DEVELOPING A MULTI–AGENT–BASED SIMULATION MODEL OF USERS' WAYFINDING AS A REPRESENTATION AND POST–OCCUPANCY EVALUATION (POE) TOOL IN A HOSPITAL

Abstract

Ease of navigation is a critical consideration for complex settings. Generally, the literature demonstrates that disorientation due to environment complexity causes frustration, anxiety, etc. in patients. Therefore, the need for an efficient flow of people is particularly important. To analyze the human wayfinding pattern in process-oriented facilities, simulation is an essential tool to advance the visualization. Agent-Based Modeling is a promising simulation method that models individual decision-making process and dynamics inside the spatial environment. The objective of this research is to study outpatients' wayfinding patterns based on different daily workflow by using simulation. One of the main post-occupancy concerns is related to actual building performance from a behavioral and social perspective after completion. This research uses a multi-story Iranian hospital as a case study. It investigates two significant parameters of time and distance as a determinant of wayfinding in this healthcare facility. The scenario-based agent simulation was developed for modeling visitor wayfinding behavior in a computer-simulated environment (NetLogo). The findings of simulation study will help architects, planners, and designers or architects to visualize and optimize users' experiences and visitors' dynamics.

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Keywords

Human wayfinding, Agent-Based Modeling (ABM), post-occupancy evaluation (POE), evaluation tool, spatial configuration

Introduction

Wayfinding is a ubiquitous goal-driven activity that leads users from one point to another (Friesen & McLeod, 2014). However, this simple concept is a very complex process that needs to be evaluated and refined. Due to decreased physical and cognitive resources, the need for efficient users' dynamics is particularly significant in healthcare facilities. Accordingly, the users' dynamics are closely linked to the architectural layout (Wurzer, 2012). Simulation helps to understand and determine the refinement of the facility operations in a new approach (Friesen & McLeod, 2014). Multi-agent modeling is a new, unexplored paradigm of modeling from AI (Artificial Intelligence) for studying social dynamics. Simulation-based evaluation could help to find the errors in people flow and optimize the space distribution based on the results. Furthermore, it could facilitate human wayfinding and evacuation dynamics, reduce the unnecessary costs associated with outpatients being lost, and improve users' experiences and frustration through correct placement of the functional units. Agent-Based Modeling can be applied as a post-occupancy evaluation tool of a built environment to study the wayfinding process (Farr et al., 2012).

During navigation, the critical challenge people face is the increased length of pathfinding. It is essential to locate where people face decision-making difficulties and how long it takes for visitors to continue their travel. But the significant question is how to virtually study the human wayfinding inside a complex built environment; in other words, which method helps to discover space layout deficiency and congestion area during human wayfinding. To find a suitable

answer, an intelligent approach—Agent-Based Modeling—is introduced in this research. ABM is also known as a computational representation of social phenomena. Computer simulation through Agent-Based Modeling helps designers and researchers to study complex, dynamic systems like human wayfinding behavior (Helbing, 2012). Modeling of the wayfinding shows how people navigate inside the building during a daily workflow. The reasoning chain of a human wayfinding scenario leads to action with incomplete knowledge of the environment (Hajibabai et al., 2007).

The structure of this study will be as follows: The literature review section discusses the previous works done regarding human wayfinding in an indoor environment. The next section is methodology, the primary data collection and scenario development, and work order process flowchart for Multi-Agent-Based Modeling, and Agent Architecture is developed. In section four, the results are presented, and the conclusion and discussion for future are discussed in the last section.

Literature Review

The aftereffects of problematic areas during wayfinding are getting lost and feeling disoriented. It also brings more consequences such as injury or death during an emergency and lost staff time (Friesen & McLeod, 2014; Farr et al., 2012). The solution to these problems includes evaluation of crowd movement, and layout configuration to decrease waiting times, length of stay, and reduce admission times (Friesen & McLeod, 2014).

Therefore, the length of journey and the walking distances, including unsuccessful wandering, are important variables to measure the efficacy of wayfinding behavior. In hospitals, as one of the large, complex facilities, the need for good wayfinding is tangible due to constant interchanges through the times (Garling et al., 1986). Research indicates that there are several approaches to assessing wayfinding in a complex, unfamiliar building. According to Baskaya et al. (2004), Hölscher et al. (2006), Johanes and Yatmo (2018), and Slone et al. (2015), a physical environment's structure can have a huge impact on an individuals' ability of orientation and wayfinding tasks.

Architects believe that even signs cannot compensate for some architectural layout defects (also known as displacements) (Farr et al., 2012). Vilar et al. (2014), Johanes and Yatmo (2018), and Maruyama et al. (2017) argued about the relation between signs and the spatial configuration. Moreover, the importance of layout concerning signs' effectiveness in human wayfinding performance was assessed. On one hand, the visibility of a sign and its configuration inside the plan layout was studied; on the other hand, wayfinder's inclination to follow environmental variables (e.g., a brighter corridor with no sign instead of a darker corridor with a sign) was demonstrated.

