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AIRPORT PASSENGER SHOPPING MODELING AND SIMULATION: TARGETING DISTANCE IMPACTS

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ABSTRACT

The ever-increasing importance of airport retail has encouraged both industry and academics to look into ways to increase airport retail revenue. Despite the growing interests in this topic, there is a lack of passenger shopping behavioral model. This paper aims to fill this gap and enhance our understanding of how the location of the shop affects passenger decision. This paper first investigates the possible passenger shopping behavioral model through an exploratory Eye-tracking exercise. Data was collected to calibrate and validate the behavioral model through the use of an Agent-Based Simulation Model. Shop locations were shown to have a significant impact on the passenger's choice and overall retail revenue. The result shows that our proposed passenger shopping behavioral model can be suitably applied in our study context. Our model can assist airport retail planner in testing different scenarios to improve airport retail revenue cost-effectively.

1 INTRODUCTION

Airports are traditionally viewed as natural monopolies; however, this fact is increasingly challenged. The airline liberalization and airport commercialization have unleashed the forces of competition among airports (Graham 2004). Airports are no longer in a truly monopolistic position as their catchment areas of airline clients increasingly overlap with each other (Painvin 2011). The airport has responded to this intensified competition by reducing aeronautical fees charged to airlines while exploring possible ways to increase its non-aeronautical revenue to ensure its long-term sustainability and profitability. One focus is the airport retail revenue (inclusive of food & beverage sales), which plays a critical role in their financial performance because it is the largest and most significant revenue source for major airports (Tseng and Wu 2019).

The rate of growth of airport retail revenue has continuously reminded people about its sheer importance to airports' financial sustainability and stability. A survey by Airport Council International (ACI) has shown that the median amount per enplanement spent at airports has increased 36% from USD 7.15 in 2009 to USD 9.75 in 2014 as illustrated in Figure 1. Despite the growing importance of the airport retail revenue, the dominant discourse airport terminal design and space allocation management have been around an engineering and aeronautical perspective with significant attention on efficiency rather than the impact of the space on passenger experience (Freathy and O'Connell 1998; Losekoot 2015). As a result, the performances of the airport terminals are usually suboptimal from a retailing perspective. The growth of airport retail revenue could be improved if the retail capability of the terminal is considered in the terminal design without significantly sacrificing the aeronautical performance.

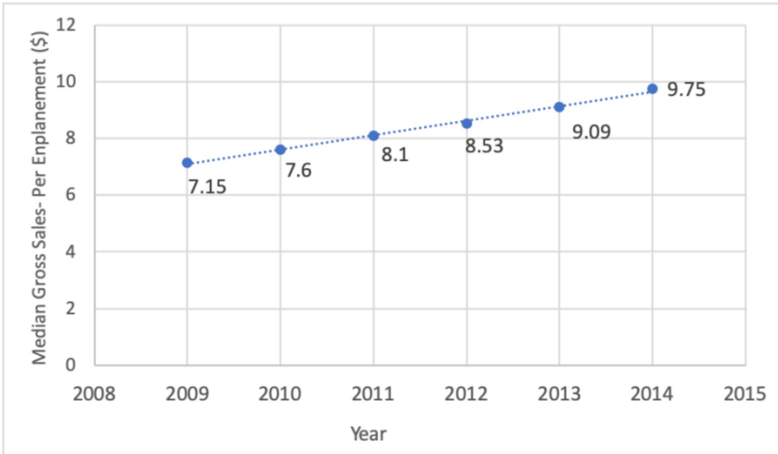

Figure 1: Worldwide Median Gross Sales- Per Enplanement between 2009-2014 (ACI 2016).

An essential feature of airport retail is the interaction between the travelers and the terminal environment. The chance for passengers to visit shops and perform purchase is determined by the attractiveness of the shop, the shop locations, and the passengers' preferences and characteristics. Such a complicated process involving behavioral and commercial elements as well as spatial factors can hardly be analyzed analytically and modeled by conventional economics modeling. Agent-based simulation can be a feasible, cost-effective alternative to analyze retail performance and facilitate terminal design because it excels at modeling the spatial movement of agents as well the interaction between agents and the environment.

