for a grand total of 4,000 cadets going through the system by the end of the simulation. While this does not necessarily capture the actual variability of cadets arriving, the intent and scope of this project is to ensure that the mess hall is as efficient as possible when operating at maximum capacity. Downtime, as well as a startup time to replicate cadets who arrive before the buffet opens are built into the model. With a clear understanding of the necessary data to create a model that would accurately depict the current state of the mess hall in the COVID-19 environment, a robust and accurate data collection plan is necessary.

3.2 Data Collection and Methodology

Prior to the project starting, no data concerning the processing time for cadets to traverse the mess hall buffet existed. As a result, ample data collection of service time and utilization for the stations was required. To accomplish this, data collection occurred over the course of two separate lunch periods for 30 minutes each. Splitting the data collection times into two separate mealtimes allowed for cross examination of the data collected for percent usage at the stations and alternative routes. It also ensured that 30 service time data points per station were collected. Data was collected in the locations shown on the entity flow diagram in figure 2 and were used to estimate the service time and percent usage for the identical locations throughout the rest of the buffet wing. Service time data was gathered by timing how long a cadet took to use a particular station. Percent usage data was gathered by counting the total number of entrances and exits into a particular station. 34 tasked cadets helped collect the data, with 10 cadets assigned to collect service times for various stations, and the other 20 cadets assigned to collect entrances and exits into various locations in the system. While there are more than 10 stations that needed service time data, once 30 data points were collected at a station, data collectors were moved to ensure that every station had 30 data points by the end of the data collection. The same collection method was used for the service time at the fruit, milk, yogurt, and cup stations. Tracking entrances and exits by specific locations provides the required data to make assumptions about the percentage of cadets who use each location in the system and the normal route that cadets take as they navigate the buffet wing.

The collected service time data was put into ProModel's "Stat::Fit" function. Autofit in the "Stat::Fit" function was used to determine which distributions fit the service time data for each station. Autofit gives a rank and an acceptance to each distribution. The acceptance and rank of the autofit combined with goodness of fit tests run on the distributions determined what distributions should be used for the service time at each station in the system. The goodness of fit tests run were the Kolmogorov-Smirnov and Anderson-Darling tests. If autofit's ranking of the distribution was the highest without being 100 and said do not reject, then the goodness of fit tests would be further inspected. If the goodness of fit tests also indicated do not reject, then the distribution in question was accepted and used in the model. The percent usage for the stations in the system was determined by dividing the number of entrances by the number of exits. Alternate routes were also accounted for by counting the number of cadets who went straight to the salad line from the plate station and cadets who left food stations 1, 2, and 3 to go to the special food station instead of going all the way to food station 4.

3.3 Validation and Verification

Since there is no prior data on average time in the system for cadets to go through the buffet lines, the model output cannot simply be compared to real world data. Data collection for validation and verification purposes was outside the author's abilities given the scope and resources of the project. Because of this, to validate and verify the model, the average time spent in the buffet wing of the mess hall was compared to the author's experience using the cadet mess hall during different times of the day and for different meal times. The wait times in the mess hall vary from day to day and meal to meal. For example, if a cadet goes to the mess hall for breakfast when the mess hall opens at 0630, there is practically no line and the only time that the cadet spends in the system is the time it actually takes for them to get what they would like to eat and drink. Alternatively, if cadets go to the mess hall at 1800 when there are generally at least 50 cadets in each line going into the buffet wing, they may spend a significant amount of time waiting. To ensure that the simulation was capturing accurate data on how long a cadet was spending in a queue, the downtime in the simulation used to capture cadets arriving to the mess hall before it opens was manipulated between 0 and 30 minutes to see the time difference between the average time a cadet spent in the system with no line compared to the average time a cadet spent in the system with a backup of 50 cadets in line. The times were compared to actual times that the author spent in the mess hall when the lines were generally similar to what was modeled. The two times were relatively comparable and, as a result, within the scope of this project it was concluded that the simulation accurately captured the current state of the system. With the model validated and verified, alternatives could be generated and compared to the status quo.

