Optimal Employee and Furniture Configuration in a Coffee Shop

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Abstract

The purpose of this study is to determine the optimal configuration of a coffee shop to maximize profit. Coffee shops are increasingly becoming destinations of social interaction as well as traditional coffee vending. In the age of technology oriented startups, coffee shops are perhaps the most common meeting grounds for young entrepreneurs. Most coffee shops are constrained by a set footprint, and therefore decisions must be made concerning tradeoffs between the physical space allotted to the customers and the space allotted to employees and coffee making equipment. Additionally, the specific configuration of resources in each of those categories must be selected to attract both new customers and retain current customers.

There are two main challenges associated with this study. First, for the results to be valid, a coffee shop must be observed to develop accurate models of employee and customer behavior. Secondly the individual components that constitute the model must be combined in a meaningful and accurate way. To guide in the creation of this model, a model published by Hwang, Joyhe, Gao and Jang [1] was referenced.

The optimization results indicate that a moderately sized coffee shop in an urban area will operate most efficiently with 11 large chairs, 17 large tables, 3 coffee machines, 1 cashier, 3 baristas, and 2 supervisors. This combination will yield approximately $0.1456/minute.

1 Introduction

In a coffee shop there are many competing variables that impact overall profitability. Generally, shop owners must allocate a certain amount of floor-space to create a comfortable environment for the customers, while still retaining the area required to efficiently serve the customers. Since most coffee shops have a fixed footprint, these two factors are in competition with each other. Additionally, the owners have to hire workers in several fixed roles, including cashiers, baristas (employees who make the drinks) and managers. Each employee category has a unique impact on how quickly a customer is served, and each has a unique pay grade. An employer is incentivized to select the optimal number of employees performing the various functions in order to maximize sales while maintaining low operating costs. Similarly, the coffee shop owner needs to choose an optimal ratio of tables to chairs to maximize seating capacity, yet keep customers comfortable enough to stay and make additional purchases. These furniture objectives are in competition since tables can accommodate more patrons, but large chairs are more comfortable.

Previous research has been conducted on restaurant modeling to identify optimal configurations. Gu, Kuang, Spangler and Zhang studied the optimal arrangement of a McDonald's restaurant in their ME555, Design Optimization, project: Optimization of a McDonald's Restaurant [4]. However, in their study, the restaurant was compartmentalized into distinct subsections (including the Kitchen Subsystem, Customer Area Subsystem, etc.), neglecting any interaction between elements of different subsections. Hwang, Joyhe, Gao and Jang published an article titled "Joint Demand and Capacity Management in a Restaurant System" [1]. Their paper modeled the wait time for service at a restaurant as an M/M/s/k queue model. This type of queue model would be applicable for the coffee shop because it takes points of service (cashiers) into account as well as maximum queue length (a length that would discourage further people from entering the service line). Hwang, Joyhe, Gao and Jang used a model in their paper that was primarily built upon in intricate probability theory.

The proceeding model takes inspiration from certain aspects of Hwang, Joyhe, Gao and Jang's work (such as exponentially saturating performance of components and the maximum tolerable service line length), but presents it in a simplified form that is less computationally expensive.

The objective of the coffee shop model is to maximize net profit. On a high level, net profit is calculated by subtracting operating costs from revenue. However, the aforementioned interactions add complexity to the system. The designated input variables include the number of large comfortable chairs, tables and machines, as well as the number of cashiers, baristas and managers. Constraints on the system can be grouped into two categories: physical constraints of the coffee shop and logistical constraints. Physically, the coffee shop can only occupy a set amount of space. This space must be divided into space needed for customer comfort as well as space for coffee production. Logistically, there must be equipment to support baristas and a managing hierarchy.

There are two categories of assumptions that have been made in the derivation of the model: assumptions relating to validity of parameters and assumptions relating to the system model that contain the parameters. First, the derivation of constants involved in the proceeding sections are assumed to be representative of the coffee shop industry. The parameters and model behavior was determined by observing trends in an Ann Arbor coffee shop (Espresso Royale) in midafternoon (see Appendix A). Second, there were numerous intrinsic assumptions made in the derivation of the model. A list of the most prominent is provided below:

1. Employees cannot switch jobs mid-shift
2. Patrons cannot leave the queue after they enter
3. There is no variation in customer tolerances of queues and seating
4. There is no variation in employee productivity
5. There are no opportunities for footprint expansion
6. The coffee being sold is attractive to the consumer
7. Only coffee is sold at the shop

2 Design Problem

The following sections describe the overarching profit optimization problem as well as the quantitative specifications of the coffee shop model and background information on how the model was derived.

