

A Simulation Based Solution for Delivering Fresh Chapati to Hostel Residents

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Abstract

We consider the case of a large-scale student accommodation at a university campus, which has its own catering facility for serving meals to the residents. In our work, we use Discrete Event Simulation (DES) to estimate various measures related to service and quality of food, and propose means for improvement. In particular, we consider the food item *Chapati* (unleavened flat-bread), and show how the production schedule and batch size affects its quality by influencing the time lag between its production and consumption. By performing a ‘what-if’ analysis, we propose an efficient production schedule that shows significant improvement in the quality of Chapati.

Keywords: Discrete Event Simulation, Large Scale Student Houses, Production Schedule

1. Introduction

Student accommodations, usually referred to as ‘student houses’ or ‘hostels’ have their own catering facilities in most Indian Universities. Accordingly, the hostel residents are expected to have all their meals, including breakfast, lunch and dinner in the hostel dining hall, also called the ‘hostel mess’. The hostel mess, therefore, has to cater to a large number of residents at the same time, and providing a reasonable quality of service becomes a challenging task.

We consider the case of one such student hostel at the Indian Institute of Technology (IIT), Bombay. More specifically, the Hostel-16 mess at IIT Bombay caters to more than one thousand residents for each meal in a 105 minute time window. Management of such large-scale operations involve an annual budget of 40 Million INR and a dedicated team of more than 50 mess workers and student council members.

The quality of food served and amount of waste generated is a key concern for the management. This is particularly the case for the food item - chapati (unleavened flatbread) which is served during lunch and dinner and is one of the staple foods in India. As such, on a usual day, more than 6000 chapatis are made in the hostel mess. Ideally, these chapatis

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should be served as soon as they are prepared and therefore, *age of chapati* (time elapsed from production to consumption), is a crucial factor in determining their quality. One immediate way of delivering good quality chapati is to make a fresh chapati every time a student arrives. However, given the scale of operations, worker capacity and time constraints, such a policy will lead to unacceptable wait times and unfulfilled demand.

The motivation of this study is to estimate various performance measures related to current mess operations and explore means of delivering fresh chapati to students. This has to be done in context of random arrival time, random service times at the food counters and random demand, while adhering to time and budget constraints. To this end, we first collect the data regarding the demand and production process, and then use DES (Monte-Carlo simulations) to analyse the system performance by reproducing the mess operations on a computer. Through our simulation experiments, we discern how the production schedule and batch size make the current chapati making process inefficient, and perform a ‘what-if’ analysis to propose changes in the production schedule that show significant improvements in the simulation results.

The use of simulation for improving operations has been extensively made in business, service and manufacturing applications, as discussed in [1], [2]. The use of Monte-Carlo simulation is justified in our case because of randomness in the demand, arrival and service process of the system. Moreover, simulation serves as a risk-free medium to evaluate and compare different alternatives.

In context of the food industry, several papers [3], [4], [5], [6], [7], [8] discuss means for improving operations in fast-food restaurants. However, these applications differ from our problem context because either, (a) they focus on increasing the profits, (b) the scale of operations is relatively small, (c) the control variables are different from production schedule and batch size or (d) ‘freshness’ is not the concerned measure of quality. In our case, the motive is not to maximize the profit but to ensure that quality service is provided in a large-scale student accommodation.

The aspect of production and inventory control in our problem is similar to manufacturing applications as in [9], [10], [11]. The closest paper to our application context is [12] which proposes a way of improving *Chapati* quality only by changing the mess layout. However, the stringent time requirements in our case, a holistic approach towards improvement and focus on ‘freshness’ as a measure of quality make our research problem unique.

Our approach to addressing the problem of food quality is depicted in Figure 1.

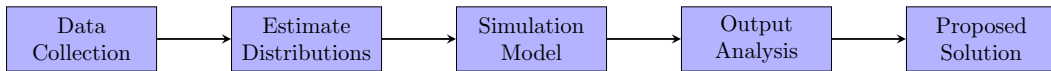


Figure 1: Problem Solving Process

In Section 2, we discuss the process of data collection. The current operations process of the hostel mess is discussed in Section 3 and problem statement is precisely stated in Section 4. The simulation model and results are presented in Section 5.