4. Results and Analysis

The model allows the current system to be understood in the form of key performance parameters that can identify the current state of the system. The model in its current state can be easily altered which allows users to modify and edit the file to analyze how potential alternatives can change the flow of cadets going through the mess hall. Comparing the key performance parameters from the alternatives to the model of the current state of the buffet wing can help determine what alternatives can alleviate the long wait times that cadets are facing. The key performance parameters used were average time in the system, average time in move logic, average time in operation, and average time where a cadet is blocked from moving on in the system. Move logic, as it pertains to this project, is defined as the average time a cadet spent moving from station to station in the buffet wing. The goal of the alternatives is to reduce the average time in the system as a whole, while specifically trying to lower the average time that a cadet is blocked in the system. It is important to try to lower the average time a cadet is blocked in the system because that would indicate that the alternatives are reducing time wasted in the system.

To compare the current state model to the alternative models, 50 simulation runs will be conducted in ProModel. The average of the key performance parameters across the 50 simulation runs will be used to compare the alternative models to the current state model. An alternative will then be selected as the recommendation based off of the results from the 50 simulations runs.

4.1 Current State Model

For the current system, the average time in the system for the cadets is 19.35 minutes, where the average time in move logic is 1.18 minutes, the average time in operation is 2.19 minutes, and the average time where a cadet is blocked is 15.99 minutes. This immediately indicates that the service times or times it takes to retrieve food from a food bin and put it on a cadet's plate are not the problem. Instead, cadets are blocked by other cadets who are ahead of them in line because the system cannot reach equilibrium. If an alternative can reduce the average time that a cadet is blocked in the system, then the overall time in the system will be reduced.

Upon further analysis of the current state, the location summary showed the average time per entry in minutes by location as well as percent utilization. The ten highest average time per entry locations can be seen in table 1, while the ten highest percent utilizations can be seen in table 2. When viewing the highest average time per entry, the four highest average time per entry locations are the four main queues that cadets use to enter into the buffet wing. Four of the top ten highest average time per entry locations are four out of the eight main food lines that cadets stand in to get main entrees. This indicates that the backup that the cadets are facing in the mess hall is concentrated in two locations: the lines to enter the buffet and the main food lines. If those two areas can be alleviated, the average time that cadets are blocked in the system will be reduced and the overall average time in the system for cadets will fall as well.

Table 1. Current State Model Top 10 Average Time Per Entry

Station	*Percent Utilization*	Capacity	Total Entries	Average Time Per Entry (min)	Average Contents
Mess Hall Line 3	0.02	Infinite	1000	21.13	176.91
Mess Hall Line 2	0.02	Infinite	1000	21.12	176.84
Mess Hall Line 4	0.01	Infinite	1000	8.72	73.01
Mess Hall Line 1	0.01	Infinite	1000	8.58	71.85
Plate Station 3	62.87	18	1000	1.35	11.32
Plate Station 2	62.84	18	1000	1.35	11.31
Main Food Line 1	30.15	12	475.34	0.91	3.62
Main Food Line 2	28.38	12	474.48	0.86	3.41
Main Food Line 8	25.19	12	446.98	0.81	3.02
Main Food Line 7	25.86	12	503.06	0.74	3.10

Table 2. Current State Model Top 10 Percent Utilization

Station	*Percent Utilization*	Capacity	Total Entries	Average Time Per Entry (min)	Average Contents
Plate Station 3	62.87	18	1000	1.35	11.32
Plate Station 2	62.84	18	1000	1.35	11.31
Food Station 5.3	43.04	4	438.70	0.47	1.72
Food Station 7.3	41.53	4	421.20	0.47	1.66
Food Station 3.3	40.21	4	412.84	0.47	1.61
Food Station 1.3	39.73	4	405.70	0.47	1.59
Food Station 2.3	39.05	4	402.52	0.46	1.56
Food Station 4.3	38.40	4	394.04	0.47	1.54
Food Station 8.3	38.21	4	385.74	0.47	1.53
Food Station 6.3	35.96	4	365.80	0.47	1.44

4.2 Alternative Models

When generating alternatives for the buffet wing, the first item to investigate was the locations with the highest time in operation as well as the locations with the highest percent utilization. Based on the findings in those areas, alternatives can be generated and compared to the current operating model. It was also key to keep COVID-19 protocols in mind when developing solutions so that the model remained flexible to change. For a future project, research can be done to investigate more efficient alternatives outside of the restrictions in place because of the virus.