2.1 Problem Statement

The assumed objective of a coffee shop is to maximize profit. This is achieved by minimizing the operational costs, while maximizing the revenue from coffee sold to its customers. These two facets of the goal are generally competing as increased service to customers, which can increase revenues, often increases operational costs. Service to the customer, in our model, accounts for both the seating as well as coffee. The model assumes that there is an optimal configuration of employee distribution and furniture space allotment for coffee shops. The paper "Joint demand and capacity management in a restaurant system" written by Hwang, Gao and Jang was referenced when creating the model.

2.2 Mathematical Model

This section describes the model quantitatively and how values were assigned to specific aspects of the business. The model assumes that a fixed pattern of events occur during the purchase of a coffee, but different combinations of variables influence how far potential customers proceed through the form (see Fig. 2). Initially, the probability of a customer to enter the coffee queue is based on the length of the line, which is a function of the number of baristas, cashiers and coffee making machines, and the probability that the customer sees an open seat. The probability of customers returning to the line after their initial purchase is dependent on how comfortable they were while consuming their first beverage; this is represented by the ratio of large chairs to tables.

2.2.1 Notation

The following tables present the variables (Table 1, pg. 4) and parameters used in the model (Table 2, pg. 4). Tables and large chairs will be referred to in the text together as furniture items. Employees will refer to the cashiers, baristas and supervisors. Equipment will solely refer to the coffee machines.

Table 1: Summary of variables used, with units

Parameter	Symbol	Units
Tables	*T*	Number of tables
Large chairs	*L*	Number of chairs
Coffee machines	*M*	Number of machines
Cashiers	*C*	Number of cashiers
Baristas	*B*	Number of baristas
Supervisors	*S*	Number of supervisors

Table 2: Summary of parameters used, with units

Variable	Symbol	Units
Net profit	*P*	Dollars
Queue length	*Q*	People
Wait Time	*W*	Minutes
Drink profit	*p*	Dollars
People passing	*O*	People/minute

2.2.2 Objective Function

As previously stated, the objective function can be expressed simply as the gross revenue minus the operating costs. However, to clearly and accurately represent the coffee shop, several other aspects need to be defined separately. The proceeding sections derive each compartment of the model individually, and then combine them into a cumulative objective function.

2.2.2.1 Derivation of Gross Profit Function

Based on observations of Espresso Royale, the model assumes that three people pass the shop per minute with the intention of purchasing coffee, however, if the line is exceedingly long and/or the patron does not see open seats, the customer may decide to get coffee elsewhere (in our model, tables have more seats and therefore are more attractive than large single chairs to the passerby). Further, our model also assumes that a comfortable patron (for example, someone sitting in a large chair) is likely to stay and get a second drink. Thus, there will be people re-entering the queue from within the shop.

To represent the total queue wait time, a model was created based on M/M/1 queuing theory [2] (the use of which was inspired by the M/M/s/k theory that was used in the Hwang, Joyhe, Gao and Jang [1]). To fully understand this representation, a basic understanding of the underlying assumptions of M/M/1 queuing is required. The "M"s represent that both the arrival rate to the queue, λ, and the service (departure) rate, μ, are represented by Poisson distributions. The "1" represents a single point of service (in the context of a coffee shop, a single cashier).

Under M/M/1 theory, the total time for a subject to move through a queue, *W*, is defined in Eq. 1. The departure rate is a function of the number of baristas and is defined in Eq. 2, assuming a single barista can make two drinks a minute. Lastly, to account for multiple cashiers, the wait time is divided by the number of cashiers working. The probability of a person to enter the line was approximated as an exponential function, with the probability of a single patron entering decreasing as the time spent in the queue increases (see Eq. 3). In our model, we assumed three potential patrons will pass per minute (λ=3). λ^* is defined as the number of the patrons whose probability of entering first falls below the minimum approach probability threshold of 20%. This represents the baseline probability if line length is far from optimal.