One focus of this study is the spatial factors affecting the retail activities of the terminal. These factors include the shop location, shop-to-passenger distance and the visual range of passengers. Previous studies in the literature have been discussing the influences of shop location and distance. For instance, Geuens et al. (2004) pointed out that different types of shopper could have different preferences for shop location and terminal layouts. Puls and Lentz (2018) further identified that passengers with different travel purpose have different needs for retail products and shop locations. The shop location would directly dictate the required distance for passengers to move in order to reach their preferred shops. Shopping center research has established the importance of minimizing walking distance for the pedestrians (Brown 1994; Reimers and Clulow 2014). However, it is rare to see a study investigating and explicitly quantifying the impact of the airport retail shop location and distance from passengers on airport retail performance.

This paper aims to explore the impact of the shop locations and the shop-to-passenger distance on airport retail performance through the simulation of passenger's shopping behavior in an airport environment. The study first establishes an understanding of the passengers' shopping and movement behavior inside the terminal by observing passengers in the actual airport environment. A conceptual behavioral model is developed to highlight the interaction between the passengers and the terminal as well as the effect of distance and shop location. The collected data and observed patterns used to calibrate and validate the visual range of passengers and the attractiveness of the shop with an average absolute percentage error of two percent. These patterns and calibrated values are input into agent-based modeling to simulate the shopping behaviors of the passengers in the terminal. A case study of swapping shop locations are performed to investigate the impact of spatial factors on retail performances. An important finding is that the more profitable shops should be placed at a more accessible location, for example, near the entrance.

The paper is organized as follows. Section 2 discusses the key factors affecting the shopping behaviors of passengers and the development of the passenger shopping behavioral model. The development of

Agent-based model based on the passenger behavioral model is explained in Section 3. Section 4 discusses the experiment and results. Section 5 concludes the findings and discusses the implications.

2 SHOPPING BEHAVIOR MODEL DEVELOPMENT

Terminal space is a key constraint to airport operators (Vaja and Dai 2012). Airport operator needs to carefully balance the use of space between processing facilities (i.e., check-in facilities) and commercial facilities (i.e., retail shops). It is crucial to understand the factors that dictate the movement and purchase decisions of passengers inside the terminal, and how these factors can be adequately modeled in order to improve the planning process (Kalakou and Moura 2014). A survey in the airport terminal and a literature review are performed for the identification of those factors from both empirical and theoretical perspectives. Then a conceptual airport passenger behavior model is proposed based on the identified factors.

2.1 Factors Affecting Passengers' Behavior

In order to develop a better understanding of passenger movement and decision making, we first need to identify the key factors that affect the shopping and movement behaviors of the passengers. These factors will be included in the following behavioral model. The factors are identified from two aspects – 1) a survey, which combines video recordings and interviews, exploring the passengers' movement and shopping behaviors in the actual airport terminal environment and 2) a literature review on the factors affecting the passengers' behaviors in the terminal.

2.1.1 Survey of Passengers' Behaviors Inside the Terminal

Exploratory Study Context

The exploratory study was conducted in a real airport environment over two weeks in January 2019. We used Pupil Lab eye-tracking glasses to observe airport passengers' actual behavior in a real airport setting. Through the use of the eye-tracking device, we have collected the world video data, which tell us what and how passenger perceives the airport environment from a first-person perspective. The data provide rich information on the interaction between the passengers and the airport terminal as well as the required details to be input in the forthcoming simulation model,

Participants

Forty passengers (21 male, 19 female) were recruited randomly to participate in the exploratory study. Only 34 of the participants completed the full exploratory study. Three samples are excluded due to the technical difficulties of the eye tracking device. Another three samples are excluded as passengers did not arrive at the gate early enough before the boarding time to complete the interview.