2. Data Collection

In order to capture variability in the operation process, we wanted to know if there is some pattern to the inherent randomness in the hostel mess system. We specifically wanted to model the probability distribution of (a) the arrival time of students, (b) the quantity demanded by any student and (c) the production rate of chapati. For this reason, we collected samples of these random variables to fit them to appropriate probability distributions in order to perform Monte-Carlo simulations. Note, the mess management committee only allowed us a period of seven days for recording the samples. As such, our inference of probability distributions is based on limited data. However, since the data was collected for a period of seven days, therefore, it reflects how the university time-table specific to a day influences the process-flow at the hostel mess.

During the seven day period the data was collected in the following manner:

1. During lunch(12:00 PM - 1:45 PM) and dinner hours(7:45 PM - 9:30 PM), the time span was divided in 15 minute slots, and we recorded how many students arrived in each of these time slots.
2. While collecting the plate each student must submit his hostel mess card which is a unique ID, identifying that the student is a resident of the hostel. We thus noted down the number of arrivals in each 15 minute time slot by counting the number of cards that were deposited during that time.
3. In order to estimate the quantity demanded of chapati we conducted a survey for a sample of more than 100 students across seven days and noted the number of chapatis each student took.
4. Next, we estimated the production rate, across seven days, by noting down the number of chapatis that were made every 5 minutes.

The ideal way to collect data in [1](#). would have been to note down the inter-arrival times i.e. time between occurrence of two arrivals. However, we chose to record the count data because our focus was on determining the peak-hours during which students arrive. For the same reason, in [4](#), we collected the data of count times rather than the inter-count times. In [3](#), we only record the number of chapatis the hostel resident took the first time he collected the food. The effect of second or third serving can be suitably modelled by changing the arrival rate.

The table below shows how the data was recorded for seven days during lunch hour:

Day	00-15	15-30	30-45	45-60	60-75	75-90	90-105	Total
Sunday	23	44	69	106	117	110	81	577
Monday	40	38	80	226	179	124	75	762
Tuesday	34	49	101	168	136	121	87	696
Wednesday	38	46	115	147	123	134	76	679
Thursday	26	36	109	161	150	146	75	703
Friday	42	84	132	138	114	102	80	692
Saturday	74	162	83	66	85	124	53	647

Table 1: Data collected during lunch hours in each 15 minute slot

On plotting the above table we observe how student arrivals evolve with time. The image below shows that the peak arrivals happen during the hours 12:30 PM to 1:30 PM i.e. between 30-90 minute time window, also depicted in Table 1. We also note that on few

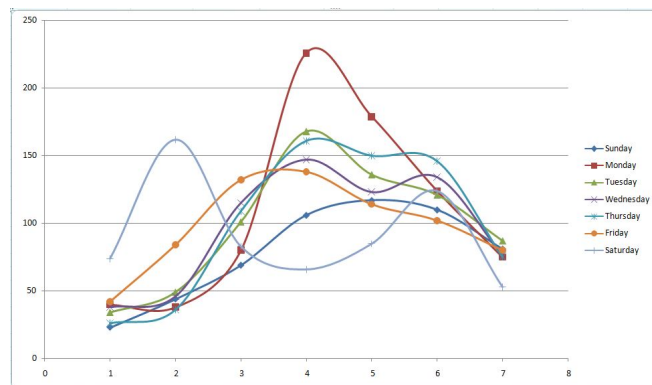


Figure 2: Plot of arrivals in 15 minute time slots for 7 days

days the plot depicts two peaks. Based on analysis of the university time-table and a survey conducted during the data collection process we make the following observations. The first peak arises when classes terminate at 12:30 for the lunch break. At that time, large groups of student usually arrive together for having lunch. However, all students don't have classes ending at 12:30 PM and there are students who have classes starting at 2:00 PM. These students usually tend to have their lunch towards the end of lunch hours, so that they can leave for class immediately after that.

In order to simulate the mess operations, two sets of events were captured carefully. First, the production process of chapati and second, the demand process. The interaction between these events was then simulated in accordance with the mess time-line — intervals in which the production happened and time window during which the students arrived. We next discuss the current demand and production process.

3. Current Demand and Production Process

The current mess system has three food counters, and any arriving resident can choose one of these food counters for taking the food. We denote these food counters as A , B and C . Each of these food counters have containers of usually 5 items. These items on a typical day could be lentils, vegetables, rice and chapati. A student arriving in mess first joins a queue for collecting the plate, where he submits his mess card and then usually joins the counter with shortest queue for collecting food from the containers. As a flow chart, the mess system is depicted in the Figure 3. The queues formed at the each mess counter are tandem queues (see [13] for more details).