The probability of each patron entering the line is then summed together to get the number of patrons entering the queue within a minute (as demonstrated in Eq. 3). For example if there was a 50% chance of four sequential patrons entering the queue, the model would treat the situation as two patrons entering the queue.

$$W = \frac{\lambda}{\mu * (\mu - \lambda) * C} \qquad \text{Eq. 1}$$

$$\mu = 2 * B \qquad \text{Eq. 2}$$

$$Q = \sum_{i=1}^{\lambda} \left\{ e^{-\frac{-i}{\mu*(\mu-i)*C}}, if\ i < \lambda^* \middle| 0.2,\ if\ i \geq \lambda^* \right\} \qquad \text{Eq. 3}$$

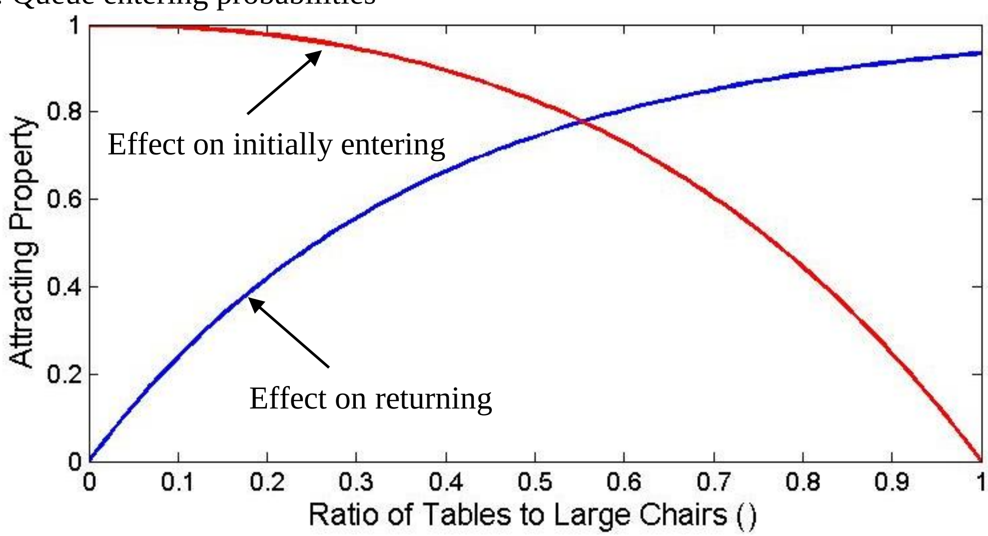
Additionally, if the patrons perceive an availability of seating, they will be more likely to enter the line. In our model, this probability, F, is represented by the ratio of tables to total furniture items, see Eq. 4.

$$F = 1 - e^{-e\left(\frac{T}{T+L}\right)} \qquad \text{Eq. 4}$$

Ultimately, comfortable patrons are more inclined to stay and purchase another drink. This is ratio of patrons is estimated to be equal to the ratio of large comfortable chairs to tables. The probability of a person entering the queue externally and internally as a function of the ratio of chairs to total seating is provided below in Figure 1. This figure demonstrates that there is an optimal location where there will be a ratio that corresponds to a maximum amount of patrons entering the shop.

$$R = \frac{L}{L+T} e^{\frac{T}{L+T}} \qquad \text{Eq. 5}$$

Figure 1: Queue entering probabilities



The average price of a cup of coffee was estimated by examining Starbuck's prices [3]. The average cost of a medium coffee in the United States is $1.65. After subtracting the cost of coffee grounds and cups, it was estimated that coffee shop profit is about $0.40 per cup. Thus the total gross revenue per minute, combining all of these features, is given by Eq. 6, below.

$$\frac{Gross\ Profit}{1\ Minute} = Q * \left(1 - e^{-e\left(\frac{T}{T+L}\right)}\right) * \left(1 + \frac{L}{L+T} e^{\frac{T}{L+T}}\right) * 0.40 \qquad \text{Eq. 6}$$

2.2.2.2 Derivation of Operating Cost Function

The modeled operating expenses include only the cost to operate the machines and pay the employees (Eq. 7). Employee pay is based on the current minimum wage and on the assumption that supervisors are at the highest pay grade, baristas are at the second highest and that cashiers are the lowest paid. Additionally, to account for the substantial amount of energy required to run the machines, a $0.05/minute/machine is added to the operational costs. Unlike employee productivity, these values are scaled linearly because there is a linear correlation between the number of employees and machines to the total operational costs.