Procedure

Passengers were randomly intercepted and asked to participate in this exploratory study after they passed the immigration area. After agreeing to participate, the participants were asked to wear a Pupil Lab eye-tracking device and fill up the first part of a survey (demographics-related questions). Then, the participants can carry out their normal activities in the terminal freely as they usually do without the eye-tracking device. No instructions are given to the participants. Instead, we met the participants again at their boarding gate where they were waiting for boarding. Participants return the eye-tracking device and then were interviewed for the second part of the survey. This part of the survey focused on their movement strategy in the airport. The movement strategy is related to how they made decisions about which area of the terminal to visit. For example, passengers could have planned their visits to certain facilities before arriving at the airport.

Data Analysis

The data from the eye tracker, consisting of the world video and the data of the eye movement, was recorded on a mobile phone that had been provided to passengers. A total of 15.5 hours of video was recorded, and the offline calibration was conducted to analyze the participant's attention and movement behaviors in the terminal. As illustrated in Figure 2, the quantitative data set (with the log-files and videos) enabled us to identify the facilities within the visual field of participants and what information the passengers received. With the second part of the survey, the disclosed movement strategy by the passengers and the actual adopted strategy can be cross-validated.

Figure 2: Example of World Video Recorded.

Exploratory Study Result

Through the analysis of the video and the survey results, the shop location and shop-to-passenger distance are found to have a significant impact on passengers' choices of movement within the airport terminal. For example, almost 65% of the participants disclosed that they have no specific strategy of allocating their time and movement in the airport terminal. Instead, they would observe what shops and facilities are available to them within their visual distance and then proceed to decide where to visit based on their individual preference. Passenger's effective visual distance is estimated to be between 5 meters to 25 meters through the eye tracking exercise. Given the limited time in the airport, it is a zero-sum game in terms of passenger time for different shops in the terminal. The shops in the terminal are somehow competing for the passengers' visit, and each visit consumes an effective amount of time, leaving less time for visits to other shops. Thus, shops would be at a disadvantage if they are not within the passengers' visual distance at the earliest opportunity.

2.1.2 Literature Review on Influencing Factors

Based on the surveying study, we found that the passengers' movement and shopping decisions in the airport context are driven by four key factors including gender, travel purpose, dwell time and shop location. A literature review is carried out in parallel to validate the findings from a theoretical perspective. Also, the literature can provide insight into how these factors can be combined to build our coming behavioral model.

Gender

Gender is identified as one of the most important factors that affect the passenger's shopping decision (Baron and Wass 1996; Pan and Zinkhan 2006; Reimers and Clulow 2009; Lu 2014). The perception that shopping is women's work is upheld by current social practices (Van Eeden 2006). Gender also affects the type of activities that the passenger prefers. Tseng and Wu (2019) verified the impact of gender on shopping behavior. They found that male passengers are more interested in airport entertainment, whereas female passengers prefer shopping activities.

Travel Purpose

Freathy and O'Connell (1998) identified how airports categorized their passengers by their trip purposes, which relate to different shopping behaviors. Travel purposes can be broadly classified into business or leisure. Puls and Lentz (2018) pointed out that airport retail operators would require more personalized strategies targeting passengers with different travel purposes because passengers with different travel purposes have different preferences for product types. Volkova and Müller (2012) pointed out that business passenger purchase less from specialty retail at airports. Airport operators should carefully consider the types of products offered at the airport according to their passenger profiles including travel purposes.

Dwell Time

Dwell time is defined as the passengers' length of stay in the airport terminal before boarding the aircraft (Wu 2016; Tseng and Wu 2019). Dwell time is shown to have a significant impact on passenger's retail spending and activity choice in an airport environment (Graham 2009; Castillo-Manzano 2010; Bohl 2014). Volkova and Müller (2012) found that longer dwell time can boost the consumption of Food & Beverage product in the airport. Adey (2007) suggested that the airport should 'increase passenger's dwell time' by holding passengers in certain areas to boost the spending before passengers move to their boarding area.

