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Banking Simulation Report

Motivation

Consider a manufacturing plant with multiple stations that products must traverse, including staging, rough cutting, fabrication, sub-assembly, paint, and final assembly. The company deals with a wide variety of products, each requiring visits to these stations. The potential paths a product can take throughout its production lifecycle are extensive. The primary motivation for understanding the movement of objects through a queue is to optimize cost, minimize wait times, and create productive schedules. Queue systems offer prospects for addressing optimization problems.

Problem Statement

The focus of the problem revolves around a simple banking scenario. Banks are made up of many elements including banking associates, customers, money, checking accounts, safes, and electronic accounts. In order to simplify the problem, we will only concern ourselves with the interactions between the customers and workers. How does changing the number of workers affect customers? What happens if there is a speedy checkout line where you can quickly cash a check? What happens to work efficiency when too few or too many workers are scheduled. These are the types of questions that the problem will aim to answer. The main interest of the banking problem is to determine the relation between customer wait times and teller efficiency while ensuring customers are served throughout the day.

Related Work

Queuing theory is defined as the mathematical study of waiting lines or queues. It involves how to deal with incoming customers and how to optimize the allocation of resources to those customers. Queuing theory can be applied to many areas including telecommunications, transportation, logistics, finance, computing and more (1). This project will not focus on the mathematics of queuing theory but it is worth noting there is an entire field of study dedicated to solving problems surrounding queues and their efficiency.

Approach (Set Up)

In order to simplify the banking problem, bounds will be set at when a customer enters the line at the bank and when the teller becomes available to help a customer. Each *Customer* will be represented as an object that contains three fields, *time, work,* and *type*. Each *Teller* teller will also be implemented as an object. The teller will also have the same three fields as the *Customer* object, *time, work rate,* and *type*.

Customer:

Time:

Represents the time a customer enters the line.

Work:

Generic unit that represents how much work is required to assist the customer.

Type:

Set according to a predetermined work limit. If a customer requires less than or equal to the work limit they will be considered a priority customer. If a customer requires more

Teller:

Time:

Represents the time that a teller is available to help a customer.

Work Rate:

Represented in units per hour. When the customer *work* is divided by the teller's *work rate* it produces the total amount of time needed to assist a customer.

Type:

Tellers can be of two types, standard or priority, and will only help the corresponding customer. The type of the teller is set prior to the simulation.

There are 3 metrics that will be tracked during the simulation, *customer wait time*, *teller idle time*, and number of *unserved customers*. Customer wait time is the time a customer waits in line before they are assisted by a teller. Teller idle time is the amount of time tellers spend not helping customers because there are no customers in line. The longer a teller stands around without helping a customer, the more inefficient the system is. Finally, unserved customers represent the number of customers still standing in line at closing. If a customer arrives at 7:59 and the bank closes at 8:00, there is a chance the customer will not be assisted.

A standard customer queue and a priority customer queue is created to simulate customers standing in line. Also, a standard teller queue and a priority teller queue are created to store all tellers. Standard customers are only assisted by tellers from the standard teller line. Likewise, priority customers are only assisted by tellers from the standard teller line. The customer's arrival time and the teller's start time are exogenous events that are calculated prior to the start of the simulation. During the simulation the teller's next available time is endogenous and determined by customer arrivals.

Approach (Logic)

The program is event based, however it does not use an event list to run. Instead it relies on the next teller becoming available in the teller priority queue. The logic is simple and follows the following pseudocode:

While (there is a Teller in the Teller Line) and (there is a Customer in the Customer Line):
Pop Teller from the Teller Line.
Pop Customer from the Customer Line.
Adjust Teller's time to when the Teller will next be available.
Add Teller back into Teller Line.

If at end of day, Customers are in Customer Line:
Update the necessary metrics
If at end of day, Tellers are in Teller Line:
Update the necessary metrics

Experiments

Initially, four types of simulations were conducted: one with 9 tellers, another with 10 tellers, a third with 11 tellers, and the fourth with 9 standard tellers and 1 priority teller. Each simulation is run 10,000 times to obtain reliable results. Tellers start at 0 hours and assist customers continuously without breaks until hour 8. A total of 160 customers arrive at the bank each day, following a randomized uniform distribution. Each customer requires a variable amount of work, which follows a truncated Gaussian distribution of (5, 2.5), ranging from 2 to 15. Initially, a distribution of (5, 0.5) was used, resulting in an average customer assistance time of

27-33 minutes. By using the (5, 2.5) distribution, the time spent with customers was spread out to 15-45 minutes, providing more intuitive results, although 45 minutes is considered lengthy for a bank visit. The customer work distribution, customer arrival distribution, number of customers, and working hours remain constant throughout the simulations.

