

# Chapter 8

## A Multi-agent Simulation Study for Congestion Minigation in a University Campus Restaurant



Takeshi Koide, Takeru Kobayashi and Maki Kikuda

**Abstract** Campus restaurants in many universities in Japan are crowded during lunch time. Managers of the restaurants usually consider to introduce some methods for the mitigation of the congestion and it is difficult to execute the introductions instantly due to the cost of the adoption. Numerical analysis on the effect of the methods will help the managers to determine if the methods should be adopted. In this study, a multi-agent simulation model is proposed to estimate the congestion at lunch break in a campus restaurant in our university. The model represents a series of customer's behaviors in the order and pick-up area in the restaurant and interactions among customers. Simulation study estimates the effect of introductions of new layouts on the congestion and the influence of the customers who make an order slowly at an order window.

**Keywords** Congestion mitigation · Multi-agent simulation · On-site survey  
Practical application · Statistical analysis · University campus restaurant

### 8.1 Introduction

Our university established a new recreation facility building last year. A main cafeteria-style campus restaurant, operated by the cooperative at our university, is popular among university members and usually very crowded during lunch break. Students have to wait for their dishes in a queue to a pick-up window for around 5 min on average. Some members give up having a lunch in the restaurant in disgust of the

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waiting and the university cooperative loses sales as well as the trust of cooperative members. Many campus restaurants in Japan are in much the same circumstances. The congestion problem is to be tackled for university cooperatives not only from the managerial point of view but also for member's benefit.

Multi-agent simulation method is a powerful approach to model complex phenomena adopted in various study fields such as sociology, physics, and chemistry [1–3]. The simulation approach especially provides critical insights to understand emergent features produced by interactions among numerous agents. The multi-agent simulation models have been also applied in service industries, such as retailing [4] transportations [5], and restaurant industries [6] in order to estimate the performance of operations to improve quality of services provided.

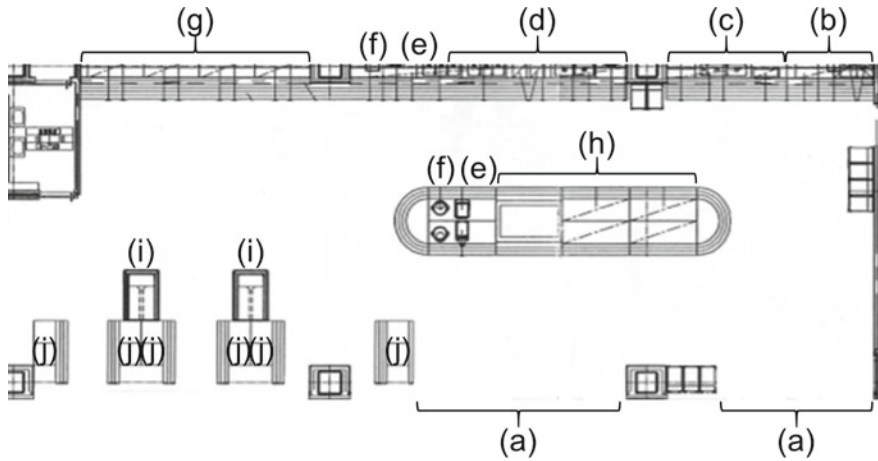
A university campus restaurant was targeted in a simulation study in [7] to reduce customer wait time. The study is based on the simulation models for fast food restaurants [8–10]. Kitakami et al. [11] constructed a multi-agent simulation model for behaviors of customers in their university campus restaurant. Using the model, they observed the transition of usage situation of restaurant seats in every area of the restaurant. They analyzed the current situation of the target restaurant but did not propose any methods to mitigate the congestion. Koide and Kikuda [12] estimated the efficiency of a priority seat system, named speed seats, for the mitigation of congestion in a university campus restaurant by using a multi-agent simulation model.

