An Agent Based Framework For Occupant-oriented Intelligent Facility Management Scheduling

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ABSTRACT

Facility managers today inevitably deal with various tasks from daily operations. With the advances in facility technologies, the amount of data available is increasingly larger and more complex, especially for campus and healthcare facilities. A significant challenge is how to improve efficiency, productivity and profitability with limited resources, budget pressures and tight schedules, while still meeting the expectations of building occupants. To address such a challenge, this paper proposes an advanced artificial intelligence (AI) framework that utilizes agent modeling to facilitate system-wide decision making for facility management. The framework is developed to help facility managers analyze and prioritize tasks according to factors such as degree of emergency, budget, and occupant satisfaction level, etc. Unlike previous construction industry agent models, this framework takes into consideration both the preferences and feedback of building occupants in the decision-making process for facility management. This paper realizes this framework through Anylogic based on a real case study and proposes a unique algorithm. The AI model will combine opinions from facility managers and occupants to automatically generate an optimal task schedule. The simulation in a residential building demonstrates that the framework is feasible for dealing with real-world operations.

INTRODUCTION

Nowadays, there is a dilemma in the field of facility management (FM) between having many FM tasks and limited resources. In a medium-sized building, occupants can typically submit more than 50,000 requests for FM service every year (Cotts et al. 2009). Therefore, fulfilling FM tasks efficiently and effectively is always a challenge for facility managers. Traditionally, FM is mainly regarded as a business function that requires facility managers' work experience and judgment to make decisions (Cotts et al. 2009). Academia is increasingly looking for more scientific ways to address various FM problems. While much research effort has been put into this issue and resulted in manyoperation methods, few have worked well because of the dynamic and complex characteristics of FM tasks (Liu and Mohamed 2008).

According to Macal and North, the challenge can be solved through agent-based modeling and simulation (ABMS), as a "third way of doing science" due to its ability to work on dynamic and complicated problems (Macal and North 2009). For example, maintenance and repair (M&R) of civil infrastructure, a function of FM, has attracted increasing attention due to the inevitable deterioration process. According to Sanford and McNeil, infrastructure facilities are sure to deteriorate with use, no matter how well constructed or maintained. Many researchers have successfully constructed ABM to work on the problem (Sanford and McNeil 2008).

Similarly, this paper adopts the idea of using ABM as a foundation to develop efficient FM with automatic M&R scheduling. With the help of ABM, this paper proposes a new FM framework that includes occupants and facility managers or operators. The interactive system generates a FM task schedule considering the needs of both occupants and facility managers.

The paper is presented as follows. Section 2 is a literature review. Section 3 presents the new multi-agent based model in FM. Section 4 implements the model and a case-study simulation.

BACKGROUND

This section discusses ABM and its application in FM through a literature review. Although there is no consensus on the definition of agent, people agree on some characters of an agent, including: autonomy, cooperation and learning ability (Nwana 1996). These characters make ABM a powerful tool in dealing with FM works.

Multi-agent System Construction Industry. ABM has been applied in the construction field for some time. This phenomenon is due to the awareness of the inherently complex nature of construction problems and the difficulty in working on them. The key in improvement is analyzing the problem by considering a human agent. One example is an ABM highway system composed of pavements, bridges, signs, signals, and decision makers (Sanford and McNeil 2008). They creatively solve the interactive process through an agent model. The study, however, did not realize a very complex framework. Watkins applies ABM in a construction site to predict and analyze congestion that may harmfully impact the efficiency of a project (Watkins et al. 2009).

Although ABM is prevailing in construction management, it has a limited scope of application in infrastructure management and facility management (Osman 2012). There is only limited research focused on ABM in facility management. Some have presented ABM as an effective decision support system in infrastructure management (Sanford and McNeil 2008). Osman offers some excellent research into an ABM framework that consists of four agents, including occupant, asset, operator and politician. It deals with the FM problem by first taking a consideration of occupant satisfaction. Level of satisfaction is solved via a behavioral model in the paper. However, Osman did not implement the whole model and the simulation only solves the problem of occupant satisfaction.

Multi-agent Resource Allocation. Later research raised the idea of ABM with multi-agent resource allocation (MARA). This can solve one kind of problem concerning limited resources. This method is also adopted in this paper. The definition of MARA can be described as, “The process of distributing a number of items amongst a number of agents” (Chevaleyre et al. 2006). Some scholars apply MARA in asset management because it can address system deficiencies concerning limited resources (Sanford and McNeil 2008). Obviously, this method is also suitable for the construction industry because of sharing entities and competence in dealing with limited resources. Additionally, the allocation of resources greatly affects the cost of a project (Liu and Mohamed). One of the best papers came from Liu and Mohamed, who construct a MARA model to allocate bays to ships. However, this model is more like a static model because the allocation process is completed all at one time. In reality, this process should go on continuously.