$$\frac{Operating\ Cost}{1\ Minute} = 0.125 * C + 0.20 * B + 0.25 * B + 0.05 * M \qquad \text{Eq.7}$$

2.2.2.3 Cumulative Objective Function

In summary, the cumulative profit function is represented by Eq. 8.

$$\frac{Profit}{1\ minute} = Q * \left(1 - e^{-e\left(\frac{T}{T+L}\right)}\right) * \left(1 + \frac{L}{L+T} e^{\frac{T}{L+T}}\right) * 0.40 - (0.125 * C + 0.20 * B + 0.25 * B + 0.05 * M)$$

2.2.3 Constraints

There two main categories of constraints, the physical constraints of the coffee shop footprint and the logistical constraints. Physical constraints account for any space limitations in the shop. Logistical constraints are used to control the number of employees in each role and to represent the necessary supervisory positions. Additionally, all six variables are constrained by the necessity of each being an integer. For example, there cannot be half a barista or a fourth of a coffee-making machine. A complete listing of the constraints is provided in Table 3, pg. 7.

Based on the proceeding constraints (six parameters and no equality constraints), the optimization problem is determined to have six degrees of freedom.

2.2.3.1 Physical Constraints

The physical constraints are largely a result of space restrictions. The shop foot print is divided into four functional areas: coffee machines, tables, chairs and the queue. The queue is a parameter quantity, but the quantity of the other three parameters can vary. For simplicity, it is assumed that each component is approximated by a 25 ft^2 area of the floor. The coffee shop observed for this paper was roughly measured to be 50 ft by 25 ft. A 35 ft by 5 ft section of the floor was reserved for the queue and cashiers. This yields a 1075 ft^2 area to be occupied by other items, including furniture and coffee making machines. Since each piece of furniture is assumed to take up 25 ft^2, a total of 43 units can be assigned. Thus, the first constraint is given by Eq. 9. The shop needs to at least have one of each variable to allow the shop to operate, hence, Eq. 10-12 are also required as constraints.

$$M + L + T \leq 43 \qquad \text{Eq. 9}$$

$$M, L, T > 0 \qquad \text{Eq. 10, 11, 12}$$

2.2.3.2 Logistical Constraints

In order to keep the coffee shop organized, there needs to be a management hierarchy. The number of supervisors required is proportional to the number of other workers. In our model, we assumed that baristas operate more independently than cashiers. To avoid a potential bottle neck at the coffee machines, the number of machines is required to be greater than or equal to the number of baristas. Lastly, a constraint limiting concurrent employees was set to eight, after interviews with Espresso Royale employees revealed that there were never instances of more than eight employees working concurrently.

$$\frac{C}{2} + \frac{B}{3} \leq S \qquad \text{Eq. 13}$$

$$C, B, S \geq 1 \qquad \text{Eq. 14, 15, 16}$$

$$B \leq M \qquad \text{Eq. 17}$$

$$B + C + S \leq 10 \qquad \text{E1. 18}$$

Table 3: Collected Constraints

Label	Type	Equation
G1	Inequality	$M + L + T \leq 43$
G2	Inequality	$M \geq 1$
G3	Inequality	$L \geq 1$
G4	Inequality	$T \geq 1$
G5	Inequality	$\frac{C}{2} + \frac{B}{3} \leq S$
G6	Inequality	$C \geq 1$
G7	Inequality	$B \geq 1$
G8	Inequality	$S \geq 1$
G9	Inequality	$B \leq M$
G10	Inequality	$B + C + S \leq 10$
G11		Int(M, T, L, C, B, S)

2.2.4 Design Variables and Parameters

There are six design parameters: the number of supervisors (S), the number of baristas (B), the number of cashiers (C), the number of chairs (L), the number of tables (T) and the number of coffee machine machines (M)

The sum of supervisors, cashiers and baristas is the total number of personnel that are present at any point in time performing that respective job. The aforementioned model assumes that none of the workers are able to switch jobs during a shift (for example, a cashier cannot switch to being a barista if the need arises)

The numbers of chairs and tables are the quantity of furniture that are available for patrons to use. Each table is assumed to have a four person capacity and each large chair can seat one person.

Lastly, the number of coffee machines represents the number of machines that is available for the baristas to make drinks. These machines consume floor space and electrical power, but contribute to the efficiency of the baristas.

