*Proceedings of the 2005 Winter Simulation Conference*
*M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.*

# REDUCING SERVICE TIME AT A BUSY FAST FOOD RESTAURANT ON CAMPUS

Sara A. Curin
Jeremy S. Vosko
Eric W. Chan
Omer Tsimhoni

Department of Industrial and Operations Engineering
1205 Beal Avenue
The University of Michigan
Ann Arbor, MI 48109, U.S.A.

## ABSTRACT

As part of an undergraduate engineering class project, a Tim Hortons restaurant on the University of Michigan campus was simulated to improve its efficiency. Using the standard simulation study steps, several service scenarios were modeled and evaluated based on customer system time. A detailed analysis of the simulation revealed that, in the current setup, the utilization of the cash registers is high (88%); consequently, several scenarios that decrease the load on the cash registers were explored. To reduce customer wait times and, therefore, serve more customers per hour, it is recommended that Tim Hortons operate with five servers. A five-person setup with three cashiers, a soup server, and a sandwich server could reduce customer system time by over two minutes per customer. As an alternative, transferring all food preparation to the secondary service location and adding a dual-purpose server could reduce customer system time by over one half.

## 1 INTRODUCTION

Simulation has been a widely accepted tool for analyzing performance in the service industry (e.g., Smith 1994). Restaurants in particular have been the topic of several studies in the last decade, including quick service or "fast food" restaurants. Both general and specific applications to the fast food industry exist in the literature. One general model of a fast food restaurant lobby and drive-thru was developed by Farahmand and Martinez (1996). Other tools such as the Quick Service Restaurant Simulation (QSRS) module (Jaynes and Hoffman 1994) and the Restaurant Modeling Studio (RMS) (Brann and Kulick 2002) also allow for broad applications in the fast food industry. Similar tools can be created for modeling specific restaurants to answer specific questions. One specific application involves applying Monte Carlo techniques to analyzing two types of buffet restaurants (Field, McKnew, and Kiessler 1997). Other fast food restaurants, such as Pizza Hut, have been modeled to increase throughput and efficiency (Kharwat 1991). As part of an undergraduate engineering class project, we modeled various service setups at a Tim Hortons fast food restaurant on the University of Michigan campus. The goal of the study was to improve efficiency by determining the setup that would reduce customer wait times the most when compared with the current service scenario, and thus allow Tim Hortons to serve more customers.

### 1.1 System Description

Tim Hortons is a fast food chain serving primarily breakfast and lunch. It is most well known for its coffee and donuts. It also offers a selection of soups and sandwiches that are popular at lunchtime. During peak customer arrival time (lunchtime, approximately 11:00AM-1:00PM), four to five employees provide service to customers. One or two of the servers act as cashiers who take orders as well as fill small orders that involve only donuts, muffins, or beverages. The remaining servers prepare soups, sandwiches, and bagels in a separate area (the "secondary service location"). Customers arrive and form a single queue in front of the cash registers. Customers ordering donuts, muffins, and/or beverages (hereafter referred to as "type 1" customers) remain at the cash register while the cashier takes and fills their orders. Customers ordering soups, sandwiches, or bagels ("type 2" customers) pay at the cash register and then enter a separate waiting area (the "secondary queue"), where their order is completed by one of the second types of servers. Upon receiving their orders, customers exit the system.

### 1.2 Questions for Study

With the current setup, bottlenecks can occur at two places: the arrival queue and the secondary service queue. At peak times, customer waiting time can be quite lengthy in one or both queues. Often, the arrival queue becomes so long that customers leave the system and enter the queue of the restaurant next door. Reducing customer wait time, then, would clearly lead to increased business for the restaurant. Therefore, we were interested in finding ways to reduce this wait time, as well as the time spent in the secondary service location. One way to accomplish this is the reallocation of servers in the system. Another way is to change the layout of the service facility (to decrease the time spent on non-value added activity such as walking). We have chosen to focus on the first option, optimal server allocation, as it is easier to implement than the second option and is expected to be more effective. Specifically, we addressed the following questions:

1. *Server allocation under current setup.* If five servers are available in the current service setup (as described above), what is the optimal allocation of human resources necessary to achieve minimum customer wait time? That is, how many should be designated as cashiers, and how many should be designated as secondary servers?
2. *Adding a "runner" position.* What effect does adding a third type of server (hereafter referred to as a "runner") who prepares the donut, muffin, and coffee orders, allowing cashiers to focus only on taking orders, have on customer wait time?
3. *Changing the service setup.* What effect does shifting the preparation of *all* orders to the secondary service location have on customer wait time?
4. *Adding an arrival queue.* Given additional space and resources, what effect does adding a separate arrival queue and set of cash registers to the secondary service location have on customer wait time?
5. *Increased arrival analysis.* Is either the current system or one of the simulated systems able to accommodate more frequent arrivals?
6. *Recommending an improved system*. Of the different system configurations considered, which has the greatest potential for reducing customer wait time when five servers are on duty and when only four are on duty?

To answer these questions, several simulation scenarios (described in detail below) were designed. The main performance metric with which these scenarios have been evaluated is average system time per customer. That is, the total time a customer spends in the system, from entry at the arrival queue, to exit. The goal of the study was to simulate different scenarios and determine how efficient they are in servicing customers. Implementing a scenario with a lower expected system time per customer should lead to more customers being served per hour, and hence more business for Tim Hortons.

### 1.3 Assumptions

In order to model the system under study, some simplifying assumptions have been made:

1. The cashiers are treated as identical, with the same tasks and abilities and the same service rates.
2. Likewise, the servers in the secondary service location are capable of performing the same tasks at the same rates.
3. Data collection has been limited to Thursday and Friday, 11:00AM-1:00PM, and is used to represent all weekdays during this time.
4. The focus of this study is on peak hours at this particular Tim Hortons and the scenarios considered may not be optimal for less busy times or at other locations with different arrival patterns.

## 2 METHODS

The data that were collected in order to properly simulate Tim Hortons during peak hours include customer interarrival times, service times in each of the service areas, and server downtimes. All data involving time were recorded in seconds.

Data collection was accomplished on two separate days using two to three data collectors. On the first day of data collection, the following data were collected: customer arrival times, the time service began at the first service location (cash register), the time food preparation began and ended at the first service location, and the time service ended at the first location for each customer. This gave us the data needed to calculate the customer interarrival times and service times at the first location, and to determine the appropriate distributions of these quantities.

The time food preparation begins and ends at the first location was necessary to establish the distribution of service time for a hypothetical third type of server (simulation question #2). We also noted whether or not each customer entered the secondary queue. This information was used to determine the probability that a customer requires service at the secondary service location and to distinguish between service times for customer types 1 and 2.

Cashier and secondary server downtimes were also observed and timed to estimate the amount of time the servers would be unavailable. This information was transferred to the model as described in the next section.

The second day of data collection was for determining the service times at the secondary service location and for recording the orders of each customer. Data collection of service times required observing workers preparing food items (sandwiches, soups, and bagels) and recording when a server began making an individual food item and when he or she finished. The differences between the two recorded times are the elapsed service times for an individual item. These were used to determine the distribution of service times at that location. The food orders were recorded by observing customers and recording the items that each received. This information was used to establish a distribution of customer orders.

Data collection was facilitated by the use of a custom-made spreadsheet application created in Visual Basic for Applications (VBA) in Microsoft Excel (Version 2002, Microsoft Corporation). The application consisted of several worksheets containing buttons that, when clicked, would display the current time in a given cell. This greatly increased the efficiency of the data collection. Accurately recording arrival and service times in seconds would have been difficult to accomplish without use of this program.

Sample sizes for the data collection varied from 4 to 258, depending on the parameter, and appear in Table 1. Sample sizes varied so much because of the data availability. The numbers reflect the relative occurrence of each of the items. For instance, the sample sizes for food preparation times of type 1 and type 2 customers shows the relative numbers of each type of customer moving through the system. From this data, 42% of the customers were of type 1, and 58% were of type 2. This data was important in the model as it was used to generate the appropriate relative numbers of type 1 and type 2 customers.