Shop Location and Shop-to-passenger Distance

'Location, location, location' is arguably the first rule of retail. The location has been widely recognized as a competitive advantage in retail (Hernandez et al. 1998; Kim and Shin 2001). The location of concession and other commercial activities can have a significant impact on the airport's retail performance (Graham 2009; Martel 2009). For example, food and beverage concessions are usually placed in a corner location behind retail shops to draw passengers to the front of the retail offering. Airport and retailers are increasingly forcing the passengers to enter a shopping location by adopting the specific terminal design (Adey 2008). Given the limited passenger's dwell time, DAŞ (2016) proposed to decrease the total walking distance for passengers inside the terminal so that more time is allowed for shopping activities.

2.2 Airport Passenger Behavioral Model

After identifying the significant factors affecting passengers' movement and shopping behavior through the exploratory study and literature review, we attempt to incorporate the Gravity Model to investigate the impact of distance as well as the other factors on passengers' shopping behavior. The Gravity model represents a milestone in research in consumer spatial behavior (Zhu 2008). The gravity model has been successfully applied in a shopping center context to predict the stores chosen by a sample of shopping center patrons (Crask 1979). Most gravity models contain two essential components, movement cost, and utility. The models assume that people are attracted to places with greater utility, but hindered by the cost of the required movement (Crask 1979; Zhu 2008).

Our Proposed Model

The chance for a passenger to visit a specific shop is determined by both passengers' characteristics and shop attractiveness. In the previous exploratory study, we find that passenger demographics such as gender and travel purpose affect the passenger preference for movement and shopping activities in the airport environment. Also, each store type (i.e., luxury store) carries its utility. Besides, the visit chance is affected by shop location in terms of the dwelling time and visual distance of the passenger. Passengers' choice set of shops is limited to the shops available within their visual range. Combining the above factors, we can express the conceptual gravity model as follows,

$$Force_{ij} = P_t \cdot (M_i M_j), \quad \text{given that } R_i \leq V_r \tag{1}$$

Where:

- $Force_{ij}$= the instantaneous attractiveness of $shop\ type_j$ towards $passenger_i$
- M_i = the utility is driven by $passenger_i$ as represented as a function of gender and travel purpose
- M_j = the utility of the $shop\ type_j$
- P_t = probability of staying in the shopping area, calculated based on dwell time
- R_i = the distance from the shopper's present location to $shop_{\ i}$
- V_r = the visual range of passengers in the terminal

3 DEVELOPMENT OF AGENT-BASED SIMULATION BASED ON AIRPORT PASSENGER SHOPPING BEHAVIOR

This section describes the integration of the abovementioned passenger behavior model to an agent-based simulation. An overview of the simulation environment, aiming to model agent behavior to the environment, is illustrated in Figure 3.

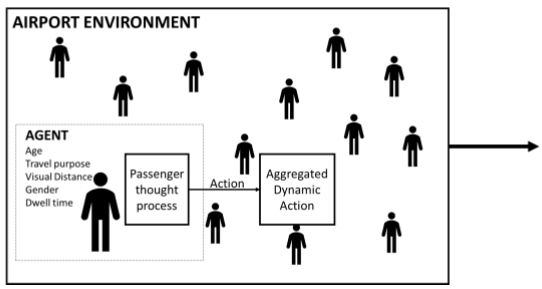

Figure 3: Schematic diagram of agent-based simulation.

3.1 Agent-based Environment Set-up

An airport simulation environment has been constructed based on a tier two airport in Asia. The simulation has been implemented in AnyLogic 8. The model was built upon a companion model, which conceptually illustrated the capability of agent-based simulation in airport retail modeling. The simulation environment covered 12 facility types in the airside of the studied airport. Each type of facility has its natural attractiveness towards the profiled-passenger (agent). Table 1 summarised the facility profile.

Table 1: Facility Profile.

