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Developing Fire Evacuation Simulation Through Emotion-based BDI Methodology

Celine Haren Paschal [a], Cheah Wai Shiang [a *], Sim Keng Wai [a], Muhammad Asyraf bin Khairuddin [a]

[a] *Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak, 94300, Malaysia*
*Corresponding author: *wscheah@unimas.my*

***Abstract*— Fire evacuation simulation is a tool to study human behavior in dealing with fire. It has been used for safety policy management studies, building safety analysis, and human safety understanding. To date, modeling the fire evacuation behavior is paying much attention in which works have been done to design and develop building model, fire model, human decision model, and human emotion decision model. As fire evacuation simulation is important, the BDI methodology is introduced by authors to ease modeling and simulation of human behavior in a fire evacuation. Continue the success of capturing and modeling the human behavior in a fire evacuation. This paper presents the influence of human emotion in fire evacuation simulation. In this paper, the emotion-based BDI methodology is presented with a walkthrough example of how emotion can influence the human decision in a fire spreading scenario. The OCEAN model of personality is used to handle the emotional properties in the methodology. Different people have different types of personalities, which can affect both decision-making and emotion in different situations. A fire evacuation simulation is developed by using the Unity3D game engine. The simulation is created based on the emotion-based BDI methodology presented. Hence, the emotion-based BDI methodology can be used to model human behavior and emotional states in a fire evacuation. Overall, the paper introduces a new insight into how to model human behavior in fire evacuation decision-making systematically.**

***Keywords*— Emotion-based BDI; emotion modelling; Unity3D; fire evacuation simulation.**

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I. INTRODUCTION

Transferring people from a place affected by the fire to another safer place is one of the procedures done during a fire evacuation [1]. The fire evacuation procedure is required to ensure people understand how to behave in an emergency when an unpredictable fire incident occurs [2]. An unpredictable incident is an incident that is difficult to predict in terms of its time of occurrence, form, or means through which it may take place and, in turn, put human lives at risk [2]. To reduce loss, people are educated on fire evacuation procedures [3]. Fire evacuation is a set of procedures that are taken to evacuate the affected area to another safer place [4]. From the review, evacuation drills and simulations are introduced to disseminate and practice the fire evacuation procedures to the public [2]. Generally, in an evacuation drill, a personal evacuation skill is developed, and the environment will be more recognizable to the public, especially in public places such as schools, supermarkets, airports, national parks, and other public buildings [2]. Hence, to improve the evacuation planning and procedures, simulations are conducted. Simulation is used to study how people react during fire evacuation to simulate how virtual agents behave in a virtual environment and have become a useful tool that could avoid injuries and reduce the budget for evacuation drill [2]. Evacuation research shows growing interest, especially in evacuation simulation, where researchers are paying attention to adding the element of human behavior [5]. The researchers are moving into designing and developing a realistic human model by considering the element of human behavior, human composition, and the environment [6], [7]. To date, modeling the fire evacuation behavior is paying much attention in which works have been done to design and develop building model, fire model, human decision model, and human emotion decision model. As fire evacuation simulation is important, the BDI methodology is introduced by authors to ease modeling and simulation of human behavior in a fire evacuation. Continue the success of capturing and modeling human behavior in a fire evacuation. This paper presents the influence of human emotion in fire evacuation simulation.

The paper introduces a new insight into how to model human behavior in fire evacuation decision-making with emotional influence systematically. Emotion is a mental response such as fear or anger, which can be affected by surrounding events [8]. Emotion can also cause a person's behavioral changes and decision-making [9]. Based on the study, emotion has affected human decisions during a fire evacuation. For example, the fear emotion during a fire evacuation can lead to panic, which will cause an undesirable decision that can harm the person itself and the people surrounding [10].

A. Related Work

Works have been done to model the human emotion through state transition diagram [11], mathematical representation [12], agent-based model [13], flowchart [14], a combination of Lazarus theory of cognitive and appraisal in a stressful situation, and fuzzy logic [15] and a combination of BDI, personality model and OCC mode (model proposed by Ortony, Clore, and Collins) while considering the effect of Yerkes-Dodson Law [16]. In this paper, the emotion-based BDI methodology is presented with a walkthrough example of how emotion can influence the human decision in a fire spreading scenario. The contribution of this research is to introduce an alternative methodology to model the human emotion in fire evacuation in a systematic manner.

II. MATERIAL AND METHOD

As mentioned, modeling human behavior in fire evacuation is a complex process. Hence, a methodology [17]– [19] is introduced to analyze, design, and implement human behavior. Grounded by the BDI theory, the methodology covers four phases and six steps. The phases are user cognition understanding, conceptual domain modelling, platform-independent design, and platform-specific design. The steps are described in detail in the following subsection.