This study extends the simulation model in [12] to apply the new cafeteria-style campus restaurant in our university in order to explore some solutions for congestion mitigation. The proposed model focuses on the area to order and pick-up inside the cafeteria restaurant and customer's behaviors are modeled more detailed than those in [12] while [12] targeted the whole area of another restaurant. In the proposed model, customer agents come to the order and pick-up area, select their menus, wait in a queue to an order window, order and pick a dish up, check out at a cash register, and exit from the area. Simulation experiments measure customer's dwell time in the area as an indicator of congestion in some different settings in order to estimate the effectiveness of layout changes and the influence of the order delays by some customers.

The rest of this paper is divided into four sections. In Sect. 8.2, the proposed multi-agent simulation model for the target restaurant area is shown. Section 8.3 explains the details of customer's behaviors in the simulation model. Section 8.4 shows the simulation experiments for the congestion and their results. Finally, Sect. 8.5 concludes the paper and discusses future works.

## 8.2 Multi-agent Simulation Model

This study targets a cafeteria-style campus restaurant in our university. The restaurant locates on the ground floor of a four-story building constructed in 2017 and its seating capacity is 1400 seats. The floor plan of the order and pick-up area of the restaurant is illustrated in Fig. 8.1. Customers come into the area from the entrances denoted

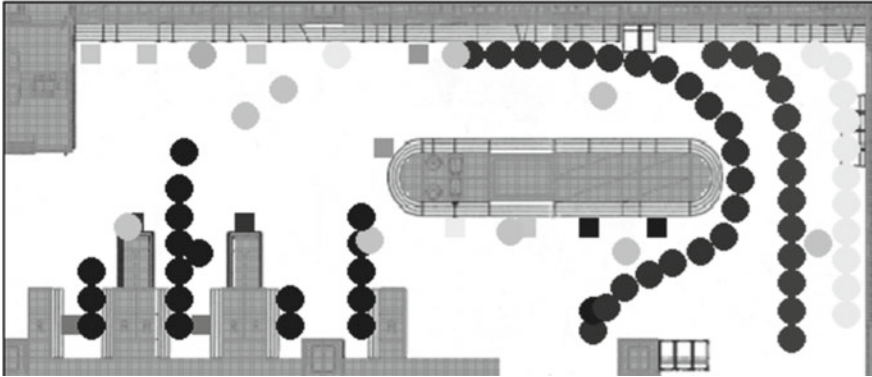


**Fig. 8.1** Floor plan of the order and pick-up area of the cafeteria restaurant

by (a). The order counter has three main windows (b), (c), and (d) for noodles, rice bowls and curries (in short RB&Cs), and main dishes, respectively. Rice and miso soup are respectively served at (e) and (f) points. More than ten kinds of side dishes are lined up in the shelves denoted by (g). The island (h), called self-deli, is a sort of heating cabinet and supplies pre-cooked dishes and boxed lunches. Some dessert items are sold at the (i) shelves. There are totally six cash registers located at the positions denoted by (j). This study aims to assess the congestion in the order and pick-up area excluding the seating area.

The constructed multi-agent simulation model in this study adopts a continuous space model whose simulation space is shown in Fig. 8.2. The simulation space is constructed based on the floor plan given in Fig. 8.1. The components (b) through (j) are allocated at the same positions as in Fig. 8.1. The simulation space is composed of grid square cells with a side ten centimeter and the size of objects in the space, such as walls, posts, self-deli, cash registers, and dessert shelves, are adjusted into the unit cell size. Some way points are adopted in the space so that customer agents steer around obstacles. The customer agents are represented by circles filled with corresponding colors to their current destinations.

The target time period in this study is set to 12:10–12:30, the most crowded time period. The arrival rate of customer agents is computed for three main windows as well as self-deli based on the practical past results of their supply quantities. This model assumes that all customers arrive individually for the sake of shorthand nevertheless most customers actually come in a group. The elapsed time for restaurant staffs to serve a menu since a customer orders the menu was set to the average elapsed time measured by on-site surveys.



**Fig. 8.2** Simulation space of the constructed simulation model

### **8.3 Behaviors of Customer Agents**

The proposed model represents the customers in the target order and pick-up area as customer agents which have the following four-stage behaviors: (1) arrival (2) move (3) queuing and order (4) payment. Some customer agents repeat steps (2) and (3) to select more than one menus. This section mentions the behaviors in detail.