Type of Facility	Impact
Bag	Conversion rate, Time & Money spent
Bookstore	Conversion rate, Time & Money spent
Cosmetics	Conversion rate, Time & Money spent
Electronics	Conversion rate, Time & Money spent
Fashion	Conversion rate, Time & Money spent
Food & Beverage	Conversion rate, Time & Money spent
Boarding Gate	No further activities
Gift	Conversion rate, Time & Money spent
Jewelry	Conversion rate, Time & Money spent
Luxury	Conversion rate, Time & Money spent
Liquor & Tobacco	Conversion rate, Time & Money spent
VIP Lounge	Time spent

The thought process of the agent, as demonstrated in Figure 4, is simulated through three stages – observation, decision and execution in the airport retail area. During the observation stage, the agent observes its surrounding with limited visual range (V_r). Thus, the agent will only choose facilities that are within its visual range. The passenger behavior model is then triggered at the observation stage. The agent will make the corresponding activity decision based on the force calculated from the gravity model. In the execution stage, passengers will move to the shop location and spend time/money according to the decision made in the previous stage.

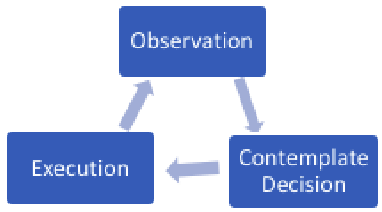

Figure 4: Passenger's Thought Process (Chen et al. 2018).

Agents are tagged with passenger profile characteristics as outlined in Table 2. These characteristics (i.e., passenger's social-demographics, movement pattern and their movement strategy) are obtained from a survey, which consists of questionnaire interviews with 300 travelers. 80% of the data are used to calculate the characteristics and calibrate the model, and 20% are kept for validation. These survey results were used to calculate (1) the inherent attractiveness of the shop as a proxy of the utility of the shop type (M_j) and (2) the state preference of the agent as a proxy of the utility driven by passenger profile (M_i). In our simulation, the probability of staying in the shopping area P_t is an empirically derived probability based on our data collected.

Table 2: Passenger Profile.

Factors	Impact on Passenger Decision
Age	Movement speed
Gender	Type of shop preference, the likelihood of purchase and early arrival at the gate
Travel Purpose	Type of shop preference, the likelihood of purchase and early arrival at the gate
Dwell time	Purchasing decision and likelihood to remain in the shopping area
Visual Distance	Only choose shops passenger within visual distance

3.2 Integrating Passenger Shopping Behavior Model and Agent-based Environment

We here use a sample agent – agent A to explain how the behavior model integrates with the simulation environment. Assuming agent A is a female leisure traveler and has 1 hour of dwell time to spend in the airside of the terminal. Agent A will move towards her pre-assigned departure gate. Based on the behavior model described in section 2, she will calculate all the shops' attractiveness within her visual range and picks the shop with the highest attractiveness. After she moved into the shop, she will spend some time (calculated from the survey and tracking data) at the shop. After she finished visiting the shop, she will move out and continue her journey towards the gate. She is continuously observing and making decisions while moving in the terminal. As her dwell time decreases over time, she will have a reduced chance to visit shops. The shops that she visited will be recorded in the system as footfall for that particular shop. If the purchase is made, the purchase amount would be recorded too. The purchasing probability and purchase amount are calculated based on a shop level using the actual data collected.

3.3 Model Calibration

The model is calibrated by comparing the simulated visit and the observed visit. The absolute percentage errors across all 12 shop types are summed up and recorded. Using the Calibration function in AnyLogic, we attempt to minimize the summation of absolute percentage error by systematically calibrating two parameters: visual range (V_r) and attractiveness of the shop (M_j). One thousand runs are conducted, and the calibration process terminates when the absolute percentage errors converged as shown in Figure 5.