We extend our early work on BDI methodology by adding the element of human emotion throughout the whole BDI development process. The adoption of BDI theory in human cognitive modeling through AOM [17] is extended by adding the element of human emotion. To add the element of emotion, the EBDI (Emotion, Belief, Desire, Intention) architecture [20] is adopted as a guideline to produce the proposed emotion-oriented BDI methodology, as shown in Figure 1.

Furthermore, we adopted the emotion models from the revisited version of the OCC (Ortony, Clore & Collins) Emotion model. Another property of emotion that is considered in the proposed methodology is the level of fear during evacuation [11], [21]– [23]. According to the hierarchical cluster analysis of emotions [24], fear is listed as one of the basic emotions. Then, according to work in [24], from the emotion fear hierarchy, the level of fear emotions is adopted [11], [21]–[23], [25]. Hence, the six general fear level (Calm-Alarm- Fear-Terror- Panic- Hysteria) [11] is used in this research to represent the human emotion during a fire evacuation explicitly. Generally, during a fire evacuation event, the main emotion involved is the emotion of fear. Hence, the proposed methodology will focus emotion of fear.

Fig. 1 shows the proposed methodology to model emotion-based human behavior through BDI theory. The proposed emotion-oriented BDI methodology consists of four phases and six steps. The phases are user cognition understanding, conceptual domain modeling, platform-independent design, and platform-specific design.

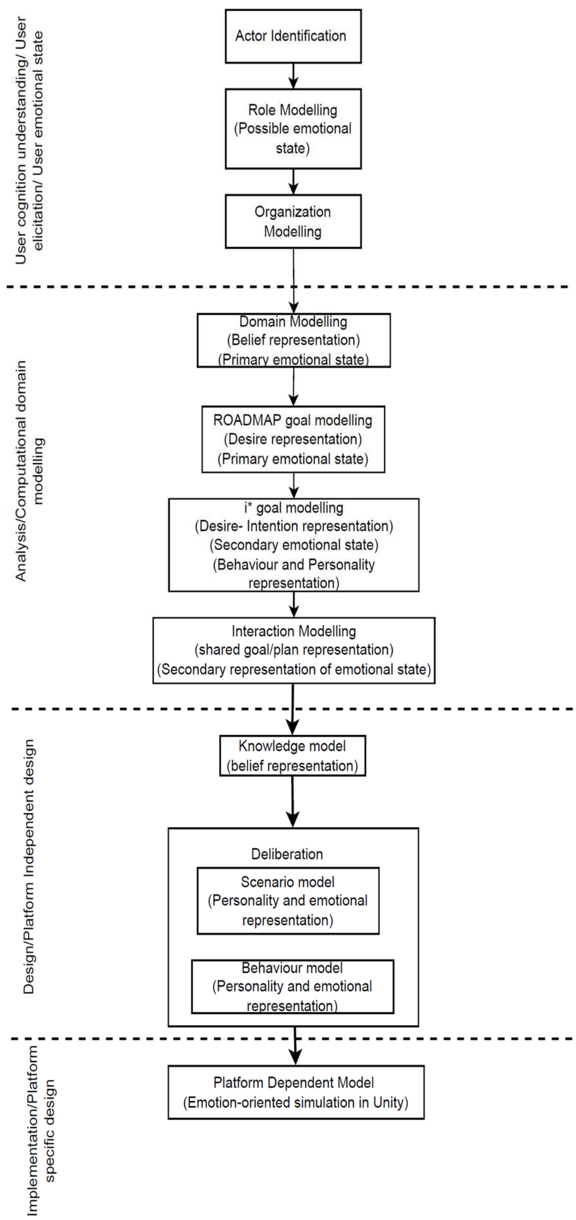

Fig. 1 Overview of the emotion-oriented BDI methodology

A Walkthrough example of the emotion-oriented BDI methodology in building evacuation is elaborated in the following section. The walkthrough example presents the role of an actor such as victims and firefighters involved in a fire evacuation scenario and the decision-making process during the evacuation. The emotional human behavior model is shown as follows to model human behavior.

A. Step 1 Actor Identification

Actor identification involves locating staff(s) or actors in a working environment. In our scenario, firefighters and victims are the important staff to hire based on the situation. After the actors are identified, the process continues with organization modeling and role modeling. The organization model represents the interaction between the organization's actors [17]. For example, in a fire evacuation scenario, the evacuating victim is one of the goals that the firefighter can do. Hence, the interaction between firefighters and victim is unidirectional, which means they involve in one way of communication. Figure 2 shows the organizational model that describes the relationship between the actors.