Alternative 1 was constructed with the idea that it can be immediately implemented if the mess hall staff so desired. The changes made were that the stations prior to the main food lines were moved outside of the system to decrease the amount of time needed to get to the queues with high backups. This involved removing the fruit, milk, and yogurt stations from their current locations. This is feasible because there are refrigerators around the mess hall that the yogurt and milk can be moved to and the fruit station can easily be placed near a location where cadets in line can grab fruit while they are waiting to enter the buffet.

Alternative 2 requires that cadets go through the buffet line before getting to the salad lines, eliminating an alternative path that five percent of cadets choose to take. It would be difficult to control where cadets decide to go when they are in line in the buffet wing, but if the time savings is significant enough, leadership may elect to implement this alternative, recognizing the high resource costs that would be required to ensure compliance.

In Alternative 3, the locations that serve desserts or special menu items like pizza are removed from the system. This alternative analyzes what occurs to the average time in the system if only prepackaged desserts are served. This alternative is feasible, but may not be desirable even if it decreases average time cadets spend in the system. Removing the special food station will decrease the number of food items available to cadets. Less variety of food items may possibly lead to cadet satisfaction decreasing, therefore the average time in the system would have to decrease significantly to outweigh the dissatisfaction of having less options in the mess hall.

Alternative 4 demonstrates what kind of an effect a different arrival rate would have on the average time in the system. All that was done to this alternative was that the 30-minute downtime that is in the current state model and other alternatives was removed. This means that 10 cadets enter each line in the buffet wing every minute, but that no queue is formed prior to the buffet lines opening. This shows the impact of what a controlled arrival rate would have on the buffet wing of the mess hall. This alternative could be implemented through the use of the cadet chain of command strictly enforcing arrival times.

4.3 Recommendations

Comparing the four alternatives with the current state model shows that the average time in the system from lowest to highest is alternative 4, alternative 1, alternative 3, current state, and alternative 2. While alternative 4 has the lowest average time in the system, this is because there is no backup when the lines are open. This allows for the system to never become overwhelmed with the number of cadets in line. While this would be the best-case scenario, it is unrealistic because the only way that this alternative could be achieved would be to restrict when cadets can and cannot enter the mess hall for meals. During the academic year schedule employed for the COVID environment, cadets have a wide variety of schedules during the lunch hours, making it difficult to implement a plan that would require precise arrival times. In a more controlled environment such as summer training, the entry and exit of cadets by company can be enforced, making this a viable option for those situations. Based on this, it is recommended that alternative 1 be implemented in the mess hall (removing fruit, milk, and yogurt stations). Alternative 1 has the second lowest average time in the system and reduces the time cadets will spend in line by approximately five minutes (as seen in Table 3). The stations that were removed in alternative 1 can easily be moved to other areas of the mess hall, meaning cadets will still have access to the food items and satisfaction will not be impacted.

Table 3. Baseline Model v. Alternative Model Key Performance Parameter Table

Model	Average Time in System (min)	Average Time in Move Logic (min)	Average Time in Operation (min)	Average Time Blocked (min)
Baseline	19.35	1.18	2.19	15.99
Alternative 1	**14.30**	**1.18**	**2.17**	**10.96**
Alternative 2	20.72	1.20	2.13	17.39
Alternative 3	19.25	1.17	2.17	15.90
Alternative 4	3.61	1.17	2.19	0.24

5. Conclusion

This research analyzes the current state of the buffet wing of the mess hall using discrete-event simulation and conducts a feasibility analysis on potential alternatives. In its current COVID-19 state, the average time a cadet spent in the system was 19.35 minutes, where 15.99 of those minutes consisted of cadets being blocked from moving forward. By relocating the fruit, yogurt, and milk stations out of the buffet wing, the average time a cadet spends in the system drops to 14.30 minutes. The overall impact to operations and satisfaction is minimal as cadets can still access fruits, yogurt, and milk if they would like to. As the COVID-19 pandemic has showed, every system needs to be adaptable and flexible to change. This research analyzes the impact of the changes the cadet mess made as a result of the pandemic and presents recommendations on how to improve the system moving forward. The model is easily adaptable and if different alternatives to the mess hall become necessary in the future, those alternatives can be simulated beforehand, allowing for informed decision making. Constant improvements can be generated, analyzed, and, if possible, implemented in the future.

6. References

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