2.2.5 Summary of Model

To maximize profits, a coffee shop must provide the highest level of customer service at the lowest operating cost. Using six parameters (number of supervisors, baristas, cashiers, tables, large chairs and coffee making machines), the model will predict the profit for a given arrangement. The objective function is repeated below, and the constraints have been collected in Table 2. The disincentive of a long line was quantified by using an M/M/1 queue model. These decisions were guided by referencing the Hwang, Joyhe, Gao and Jang publication [1]. Figure 2, below, demonstrates the potential paths of a patron through the sysem. Section *2.2.2 Objective Function* summarizes how the objective function was derived from these individual probabilities, as well as the rational for the particular modeling form. The model has six degrees of freedom.

Figure 2: A compartmentalized demonstration of the probabilities of a customer to move to another state within the coffee shop system. The red line indicates the route which maximizes the profit a shop obtains.

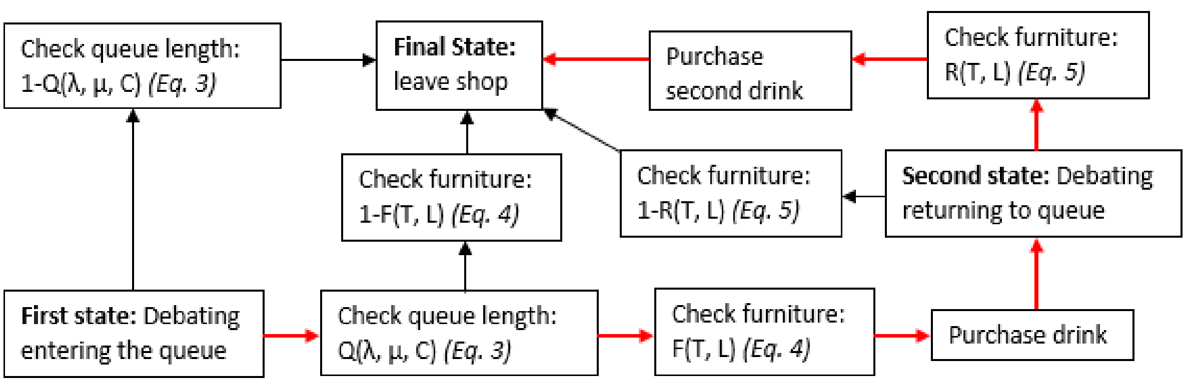


Table 3: Collected Constraints

Label	Type	Equation
G1	Inequality	$M + L + T \leq 43$
G2	Inequality	$M \geq 1$
G3	Inequality	$L \geq 1$
G4	Inequality	$T \geq 1$
G5	Inequality	$\frac{C}{2} + \frac{B}{3} \leq S$
G6	Inequality	$C \geq 1$

G7	Inequality	$B \geq 1$
G8	Inequality	$S \geq 1$
G9	Inequality	$B \leq M$
G10	Inequality	$B + C + S \leq 10$
G11		Int(M, T, L, C, B, S)

The parameters used in the following objective function and table of constraints were obtained by observing an Espresso Royale shop in Ann Arbor, Michigan on two separate occasions. For more information on data collection, refer to Appendix A.

2.3 Model Analysis

The proceeding sections summarize the monotonicity analysis and tables, the active constraints, and the simplifications made to the objective function.

2.3.1 Monotonicity Analysis

The behavior of the objective function was evaluated at variable quantities between one and twenty-five to determine the model's behavior in relationship with respect to each variable. This information was subsequently compared to the bounding nature of the constraints to determine which constraints were active, assuming the objective function is to be maximized. Table 4, pg. 8, demonstrates the results of this analysis.

Table 4: Monotonicity Analysis Results

Function	L	T	M	C	B	S
Objective			-	-		-
G1	+	+	+			
G2			-			
G3	-					
G4		-				
G5				+	+	-
G6				-		
G7					-	
G8						-
G9			-			
G10				+	+	+
G11						

Since the objective function should be optimized, the active constraints, using monotonicity analysis are G9, G6, and G8, containing *M*, *C* and *S*, respectively. The remaining parameters *L*, *T* and *B*, will likely have interior optimums.

2.3.2 Simplifications

The initial model had an exponentially saturating barista efficiency while making drinks. This behavior was chosen in order to eliminate a situation in which an unrealistic number of baristas working, since having too many baristas would congest the kitchen. As modeling progressed, the optimum number of baristas never increased greater than five. Thus, the model never got to a regime where the saturating effect affected the model, and, subsequently, the saturating effect was removed to simplify the model during parametric studies and sensitivity analysis.