#### **8.3.1 Arrival**

A customer agent is randomly created in every 1.6 s. Customer agents determine a destination for their menus among noodles window, RB&Cs window, main dishes window, and self-deli island with a probability of 22%, 23%, 43%, 12%, respectively. The selection probability is determined based on the practical supplied amount of menus served at each destination. The three windows have each queue and the customers who select one of the three windows set his/her destination to the position of the end of the queue. The customers who select self-deli island proceed there directly since self-deli does not have a queue. The customer agents arrive at the simulation space from the entrance closer to their destination.

#### **8.3.2 Move**

After arriving at the entrance, a customer agent walks toward its destination. While a customer agent walks to the end of a queue, another customer agent is sometimes added to the end of the queue and the position of the end of the queue varies. In order

to deal with the situation, customer agents periodically confirm the position of their destination and update it.

The walking scheme is designed to simplify that in [13]. A customer agent basically travels at 40 cm/s and slows down if there are some other customers in the circular area 40 cm ahead of the customer with a radius of 35 cm. When the number of customers in the area is from one to three, from four to six, from seven to eight, and more than eight, the travelling speed is declined by 60%, 70%, 80%, and 90%, respectively. When there is an obstacle in the direction of forward movement, the traveling direction is changed to either left or right direction without obstacles. The simple avoidance scheme sometimes occurs unrealistic quirky movements. In order to overcome the problem, some way points are installed in the simulation space and customer agents travel through the way points to avoid obstacles.

### 8.3.3 *Queuing and Order*

When a customer agent arrives at the end of its target queue, the agent starts to wait in the queue. The outlines of the queues to each window are designated in the simulation model and the customer agents in a queue make a line along the corresponding outline.

The head consumer agent in a queue orders a menu at a window and waits for the menu to be served. The elapsed time to serve a menu is determined based on the on-site surveys, shown in Table 8.1. The side dishes and desserts are actually not served and the elapsed time in Table 8.1 means the time to choose and pick up a dish from shelves. The head consumer is relieved of the queue after receiving the ordered menu. The next consumer in the queue moves in front of the window and the other consumers fill up the front.

Some customers consider to pick up other menus, such as rice, miso soup, side dishes, and desserts, after their first menu. The probability to consider the additional menus is set as shown Table 8.2. The customer who selected a main dish, for instance, consider to pick up rice, miso soup, side dishes, and desserts with a probability of 90%, 80%, 50%, and 10%, respectively. When a customer who considers to pick up side dishes, the customer actually picks up from zero to four dishes. The number of picked side dishes is assumed to have the binomial distribution with occurrence probability 30%. When a customer who considers the other types of additional menus, the customer always picks up one item of the type.

**Table 8.1** Elapsed time for a menu at windows and spots (s)

Noodles	RB&Cs	Main dishes	Self-deli
18	37	6	5
Side dishes	Rice	Miso soup	Desserts
5	3	5	3

**Table 8.2** Probability to select additional menu

First/additional	Rice (%)	Miso soup (%)	Side dishes (%)	Desserts (%)
Noodles	1	5	50	10
RB&Cs	0	20	30	10
Main dishes	90	80	50	10
Self-deli	0	10	20	10

### 8.3.4 Payment

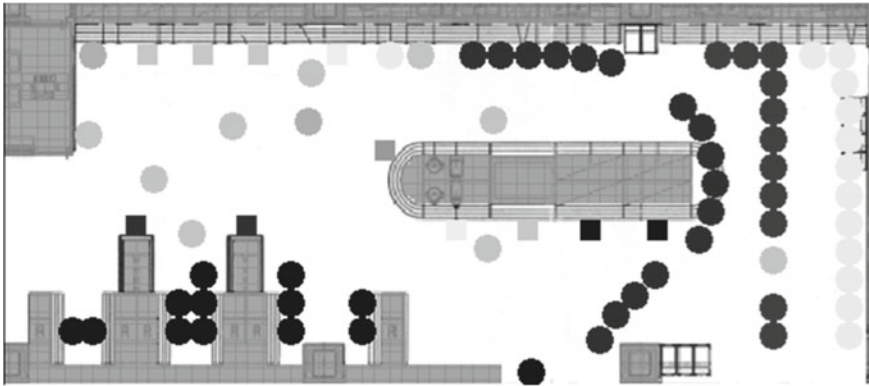
Customer agents having their all menus travel toward a cash register to make a payment. The customers select the register with the shortest queue among six registers. The closer register is selected if there are some registers with the same smallest length of queue. The head customer in a queue waits for the payment processing whose elapsed time is set to 15 s determined based on the on-site surveys. The customer agent leaves from the order and pick-up area and is eliminated from the simulation space.