The production of chapati begins 45 minutes before the hostel mess opens for students. For instance, during dinner hours mess opens at 7:45 PM but mess workers start making chapati at 7:00 PM. There are six workers who make chapati and while collecting data we found that they make on average 20 chapatis every minute. The production rate is initially

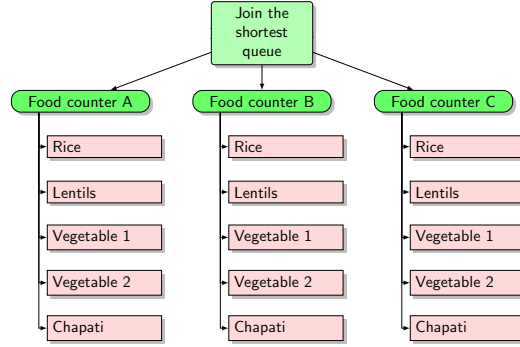


Figure 3: Arrival flow in the hostel mess



Figure 4: Time line for chapati production process

as high as upto 30 chapatis per minute and gradually decreases to 10 chapatis per minute towards the end. Once these chapatis are made they are stored in a vessel (stack) from which containers at each of the food counters are refilled. Chapati container at each food counter has two components - one for *ghee* chapati and one for *non-ghee* chapati. Whenever, any of these components become empty both the components are filled upto size 40-50, with latest batch of chapati. This is done for chapati containers at each of the three food counters. An important point to note is that all chapati containers and the vessel from which the containers are refilled are *stacks*, that is, they follow a Last In First Out (LIFO) policy. This means the chapati that is placed last (or placed on the top) is the first to be served. In the instance in Figure 5, initially the inventory of chapati in the vessel was 0 and since

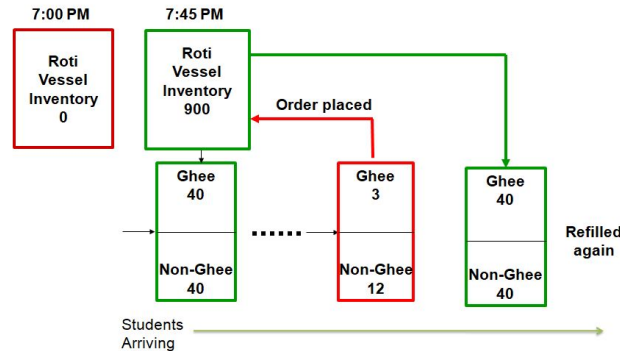


Figure 5: Example of chapati refilling at one of the food counters

production began at 7:00 PM, therefore it was 900 units when mess opened for students. This is an average estimate based on the average 20 chapatis/min rate at which the workers are producing chapati. The chapati container at each of the food counters was filled upto batch size of 40, and as and when it dropped below 4, at any of the ghee or non-ghee components, both components were refilled again upto the batch size. We note that the production schedule and batch size of the chapati components is something we can change, subject to some constraints.

4. Problem Statement

In order to design an efficient chappati production process we state the problem statement precisely. The objectives of our problem are as follows:

1. Minimize the **age of chapati** delivered to each student: the time between production and consumption of the chapati.
2. Minimize queue length and waiting time.
3. Meet entire demand.

As we discussed earlier, the best way to provide students with the latest chapati is to make a chapati after the student arrives. However, this will result in substantial increase in the waiting time and queue length. Therefore, we must optimize to achieve a balance between these objectives. The problem becomes challenging because we have the following constraints:

1. Only 105 minutes of maximum time could be devoted for making chapati, with 30 minute break in total 150 minute time window.
2. Production rate of chapati is random with average 20 chapatis made every minute and maximum 30.

The variables that we can change to improve the existing process are:

1. Container batch size in each wing for ghee and non-ghee chapati.
2. Production time intervals and break interval in 150 minute time window.
3. Queuing system in the mess, could be the one we proposed.

The random variables part of this process are as follows:

1. Arrival time of students.
2. chapati quantity demanded by each student.
3. Production rate of chapati.
4. Service time at each counter.

