Designing Market Stall Layout by Agent-Based Simulation

Chayanit Trakulpipat , Sukree Sinthupinyo

***Abstract*—The best-fit market layout design for human group behavior is one of the most difficult tasks because an individual's behavior could add complexity to the decision of the entire group. The purpose of this research is to study a method of designing a market stall layout using an agent-based simulation and improving each layout using Genetic Algorithm because we can not know the desirability of each layout. Hence, we employ Genetic Algorithm using happiness value as a fitness function to attack this problem. The results would be used to design the best-suited environment for the customer behaviors. The key factor presented in this paper is the average happiness value, which is used as a fitness function. In our experiments, we compared three different layouts that are categorized by product types, randomized product types, and changes in the product positions.**

***Index Terms*—Agent-Based Simulation, Genetic Algorithm, Crowd Simulation.**

I. Introduction

In Thailand, the fresh market where merchandise trades occurred, have been the center of people's life. The market have been evolved and developed due to the population growth and migration. Nowadays the fresh market are still an important part of the Thai people. But because of the population growth space became limited. The vendors started to overflow the streets. There were no regulations for these vendors and they would rather place their stalls on the pedestrian walkway, instead of in the arranged marketplace. This has become one of the major problems in Bangkok, the capital of Thailand.

The Healthy Market Project by Jariya Bunyanokhroh[1] of the Ministry of Public Health was initiated to elevate the market standard of Thailand to the international level. She aimed to investigate the influences of healthy markets and government projects towards people's quality of life. Her study also focused on finding a way for the project improvement. The Healthy Market Project covers four areas: people's understanding of the project, the public health, food safety, and consumer's rights. The sampling agrees that only the markets which meet the criteria of the Healthy Market project should be acceptable. With respect to the public health, the sampling (42.68 percent) also highly agree on the market hygiene, but are less concerned with the issue on appropriate settings. Hence, an attractive layout design would be one of the solutions to this problem.

The crowd simulation is a branch of the agent-based simulation researches, which have been widely used in a variety of works especially in the design of the construction environment. Human is a social animal with different social activities in varieties of places such as department stores, banks, restaurants, public parks, and markets. These social activities create the diversity of behaviors in reaction to different environments. Hence, it is a challenge to design a well-suited software architecture to handle these dissimilar behaviors. Yet, there have been many efforts to model the constructions complying with those complex behaviors by studying and simulating the group behavior in each event. A typical example of the simulation in graphic designs is the computer games. The results of this study should be able to help those who are responsible for layout designs to better understand ongoing problems and find better solutions.

This paper presents a market layout design based on the agent-based simulation and the Genetic Algorithm method. The goal is to find a good market layout design that well corresponds to the behaviors of the customer group. The best layout design is the one with the highest average happiness value obtained from experiments run by the multi-agent simulation.

This paper begins with the project background. The second part is the related theories and research studies. The third part covers the methodology. The fourth explains the results from the experiments and the last part is the conclusion.

II. Related and Previous Works and Consumer Behavior Theory

A. Related and Previous Works

Earlier studies of the agent simulation research include Reynold's study of group behaviors such as flocks of birds, herds and schools of fish [2]. Later Tu and Terzopoulos [3] proposed a behavioral model for schools of fish during mating, escaping from predators and hunting. Dirk Helbing [4] used closed-circuit televisions to study human behaviors in time of emergency such as during fire alarms. He also studied pedestrian behaviors in those emergency situations [5].

Braun et al. [6], utilized Dirk Helbing's model, presented a parametric model of crowd evacuation from inside of the buildings with lots of rooms and obstacles. The results were

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measured as three outcomes: saved, injured, or dead. Pan et. al. [7] used a multi-agent based framework to study human behaviors during emergency evacuations from buildings. He categorized human behaviors in this emergency situation into three groups: competitive, queuing, and herding. Jan Dijkstra et. al. [8] used the Cellular Automata Grid method in designing a multi-agent system model of purchasing behaviors of those in the malls with T-junctions. Mankyu Sung [9] presented an approach to control the crowd behaviors in complex environment. In this model he used a two-level agent architecture. The high level architecture separated each environment for behavioral control. In the low level the agent behavior was monitored and randomly selected for use in the high level architecture. Haklay et. al. [10] applied the SWARM and GIS techniques to study human behaviors as a result of landscape change. They utilized Helbing and Molnar's behavioral models. Celine Loscos et. al. [11] used the Trajectories method to study the agent decision in choosing the best path to avoid collision in the high traffic areas. The agent's choices of paths were randomly selected in two different situations, normal traffic and high traffic.

B. *Consumer Behavior Theories*

The knowledge of consumer behaviors is central to marketing study as never before. Marketing starts and ends with the consumers. Consumer behaviors need to be thoroughly examined to maximize the marketing strategies. The consumer behaviors and decision making processes are described as below [12].