## 8.4 Numerical Experiments

The proposed multi-agent simulation model was developed on artisoc [14], the multi-agent simulation platform made by Kozo Keikaku Engineering Inc. Two kinds of numerical experiments using the model have been conducted. The first is to estimate the effect of new layouts for the order and pick-up area on the lunch break congestion. The second is to investigate the effect of time delay by customers who make an order slowly. Through the execution of simulation, dwell time of customers is measured as the time period from arriving the order and pick-up area to leaving from it. This study adopts the dwell time as the indicator of the target congestion since customer's dwell time becomes longer due to heavier congestion.

### 8.4.1 Effect by Layout Changes

Preliminary experiments confirmed that the right side of the order and pick-up area, where there are three queues to the main order windows, has more customers than the left side as shown in Fig. 8.2. The customers in the two queues from the right, for a noodle or RB&C, have to cross other queues in walking to a cash register. The crossing extends the walking time and it might occur an accident to collide other customers. Increasing the space between queues sounds efficient to relax the congestion in the right side of the area.



**Fig. 8.3** Simulation space of a new layout, named Layout (1)

On the contrary, the left side of the area has enough space for customers to travel in Fig. 8.2. The preliminary experiments also confirmed that there are not so many customers in the queues for cash registers. It is preferable for the restaurant manager to close one cash register because the staff for the closed register is free and able to be assigned to another task. This numerical experiment also estimates the effect the register closure on the customer's congestion.

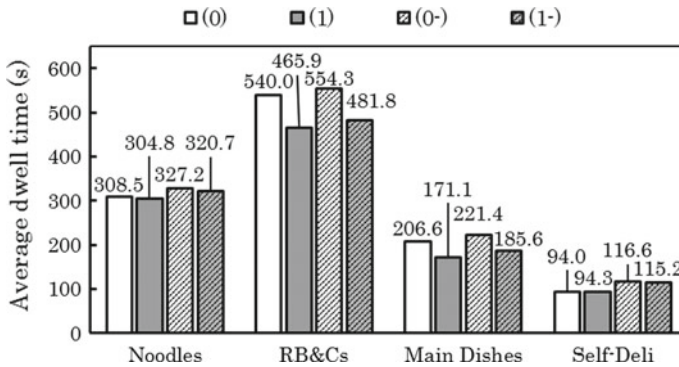
A new layout is shown in Fig. 8.3 where a right part of the self-deli island is detached so as to extend the spaces among the three queues for noodles, RB&Cs, and main dishes. The queues for RB&Cs and main dishes are partially separated to make space for customers who cross the queue. The separation reduces two and six customers in the respective queues for RB&Cs and main dishes inside the area. Since the elapsed time to order a menu at the head of the queues is given as shown Table 8.1, 74 (37 times 2) s and 36 (6 times 6) s should be reduced in the dwell time of customers in the queues for RB&Cs and main dishes.

The layout is proposed to makes customers to be easy to travel after obtaining their menus and called Layout (1) in the following. The original layout is named Layout (0) as a target for comparison of Layout (1). This experiment introduces two more layouts where the rightmost cash register is closed in Layouts (0) and (1). The layouts are named Layouts (0-) and (1-), respectively.

The simulation has been executed fifty times for the four layouts to measure the dwell time of customers. The results of the simulation are summarized in Fig. 8.4.

Figure 8.4 indicates that the customers for RB&Cs require longest dwell time followed by noodles, main dishes, and self-deli. The dwell time for main dishes is shorter than that for noodles because of the difference between the corresponding elapsed times shown in Table 8.1 while the length of queue for main dishes tends to be longer than that for noodles.