Multi-agent Resource Allocation in FM. Based on the above analysis, this paper introduces a MARA model for FM. FM is also a complicated activity that needs a dynamic decision support system. Although there are many available software systems that support the FM decision-making process such as Computerized Maintenance Management Systems (CMMS) (Halfawy and Froese 2007; Cotts et al 2009), they do not consider the interaction between occupants and facility managers. After all, occupants are service receivers; therefore facility managers must also meet their requirements, rather than only considering the building. The model in this paper incorporates the advantages of the above papers and solves this deficiency. The decision support system can automatically produce a schedule for facility managers and in particular, consider occupant opinions in the decision-making process. Later parts of the paper will implement the model and present a case-study simulation. The adaptability of the model allows it to work well in a number of different situations.

MULTI-AGENT MODELING IN FACILITY MANAGEMENT

This section proposes a multi-agent resource allocation system for FM. There are three kinds of agent in a FM system: occupants, facility manager and tasks. Both occupant agents and the facility manager agent are standard types that are capable of taking actions in response to other information. They have different properties and are capable of taking many actions. The task agent is static without action or behavior in the communication process. The task agents have many properties that may largely affect the behavior of occupants and the facility manager. Most of the task agent properties are based on case-based reasoning when required and therefore the properties may change at different times.

Occupant Agent. The main properties of occupant agents are preferred solution and level of satisfaction. For every task, occupants have their own preferred solution, such as schedule time. Occupant feedback to a solution produces the level of satisfaction, which should affect the behavior of facility managers. Occupant agents can evaluate the problem and solution sent by facility managers. Problem evaluation concerns the emergent degree in a certain situation and such considerations. Occupant agents connect to the facility manager agent by sending a problem report message to the facility manager agent and receiving a problem solution message.

Facility Manager Agent. Similar to occupant agents, the facility manager agent behaves differently according to different situations. The properties mainly concern resource limitations. A facility manager has a limited schedule for work time, budget and human resources. Naturally the action or behavior is focused on how to effectively allocate resources toward solving various tasks. Furthermore, a facility manager needs to evaluate task factors and create a time schedule to deal with the tasks.

Task Agent. The task agent is the only static agent and is without active actions, but tasks affect other agent behavior. Different tasks have properties based on historical data such as frequency and emergency level. Tasks also have properties that indicate approaches to solving them, such as finish time, required human resources and materials. All of these properties are closely bound by the resources of the facility manager agent. In an ideal system, these properties are calculated based on case-based reasoning from a large pool of cases. For example, by searching for the most similar task in a case pool, it is possible to evaluate the needed human resources.

MODEL IMPLEMENTATION

The above section defined the basic agent-based framework for solving and scheduling FM tasks. It is a model that can be extensively applied in almost every part of FM. To test its feasibility, a specific maintenance and repair (M&R) scheduling problem was solved by applying this framework. The case study was a normal residential building and data was collected from interviews.

Model Working Procedure. The case study aims at producing a FM tasks schedule automatically for the two facility managers in a residential building. If a FM requirement is needed:

1. Occupants can log into a user-oriented interface to input the specific details of a problem. At the same time, the occupant is able to choose their preferred date and evaluation on the emergent degree of the problem, which is the E_{user}.
2. A problem database collects all the real-time problems reported by the occupants. The system will then automatically convert all the current problems into a file visible to the facility manager so they will have a general view on what needs to be done.
3. The facility manager has a limited budget and amount of human resources to fulfill the work of facility management. Therefore, after receiving the tasks, the FMer agent needs to allocate limited resources to solve tasks according to priorities.
4. Once the FMer agent makes an allocation plan, an occupant agent will evaluate it based on its own situation, which is connected to the preferred processing time.
5. If the evaluation outcome of an occupant agent is not satisfied, the FMer agent will receive negative feedback and proceed to change its plan. The FMer agent will continue to evaluate scenarios until the occupant agent agrees with the schedule.
6. The last resource allocation plan corresponds to a schedule including the evaluated start time and end time of the task. A schedule report covering the overall future plan is available to both occupants and the facility manager. Occupants are able to see the start time pertaining to their own problems. Meanwhile, the facility manager will have a detailed work schedule.

Algorithm

Interaction Procedure. Occupant agents input all the problems into a web interface with their preferred data and evaluation of emergent degree. It can be represented as (a, b, c), which a represents the number of problems, b represents preference data, and c represents evaluation of emergent degree.

When scheduling the tasks, managers need to consider two factors: the objective emergent degree ranked by them and the subjective emergent degree submitted by occupants. The objective emergent degree is given in the above procedure.

Obviously, occupants may sometimes have some special need for a particular problem, which can dramatically increase the emergent degree for that particular instance. Therefore the total emergent degree can be represented as $E_{total} = \omega_{fm} \times E_{fm} + \omega_{user} \times E_{user}$. Theoretically, two weights can be adjusted based on a manager's opinion. In some cases, a manager may consider more on occupant's satisfaction and give the occupant weighting a larger value. This is also reflected in our model so that it can be applied to any building.

The weighting by an occupant ω_{user} is not a constant value even in one building. The weighting of an occupant's evaluation will increase when the occupant assigns a higher score to a task. The exponential function with base e is adopted to depict the relation. The When a normal task is extremely urgent for an occupant; the task will be addressed in advance.