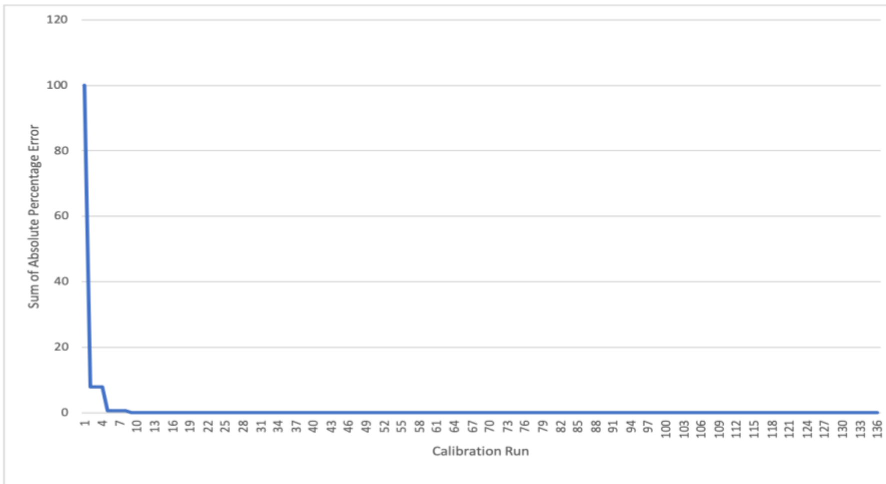

Figure 5: Calibration.

4 EXPERIMENT AND RESULTS

4.1 Base Model

Each facility's space is drawn up to scale, and shops are placed at their actual location based on the airport floor map. The simulation environment is shown in Figure 6. Entrance area is the area where passengers finish their immigration checks and begin their movement toward their pre-assigned departure gates. There are altogether 12 facility types (15 retail stores in total with 2 Fashion store, 2 Liquor & tobacco stores, 2 Cosmetic stores, 2 F & B Stores) in the airside part of the terminal.

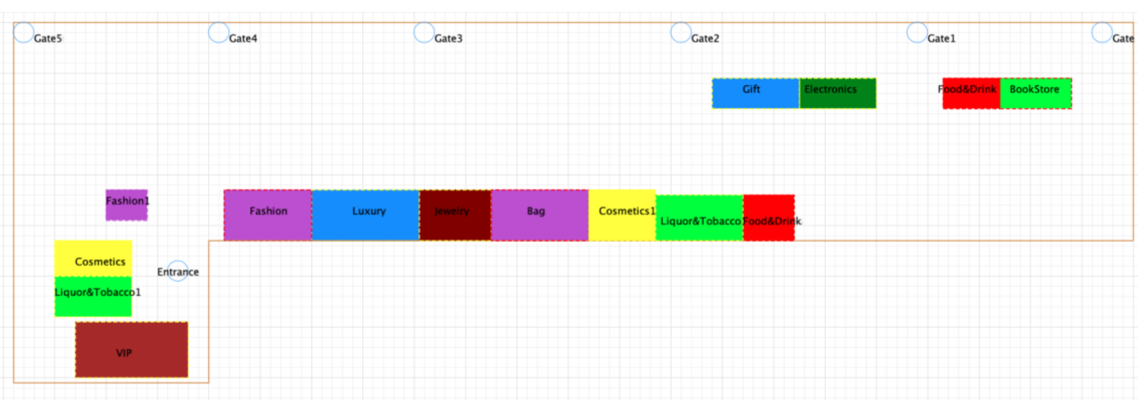

Figure 6: Floor Map of the Airport.

Based on our exploratory study, a 15-meter visual distance is set as the baseline. The attractiveness of the shop (M_j) is the default value obtained from the survey. The initial run on default values (without calibration) has a simulated shop visit as shown in Figure 7.