In Layout (1), customer's dwell time for all types of menu except for self-deli is shortened in comparison with in Layout (0). The t-test to estimate the difference between the population means of dwell time in Layouts (0) and (1) has been employed



**Fig. 8.4** Average dwell time of customers for each first choice in the four layouts

with considering the inevitable decrease by 74 s and 36 s for RB&Cs and main dishes, respectively. The test using a level of significance of 0.05 concludes that Layout (1) reduces the average dwell time for noodles by 2 s compared with Layout (0), and causes no significant change for the other first choices. In comparison with Layout (0-) to Layout (1-), only noodles have significant difference on the average dwell time of customers by 5 s at a level of significance of 0.05.

The change from Layout (0) to Layout (0-), which means closing one cash register, increases the overall average dwell time by 17.0 s, which is 107% of that for Layout (0). The degrees of the increase for noodles and self-deli are respectively 18.8 s and 22.6 s, greater than those for RB&Cs and main dishes. This is because the closed cash register locates on the rightmost and the register is convenient for customers who select noodles and self-deli. The t-test with the same significance condition concludes that the closing of the register increases customer’s dwell time by 17, 12, 14, and 21 s for noodles, RB&Cs, main dishes, and self-deli, respectively.

The above discussion concludes that the new layout shown in Fig. 8.3 itself has little contribution to the reduction of customer’s dwell time except for the customers for noodles, while the generated space between the queues might decrease collusions and relax customer’s mind. The reduction of one cash register makes a staff free while customers wait 17 s longer to obtain their meals on average.

### 8.4.2 Effect by Customer’s Order Delay

At the windows in the cafeteria counter, a menu is served in a dish after a customer make an order. Some customers, who are usually guests outside the campus or new students, take long time to decide what to order at the head of a queue. The order delay directly increases waiting time for other customers in the queue. This subsection estimates the influence of the time delay.



The experiments in this subsection have two kinds of parameters  $\alpha$  and  $\beta$  where  $\alpha$  is the rate of the slow customers and  $\beta$  is the time delay on the second time scale. The values of  $\alpha$  and  $\beta$  have been set from 10% to 50% with 10% increments in between and integers from 0 to 5, respectively. For all combinations of the values of  $\alpha$  and  $\beta$ , the simulation has been executed fifty times to measure customer's dwell time.

Figure 8.5 represents the simulation results of customer's average dwell time for noodles, RB&Cs, and main dishes where the result for self-deli is omitted since self-deli does not have its queue. In Fig. 8.5, the average dwell time for all types of menus increases approximately linearly with respect to time delay  $\beta$  for any values of  $\alpha$ . The average dwell time for main dishes is more sensitive than the others to the value of  $\beta$  since the length of the queue for main dishes is longer than those of the others. Figure 8.5 also shows that the increment with respect to  $\beta$  is greater for greater value of  $\alpha$  for any types of menus.

The regression lines for each data series in Fig. 8.5 have been derived and the slopes of the regression lines are displayed in Fig. 8.6. Figure 8.6 clarifies that the customers for main dishes are influenced more strongly than the other types of menus by the existence of slow customers to order. The data series in Fig. 8.6 approximately vary linearly with the value of  $\alpha$  and the sloped for the data series also have been derived. As a result, the average dwell times  $T$  is approximately expressed by Eq. (8.1).