Table 1: Sample Sizes

| Data Collection Parameter | Sample Size |
|---|---|
| Downtimes | 4 |
| Food Orders | 82 |
| Bagel Preparation Time | 19 |
| Soup Preparation Time | 44 |
| Sandwich Preparation Time | 53 |
| Cash Time | 115 |
| Customer Inter-Arrival Time | 258 |
| Food Preparation Time (Type 1 customers) | 58 |
| Food Preparation Time (Type 2 customers) | 81 |

### 2.1 Input Modeling

Each set of data points representing a distribution of service or inter-arrival times were analyzed using Stat::Fit (Version 2, Geer Mountain Software Corporation) in order to fit a general distribution (Table 2). An interesting point about the data was that the food preparation times at the cash register were different for the two types of customers. Because of this, the two time distributions were separated. All distributions were selected based on performance on goodness of fit tests carried out in Stat::Fit, visual examination of histograms, and an attempt to match distributions of similar elements (see "Why not just use the best fit" in Biller and Nelson 2002).

Table 2: Fitted Distributions

| Item | Distribution |
|---|---|
| Bagel Preparation Time | Gamma(0, 3.4, 6.65) |
| Soup Preparation Time | Lognormal(0, 41.43, 16.56) |
| Sandwich Preparation Time | Lognormal(0, 50.28, 20.60) |
| Cash Time | Lognormal(0, 34.89, 33.88) |
| Customer Inter-arrival Time | No Fit |
| Food Preparation Time (Type 1 customers) | Exponential(0, 19.3) |
| Food Preparation Time (Type 2 customers) | Weibull(0, 0.743, 11.4) |

Customer inter-arrival times did not fit well to any of the common distributions. Nonetheless, it could be argued that the distribution was most likely to be exponential because of the nature of the arrival process, and graphically it "looked" exponential. Therefore, initially, the distribution was modeled as an exponential distribution. However, we decided to use a continuous empirical distribution because it more appropriately reproduced observed data.

Food orders were also modeled using an empirical distribution. The orders were divided into eight different possibilities and each given a probability of occurrence. In the model, a random order is generated from the empirical distribution for each customer who enters the secondary queue, and is used to determine that person's service time.

Finally, because so few downtimes were observed, rather than fit the data to a distribution in Stat::Fit, we used reasonable uniform distribution approximations for cashier and secondary server downtimes.

### 2.2 Model Description

The base model of Tim Hortons, implemented in ProModel (Version 6, PROMODEL Corporation), is a representation of the present system. We modeled the arrival queue, the two cash registers, a waiting area for soup/sandwich/bagel customers, and the secondary serving area. The primary entities moving through the system are the customers, which arrive at an empirical distribution determined by observed data. In addition, the sandwiches, soups, and bagels are also modeled as entities so that when an order is placed, the order "arrives" at a "dummy" location and when it is completed, the order and the customer "join" together before exiting the system.

Furthermore, the customer entities each have an attribute indicating what their order is, as well as one that tracks the time they enter the system. The food orders are determined using an empirical distribution developed by actual data taken. A customer's food order determines which soup or sandwich resources they need, and for how long.

There is normally one worker at each cash register, each serving one person at a time, and this is represented by two identical cash registers in the model. However, at the secondary service location, there is one server dedicated to making soups, and one dedicated to sandwiches. When a customer orders a bagel, whoever is first available between these two workers prepares the bagel. As a result, the soup and sandwich workers are modeled as resources.

Variables are used to calculate statistics such as mean system times for type 1 and type 2 customers.

For each scenario, the model has a 0.5 hour initialization period with 150 replications of two hours each. The 0.5 hour warm-up time is necessary so that the system does not start out empty (the actual restaurant has already been open for several hours prior to the period of interest). Because the run time is so short (two hours), many replications are necessary. Initially, 50 replications were run but the resulting confidence intervals were too wide, and, consequently, 150 was chosen as the target number of replications. The distributions are each set with a particular stream to make comparisons with the base model valid.

We ran the scenarios detailed in Table 3 and Figure 1 to address the questions posed above. The models fall under four categories, in accordance with the simulation questions posed in the introduction.

