Membrane Technology
ISSN (online): 1873-4049

The Application of Intelligent Agent-Based Model Method in the Operation Process of the Catering Industry

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Abstract:
The Intelligent Agent-Based Model method, by modeling many interacting individuals and simulating the behavior of individual agents, demonstrates the operation of complex multi-agent systems from a micro to a macro level. It can be effectively utilized to study the operational process of the catering industry surrounding rural scenic spots. This study takes the catering industry surrounding a tourism scenic spot in the southern countryside of Guizhou, China as an example. The emergence and development process of the catering industry is analyzed and the interaction process between tourists and restaurants is modeled. The consistency between the simulation results of restaurant customer flow and the field survey findings indicates that this model could be used to simulate the actual operation of the restaurant. The simulations shows that when the tourist traffic is high, the Matthew Effect on the distribution of customer flow among restaurants is not significant, and the impact of restaurant location is limited. However, when the tourist traffic at the scenic spot is low such as during the off-peak season, the location of restaurants has great influence on the customer flow. Furthermore, establishing partnerships with travel agencies represents an alternative solution for restaurants.

Keywords: Intelligent ABM Method, Customer Behavior Modeling, Operation Process Simulation, Multi-agent modeling, Crowd Simulation.

INTRODUCTION

The Agent-Based Model (ABM) Method is a simulation approach that employs multi-agent modeling. This method involves setting up a certain number of individuals (Agents) with a degree of autonomous consciousness, simulating complex social phenomena through their actions and interactions, and achieving the effect of generating macro-phenomena from individual micro-behaviors. The ABM method has been widely applied in various fields such as energy system control [1], disaster crowd evacuation [2,3], land use [4-7], opinion dissemination [8,9], virus transmission [10], etc. Currently, there is limited application of ABM method in the study of business operations and development processes, particularly in the research concerning the operational processes of restaurants located within the ancillary facilities surrounding tourist scenic spots. In this study, the ABM method is used to model the interaction between restaurants and customers, simulating the development process of the catering industry surrounding scenic spots, and exploring the key factors that influence the development of the catering industry in such areas. The catering industry surrounding a scenic spot in the southern countryside of Guizhou Province, southwestern China, is selected as the research object. By employing the Agent-Based Modeling (ABM) approach, this study explores the emergence and development process of the catering industry around rural scenic spots from the perspective of individual micro-behavior leading to macro-phenomena.

RESEARCH METHODS

Factors Influencing the Catering Industry

The development of the catering industry is influenced by numerous factors, including total employment in the catering sector, permanent resident population, per capita income, consumer price index, and tourist numbers [11,12]. Specifically for individual restaurants, their customer count is affected by a series of factors such as brand, location, dish quality, dining environment, price, and the consumption level of potential customers [13,14].

The catering industry surrounding rural scenic spots exhibits the following characteristics:

- The primary customers of these restaurants are tourists visiting the scenic spots, and the number of customers can vary significantly between peak and off-peak tourist seasons.

-Considering the flow of tourists, the catering industry surrounding scenic spots is mainly concentrated at the entrances and exits of the scenic spots, where land area is limited, resulting in restrictions on the number and size of restaurants.

-Rural scenic spots may be located far from nearby towns, making it more likely for tourists to dine nearby, and they tend to be less sensitive to food prices.

-Dining at the scenic spot is not the main purpose for tourists; some tourists make spontaneous decisions about which restaurant to dine at, while others plan ahead and make reservations. Therefore, the location and attractiveness of restaurants can affect their customer count.

Therefore, this paper primarily considers the number of tourists at scenic spots, the location of restaurants, and their attractiveness as major influencing factors, while the size and price of restaurants are considered secondary factors.

Simulation Method Design

This study employs Anylogic as the ABM simulation tool to establish action rules for agents. The ABM simulation environment and rule settings for this study include:

Simulation Space: The catering area near the entrance of a tourist scenic spot in southern Guizhou Province serves as the simulation space, as shown in Figure 1. The numbers in the figure represent individual restaurants. The mark P in the figure represent the entrances to the catering area from the parking lot, while the mark X marks the exit of the scenic spot. Tourists may choose to dine before entering the scenic spot, entering the catering area from P, or after visiting the scenic spot, entering from X.