1. Need recognition – the realization of the difference between the desired situation and the current situation. This realization serves as a trigger for the entire consumption process. This process can be affected by several factors such as changed in circumstances, time, a new product purchase and consumption which might trigger the need for other products.

2. Search for information – consumers seek information, initially from internal, then external sources, to help decide how best to satisfy their needs. Beginning with the internal source is a search for information, individual memory or experiences with a product or service. The external source is economic and psychological perspectives derived from advertising, brands, and cost from the sales people.

3. Pre-transaction alternative evaluation – assessment of available choices that can fulfill the realized needs by evaluating benefits the products may deliver, followed by the reduction of the number of options. In this step, a number of alternatives are evaluated and the final option, which is believed to best satisfy consumer needs, is chosen.

4. Transaction – the step of purchase. The product has already been chosen but the purchase might not have been done because motivations and circumstance can still change by new information or other products in the store. The final decision also depends on when and where to buy and/or how to purchase. Thus, the final decision can be fully planned, partially planned or totally unplanned.

5. Post-transaction alternative evaluation – assessment of whether and to what degree the consumption of the alternative produces satisfaction. The result of this step can be either satisfaction or dissatisfaction. Satisfaction is the result of a post-consumption evaluation if a chosen alternative met or exceeded expectations of the customer.

III. THE AGENT-BASED SIMULATION

With the capability of agent in assigning the action, our agent behavior model is based on a set of consumer behavior [12].

To simulate a virtual market for agents to go shopping, the virtual market consists of (1) Stalls for booths of product showcase, (2) Spaces as empty area where agents can move freely between stalls (3) Gateway or an entrance or exit in and out of the environment.

A. *Agents' Behavior Model*

To study the efficiency of agent movement we set up three states for the agent: Finding target, Reaching target, and Being successful. Below we describe these states respectively. For each state, we give a general description of the motivation and role of the behavior and the actions associated with the behavior.

- Finding target

The simulation starts with an agent enter into the environment at the gate. The agent already has a list of product and must decide what the first desired product is. When the agent makes the decision for a planned route, the planned route chosen is the shortest path from the origin to the destination (see Fig. 1). At this stage, the ability of the agent movement is casual walk, right, left, turn, detour, and side-shift for collision avoidance while walking the agent stays away from other agents. If two agents encounter, they would steer to the side to avoid running into each other (see Fig. 2a). The agent identifies stall areas and an open space (see Fig. 2b).

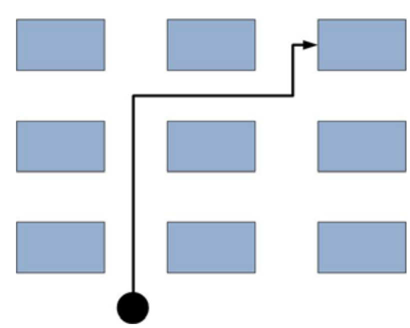

Figure 1: Show the agent-routing

- Reaching target

When the destination target is reached, the agent stops there for a period of time to purchase the product but if there are other agents purchasing the product in the same area, the agent will take in the queue. If the agent comes across the stores offering similar products, the agent will randomly select a store. Finally, when the agent finished shopping, it will check the shopping list. If the shopping list is not complete, the agent will walk to the next destination target, but if the list is complete, the agent will leave the destination target.

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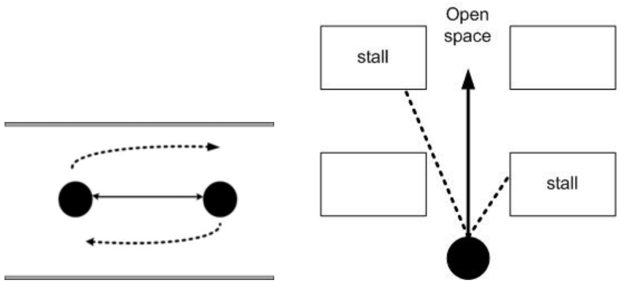

(a) (b)

Figure 2: (a) Steering to avoid collision (b) Sensing objects in a virtual environment

- Successful

In the final step if the agent finishes the shopping, it will exit through the nearest gate.

As shown in Fig. 3, the pseudo code of our agent is as follows:

1. Make a decision by selecting one of the merchandises.
2. Choose a direction for the next move.
3. Walk under the following approach:
   - Find the destination target.
   - Determine the shortest path from the current position to the destination target.
   - Avoid bumping into any other agents.
4. Repeat all the above steps until all the merchandises have been purchased.