Table 3: Model Scenarios

| Scenario | Changes to base model | Number and Type of Servers | | | | |
|---|---|---|---|---|---|---|
| | | Cash | Soup | SW* | Other | Total |
| Base Model | No change | 2 | 1 | 1 | | 4 |
| 1.1 | Add 1 cash register | 3 | 1 | 1 | | 5 |
| 1.2 | Add 1 dedicated sandwich server | 2 | 1 | 2 | | 5 |
| 1.3 | Add 1 dedicated soup server | 2 | 2 | 1 | | 5 |
| 1.4 | Add 1 dual-purpose server | 2 | 1 | 1 | Dual | 5 |
| 2 | Add a runner | 2 | 1 | 1 | Runner | 5 |
| 3.1 | Transfer all food prep to secondary location | 2 | 1 | 1 | | 4 |
| 3.2 | Transfer all food prep to secondary location | 1 | 1 | 1 | Dual | 4 |
| 3.3 | Transfer all food prep to secondary location | 2 | 1 | 1 | Dual | 5 |
| 4 | Two separate arrival queues | 4** | 1 | 1 | | 4 |

**Sandwich server*
***Two usual cashiers plus the secondary servers (see description below)*

The first set of models deals with the first simulation question. That is, under the current service setup, if five servers are on duty, what is the best way to utilize the fifth server?

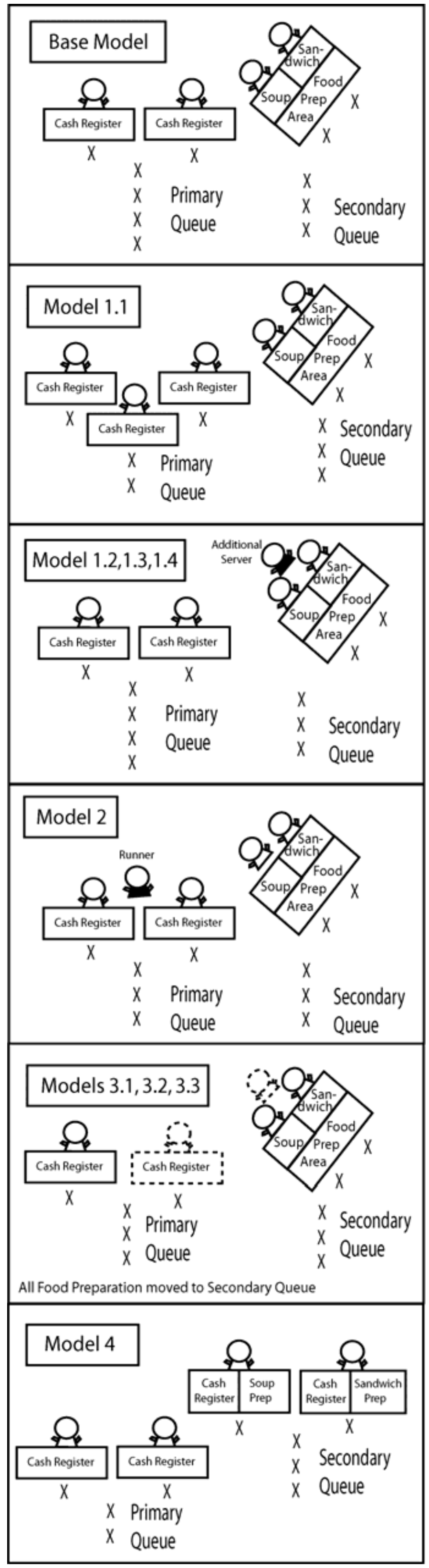


Figure 1: Model Scenarios Diagram

The second model addresses what would happen to customer wait times if a "runner," who prepares all small orders currently filled by the cashiers, were added.

The third set of models deals with changing the current service setup such that *all* food orders be filled at the secondary service location, allowing cashiers to *take* orders only, and not fill them. There are three variations of this model, two with four servers and one with five.