When simulating the scenario with one priority teller and nine standard tellers, a decision had to be made regarding who would be allowed in the priority line. Through trial and error, it was decided that customers requiring less than 18 minutes of work would be allowed in the line, as this minimized customer wait time. Analyzing the data revealed that 18 minutes corresponded to the lower 10 percent of the customer distribution, which is logical considering there is one priority teller available out of the ten total tellers. The priority line limit remains constant throughout experiments.

The number of customers not served, customer wait time, and teller idle time were monitored during the simulations. The following table presents this data for the four simulations:

Metrics		Number of Tellers in Simulation (Standard, Priority)			
		(9, 0)	(10, 0)	(11, 0)	(9, 1)
Standard Customer	*Count*	160	160	160	140.4
	Not Served	30.2	17.4	7.3	20.4
	Wait (min)	36.06	23.94	13.08	29.82
Priority Customer	*Count*				19.6
	Not Served				0.5
	Wait (min)				10.86
Total Customer	*Count*	160	160	160	160
	Not Served	30.2	17.4	7.3	21
	Wait (min)	36.06	23.94	13.08	27.54
Standard Teller	*Idle Time (hour)*	2.821	4.044	6.689	3.401
Priority Teller	*Idle Time (hour)*				3.144
Total Teller	*Idle Time (hour)*	2.821	4.044	6.689	6.546

Table 1: *Metrics for 4 simulations. Type of simulation is listed at the top of the table corresponding to 9, 10, 11 or (9 standard, 1 priority) tellers. Key metrics are Total number of customers, customers not served, customer wait time, and teller idle time.*

Results and Discussion

The results of the simulation are straightforward. When more tellers are available to help customers throughout the day, more customers receive assistance and they wait less time. This can be seen in *Figure 1* and *Figure 2*. It is important to reiterate that customers designated for the priority line can only be helped by priority tellers. Also standard customers can only be helped by standard tellers.

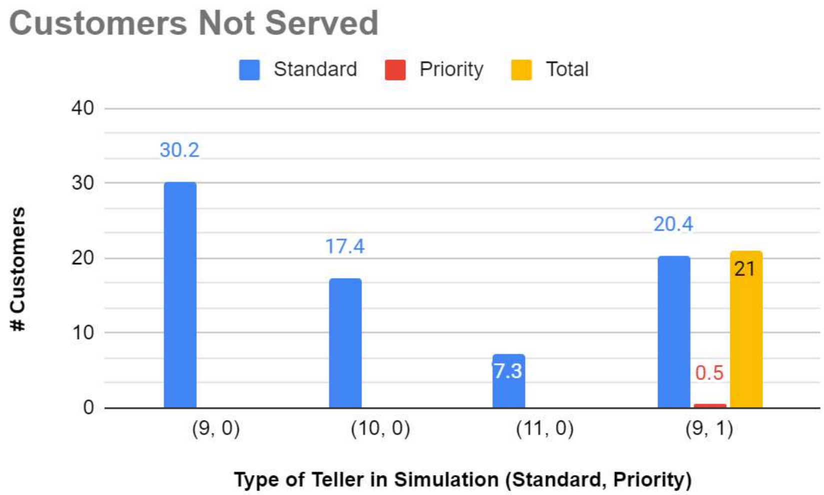

Figure 1: *Customers Not Served in an 8 hour banking day. The graph tracks all 4 simulations on the x-axis. The y-axis represents the number of customers that stood in line and were not helped by the end of the day.* ***Results:*** *As the number of tellers increase, so does the number of customers receiving assistance.*