A number of studies (Friesen & McLeod, 2014; Maruyama et al., 2017; Torrens, 2019; Raubal, 1999) suggested that simulation is a novel and cost-effective approach for studying human wayfinding behavior in the complex, unfamiliar environment. Furthermore, human wayfinding could be analyzed regarding plan configuration through simulation methods.

Prior studies evaluated the wayfinding behavior of people in complex buildings. They applied various methodologies to prove that floor plan spatial organization correlates with ease of navigation. Research was conducted using different methods such as real observation of visitors, questionnaires, and sketch maps. Contrary to first studies, some used Virtual Reality simulation, 3D simulation of a person, and Agent-Based Modeling. In addition, a few studies were conducted based on simulation and real word examination. However, all of those studies focus on single human object wayfinding performance. This research is the first to use direct observation with camera installation and an Agent-Based Modeling technique. This is the novel approach for studying human wayfinding; moreover, this study looks at the wayfinding behavior as a crowd motion or movement. Hence, several people are doing wayfinding simultaneously which makes more sense with what is happening in the real world. Therefore, several agents are implemented in the simulation process.

Methodology

In this study, two dependent variables, travel length (time) and travel distance, are chosen from the literature review as an important factor for wayfinding evaluation. The developed simulation model gives us the congestion points and the simulation of real hospital environment brought two calculated numbers: total journey time and total journey distance. The case study for studying outpatient's wayfinding is the built multi-level Ali Nasab hospital located in Tabriz, Iran. The workflow scenario of outpatients with the main destination of the surgical clinic is developed in this study. The sample size is the outpatient for a regular one-day visit to the hospital. It needs to collect data from the test case. In this study, Dr. Ali-Nasab Hospital (ANH), is selected for implementing the simulation. ANH is one of the largest and most well-equipped healthcare centers in the northwest of the country.

This research describes workflow scenario development based on visitor data to model multi-agents for wayfinding simulation. The primary data collection for developing the model is done as follows: getting permission from the IRB and hospital administer are required. The daily scenario of surgical clinic outpatients including sub-destinations (laboratory, pharmacy, and radiology) are developed. The flowchart of eight scenarios is developed.

Data Collection

The visitors' data are collected to develop wayfinding scenarios and flowchart. The visitor's data consist of the walking speed of each outpatient, the number of surgical clinic outpatients per day (N=130), the distribution of visitors per sub-destination (laboratory, pharmacy, and radiology). The outpatients' speed is defined as 0.11 m/s (Ozer et al., 2012). Main destination is called the functional unit that outpatients primarily are decided to check. Sub-destination are the places where doctors refer to outpatients who went to surgical clinics. The flowchart is developed in Microsoft Visio.

The eight scenarios are generated for outpatients with the surgical clinic as the main destination. Figure 1 presents the flowchart of outpatients. In all 130 outpatients, the main destination is the same but the population distribution for sub-destination is selected randomly 40 of the participants distributed to sub-destinations.

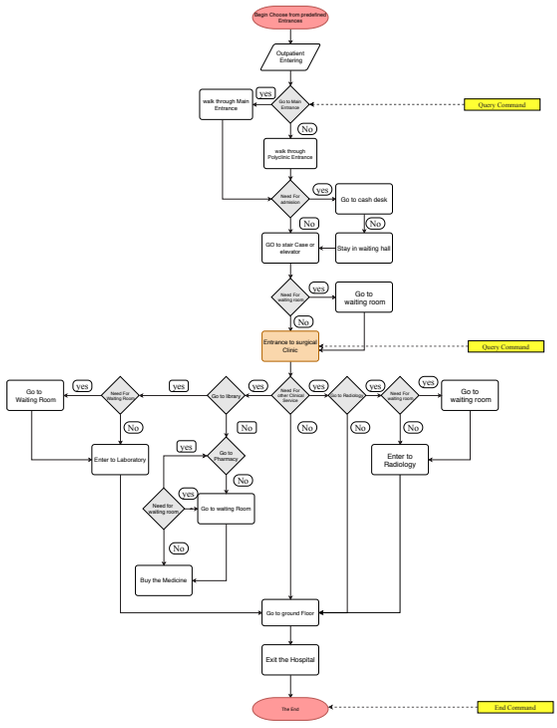

Figure 1: The outpatient workflow flowchart with surgical clinic as main destination. (Source: Author.)