The fourth model simulates two separate arrival queues, based on whether a customer would like items from the secondary service location. The servers at this location would take *and* fill customer type 2 orders (orders requiring soups, sandwiches, or bagels), while the original cashiers would still take and fill orders for type 1 customers (coffee, donut, and muffin orders only). Note that this setup requires the addition of two cash registers.

## 3 RESULTS

The base model was verified and validated using several basic subjective methods: animation, operational graphics, internal validity, face validity, subjective predictive validity, and parameter variability (see Sargent 2003 for a discussion of these techniques). For predictive validity, a handful of Tim Hortons customers, including some of the authors, confirmed that the outputs of the model (e.g., wait times and queue lengths) were similar to those observed at the restaurant during peak hours. Statistical analysis was not performed due to project time constraints.

### 3.1 Model Outputs

Each scenario was run, starting with the "base model" (current Tim Hortons setup). Individual 95% confidence intervals on average customer system time were computed for each. Separate statistics were kept for those customers exiting after receiving service at the cash register (type 1 customers) and those entering the secondary service location (type 2 customers). This was done because the latter are expected to have longer service times and calculating an overall average would mask important information. Average customer system time and 95% confidence intervals for customer types 1 and 2 are shown in Table 4. Each model's results are described in detail and compared with the base model in the following sections.

### 3.2 Output Analysis

For the base case, the average time a type 1 customer spends in the system is 201 s (3:21 min). A type 2 customer spends an average of 295 s (4:55 min) in the system.

Table 4: Model Output

| Scenario | Average System Time (type 1) (s) | 95% C.I. (s) | Average System Time (type 2) (s) | 95% C.I. (s) |
|---|---|---|---|---|
| Base Model | 201 | (184, 218) | 295 | (277, 313) |
| 1.1 | 69 | (68, 71) | 170 | (164, 175) |
| 1.2 | 201 | (184, 218) | 254 | (237, 272) |
| 1.3 | 201 | (184, 218) | 271 | (253, 289) |
| 1.4 | 201 | (184, 218) | 246 | (229, 263) |
| 2 | 116 | (107, 125) | 218 | (208, 228) |
| 3.1 | 350 | (320, 380) | 394 | (365, 423) |
| 3.2 | 1080 | (1015, 1146) | 1121 | (1057, 1185) |
| 3.3 | 91 | (88, 94) | 134 | (131, 137) |
| 4 | 63 | (62, 64) | 1110 | (1046, 1174) |

Confidence intervals on mean system time have been computed for each scenario and compared with the base case. The individual confidence level is 95%. Because of the Bonferroni inequality,

$$\text{P(all statements } S_i \text{ are true)} \geq 1 - \sum_{j=1}^{C} \alpha_j = 1 - \alpha_E$$

where $S_i$ is the event that the $i^{th}$ confidence interval contains the mean system time, for all confidence intervals i=1,..C, and

$$\alpha_E = \sum_{j=1}^{C} \alpha_j$$

is the overall error probability, comparisons between two models have an overall confidence level of 90% (Banks et al. 2001). Common random numbers were used to increase the statistical power of the tests. Since all scenarios were faced with arrivals at the same times, and similarly for the other distributions, differences between scenarios are likely to be real.

The following subsections compare base model output with that obtained from the various scenarios. In analyzing model output, it was important to consider not only scenarios with statistically different waiting times, but those with practically significant differences. Two scenarios were considered practically different if their resulting customer system times differed by more than 30 s. Using this criteria, all scenarios that were found to be statistically different from the base model were also practically different, so any improvement in customer system time is expected to have a real impact on Tim Hortons' customer throughput. Models 1.1, 2, and 3.3 reduce the average system time by a practically significant amount for both types of customers when compared with the base model and are circled in Figure 2.