Allocation Algorithm. The manager will calculate all the emergent degrees of various tasks and assign them a rank. The task with the highest emergent degree will be addressed first.

1. The manager agent will search for time based on the preferred date to see if there will be enough time to finish the job. If so, the job will be inserted into the schedule. If not, the system will automatically search for the nearest time to the preferred date.
2. The occupant is able to agree with or reject the solution from the manager agent. If they do not agree with the result, they can send back a response and the manager agent will continue searching for an acceptable time.
3. An urgent problem will be inserted into the schedule on the next day by replacing scheduled tasks with a minimal E. However, the replaced tasks will have a 20% bigger E_{total} when allocated to the next time. With this rule, a particular task will not be continually replaced.

Case Study Background and Assumptions. The example building is a nine-floor student apartment containing more than 200 residential units in Atlanta. The interviews were conducted in October and November of 2013. Two facility managers are responsible for all the daily M&R tasks reported by occupants. According to the managers, they receive quite a large number of work requests every day and find it hard to schedule a suitable plan that addresses all of the problems. Even though they are busy throughout the day, they still cannot satisfy the requirements of most of the occupants. To simulate a solution for this problem, we first listed the top five frequent problems based on the facility managers' experiences and corresponding finish times.

Table 1. Data of FM Tasks

Problem	Problem Index	Finish Time	Emergent Degree
Plumbing	0	3 h	5
Locks	1	0.5 h	4
HVAC	2	2 h	3
Lights	3	0.5 h	2
Washing Machine	4	1 h	1

The emergent degree in the fourth column was determined by the facility managers based on their work experience and preferences. In this chart, all the problems are normal, meaning none were considered as extremely urgent.

In our model, problems are produced through a random simulation every day, but the total number for a week was an estimate based on input from the facility managers, which were thirty tasks over a period of seven days. The work hours for facility managers was set at eight hours every day from 8 a.m. to 4 p.m.

Problem collection is a dynamic procedure that happens at any time during the day. However, as the problems were produced by the simulation, we needed to assume that the problems were collected at the end of the day and the schedule made from the next day.

Result Analysis. The model was simulated with Anylogic (2013). The first simulation was for problems over a week with an estimated total of 30 problems. The problems over each day were as follows. The problems on Friday are not mentioned because they will be solved in the next week.

Table 2. Simulation Result for FM Tasks

Mon	**Tue**	**Wed**	**Thu**
3, 4, 2, 2, 1, 1	4, 2, 0, 4, 4, 4, 3, 1	2, 3, 4, 3, 3	4, 2, 3, 4, 3, 0, 1, 1

The number in the second row is the index number of the problems. In reality, they are reported by occupants. The main page of the program in Anylogic includes the simulation over four days because we assume that all the problems can be solved from the next day. Therefore, no tasks will be solved on Monday. The simulation results are described in four time schedules and two of them are listed below:

Table 3. Schedule at the End of the First Day

Tue	Wed	Thu	Fri
4(0):8-8.5	3(3):8-10	3(2):8-10	4(1):8-8.5
			1(4):8.5-11.5
			2(5):11.5-12

Table 4. Schedule at the End of the Fourth Day

Tue	Wed	Thu	Fri
4(0):8-8.5	3(3):8-10	3(2):8-10	4(1):8-8.5
2(7):8.5-9	3(12):10-12	5(11):10-11	1(4):8.5-11.5
	4(6):12-12.5	1(10):11-14	2(5):11.5-12
		2(17):14-14.5	1(8):12-15
		5(21):14.5-15.5	

Table 1 is the schedule made at the end of the first day. Table 2 reflects the schedule made at the end of the fourth day. In every grid, the problem and associated occupants, as well as schedule time is displayed for facility managers. The numbers in the parentheses represent an index of occupants.

In this simulation we did not consider occurrence of an emergent problem such as leakage, which needs to be addressed immediately. According to the algorithm, however, facility managers can directly insert the emergent problem into the schedule and extract the scheduled problem with minimal E_{total}. The extracted problem is subsequently allocated with a larger E_{total} and being allocated for another time.

CONCLUSIONS AND FURTHER RESEARCH

This paper applied ABM in FM to address the complex and dynamic characteristic of this field. The proposed decision-making system in this paper helps a facility manager to solve M&R problems with a consideration of occupant preferences. Through this system, the facility manager can complete problems based on a clear schedule, and also largely satisfy the needs of occupants. The framework is flexible and can handle a variety of cases because variables in the model can be adjusted. A case-study was provided to apply the framework. The satisfaction level of occupants can be improved by considering their requirements. This case gave a good example on how to applying the ABM framework in FM.

The limitation of the paper is it mainly considers the satisfaction level of occupants to make the schedule. However, more critical factors are recognized to impact the FM such as influence on energy efficiency. Therefore author is working on evaluating the energy influence of different FM works, which might be more attractive for facility owners to receive this AI model. By adding this factor into the ABM framework, while considering the satisfaction level of occupants, the ABM framework will indeed be beneficial for every stakeholder. And the AI model can be extensively applied in FM to replace the manual decision procedure.

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