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Novel Applications of Agent-Based Modeling in Emergency Medicine Research – A Systematic Literature Review

Jason M. Adleberg, B.S.E.¹, Christina L. Catlett, M.D.¹, Richard E. Rothman, M.D., Ph.D.¹, Katie Lobner, M.L.I.S.², and Yu-Hsiang Hsieh, Ph.D.¹

¹Department of Emergency Medicine, Johns Hopkins University School of Medicine, Baltimore, Maryland ²William H Welch Medical Library, Johns Hopkins University School of Medicine, Baltimore, Maryland

Agent-based modeling (ABM) is an emerging method of computational modeling that simulate a set of ‘agents’ to interact with other agents and the environment around them in large complex systems and to take actions and make decisions based on a set of simple rules with which they are programmed.[1–3] This approach has been used to recreate a virtual ED where simulated patients and clinical providers move and interact over a period of time. Individual simulations can be run thousands of times, in order to collect robust statistical data.

As emergency medicine (EM) research is often concerned with the spatial and temporal dynamics of interactions between patients and providers, incorporation of ABM will give researchers a new set of tools to study challenging topics in EM research. However, little is known regarding the extent to which ABM methodologies have spread across the field of EM research. This paper will conduct a review of literature within the past 15 years that incorporates elements of ABM.

We conducted a systematic literature review of applications of ABM in EM for the key words ‘agent-based model’, ‘agent-based modeling’, ‘individual-based model’, ‘individual-based modeling’, ‘simulation’, ‘emergency department’, ‘emergency room’ on the PubMed, EMBASE, Cochrane, Science Citation Index, and Scopus databases. In addition, we also conducted a literature search of bibliographies from retrieved articles. The inclusion criteria were ABM and EM research and the exclusion criteria included non-original research articles, non-English publications, publication before the year 2000, and ABM simulations which did not involve an ED, such as best practices for ambulance dispatch and in-field disaster management.

Two reviewers assessed titles and abstracts for relevancy on 1,856 papers from the literature search in July 2014 (Figure) and then on 161 articles for full-text review on the use of ABM

Please address correspondence to: Dr. Yu-Hsiang Hsieh, Johns Hopkins University Department of Emergency Medicine, 5801 Smith Avenue, Suite 3220 Davis Building, Baltimore, MD 21209, Phone: 410-735-6413, Fax: 410-735-6425, yhsieh1@jhmi.edu.

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after initial screening. After eliminating papers with overlapping or duplicate material, 9 papers were selected. Information from each article regarding overall study characteristics (including the first author, country, language, and date of publication), initial number of agents included in each simulation, and software used was extracted and summarized.

Overall, nine articles met our inclusion criteria (Table 1).[4–12] Three of the nine papers used NetLogo,[13] an established software package, to conduct their simulation (Table 2). Other simulations either used custom computer code (e.g. the C++ scripting language) to conduct their analyses, or did not explicitly document the details of their implementation.

The number of agents in the nine models ranged from roughly 200 patients in an ED, to 4,900,000 people in a metropolitan area. Patients in virtually all ED simulations were assigned a level of triage as a characteristic. Global variables controlling the simulations also were similar: these included number of beds of the virtual ED, average waiting time for a patient to be seen, and arrival rate of patients. Each of these nine articles addresses either of two broad categories: seven address ED operations, and two address infection control in the ED.

Each article under ED operation category applied ABM to build a simulated ED. Among them, a model ED was used to investigate the effect of various ED operation strategies (re-triage, triage and radiology process, patient diversion, staff allocation) on patient wait time or ED crowding was studied in both single ED and a network of several EDs. Parameters relating to ED patient flow, staffing, and physical layouts were included in these models.

Both articles under infection control category applied ABM to build a simulation model to investigate strategies to reduce nosocomial infection in metropolitan EDs during an influenza epidemic. In addition to the considerations of ED patient flow, staffing, and physical layouts, parameters related to infectious disease transmission including contact rate, susceptibility/immunity, and transmission probability were included in these models.

Discussion

Our finding demonstrate that only a handful of studies have applied ABM methodology in EM research, indicating that ABM is still a novel and emerging methodology for EM researchers. This sentiment is additionally demonstrated in a recent narrative literature review article that ABM was not one of the modeling approaches for ED patient flow and crowding research.[14] However, each of the nine articles identified here illustrates the value of applying ABM methodology to EM addressing two main issues: ED operations and infection control, although other subjects within EM may be appropriate for ABM as well.

The obvious challenge for the implementation of ABM within EM is the lack of familiarity of EM researchers with this cutting-edge computational approach. Didactic talks and workshops on ABM at local, regional, and national EM conferences will introduce a basic awareness of the principles of ABM to EM researchers and practitioners. In addition, cross-disciplinary collaboration with ABM experts in other fields will benefit the growth and development of ABM applications in EM research.