Figure 1. Plan of simulation space

Agent Restaurant represents each restaurant in this catering area which locates at fixed positions along the roads within the simulation space. Each Agent Restaurant has a set of parameters, Crucial ones include:

-Lo: The location of the Agent Restaurant in the simulation space.

-Pr: Average price for each customer, values 1~100.

-MT: Maximum number of customers, limited by the area of the restaurant, values 10~100.

-CT: The number of customers in the restaurant at this moment, values 0~100 with an initial value of 0.

-Fa: Popularity in social medias, e-commercial platforms,etc., values 0~10, the higher the better. This value is influenced by the quality of the food, the investment of restaurant advertising, etc.

-FR: Food category of the restaurant. In this study, the food is classified into 5 categories: 1 Fast food, 2 Local food, 3 North Chinese food, 4 South Chinese, and 5 Western food.

-DR: Dining environment level of the restaurant, values 0(worst) ~10(best). This parameter consists of cleanness, decoration, service, environment, etc.

Agent Tourist represents each group of tourists instead of a single tourist to enhance simulation efficiency. Tourist may choose a restaurant to dine and become its customers. Each Agent Tourist has a set of parameters, Crucial ones include:

-Pe: The number of tourist in the group, values 1~10.

-Ve: The Moving velocity of Agent Tourist. Tourists wander around the dining area while choosing restaurants. They don't move very fast, hence V is set to 40~60m/min.

-At: Tourist has chance of being attracted and advancing directly to a certain Restaurant with high popularity in social medias and e-commercial platforms. This parameter values 0 for not attracted by a certain Restaurant, or the number of the Restaurant which Tourist will advance to.

-Pa: Tourists may feel impatient if they have visited several restaurants and still haven't found a satisfactory one. The parameter Patience represent the maximum number of restaurants Tourist may visit. The value is between 1 and 23 (the number of Restaurant in this study).

-Bu: Anticipated cost for this dinner per individual, values 10~100.

-FT: Preference of food category of Tourist, values 1~5 with the same meaning of Food_Category_R. Food_Category T may be a list but not a single value since each tourist group may have multiple preferred food categories.

-DT: Tourist has some requirements for the Restaurant such as cleanness, decoration, service. Dining_Enviroment_T represents these requirements, values 0~10.

- Omin: Few customers in the restaurant suggest that the restaurant may have deficiencies such as bad quality of food, bad environment, dirty, etc. Hence Tourist would avoid restaurants with few customers. Occupancy_min represent the minimum occupancy of the restaurant required by Tourist and values between 0~100%.

-Omax: Famous restaurant may attract many customers hence the restaurant may become noisy and crowded, restaurant services may be delayed and customers may have to wait longer. Thus, Tourist would not choose the overcrowded Restaurant. Occupancy_max represent the maximum occupancy of the restaurant Tourist can tolerate.

Two types of Agent Tourist are generated (from Mark P or X): whether they have predetermined their dining Restaurant or not. Tourists who have not predetermined their restaurant (At=0) will search for one within the dining area and move along the roads at a speed Ve. At intersections, they will randomly turn but prefer to go straight. As Agent Tourists pass by various Restaurant agents during their movement, they will interact with the Restaurant for a certain period of time (1 to 3 minutes) and decide whether to dine at that Restaurant. There are some requirements:

$$\mathrm{FR} \in \mathrm{FT} \tag{1}$$
$$\mathrm{Pr} \leq \mathrm{Bu} \tag{2}$$
$$\mathrm{DR} \geq \mathrm{DT} \tag{3}$$
$$\mathrm{MT} \geq \mathrm{CT} + \mathrm{Pe} \tag{4}$$
$$\mathrm{Omin} \leq \mathrm{CT}/\mathrm{MT} \leq \mathrm{Omax} \tag{5}$$

When all conditions (1) to (5) are met, the Tourist will choose to dine at that Restaurant, and CT of Restaurant will increase Pe of Tourist.