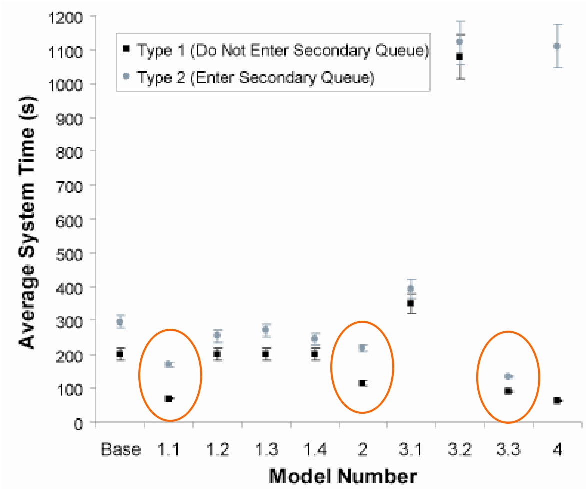


Figure 2: Illustration of Model Output with Emphasis on Models that Decrease Average Customer System Time by a Practically Significant Amount

### 3.2.1 Determining Optimal Server Allocation Under Current Service Setup

Adding a third cash register (scenario 1.1) to the system reduces total customer system time considerably. In the base model, the cash register utilization was 88%, while the soup and sandwich servers were utilized only 49% and 61% of the time, respectively, indicating that the cash register could be the source of bottlenecks in the system. Therefore, it made sense to consider adding an additional cash register. Indeed, for type 1 customers, total system time is reduced to roughly one third the original time. For type 2 customers, total system time is reduced to roughly 60% of the original time.

Adding a second sandwich preparer (scenario 1.2) to the secondary service location decreases system time by a significant amount (roughly 41 s) for type 2 customers. As expected, total system time for type 1 customers is unchanged. Adding a second soup preparer (scenario 1.3) to the system does not significantly reduce customer system time.

Adding a dual-purpose server (who can prepare soups, sandwiches, or bagels) to the secondary service location (scenario 1.4) reduces type 2 customer system time from 295 s to 246 s.

### 3.2.2 Adding a Runner

Adding a runner (who prepares food items for the cashiers) into the current system (scenario 2) significantly improves the system with respect to average system time per customer. The average system time of a type 1 customer is reduced by 85 seconds, and the average system time of a type 2 customer is reduced by 77 seconds.

### 3.2.3 Changing the Service Setup

Modifying the model so that every customer's food preparation is done at the secondary service location had mixed effects. Making this change but leaving the worker allocation the same as in the base model (scenario 3.1) results in an increase in customer wait times. In addition, a very large queue forms in front of the secondary service location because of the increased arrivals.

In an attempt to alleviate this, worker allocation might be shifted to have one less cashier, but one additional dual-purpose server, a worker capable of making both soups and sandwiches (scenario 3.2). This helps reduce the backup at the secondary service area, but unfortunately results in a much larger queue in front of the cash register, causing very high system times for both types of customers.

By shifting all the food preparation work to the secondary service area, adding a dual-purpose worker to that area, and keeping the cash register staffing the same (scenario 3.3), the average wait times of both types of customers are reduced by more than half.

### 3.2.4 Adding an Arrival Queue

Separating the two services completely, by adding a separate queue (scenario 4), drastically improves the total customer wait time for type 1 customers. As these customers no longer have to wait behind type 2 customers, their wait times decrease to one third the original time (63 s versus 201 s in the base model). However, average system time for type 2 customers increases to over eighteen minutes. Requiring that the soup and sandwich servers act as cashiers greatly increases the time type 2 customers spend waiting in queue, and hence in the system overall.

## 4 CONCLUSIONS AND DISCUSSION

After running the ten models described above (see Table 3 and Figure 1), we were able to answer the questions posed in the introduction. Under the current service setup, adding a third cash register appears to be the scenario that reduces customer system time the most. Adding a runner also has the potential to reduce time spent in the system. Changing the service setup so all food is prepared at the secondary service location can decrease system times by roughly one half that of the base model with the addition of a dual-purpose server. However, adding a second arrival queue does not appear to be an improvement to the system.

#### 4.1.1 Optimal Server Allocation under Current Service Setup

In proposed scenarios 1.1, 1.2, 1.3, and 1.4, the cashiers and secondary service workers would perform the same tasks as they do under the current Tim Hortons setup. Therefore, these scenarios would require little transitioning from an employee's standpoint. Of these, the scenario that decreased total average system time for both types of customers the most was adding a third cash register. Adding a third worker to the secondary service location has the potential to reduce system time for type 2 customers, but not by nearly as much as adding another register. Clearly, the cash register is the major bottleneck in the system. Any way to speed up that portion of service will move customers through the system faster, and as a result allow Tim Hortons to serve more customers per hour.