5. Simulation Model and Results

Using the simulation model, we will virtually reproduce the mess operations, by generating random arrivals, generating chapatis according to the random production process, along with random quantity of demand for chapati. The distributions from which these random samples are drawn, and the process that the arrivals will follow is imitated by observing day-to-day mess operations. Essentially we simulate the arrival (demand) and production process and their interaction at the food counters. We depict an overview of our simulation model in the Figure 6. The arrival process and production process is depicted in Figure 3 and Figure 5 respectively. The student arrival and production schedule is depicted in Figure 4.

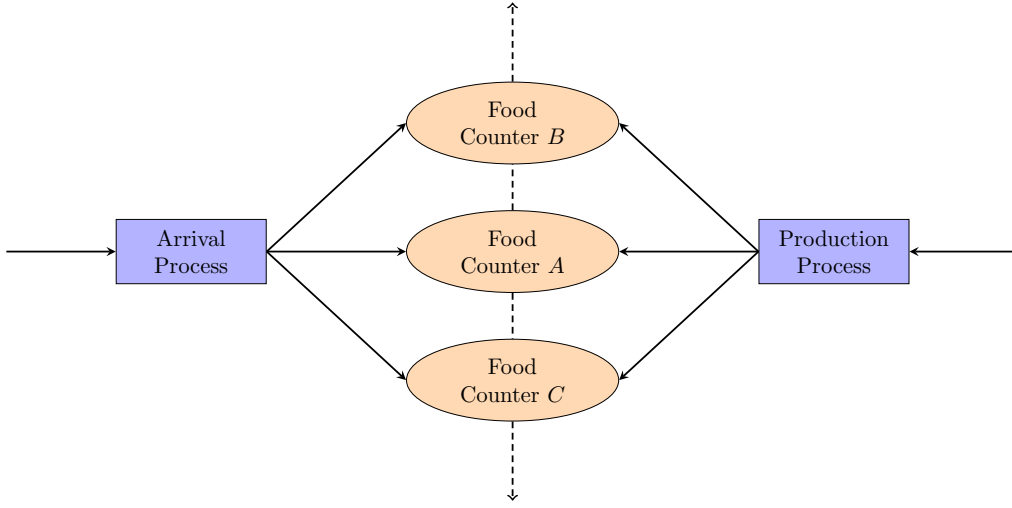


Figure 6: Overview of Simulation Model

5.1. Model Assumptions

We make the following assumptions in our simulation model:

1. Number of arrivals are modelled as non-homogeneous Poisson process with parameter λ_i varying for each 15 minute time slot i as per the data collected in Section 2.
2. Chapati demanded by each student $\sim \text{IntUniform}(1,4)$
3. Production rate of chapati $\sim \text{Exponential}(\lambda = 20 \text{ chapati/min})$ in first slot(90 mins) and $(\lambda = 10 \text{ chapati/min})$ in second slot (15 mins).
4. Service time at each counter $\sim \text{Uniform}(5,15)$ seconds.
5. Container batch size is set to 40 for both ghee and non-ghee chapati and both the components are refilled when either of them falls below 4.
6. Student randomly chooses between ghee and non-ghee chapati.
7. In case, the chapati vessel doesn't have sufficient inventory then we refill based on what other counters may be demanding and the queue length at each of these counters.

8. When chapati vessel becomes empty, along with chapati containers then in that case, we *passivate* the chapati container. It is further assumed that students will queue up untill chapati is refilled again.

Modeling arrivals as Markov Modulated Poisson Process, as in Assumption 1 is common in literature for modelling traffic phenomena (see [14], [15], [16] and references therein). Further, evidence from multiple production environments [17], justify the Assumption 3. Assumption 2 and 4 was verified using Goodness-of-fit and Kolmogorov Smirnov test. Other assumptions are made to imitate the observed behaviour. The simulation model was programmed in Python using Salabim package [18]. The simulation process was run for 150 minutes.

5.2. Output Analysis of the current process

A single simulation run of the current production process gives the following results. The age of the chapati in the Table 2 denotes the time difference between production of chapati and its consumption by the hostel resident. Queue length is also stated in table below because we wanted to understand the impact of current production policy on the queue length.