Previously the effect of the long queue line was evaluated by calculating a cumulative probability of a group of patrons to enter a queue as a function of the number of patrons passing, and the number of employees working. This, however, was overly sensitive to the number of baristas and failed to account for the changing probability of the patrons to enter the queue over the minute. Thus, the new model was developed that calculated the probability of each patron individually, and used the sum of the probabilities to calculate the number of patrons entering the shop.

3 Model Optimization

After the model was constructed and iterated to its final form, MatLab's Optimization ToolBox was used to identify the optimum variable values. Microsoft Excel was initially selected because it allows variables to take integer values, however due to coding difficulties, the model was later translated to MatLab. Within the MatLab Optimization Toolbox, the SQP algorithm within fmincon was used.

3.1 Optimization Results

The using the current iteration of the model in the MatLab, the optimum configuration is 11.01 large chairs, 16.99 tables, 2.37 coffee machines, 1.00 cashier, 2.37 baristas and 1.28 supervisors. This would yield a profit of $0.3512/minute. After rounding the results to the nearest whole number that satisfies that constraints the resulting values are: 17 large chairs, 11 large tables, 3 coffee machines, 1 cashier, 3 baristas, and 2 supervisors. This yields $0.1456/minute. Extrapolating over a year, with the shop open 12 hours a day, the annual profit would be $38,263.

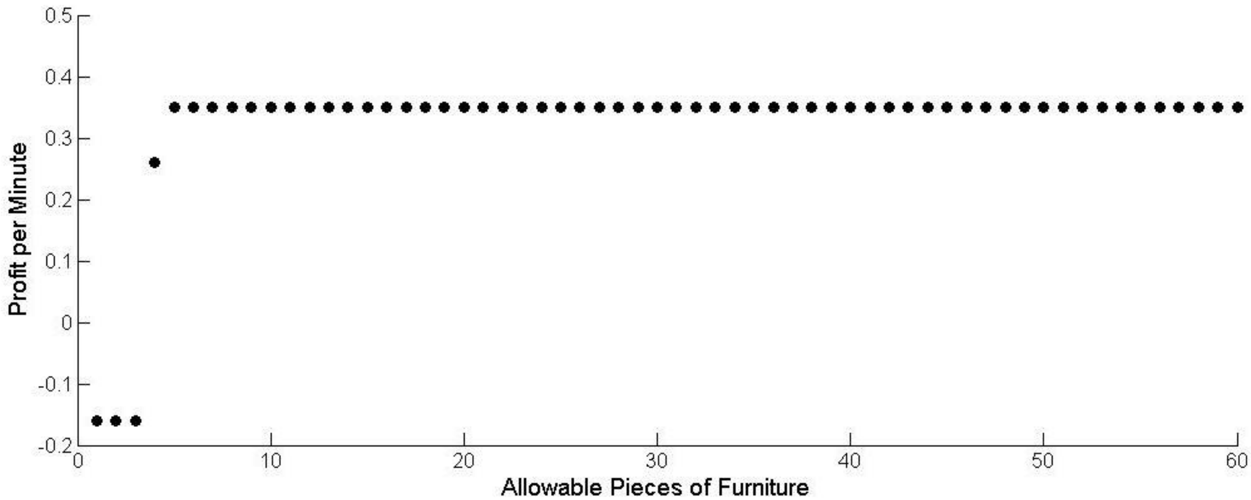
As predicted during the monotonicity analysis, *L*, *T* and *B* were all internally bounded, while *M* was constrained by G9, *S* was constrained by G5, *C* was constrained by G6. The MatLab output was also evaluated to ensure that the optimal point successfully met the criteria to be considered a KKT point. All in equality constraints have lagrange multipliers of zero except for G5, G6 and G9, which had multipliers of 0.05, 0.25 and 0.25, respectively.

Since the sequential quadratic program algorithm was used the solution produced is a local solution. This condition was addressed by using a wide variety of feasible starting positions. All variables were swept from values of 20 to 5, but yielded the same maximum profit, furniture ratios, and employee quantities for all initial starting points.

3.2 Sensitivity Analysis: Available Furniture

A sensitivity analysis was conducted on constraint G1 to determine if allowing more furniture items would influence coffee shop profit. The maximum quantity of furniture allowable was increased one piece at a time, from 43 to 57 pieces. At each new value of the constraint, the model was optimized again and the maximum profit was recorded; these values are demonstrated below in Figure 4, below.