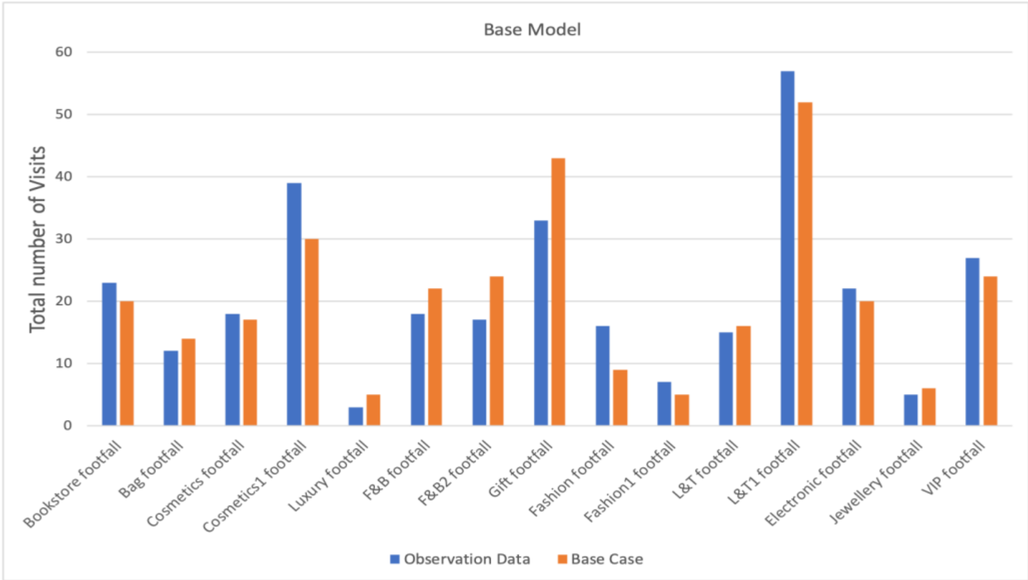

Figure 7: Compare Base Case Result Against Observation Result.

Validation

We have used historical data to test the validity of our calibrated model. We have used 240 samples to construct the model and the remaining 60 samples to test whether the simulation model behaves as per historical data as suggested by Sargent (2013). The calibrated parameters were updated in the simulation and used to test the model. We ran the calibrated model for ten replications with random seed and took the average visiting footfall. The validation result achieved a sum of absolute percentage error across 15 shops of 28% and an average absolute percentage error of 2%. The validation result is presented in Figure 8.

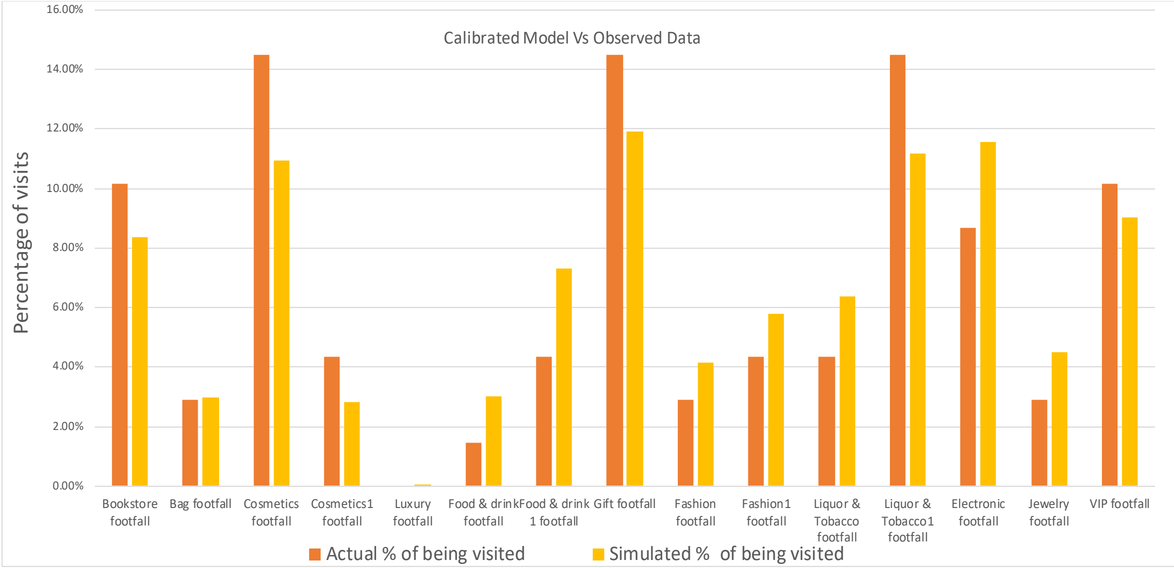

Figure 8: Validation Result.