Total Inventory left	146
Maximum queue length	5
chapati Delivered/chapatis Made	1864/2010
Students-served/Students-arrived	751/756
Maximum age of chapati (mins)	148.355034
Average age of chapati (mins)	53.510773
Std. dev. of age of chapati (mins)	43.46406
Median age of chapati (mins)	43.350517

Table 2: Performance parameters for the current process

These results were initially surprising as we didn't expect a person would be getting an average 53 minute old chapati. However, we realised that this could indeed be possible. Note, that the first chapati is made 45 minutes before arrival. In fact, first 300 chapatis are made 30 minutes before the first student arrives. Since the containers are filled with latest batch of chapati each time, these 300 chapatis must be given to students when they have substantially aged. This also indicates that the estimated average age of chapati might be too high because few students may be getting very old chapati. Thus, to understand if the average is influenced by the outliers, therefore, we also compute the median age of chapati.

This indicates that the situation is even worse. More than half of the population is getting a chapati which is at least 43 minutes old. To understand why is this happening, we plotted how the students are arriving over time and average age of chapati delivered to that student. On x-axis we have discrete integer points indicating each successive student. On y-axis, in blue is the time at which the student arrives. Red data points indicate the production time of chapati that each successive student gets. This picture provides a lot of

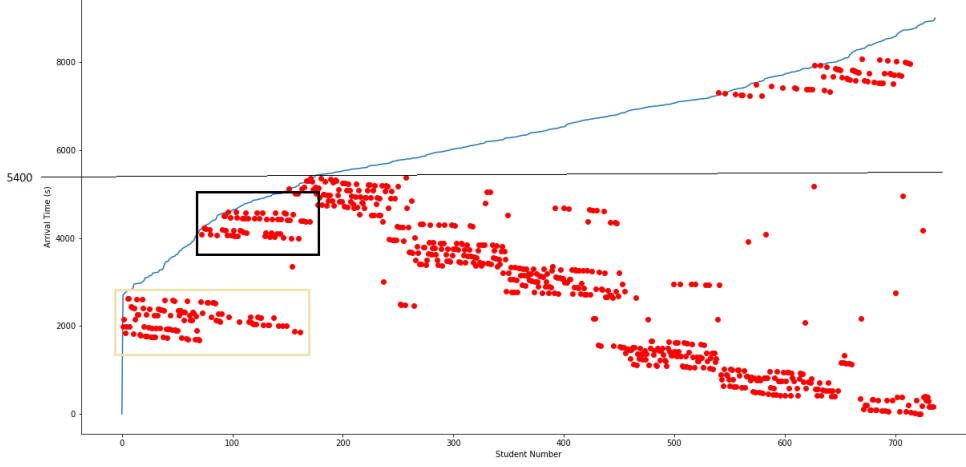


Figure 7: Arrival Time of student, Production time of chapati

valuable information about the current process and we explain as follows. First, we note that closer the red dots are to the blue line, better it is. As red dots indicate the time at which chapati was made, therefore a red dot closer to the blue line indicates that student arriving at that time got the latest chapati. Next, we observe that from 5400 seconds (8:30 PM), students over time are getting older chapati. This is because at that time chapati production has been paused as depicted in Figure (4). Therefore, from this point onwards the chapati vessel is not filled with latest chapatis and existing inventory in the vessel is used for refilling the containers. Further, we note that usually these dots happen to be in a bunch. This is highlighted by the yellow and black rectangle. The reason this happens is because each student randomly joins one of the containers in wing A, B or C. At any point of time the queue length is equally divided among the three food counters. The chapati containers at each of these food counters will clearly won't have chapati that was produced at the same time. The difference in production time of chapati at these counters is highlighted by the vertical length of the rectangle. The horizontal breadth of the rectangle represents the batch size - which we are currently taking to be 40. So whenever a batch gets over at any of the ghee or non-ghee components a latest batch of chapati is ordered. This is how we move from the yellow box to the black box. Towards the end of the graph, we note some red points close to the blue line. This is because at that time the production has started again as shown in production time line in Figure 4. In Figure 8 and Figure 9 we depict how the inventory in vessel/kitchen and how the inventory at chapati containers of the three food counters evolve over time.

These pictures also highlight the peak rush-hour happens to be during 8:30 - 9:15 interval and the production is paused from 8:30 to 8:45 PM. Note, the first drop in the kitchen inventory comes when the mess opens at 7:45 PM and containers are filled for first time.