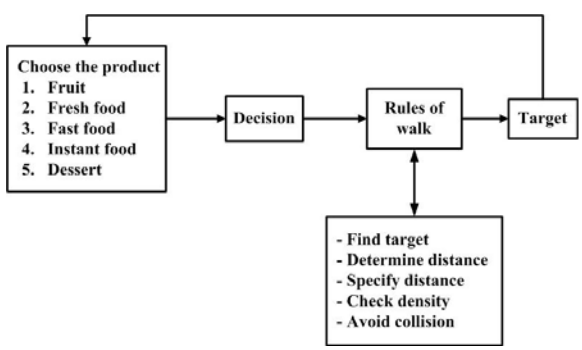

Figure 3: The procedure of the agent

B. Goal for Agent

In this paper the goal for the agent is happiness value, which comes from purchasing the product. In the real world each consumer has different goals in product purchasing [13]. Some consumers have lists of products to purchase, some browse the merchandise before making a decision, and some do impulse buying. Hence, in this paper we developed three targets for each agent, super-goal, goal and sub-goal as detailed below.

- Super-goal
  At this level the agent already have in mind a list of products to purchase. The agent purchase products based on the product weight by choosing in order of preference from the lightest (most preferable) to the heaviest. The weight factors of each product in our experiment are fruit = 5, fresh food = 4, fast food = 3, instant food = 2, and dessert = 1.
- Goal
  Agent that enters into the market already has got a list of products like the target of the super-goal, but there is a difference in planning of purchase. Beside this, agent does not make product purchasing in order before enter into the market, but agent acquires products as it like or as it found instead.
- Sub-goal
  At this level the agent enter the environment with a list of products, but have not decided which store to purchase them from. Thus, the agent will walk around the environment to decide which store to purchase. The agent are allowed to walk around only once.

IV. Designing a Market Stall Layout by Using GA and Experimental Results

The ultimate goal is to find the best market stall layout. But there is no direct method to assess how effective a stall layout is. Hence, in this paper, we propose the idea of using the agent-based simulation to approximate the desirability of each layout, then applying the Genetic Algorithm method to adjust the layout to suit consumer behaviors.

A. The Method in Genetic Algorithm

Genetic Algorithm is a general-purpose search technique used in computer science, in which the most suitable answer is selected based on the idea from nature selection of Charles Darwin, 1859. The Genetic Algorithm method consists of iterated cycles of evaluation, selection, crossover, and mutation. The methods in the Genetic Algorithm were employed in designing the urban layout [14].

The settings in our experiments are described as follows:

1. Encryptions of the chromosome in designing the layout are as follows:
   - X-coordinate point of stall
   - Y-coordinate point of stall
   - The category of merchandises i.e. fruit, fresh food, fast food, instant food, and dessert

The coding method we used to define the layout design is shown in Fig.4. A chromosome shows a virtual market that consists of many stalls. Each stall's information is specified by its location, and category of product.

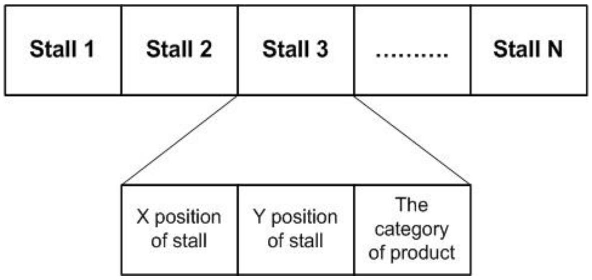

Figure 4: Coding Method

2. To find the fittest chromosome, we employ the idea of behavior model from [15] as our fitness function as in (1). The chromosomes which will survive and exist in the next generation are the ones that represent the layout design with agents' high average happiness value. The happiness value of the chromosome is calculated by

$$Wb = Wb_{ideal} + \sum_i \alpha_i D_i \qquad (1)$$

Where Wb is the happiness value of an agent, Wb_{ideal} is the starting happiness value of the agent which is set as 100, α_i is the weight factor of actions, and D_i is the number of times that each action occurs or the number of products that agent can buy or cannot buy. The actions concerned in our experiment are described below.

- If the time is up but the agent still cannot buy the target product, α_i = -5
- If the agent can buy the target product, α_i = 5
- If the agent bumps into another agent , α_i = -2.5

When the simulation period is over, if the agent's happiness value is greater than 100, the value is set to 100. The average happiness value is finally calculated by dividing the sum of all agents' happiness value by the number of agents.

3. The procedure of finding Selection, Crossover, and Mutation. The Genetic Algorithm operators are applied to the remaining individuals. The number of population is 100. The selection of individuals for reproduction is fitness proportionate. Half of the populations with a higher fitness value survive in the next generation. In this research, we used the Roulette Wheel selection method. For crossover method, we used uniform crossover to create new offspring by random pick. We fixed the crossover rate to 0.5 and mutation rate to 0.1. One stall in the selected chromosomes is randomly selected and its properties are changed according to the change in strategy. All settings in the Genetic Algorithm are shown in Table. 1.