4.2 Case Study – Moving Gift Store to a More Accessible Location

After the completion of the validation test, we performed a scenario study to observe the impact of shop location and distance on airport retail performance. The gift store is the most preferred shop type in the survey. However, the actual visit result to gift store is significantly behind the visit to the Liquor and Tobacco store that is placed near the entrance area. In the result presented in Figure 9, we attempted to relocate the gift store to a better location (by swapping its location with the fashion store). The result after switching the shops is compared to the data with the original layout. Although the gift store achieved a higher number of visits after relocation, the total spending across all shops decreased by 8.5%. This means that even though the gift shop now occupies a more accessible location and it attracts more passengers to visit the shop, as passengers spend more time in this shop, it reduces the likelihood of them visiting other more profitable shops. This means when airport retail operators decide the shop locations, more profitable shops (in terms of spending over time) should be placed at a better location.

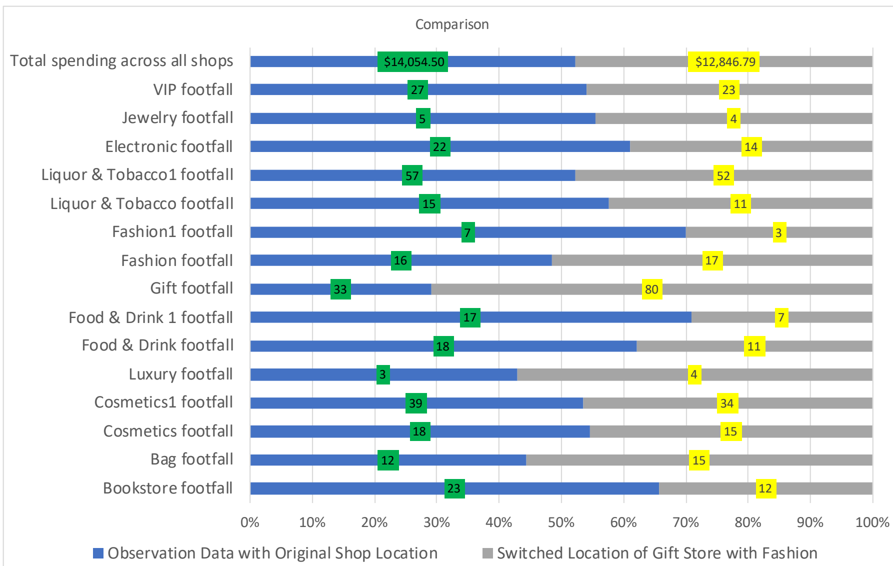

Figure 9: Scenario Study.

5 CONCLUSION AND FUTURE RESEARCH

The paper presented a calibrated and validated passenger behavior model that can simulate the passenger's movement pattern and shopping decisions. While the simulation has achieved its aim by demonstrating the importance of location and distance to airport retail performance, it should be further improved. First of all, this model only recreated the most common movement strategy adopted by passengers. Other movement strategy adopted by passengers should be represented in the simulation to ensure a better representation of the entire passenger population. Secondly, the sum of the absolute percentage error should be reduced to enhance the validity of the model further. Thirdly, the model should be expanded to accommodate other activities in the airside of the terminal. Future research should look into solving these key issues. This will help to fulfill the ultimate goal in providing a valuable simulation tool to airport retail planners in evaluating and exploring how existing terminal space could be better used to improve airport retail performance.

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