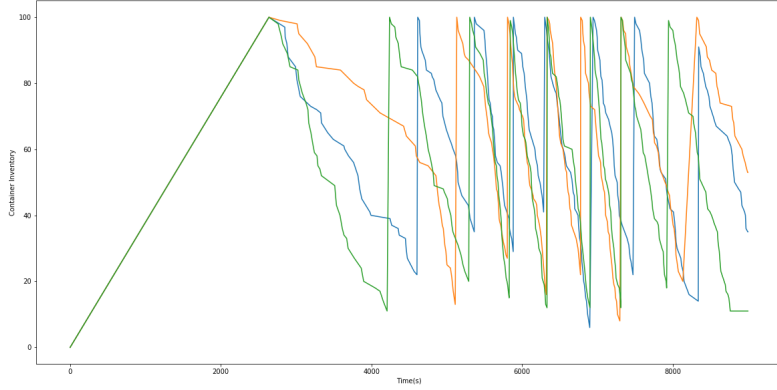


Figure 8: Container inventory at three food counters, under the current process

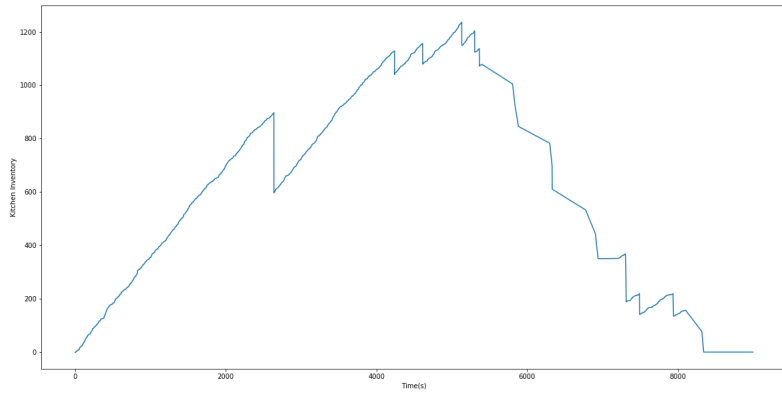


Figure 9: Inventory in the kitchen under the current process

5.3. Proposed Production Process

We notice that the current system has sub-optimal production schedule — the production is paused during the peak time. Keeping this fact in mind we propose the following plans for production.

1. Set production schedule to be 7:30 to 9:00 PM with assumed production rate of 20 chapati/min.
2. Set production from 7:00 - 8:00 with assumed rate 18 chapati/min and 8:30 -9:00 with rate 20 chapati/min.
3. Change the vessel from a stack to a queue.

5.4. Output Analysis of the proposed process

On changing the production schedule to between 7:30 to 9:00 PM as in Proposition 1 in (5.3) we get the results in Table 3. As before, the average age of chapati and median age of chapati are two most important statistics for us. There is a considerable improvement in

Total Inventory left	51
Maximum queue length	9
chapati Delivered/chapatis Made	1819/1870
Students-served/Students-arrived	709/751
Maximum age of chapati (mins)	114.196607
Average age of chapati (mins)	29.665892
Median age of chapati (mins)	12.610254
Std. dev. of age of chapati (mins)	29.898257

Table 3: Simulation results for Proposal 1

these results owing to the fact that we are producing now during the peak time also. The average age of chapati has dropped to 29 minutes from earlier 53 minutes and the median age of chapati have dropped to 12 minutes from earlier 43 minutes. This improvement is highlighted in the graph below: Evidently, far more red dots are closer to the blue line

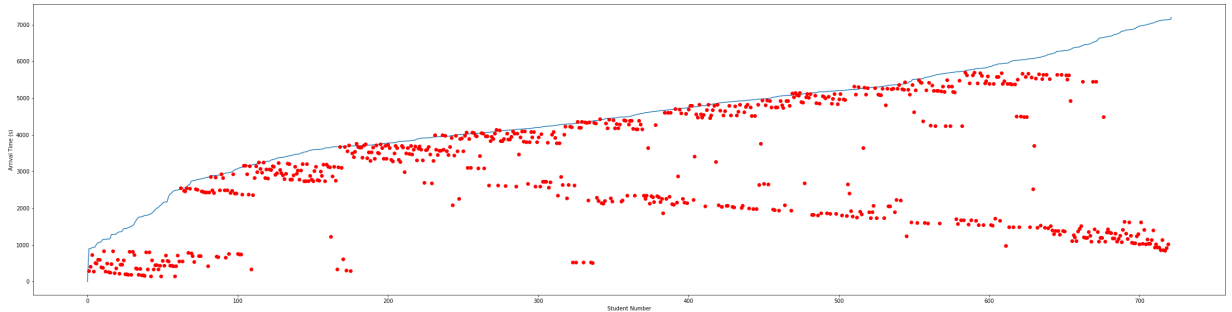


Figure 10: Arrival Time of student, Production time of chapati under Proposal 1

now. However, this system will not meet the demand as depicted by the statistics in the table. Note, only 709 people were served out of 751 people when the simulation run was stopped. The remaining inventory of chapati is only 51 which is not adequate to serve 42 people as each person on average demands 2.5 chapatis. Therefore, this production plan is not implementable.