Under the base scenario (2 cash registers), using a weighted average system time of 256 s for both types of customers, Tim Hortons can serve roughly 14 customers per hour. Under the proposed scenario (3 cash registers), Tim Hortons can serve twice as many customers per hour (using 128 s as a weighted average system time). Although detailed cost analysis was not carried out in this study, it is clear that the addition of a cash register would be profitable.

#### 4.1.2 Effect of Adding a Runner

Adding a runner (scenario 2), which is also very easy to implement, significantly lowers the system times of both types of customers that come to Tim Hortons. This is because it reduces the customer processing time at the cash register. It seems to take quite a bit of time for a cashier to prepare customer orders as well as take their cash. With a runner, food preparation can begin well before the customer has finished paying for his or her order. Each customer now waits a significantly shorter portion of time to get his or her food at the cash register, and therefore waits that much less time in the system as a whole.

#### 4.1.3 Effect of Shifting all Food Preparation to the Secondary Service Location

Unlike the first two groups of scenarios, scenarios 3.1, 3.2, and 3.3 require a change in the way customers are served. In these models, all food is prepared at the secondary service location, while the cashiers are responsible for taking orders and payment. By shifting all the food preparation to the secondary service location, the load lightens on the cashiers but increases on the secondary servers. To best deal with this, it is necessary to add a third worker to the secondary service location (scenario 3.3). With this setup of shifted food preparation and an extra food preparer, Tim Hortons can cut average customer system time in half.

#### 4.1.4 Effect of Adding a Second Arrival Queue and Two Additional Cash Registers

Adding a second arrival queue (scenario 4) seems to reduce type 1 customer waiting time the most; however, this setup greatly increases waiting time for type 2 customers. Therefore, this scenario is not recommended for the Tim Hortons studied, unless the mix of type 1 and type 2 customers changed dramatically. Additionally, one could explore the effect of adding a dual-purpose server or a runner to the secondary service location to see if type 2 system times could also be reduced.

### 4.2 Sensitivity Analysis: Examining the System Response to Increased Arrivals

In the future, it is expected that Tim Hortons might experience an increase in demand due to the construction of a new nearby student housing facility. This section addresses this "what-if" scenario. That is, to what extent can the system handle an increased customer arrival rate?

To evaluate how the systems react to increased arrivals, the base model, scenario 1.1, and scenario 3.3 were run with a 25% increase in arrival rate (20% decrease in inter-arrival time). These scenarios were chosen because they result in low customer system times and are easily implemented. The resultant times are listed in Table 5, along with the base model output (shown in italics) for comparison.

Table 5: Models with Increased Arrivals

| Scenario | Average System Time (type 1) (s) | 95% C.I. (s) | Average System Time (type 2) (s) | 95% C.I. (s) |
|---|---|---|---|---|
| *Base Model* | *201* | *(184, 218)* | *295* | *(277, 313)* |
| Base Model: 25% faster arrivals | 692 | (643, 741) | 800 | (751, 849) |
| Model 1.1: 25% faster arrivals | 90 | (86, 94) | 284 | (265, 303) |
| Model 3.3: 25% faster arrivals | 136 | (129, 142) | 179 | (173, 186) |

The current setup (base model) does not handle increased arrivals well. If customer inter-arrival times were 20% shorter, the average wait times in the system increase by over eight minutes for both types of customers (over a 200% increase for type 1 customers and more than a 150% increase for type 2 customers).

On the other hand, scenario 1.1, with the added register, handles increased arrivals much better. With customers arriving into the system 25% faster, the wait times only increase by averages of 21 s (30%) for type 1 customers, and 114 s (67%) for type 2 customers.

Scenario 3.3, with 25% more arrivals, had type 1 customers waiting 45 s (49%) more and type 2 customers waiting 45 s (34%) more.