If not all conditions (1) to (5) are met, the Agent Tourist will leave the Agent Restaurant and decrease their Pa by 1. If Pa drops to 0, this group of tourists will have exhausted their patience and will no longer visit any other restaurants, 3.2instead leaving the catering area.

If an Agent Tourist dines at an Agent Restaurant, they will stay for a certain period (ranging from 20 to 60 minutes). This time is related to the type of food served at the Restaurant, with faster service for fast food and longer service for other types. It is also related to the number of people in the Tourist group, with shorter times for smaller groups and longer times for larger ones. After the dining time ends, Agent Tourist will leave the simulation space, and the CT of Agent Restaurant will decrease by the Pe of Tourist.

Agent Tourists who have predetermined their dining restaurant (At > 0) will proceed towards the restaurant with the number At as their destination. The Fa of an Agent Restaurant No.k influences the probability that At = k:

$$\mathrm{P(At = k)} = \mathrm{Fa_k} / \textstyle\sum_{i=1}^{n} \mathrm{Fa_i}, \tag{6}$$

with Fa_i the parameter Fa of Agent Restaurant No. I, and n the number of Agent Restaurant in the simulation. Upon reaching their destination, Agent Tourist will dine at the restaurant if conditions (3) to (5) are all met. Otherwise, the Agent Tourist will set At to 0 and proceed with the restaurant selection process from the current location, like other Agent Tourists with At = 0.

DATA SOURCES AND SIMULATION RESULT ANALYSIS

Data Sources

The catering area, serving as the simulation space, measures approximately 400 meters east-west and 300 meters north-south, accommodating a total of 23 various types of restaurants. The locations of each restaurant are marked on Figure 1. Each restaurant is modeled as a corresponding agent, numbered from 1 to 23. Questionnaires were conducted among the restaurants to determine their respective parameters. Surveys of customers were also conducted in the catering area between December 2 and December 12, 2023, as well as between April 28, and May 7, 2024. The results of these surveys were used to set the parameters for Agent Tourists in the simulation.

Through interviews with the scenic area management, it was learned that there is a significant difference in tourist flow between the peak and off-peak seasons. December 2023 was considered an off-peak season with approximately 4,000 to 5,000 visitors. In contrast, April 2024 was a peak season with tourist flow reaching 36,000 to 40,000 people. Considering that the scenic area has two main exits, it is assumed that 50% of the tourist flow passes through the catering area. Therefore, during the peak season, the average tourist flow in this catering area is approximately 19,000 tourists, while during the off-peak season, it is about 2,300 tourists. The two surveys also revealed that only 10 restaurants (No.1~10) were open during the off-peak season, while all 23 restaurants were open during the peak season.

Due to limitations in research conditions, data such as revenue and costs for all restaurants could not be obtained. Therefore, this study focuses on the customer flow at each restaurant, particularly the relative customer flow among them. The customer flow at each restaurant over a period of time is simulated and compared with the actual customer traffic collected on-site to validate the model.

Simulation Results

In this study, simulation time unit for the ABM simulation is set to 1 minute. Field investigations revealed that the primary dining times for tourists are between 11:00 and 15:00, and between 17:00 and 21:00 each day. Therefore, the duration of each ABM simulation is set to 240 minutes to simulate a single dining period.

Assuming that 40% of the daily tourist flow in the scenic area intends to dine in the catering area, they become potential customers. With 90% of the daily tourist flow concentrated in the midday and evening periods, the total number of potential customers during each period is 7,600 during the peak season and 920 during the off-peak season.