Table 1: Parameter for Genetic Algorithm

Parameter	Values/Method
Crossover	Uniform 0.5
Mutation rate	0.1
Selection	Roulette

B. Experimental Results

In this section, we show the results of three layout design approaches. The first layout design, as we later call Fixed Layout, comes from the market design from [1] in which the stall size is 1 meter x 1.5 meter, each stall is 2 meter apart and is arranged by product category. The other two methods are from the Genetic Algorithm. One method is the layout design approach which changes only the category of goods (Category Change), while the other method is the approach which changes position of the stalls (Position Change) as shown in Fig. 6.

In each run, we used 700 agents. The agents can move 0.2 meter per second. The simulation period is 180 seconds.

We used the Fixed Layout method as the base case in this experiment. Table. 2 shows the average agents' happiness in three layout design approaches. The results show that the average happiness of the agents from Category Change is the highest. A trend of the average happiness value of agents obtained from each generation is shown in Fig. 5.

One reason that the average happiness values from Product Change are slightly lower than those from Category Change is the size of search space. The search space in Product Change is much smaller than the space in Category Change. Because changes in position of Product Change are in continuous domain, this makes the search space of Product Change extremely large.

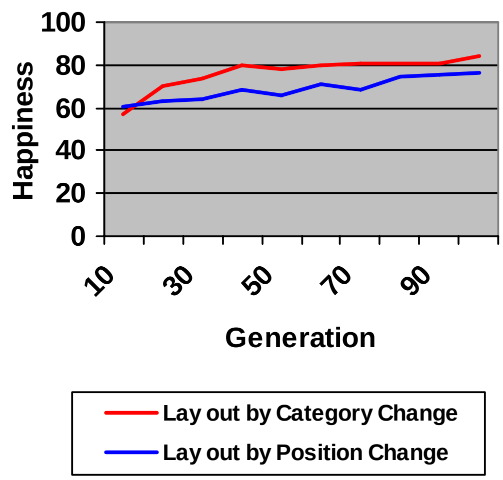

Figure 5: The average agents' happiness value in each generation runs by Genetic Algorithm.

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Table 2: Happiness values obtained from the experiments are shown in Mean ± Standard Deviation

Fixed Layout	Genetic Algorithm (after 100 generations)	
	Category Change	Position Change
71.65 ± 43.73	84.03 ± 34.81	76.64 ± 39.97

V. Conclusion

We have introduced an approach which combines Genetic Algorithm with agent-based simulation. The key idea of this work is the method we used to evaluate the strength of each layout design. We cannot directly evaluate the desirability of a layout design from its geometry. Hence, we employ the agent-based simulation to attack this problem. We have proposed a fitness function which is determined from agents' happiness when shopping in the pseudo-market. The results which come from the simulation in 100 generations show that the layout design from the Genetic Algorithm in which the change in only category of goods in each stall can be made yields the highest average happiness value.

The experimental results show that the best market stall layout design is the one with adequate space for two-way traffic. The market stall layout design derived from the Genetic Algorithm method yields product variety. This congregation of mixed products helps facilitate purchasing, saves consumers' time, and encourages impulse buying.

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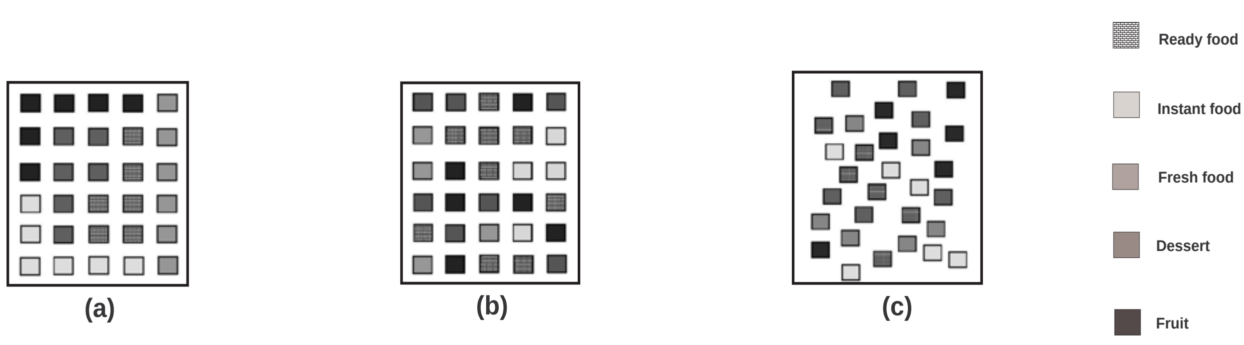

Figure 6: (a) Fixed Layout (b) Category Change simulated in 100 generations (c) Product Change simulated in 100 generations.