In summary, both scenario 1.1 and 3.3 are better suited toward handling additional arrivals than the current model. In the event that Tim Hortons might experience a long term boost in arrivals, serious consideration should be given to adopting one of these service setups to better accommodate these arrivals.

### 4.3 Recommendations

The study used scenarios involving four and five workers. None of the four-person scenarios resulted in a practical improvement over the current service scenario. Therefore, our recommendation is to operate with five workers and adopt either scenario 1.1 or 3.3, as they decrease average system time the most. Selection between these two depends on whether Tim Hortons desires to purchase another cash register or not. As mentioned earlier, a detailed cost analysis was not carried out, but simple estimation makes it clear that doing so would result in a relatively quick return on investment.

## REFERENCES

Banks, J., Carson, II, J. S., Nelson, B. L., and Nicol, D. M. 2001. *Discrete-Event System Simulation.* 3rd ed. Upper Saddle River, New Jersey: Prentice Hall.

Biller, B. and Nelson, B. L. 2002. Answers to the top ten input modeling questions. In *Proceedings of the 2002 Winter Simulation Conference*, eds. E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, 35–40. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers. Available via <www.informs-sim.org/wsc02papers/005.pdf> [accessed September 1, 2004].

Brann, D. M. and Kulick, B. C. 2002. Simulation of restaurant operations using the restaurant modeling studio. In *Proceedings of the 2002 Winter Simulation Conference*, eds. E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, 1448–1453. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers. Available via <www.informs-sim.org/wsc02papers/197.pdf> [accessed March 7, 2005].

Farahmand, K. and Martinez, A. F. G. 1996. Simulation and animation of the operation of a fast food restaurant. In *Proceedings of the 1996 Winter Simulation Conference*, eds. J. M. Charnes, D. J. Morrice, D. T. Brunner, and J. J. Swain, 1264–1271. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Field, A., McKnew, M., and Kiessler, P. 1997. A simulation comparison of buffet restaurants: applying Monte Carlo modeling. *Cornell Hotel and Restaurant Administration Quarterly* 38(6): 68-79.

Jaynes, S. L. and Hoffman, J. O. 1994. Discrete event simulation for quick service restaurant traffic analysis. In *Proceedings of the 1994 Winter Simulation Conference*, eds. J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila, 1061–1066. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Kharwat, A. K. 1991. Computer simulation: an important tool in the fast-food industry. In *Proceedings of the 1991 Winter Simulation Conference*, eds. B. L. Nelson, W. D. Kelton, and G. M. Clark, 811–815. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Sargent, R. G. 2003. Verification and validation of simulation models. In *Proceedings of the 2003 Winter Simulation Conference*, eds. S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, 37-48. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers. Available via <www.informs-sim.org/wsc03papers/006.pdf> [accessed September 1, 2004].

Smith, D. J. 1994. Computer simulation applications in service operations: a case study from the leisure industry. *The Service Industries Journal* 14(3): 395-408.

## AUTHOR BIOGRAPHIES

**SARA A. CURIN** is an Operations Research Analyst at ZS Associates in Chicago, IL. She recently graduated from the University of Michigan with a Bachelors of Science degree in Industrial and Operations Engineering. Her e-mail address is <scurin@engin.umich.edu>.

**JEREMY S. VOSKO** is a senior at the University of Michigan majoring in Industrial and Operations Engineering. He completed an internship as a Trader Assistant at DRW Trading Group in Chicago this past summer. His e-mail address is <jvosko@umich.edu>.

**ERIC W. CHAN** is a Business Analyst at Deloitte Touche Tohmatsu in Cleveland, OH. He graduated from the University of Michigan in April 2005 with a Bachelors of Science degree in Industrial and Operations Engineering. His e-mail address is <ewchan@engin.umich.edu> .

**OMER TSIMHONI** is an Adjunct Assistant Professor at the Department of Industrial Engineering of the University of Michigan and an Assistant Research Scientist at the University of Michigan Transportation Research Institute (UMTRI). He received his Ph.D. from the University of Michigan in 2004. His primary research interest is in the application of simulation to cognitive modeling and human factors. His e-mail address is <omert@umich.edu>.