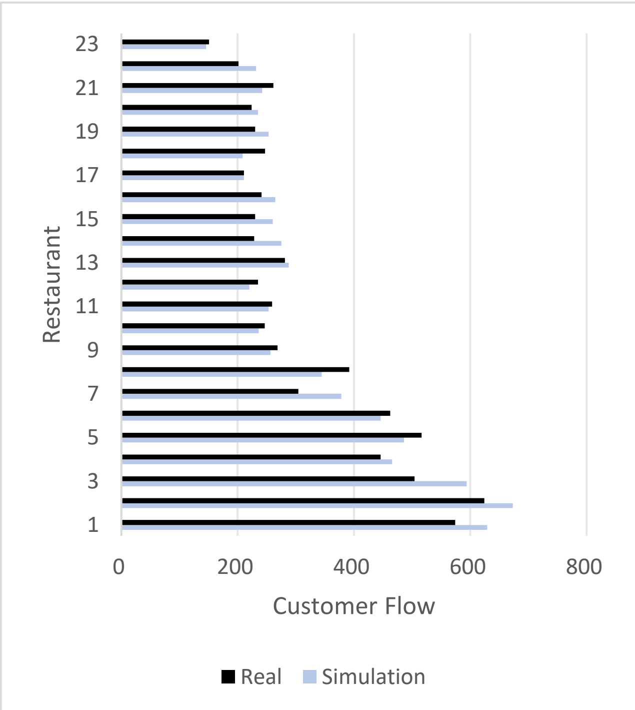

Figure 2. Customer flow of Restaurant in the peak season

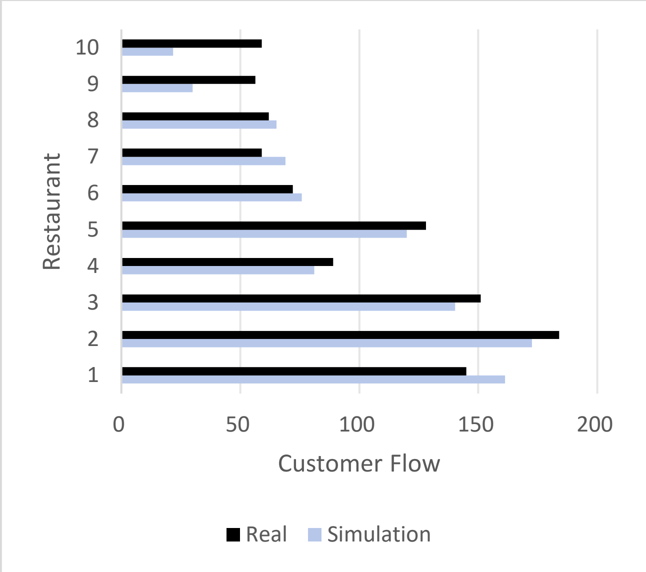

Figure 3. Customer flow of Restaurant in the off-peak season

Due to the presence of numerous random factors in the generation and interaction of Agents Tourist, this study adopts the method of increasing the number of simulations to eliminate the impact of random factors. 100 simulations were conducted for both the peak and off-peak seasons, and the average values of the simulation results were calculated.

Simulation results and survey result of total customer flow for each restaurant are shown in Figures 2 and 3.

Analysis of Simulation Results

By comparing the simulation results with the actual survey findings, it can be observed that all stores achieve simulation results that closely approximate the actual survey in terms of footfall distribution during peak seasons. For off-peak seasons, the footfall distribution of most stores is also generally consistent with the simulation results. An examination of the customer flow at various restaurants reveals some patterns:

1. Regardless of peak or off-peak seasons, the restaurants with the highest customer flow are those located near the entrance where tourists generate. During peak seasons, it is observable that the customer flow at restaurants located on the main street (No.1~8) is higher than that at restaurants on branch roads. During off-peak seasons, many restaurants are closed, and the restaurants that remain open (Restaurant 1~10) are mainly located near the entrance. It can be concluded that the location of a restaurant has a significant impact on its customer flow.

It should be noticed that during the off-peak season, the actual customer flow at Restaurants 9 and 10 was significantly higher than the simulation results. Restaurants 9 and 10 were far from the main street and the entrance where tourists generate, suggesting a lower customer flow, and their surrounding restaurants were closed during the off-peak season. However, the survey showed that Restaurants 9 and 10 were not only open but also had a customer flow close to that of restaurants on the main street. It was found that Restaurants 9 and 10 serve local cuisine at low prices and had partnerships with several travel agencies, where tour groups are organized to dine. During the off-peak season, tour groups (20-40 people per group) increased the customer flow at Restaurants 9 and 10.