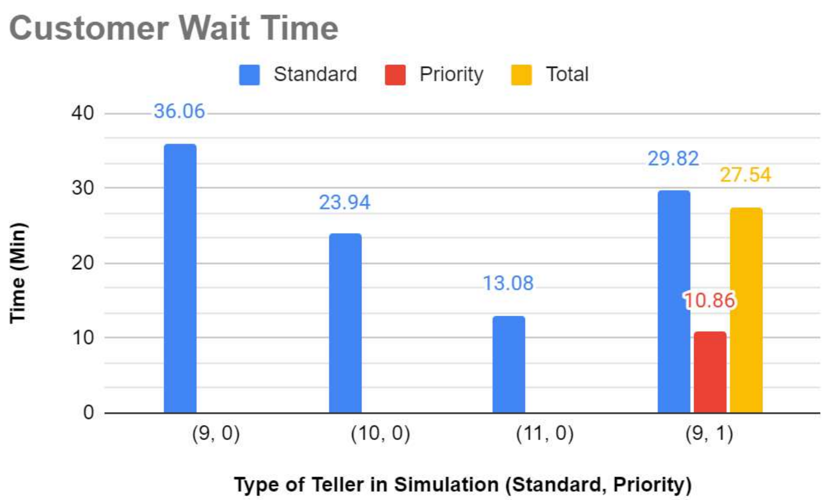

Figure 2: *Customer Wait Time in an 8 hour banking day. The graph tracks all 4 simulations on the x-axis. The y-axis represents the amount of time a customer spends standing in line.* ***Results:*** *As the number of tellers increase, the average customer wait time decreases.*

More substantial results are found when looking at the simulation with 1 priority teller and 9 standard tellers as compared to the simulation with 10 standard tellers. The priority line actually increases the overall wait time of customers from 23.9 to 27.5 minutes on average. However, customers who have less than the 18 minute threshold of work only have to wait 10.9 minutes instead of the 23.9 minutes had the priority line not been available. This is a reduction in wait time of 54% for customers that don't need much help, while it is only 15% increase for customers who require more work.

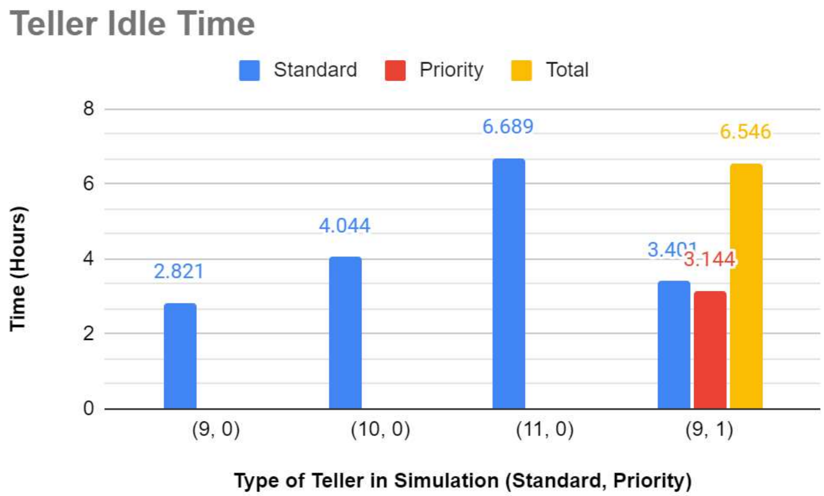

Figure 3: *Teller Idle Time in an 8 hour banking day. The graph tracks all 4 simulations on the x-axis. The y-axis represents the total time the sum of all tellers spend, not helping customers. This measures as an efficiency test of the bank's scheduling.* ***Results:*** *As the number of tellers increases, the amount of time a teller spends being idle increases.*

It is clear that the amount of time a teller spends standing around increases with the number of tellers available. When comparing the idle time of 10 tellers to the total idle time of the priority queue, there is an increase from 4.04 to 6.5 hours. This is a 62% increase in the teller idle time in order to add a priority queue.