Next, we simulate the Proposal 2 described in Section 5.3. The production time is now from 7:00 to 8:00 PM and then from 8:30 to 9:00. The statistics at end of the simulation run are presented in Table 4.

Total Inventory left	121
Maximum queue length	6
chapati Delivered/chapatis Made	1922/2043
Students-served/Students-arrived	765/771
Maximum age of chapati (mins)	147.221296
Average age of chapati (mins)	35.918296
Median age of chapati (mins)	17.407036
Std. dev. of age of chapati (mins)	39.087259

Table 4: Simulation results for Proposal 2

This plan is not better than the first proposal because the average and median age of chapati both have increased. However, it meets the complete demand and is better than the existing system. This means we have identified a production plan that is both implementable and meets the desired requirements.

We also simulated the Proposal 3 where the inventory storage unit was considered as queue instead of a stack. While this not implementable in reality we simulated it under the current production schedule and got the results in Table 5. Comparing this with the

Total Inventory left	146
Maximum queue length	5
chapati Delivered/chapatis Made	1864/2010
Students-served/Students-arrived	751/756
Maximum age of chapati (mins)	101.371069
Average age of chapati (mins)	60.077018
Median age of chapati (mins)	59.728321
Std. dev. of age of chapati (mins)	11.290010

Table 5: Simulation results for Proposal 3

results that we got in Section (5.2) we observe that situation has now worsened and students are getting on average 1 hour old chapati. This is because under the current system the production begins at 7:00 PM while first arrival happens at 7:45 PM. This means that every student will get an atleast 45 minute old chapati. This is also depicted in the picture below.

From the image above we make the following remarks:

1. We first notice that there are some red points closer to the blue line towards the end. This is because in the current system the production restarts at 9:00 PM until 9:15 PM. Some arrivals in this slot will get newer chapati.
2. While this proposal didn't perform well under the current mess system we believe that it will work great if production begins close to the time of mess opening. However, that may result in queues and demand may not be met.

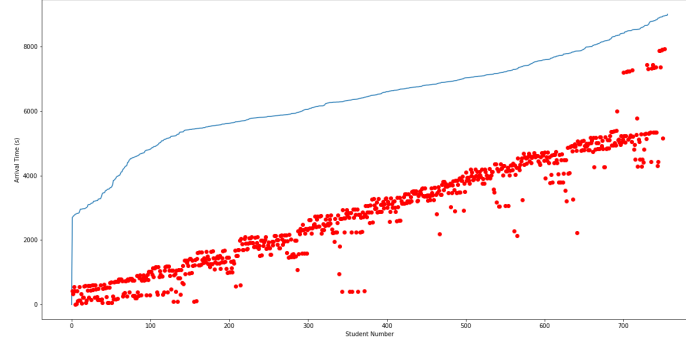


Figure 11: Arrival Time of student, Production time of chapati under Proposal 3

6. Conclusion

We used DES (Monte-Carlo) simulation to highlight the inefficiency of the current mess system, where the average age of chapati delivered is 53 minutes and the median age is 43 minutes. On validation, we found these numbers were close to the actual reality. To explore the possible reasons for this phenomenon, we plotted the arrival time and production time of the chapati delivered to each successive student. In our simulation results we observed the difference increased substantially during the thirty minute break when the mess workers took a break. This difference was significant because the 30 minute period was the peak-time when hostel residents arrived for having their meals. Consequently, majority of the students got chapati from old stacked up inventory. From this analysis, we could conclude that the reason behind poor quality of chapati is the sub-optimal production schedule. Accordingly, we used simulation to design an efficient production schedule to minimize the age of chapati, subject to time-line and demand constraints. Our proposed solution, show a 60% improvement in age of chapati delivered to the hostel residents.

In future work, we plan to extend our study to other food items. We also aim to model the mess operations as a Partially Observable Markov Decision Process (see [19]) to determine the optimal production schedule.

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