It can be concluded that when developing the catering industry around tourist attractions, the preferred location should be where there is a high customer flow. However, such venues often have higher rent and costs. Therefore, cooperating with travel agencies and serving local cuisine at low prices in locations away from high customer flow areas, where rent and costs are lower, is also a good choice for restaurants.

2. The change of customer flow distribution between the peak season and the off-peak season is also considered. For Restaurant 1~10 which operate both in peak and off-peak seasons, their customer flow are normalized by dividing it by the highest customer flow (Restaurant No.2) the results are shown in Figures 4.

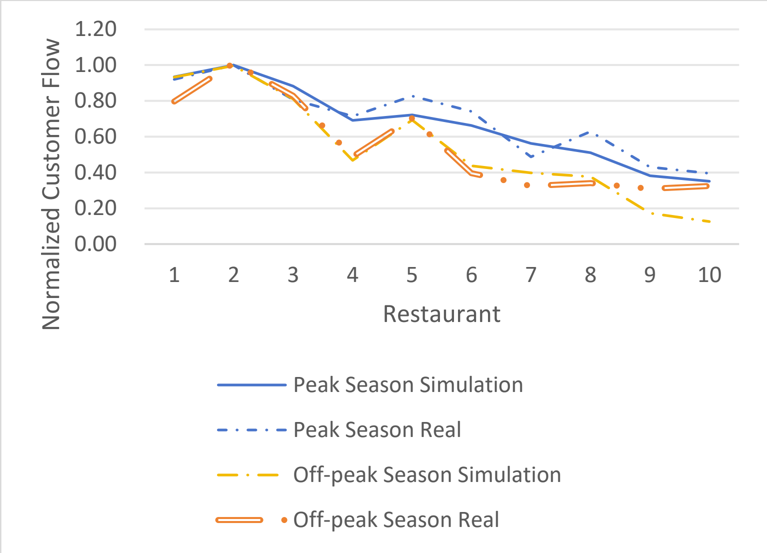

Figure 4. Normalized Customer Flow for Restaurant 1~10 during Peak Season and Off-Peak season

In figure 4, the lines representing the normalized customer flow in peak season are above the ones for the off-peak season, for both simulation and real cases. It shows a reduction of customer flow difference between restaurants in the off-peak season compared to the peak season.

By studying the simulation process, it was discovered that due to geographical constraints, each restaurant had limited space. During the peak season, with a large total customer flow, well-located and larger restaurants, such as Restaurants 1-6, quickly obtained many customers, with the number of customers in the restaurants exceeding 90% of their maximum capacity. Subsequent tourists would then stop entering these restaurants and gradually enter more remote ones. Hence, the sufficient total customer flow during the peak season kept all restaurants basically at saturation, preventing those with better locations and conditions from obtaining more customer flow due to the Matthew Effect. In contrast, during the off-peak season, with fewer total customers, restaurants in high-visibility spots did not experience customer saturation, allowing them to continuously attract limited customers and reduce the flow to other restaurants. Smaller restaurants which locations with less traffic had fewer customers and insufficient revenue, leading them to adopt cost-reduction measures such as reducing staff and marketing investments, which would further reduce the willingness of customers to dine. Hence the Matthew Effect is more significant in the off-peak season than in the peak season.

From the previous discoveries, it is concluded that for the scenic area with relatively low tourist traffic, the strategic placement of restaurants is crucial. Restaurants should aim to be located at high-traffic spots such as the entrance to the catering area or along major pathways where potential customers are likely to pass by first. These high-traffic spots often come with higher rent and operational costs. To address this challenge, collaborating with travel agencies and opening restaurants that serve local cuisine at affordable prices in less crowded, lower-rent areas can be a strategic and viable option.

When the tourist flow is substantial, the impact of restaurant location is relatively minor. This is because a large number of visitors ensure that even remotely located restaurants can attract customers. In such scenarios, restaurants have a broader range of potential locations to choose from without worrying too much about accessibility or visibility.