When looking at the customer wait time chart, it is unclear whether or not there is a direct relationship between number of tellers and customer wait time. One last set of experiments was performed to check what happens when additional tellers are added or subtracted from the experiment. *Figure 4* and *Figure 5* show the results:

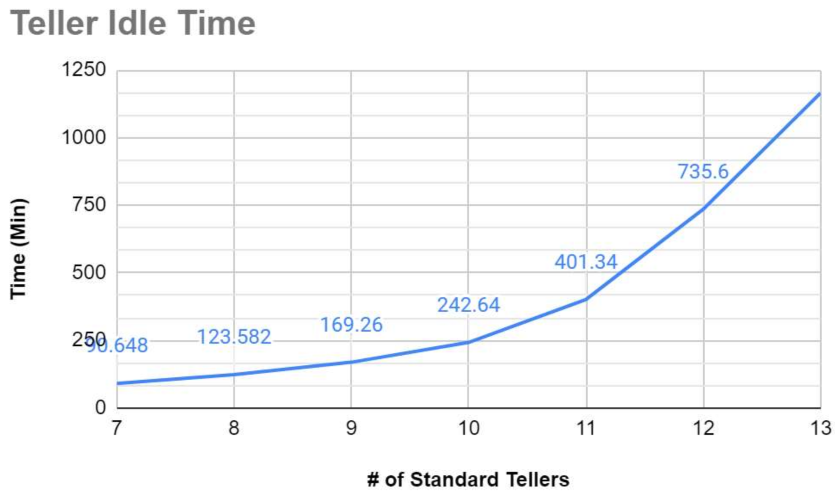

Figure 4: *Teller Idle Time for 7-13 tellers in the simulation. In this graph an additional 3 simulations were added.*

In the case of teller idle time, as the number of tellers move towards zero, the graph no longer resembles a linear relationship. Although, as the number of tellers continues to increase a linear relationship begins to appear. This makes sense as eventually all customers will be helped, and each new teller will be standing around for their entire shift. For the meaningful portion of the curve (excluding the limits) teller idle time is not linear. Each additional teller spends increasingly more time standing around.

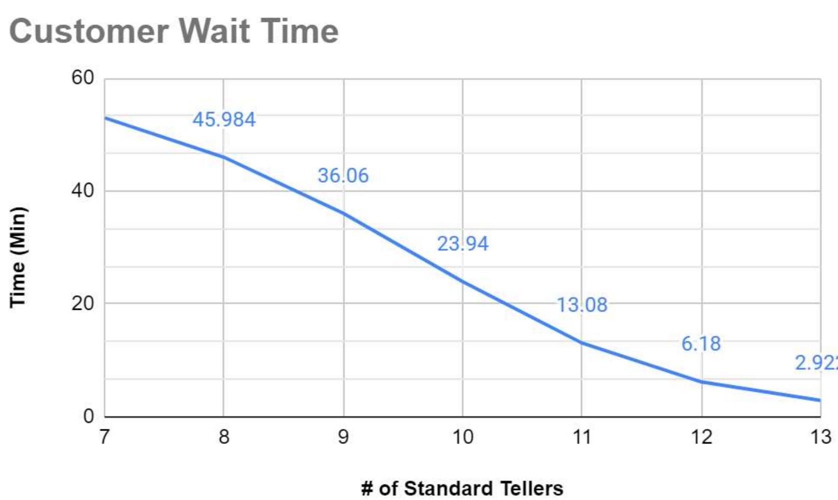

Figure 5: *Customer Wait Time for 7-13 tellers in the simulation. In this graph an additional 3 simulations were added.*

In the case of customer wait time, the results are also non linear. Each new teller added after ten tellers approximately halves the waiting time. At 13 customers the wait time was only 2.9 minutes and it is not logical to add any more tellers.

Conclusion and Future Work

In the future it would make more sense to use an event list for the banking simulations. While the implementation was simple and the problem did not require complicated logic, there were limitations of the program. Implementing the logic to allow a priority customer to enter the standard line proved challenging due to the absence of an event list. Also, creating additional types of events such as lunches necessitates the implementation of an event list.

By running simulations on queues new data trends are discovered. In the banking simulation a handful of trends were found. Increasing the number of tellers decreases customer wait time, increases the number of customers that can be served, but also increases the amount of time that tellers stand around waiting for customers. When a priority line is introduced for customers that only need a minimal amount of work, the total customer wait time was moderately increased while wait times for the priority customers were substantially decreased. The priority queue also carried an additional cost of reducing the teller’s efficiency.

References:

1. https://queue-it.com/blog/queuing-theory/#2-how-did-queuing-theory-start