Figure 4: The profit resulting from increasing allowable furniture



This results demonstrate that simply having more floor space (modeled by furniture number) will not increase profits. After five pieces of furniture allowed, the ratio of furniture items to each other was constant. This indicates that after a threshold, the type of furniture used in a shop has a greater effect on a patron's likelihood to enter the shop than simply the quantity of those items.

3.3 Sensitivity Analysis: Supervisor's Ability.

Clearly, the number of supervisors is constraint bound; the supervisors do not contribute directly to profit, but are required to maintain order. Thus, the number of supervisors is highly sensitive to the constraint; a more adept supervisor will be able to monitor more employees and reduce the operational costs of the shop. Figure 5, below, demonstrates the profit per year if supervisors are able to monitor a varying number of employees. The number of supervisors saturate as the variable transitions to be bounded by G8, rather than G5

Figure 5: The profit per minute at different management efficiencies

3.4 Parametric Study: Patrons Passing Shop

Originally, three people were estimated to pass a coffee shop every minute with the intent of getting coffee. To observe the effect of this parameter on the optimum configuration, the parameter was swept from one patron to 14 patrons a minute. To accommodate this sweep, an iterative script was created on MatLab. At each iteration, the problem was reoptimized at the new parameter value.

The results of this demonstrate that the number of patrons do not affect the optimal ratio of tables to chairs. The predicted profit increases because there is a consistent profit incentive to add more baristas to accommodate increased patrons. Therefore, aside from requiring additional baristas (requiring more supervisors and coffee making machines) to accommodate the increased customers, the sweep did not indicate any significant deviations in allocation of resources between the six variables.

Figure 6: Effect on profit of changing the number of patrons passing

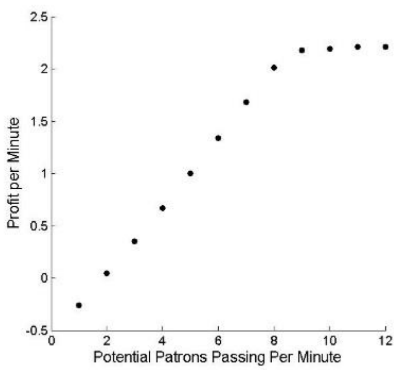


Figure 7: Effect on furniture of changing the number of patrons passing

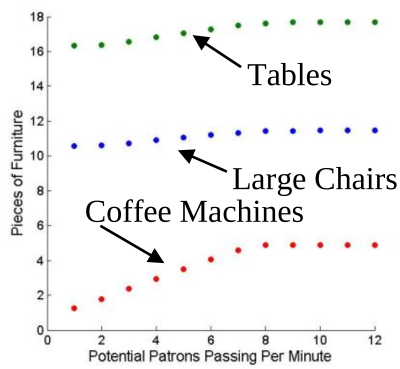
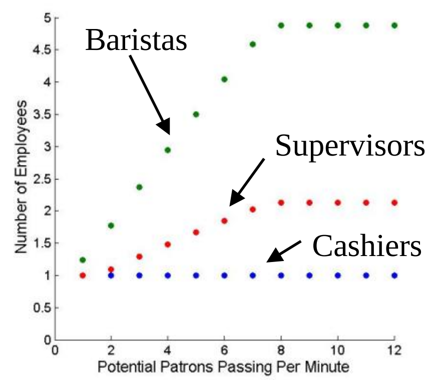


Figure 8: Effect on employees of changing the number of patrons passing



4 Discussion

The results of the coffee shop have implications that lead to design rules that can be applied to similar systems. Most prominently, an efficient supervisor can greatly reduce operational costs and improve the system's efficiency. Additionally, the results demonstrate shortcomings of the current model, particularly that the layout of the coffee shop is not factored into the model.

4.1 Design Rules Identified

Efficient supervisors can exponentially lower operating costs in systems where management make up a significant proportion of employees. These results are demonstrated in the sensitivity analysis in section *3.3 Sensitivity Analysis: Supervisor's Ability*. In our model, the supervisor was not able to physically assist in any portion of the coffee making process; if this practical, and necessary, capacity of the supervisor was taken into account, the supervisor would have an even larger effect on the overall profitability of a shop.