CONCLUSION

This study thoroughly analyzes the emergence and development process of the catering industry surrounding rural scenic spots, as well as its operational characteristics. By adopting the Agent-Based Model (ABM) method, the interaction process between tourists and restaurants is modeled. Taking the catering industry surrounding a tourist attraction in the southern countryside of Guizhou Province, located in the southwest of China, as an example, the study simulates the process of tourists choosing restaurants. The outcomes of the simulation regarding customer flow demonstrate a strong correlation with the results obtained from field investigations, suggesting that this model is capable of representing the operational process of restaurants surrounding tourism scenic spots.

The research findings indicate that when the tourist flow at the attraction is high, the Matthew Effect on the distribution of customer traffic among various restaurants is not significant, and the impact of restaurant location is limited. However, when the tourist flow at the scenic spot is low, such as during the off-season, the location of restaurants surrounding the tourist attraction should be in areas with high traffic. Alternatively, restaurants can serve local specialty foods at affordable prices and establish cooperation with travel agencies as viable strategies.

In future research, various operational strategies will be incorporated into the simulation to predict their impacts on restaurant performance, thereby enabling the optimization of restaurant operations.

ACKNOWLEDGEMENT

This study is supported by 5·5 Engineering Research & Innovation Team Project of Beijing Forestry University (No: BLRC2023C04).

REFERENCE

[1] WANG Y D, HU J J, LIU N. Energy management in integrated energy system using energy-carbon integrated pricing method. IEEE Transactions on Sustainable Energy, 2023, 14 (4): 1992-2005

[2] XIE W, LEE E W M, LEE Y Y. Simulation of spontaneous leader-follower behaviour in crowd evacuation. Automation in Construction, 2022, 134: 1-10.

[3] XIE J Y, ZHANG L. Application of cellular automata with improved dynamic analysis in evacuation management of sports events. Journal of Sensors, 2022, 2022: 1-11

[4] Bert F E, Podestd G P, Rover S L, et al. An Agent Based Model to Simulate Structural and Land Use Changes in Agricultural Systems of the Argentine Pampas. Ecological Modelling, 2011, 222 (19): 2486-3499.

[5] Gaube V, Kaiser C, Wildenberg M, et al. Combining Agent-Based and Stock-Flow Modelling Approaches in a Participative Analysis of the Integrated Land System in Reichraming, Austria. Landscape Ecology, 2009, (9): 1149-1165.

[6] Haase D, Haase A, Kabisch N, et al. Actors and Factors in Land-Use Simulation. Environmental Modelling & Software, 2012, 35(C): 92-103.

[7] Sceinemaches P. Berger T. An Agent-Based Simulation Model of Human-Environment Interactions in Agricultural systems. Environmental Modelling and Software, 2011, 26 (7): 845-859.

[8] Huang C, Hu B, Jiang G, et al. modeling of agent-based complex network under cyber-violence. Physica A: Statistical Mechanics and its Applications, 2016, 458: 399-411.

[9] Jiang S, Peng W. The evolution of internet public opinion in emergent event with agent-based modeling and simulation. Open Cybernetics & Systemics Journal, 2015, 9 (1): 1490-1495.

[10] Mehta K N, Chang W V. Weight Status and Restaurant Availability. American Journal of Preventive Medicine, 2007, 34 (2): 127-133.

[11] Filimonau V, Matute J, Kubal-Czerwińska M, et al. The determinants of consumer engagement in restaurant food waste mitigation in Poland: An exploratory study. Journal of Cleaner Production, 2020, 247: 119105-119105

[12] Dunford K E, Wu H J, Wellard-Cole L, et al. A comparison of the Health Star Rating system when used for restaurant fast foods and packaged foods. Appetite, 2017, 1171-1178.

[13] Ali F, Harris J K, Ryu K. Consumers' return intentions towards a restaurant with foodborne illness outbreaks: Differences across restaurant type and consumers' dining frequency.Food Control, 2019, 98, 424-430.

[14] Elizabeth Y, Murat K, Jorge R .Financial recovery strategies for restaurants during COVID-19: Evidence from the US restaurant industry. Journal of Hospitality and Tourism Management, 2021, 47, 408-412.