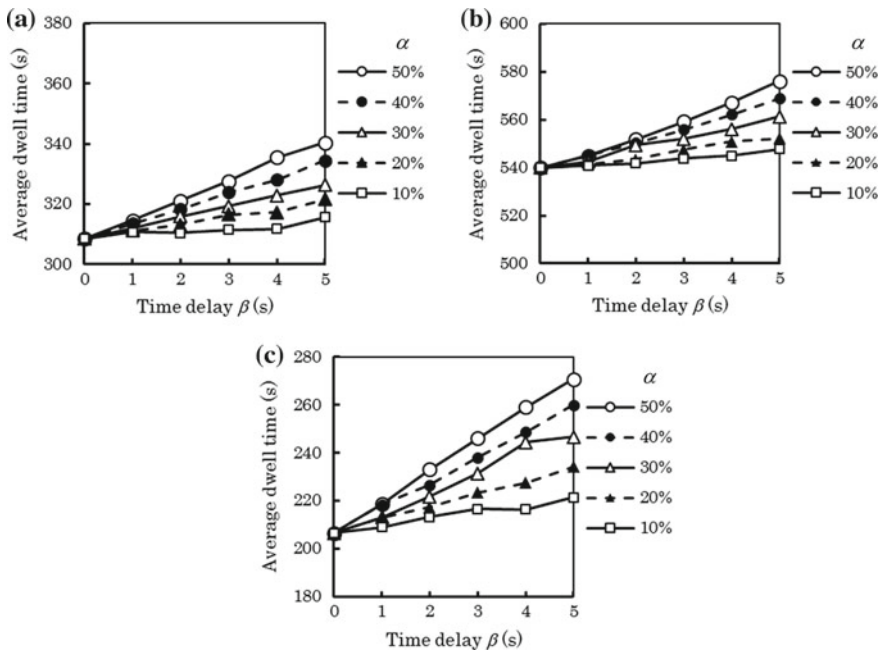
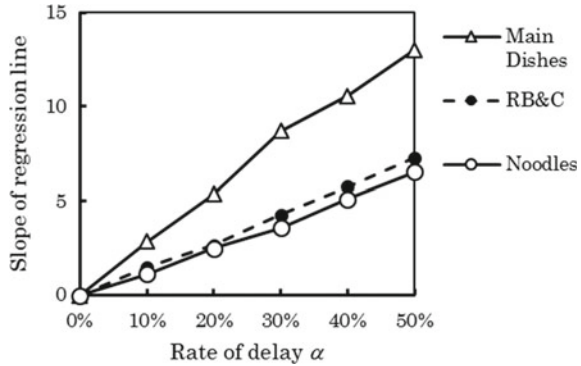


Fig. 8.5 Average dwell time of customers with delays a noodles, b RB&Cs, c main dishes

**Fig. 8.6** Slope of regression lines for data series in Fig. 8.5



$$T = \begin{cases} 13.0\alpha\beta + 308.5 & \text{(noodles)} \\ 14.5\alpha\beta + 539.3 & \text{(RB\&Cs)} \\ 26.1\alpha\beta + 206.7 & \text{(main dishes)} \end{cases} \quad (8.1)$$

In Eq. (8.1), the first terms in the right-hand side mean the influence by the order delay and the constants mean the dwell time of customers with no order delay. A decrease of 1% in  $\alpha$  or  $\beta$  reduces the influenced time by 1% in any type of menus. The decrease of the value of  $\alpha$  or  $\beta$  for main dishes is approximately twice as effective as that for noodles and RB&Cs.

From the managerial point of view, it is important to display a menu list clearly so that even indecisive customers instantly decide their menu and their order delay becomes shorter. Bigger signs of menus might be effective to help customers in a queue to decide their orders before reaching the head of the queue.

### 8.5 Conclusion and Future Works

This paper constructed a multi-agent simulation model to estimate the congestion in a campus restaurant at our university. Experimental simulation study using the model has been conducted to investigate the effect on the congestion by changing the present area layout and the influence by the existence of customers who make an order slowly. The simulation study has revealed that the proposed new layout has little effect on the congestion and the closure of a cash register surely increases the dwell time of customers in the order and pick-up area. The influence on customer's dwell time in queues to three main windows by order delays has been expressed as an equation of the rate of the slow customers and the time delay.

The proposed model could be modified to deal with the queues outside the simulation space in the model. In a real situation, some queues extend up to the outside of the target area and some customers change their preferences on menus to select

another shorter queue so that their dwell time makes shorter. Furthermore, other evaluation scales could be considered to estimate the congestion in the restaurant, such as waiting time in each queue and times of near collisions, which will be discussed in a forthcoming paper.

**Acknowledgements** The authors are grateful to the manager and the staffs in Konan University Cooperative for cooperation of on-site surveys and useful discussion. We also thank Tetsuya Miyoshi for his helpful comments on the pedestrian modeling and for introducing his related papers. This work was partially supported by MEXT, Japan.

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