Further, it appears that there is an optimal ratio of tables to chairs (approximately three tables per two large chairs) that is retained through the parameter sweet. For a shop to be successful, it may be wise to follow this trend.

4.2 Model Critique

Through the process of optimizing the model, there were several shortcomings in the model that limited its ability to provide a practical solution. Most notably is its inability to consider the placement of furniture. For example, strategically placing high capacity tables near the door could entice patrons to enter, while large comfortable chairs in the interior could encourage them to get another drink. Further, the model was unable to capture the same probabilistic deterrent of a long line that is present in classical M/M/s/k queue formulation. Thus, during the parametric sweep of patrons passing the shop, additional constraints needed to be put in place to prohibit the line from getting excessively long.

Similarly, an occupation saturation of furniture was not included in the model. This was due to the assumption that the level of patrons entering the shop would never be large enough such that the shop would not be able to accommodate them. If tables were assumed to seat four persons, while chairs could seat one, there is (optimally) 79 available seats. If each person that enters the shop stays (there are no patrons that purchase a drink and leave), each patron would need to stay for over thirty minutes for saturation to occur. However, if half of the patron purchase a drink and go elsewhere, each patron would need to stay for approximately an hour for saturation to occur. If this threshold is passed in the locale of interest, the model may need to be altered to be applicable in other contexts.

Further, the influence of cashiers on the model was clearly undervalued. As the parameter related to patrons passing the shop increased, the optimal number of cashiers did not change. Under a practical system, one would expect that the number of cashiers at a busy coffee shop be larger than at a smaller shop. If this model is to be applied in a dense urban area, the effect of cashiers should be re-evaluated and magnified.

5 Conclusions

Although coffee shops come in many varieties, there are unifying characteristics that can be identified between them. Using knowledge of customer behavior in the locale, an empirical model can be created that predicts how various variables affect the overall profitability of the coffee shop. The model was created by observing customer trends in a semi-urban coffee shop located near a college campus. The results indicated that the largest profit can be achieved by having 11 large chairs, 17 large tables, 3 coffee machines, 1 cashier, 3 baristas, and 2 supervisors. This combination will yield approximately $0.1456/minute.

The aforementioned result is valid only for similarly sized coffee shops in this locale, however parameters of the problem may be tuned to reflect the specific characteristics of another area. In that context this model may be appropriate for other coffee shops as well.

6 Acknowledgements

As previously stated, Hwang, Joyhe, Gao and Jang are acknowledged for their suggestion of the disincentive of a long queue line as well as the logarithmic employee productivity.

6 REFERENCES

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Appendix A: Raw Data and Collection Techniques

Information was gathered in three ways: passively observing qualitative trends in usage behavior, conducting short questionnaires with employees, and reviewing online literature about coffee shop usage.

During the periods of passive observation, the author sat near the front of the shop and alternated between counting potential patrons passing the shop, watching the employees, and recorded any significant trends in customer behavior. There seemed to be a spike in customers every thirty minutes; this is presumably because of the coffee shop's proximity to the University of Michigan and its hourly class schedules. While generally, there were closer to between one and two customers entering the store every minute, three customers per minute was chosen for this study to normalize the periodic surges of customers. The raw data is presented below in Table A1.

Table A1: Raw data of potential patrons passing the shop

Time Period	Number of Patrons
4:00-4:15	19
4:30-4:45	17
5:00-5:15	20
5:30-5:45	12
3:15-3:30	17
3:45-4:00	21
4:15-4:30	16

Coffee shop employees were asked two questions: (1) "How many drinks can a barista complete in three minutes?" and (2) "Generally, how many employees are scheduled to work concurrently?". The questions were both posed to cashiers when purchasing drinks during observation periods, as well as to acquaintances of the author who work at coffee shops. The results of this questionnaire influenced the estimated efficiency of baristas as well as gave a reference by which to judge the validity of the predicted optimal number of employees. In addition to responses acquired, several other local coffee shops were visited to quickly count the employees on hand at that particular time. This data is included in Table A2, along with the verbal responses.

Table A2: Raw data of questionnaire responses and observances

Source	Question 1	Question 2
Cashier 1	5	4
Cashier 2	4	4
Barista 1	5	4
Acquaintance 1	6	3
Acquaintance 2	6	5
Obsv. (Starbucks)		4
Obsv. (Comet Coffee)		2
Obsv. (Mujo's)		5