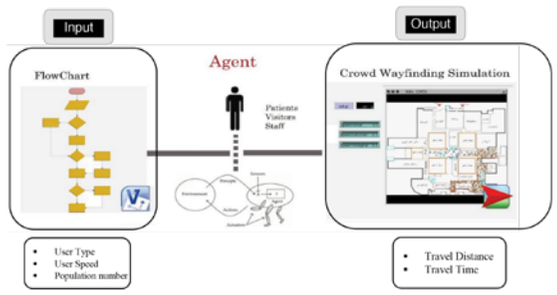

Figure 2: Representation of simulation process. (Source: Author.)

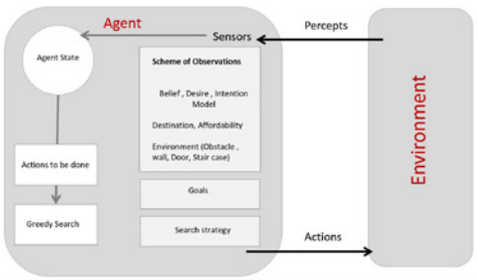

Figure 3: Interaction of agent (reactive, deliberate) with environment. (Source: Author.)

Figure 4: Simulated agent movement angle. (Source: Author.)

Developing Multi-Agent Simulation

The model is written in Netlogo version 4.0.2. Netlogo is a programmable modeling environment for simulating natural and social phenomena that is well suited for modeling complex systems (Wilensky, 1999). The schematic plan of the hospital was created. Its floor plans were generalized in AutoCAD to abstract unusable details because the excessive information takes too much memory; this schematic floor plan layout was imported to the Net Logo environment. In this study, the simulation was focused on the first and second floor where the destinations are located. And the crowd population is concentrated on this floor (Sokhansefat et al., 2012). Figure 2 represents the simulation process.

Agent Architecture

Internal representation of the world determines the architecture of the agent. Reactive agents have minimum internal representation and follow the action-condition rule; however, deliberative agents have symbolic representation. Deliberative architectures derived from the Artificial Intelligence (the Sense-Plan-Act paradigm) in which the control system include three components: the sensing system, the planning system, and the execution system. And the control flow is from the sensor to the actuator. The architecture of an agent is based on the structure of decision-making process (Sokhansefat et al., 2012). In this model, agents are reactive with an internal state (the mixture of reactive and deliberative reasoning), meaning that the agents are aware of the current situation in the environment and at the same time they are goal oriented. In this study, the concept of affordances is defined as a physical boundary or direction such as crossing the wall to reach a space or accessible spaces like corridors and doors. The relationship between agents, architectures, and programs in this model can be summarized as follows.

Program (Reactive Agent with Internal State) + Architecture (Belief, Desire, Intention Model) = Agent

Figure 3 represents the agent architecture and its interaction with the environment.

Agent Search Method

The search algorithm in the environment is a greedy best-first search. A node closer to the target is first expanded. The evaluation function, which estimates the travel time from a state (current state) to the target state, is called the exploratory function. In this simulation model, the greedy search algorithm determines how the agent moves or searches in the environment (Russell & Norvig, 2019). Alternatives (in front of) to the agent are generated randomly. The agent has 45° right- and left-turn movements. This kind of rotation changes the behavior of the agent to the real behavior of humans (people) in the environment. Figure 4 shows the agent motion angle.

Results

As a result, the total length of journey for a specific scenario and the total distance of a wayfinding process was calculated. The results are outlined in Table 1.

Destination	Scenario type	Distance/length of wayfinding	/hr
Surgical clinic	Scenario one (Exit)	Distance	4.28
		Time length	10
	Scenario two (Radiology)	Distance	3.59
		Time length	9.07
	Scenario three (Laboratory)	Distance	11.69
		Time length	11.06
	Scenario four (Pharmacy	Distance	5.5
		Time length	13.91

Table 1: The calculated distance and length journey. (Source: Author.)

The outputs are as follows: To consider the agent-based models of user motion as an effective tool for the urban and architecture field. To develop a model for evaluating design concepts in the primary phase of design or built buildings on the base of the user's movement. To evaluate the contribution of Agent-Based Modeling as an evaluation tool in the field of wayfinding, the ability to generate abstracted models of the real environment to study the effect of one environmental factor in wayfinding the experience of users. The utility of this model can be studied in various other large facilities such as an airport, university, and buildings that are important in terms of navigation and user behavior. To offer optimized adjacency relations matrix for space destitution in plan layout.

Conclusion

This study focuses mainly on the new way of ABM application for post-occupancy evaluation of human wayfinding. It majorly focuses on the simulation of the user's scenario-based or workflow egress model. The outcome of the simulation is the total travel time and distance for the sample outpatients. This study is considered as the first phase of the floor plan assessment. Alternative plan or optimization of spatial configuration can be performed based on the previous simulation results, and then the second phase of evaluation requires to be done for repeating the simulation in the new layout. Comparison of the two-phase simulation shows the difference of travel length and travel distance. It is concluded whether the spatial layout is optimized or not. If the space configuration is optimized, human navigation will be improved.

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