Another barrier is that as ABM has a symbiotic relationship with computing technology,[15] practitioners of ABM require some degree of comfort with software skills.[16, 17] In the future, simpler user interfaces for ABM programs, should help to decrease the learning curve for the application of ABM to EM research.

In conclusions, our findings demonstrate that ABM can be of tremendous utility in studying ED operations, staffing patterns, patient triage algorithms, patient flow, wait times, and infection control strategies. This innovative approach to modeling can improve efficiency of ED operations and patient management as well as patient safety.

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Figure 1.
Steps in selection of studies to be included in meta-analysis

Table 1

Descriptive data of included articles

Category	First Author	Title	Year	Journal	Type
ED Operations	Jones ^[4]	An agent based simulation tool for scheduling emergency department physicians	2008	AMIA Annual Symposium proceedings	Conference Proceedings
	Rahmat ^[5]	Agent-based Modeling and Simulation of Emergency Department Re-triage	2013	2013 IEEE Business Engineering and Industrial Applications Colloquium	Conference Proceedings
	Taboada ^[6]	An agent-based decision support system for hospital emergency departments	2011	11th International Conference on Computational Science	Conference Proceedings
	Wang ^[7]	An Agent-based Simulation for Workflow in Emergency Department	2009	Proceedings of the 2009 IEEE Systems and Information	Conference Proceedings
	Laskowski ^[8]	Uncertainties Inherent in RFID Tracking Systems in an Emergency Department	2010	2010 IEEE Workshop on Health Care Management	Conference Proceedings
	Laskowski ^[9]	Models of emergency departments for reducing patient waiting times	2009	PLoS One	Journal Article
	Neighbour ^[10]	Agent based modeling of “crowdinforming” as a means of load balancing at emergency departments	2010	Online J Public Health Inform	Journal Article
Infection Control	Laskowski ^[11]	Agent-Based Modeling of the Spread of Influenza-Like Illness in an Emergency Department: A Simulation Study	2011	IEEE Transactions on Information Technology in Biomedicine	Journal Article
	Aleman ^[12]	Accounting for Individual Behaviors in a Pandemic Disease Spread Model	2009	Proceedings of the 2009 Winter Simulation Conference	Conference Proceedings

Table 2

Modeling characteristics of included articles

First Author	Brief Description	Study Population	No. of Agents	Software	Agent Variables
Jones ^[4]	Patients move through various stages of a representative ED waiting for physicians, and a histogram of waiting times is created.	Representative ED pop. of a 520-bed Level 1 trauma center	~33,000	NetLogo (v4.0.2)	beds, avg. weekly patient arrivals, % of ambulance arrivals
Rahmat ^[5]	Patients enter a representative ED with one of three triage levels. A re-triage process is implemented, and differences in mean wait times are recorded.	Representative ED population of Hospital Universiti Sains Malaysia	689	N/A	Triage level, treatment duration, deterioration pattern, work shift, weekday/weekend
Taboada ^[6]	Patients of diverse backgrounds enter a detailed model ED, and the optimal combination of staff to treat them is studied.	Hospitals of Mataro and Sabadell, Catalonia, Spain	~400	NetLogo	Age, medical history, communication skills, symptom severity, level of experience (ED staff)
Wang ^[7]	Patients enter a representation ED and wait to be triaged and seen by physicians and radiologists. Mean wait times and triage algorithms are varied to study the consequences of average wait time.	Representative ED population of Univ. Virginia hospital	~1,000	NetLogo (v4.0.3)	avg. triage time, patients/hr, beds, physicians, radiologists
Laskowski ^[8]	Patients are tagged with RFID (Radio Frequency Identification) tags, and the system of tags and monitors is evaluated for feasibility.	Non-specific	200	Custom (C++)	Location, triage score
Laskowski ^[9]	Patients enter an ED staffed with a variable number of healthcare workers, and average expected waiting times are simulated.	Non-specific	N/A	Custom (C++)	Triage score, healthcare staff
Neighbor ^[10]	Patients are informed of expected wait times at local hospitals, and the consequences of avg. patient wait times is investigated.	Representative population of Winnipeg, Canada	650,000	Custom (C++)	Location
Laskowski ^[11]	The spread of an influenza-like illness is monitored in a representative ED.	Representative ED pop. of Winnipeg Regional Health Authority Hospital	~700	Custom (C++)	Waiting room capacity, transmission probability, number of doctors, arrival rate of infected patients
Aleman ^[12]	The spread of a highly contagious flu is simulated in a major metropolitan area. Infected agents seek different courses of treatment, which affects the secondary rate of infections.	Representative pop. and hospital network of Greater Toronto Area	4,900,000	Custom (C++)	Healthcare worker or patient, Seeking treatment once infected