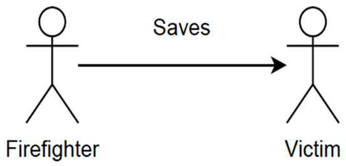

Fig. 2 Organizational model

B. Step 2 Primary Emotion Modelling

Primary emotion modeling involves modeling the first emotion an agent or actor feels during an event or situation. The modeler can list all possible emotions according to each role's responsibility. The role model is adopted to model the primary emotion of the actor. Table 1 shows the role model for firefighters, which the responsibilities of the firefighter are to “evacuate the victim, stabilizing the injured victim, firefighting, rescue victim”. The constraints are “too many victims, too many injured victims, the fire is uncontrolled, lack of rescue equipment or team member”. The possible emotions related to the responsibilities and negative emotions related to the constraints are listed in Table 1. For example, the responsibility of evacuating the victim, the firefighter might have the fear emotion or the opposites of fear emotion, which is the hope emotion. This means the firefighter can either feel hopeful or fear when evacuating the victims. The determination of positive emotion will be related to the responsibilities and what the actor might feel when fulfilling the responsibility. While the negative emotion will represent what the actor feels when the constraints happen or when the responsibility is not met.

TABLE I
ROLE MODEL FOR THE ROLE FIREFIGHTER

Role	Firefighter		
Description	Respond to emergency (that needed rescue)		
Responsibilities	**Positive Emotion**	**Constraints**	**Negative Emotion**
Evacuate the victim	Hope	Too many victims	Fear
Stabilizing the injured victim	Hope	Too many injured victim	Fear
Firefighting	Hope	The fire can’t be controlled	Fear
Rescue victim	Hope	Lack of rescue equipment or team member	Fear

C. Step 3 Belief Modelling with Primary Emotion Modelling

This step involves modeling the actors' primary emotion, fact, or general belief. The domain model is adopted to further model the primary emotion and the belief. In domain modeling, the primary emotions will be represented based on the different entities and the relationship between different entities when an event occurs. The emotions will be represented by a heart shape (positive emotion) and spade shape (negative emotion) [26], [27] as stated in Table 2.

TABLE II
NOTATION FOR THE EMOTION-ORIENTED DOMAIN MODEL

Notation	**Meaning**
	Domain entities (i.e., smoke)
	Role/Agent
	Positive emotion (i.e., hope)
	Negative emotion (i.e., fear)

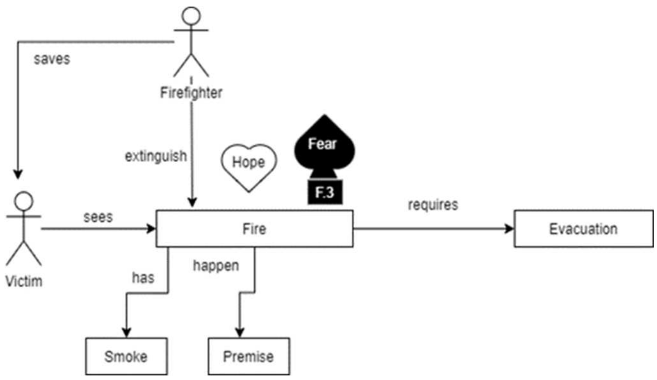

Fig. 3 Emotion-oriented domain model

In a fire evacuation scenario, they are two main actors involved: the Firefighter and the Victim. Both the victim and firefighter believe that there is fire since smoke is seen at the premises. Both actors also believe that evacuation is required. Then, the firefighter needs to save the victim. The possible emotion felt by the victim when they encounter the fire or smoke will be fear or its opposite emotion, which is hope. Fear is classified as a negative emotion as it is an expectation of a negative outcome, and with fear, a human can learn to avoid dangerous signals [28]. Whereas hope is classified as a positive emotion as it expects a positive outcome, and humans can respond positively if the hope emotion is felt [28]. In terms of this scenario, both actors can either feel either the fear emotion first or the hope emotion.

D. Step 4 Modelling emotion, desires, and intention (Secondary Emotion)

This step models the secondary emotion, desires, and intention of the emotion-oriented BDI cognitive architecture. The secondary emotions are the emotion that appears after the primary emotion, which can also replace the primary emotion. For example, in a fire evacuation situation, the primary emotion or the first emotion felt by the victim is the calm emotion. After seeing the fire spread, the actor's emotion can change into fear, which is considered the secondary emotion. Hence, two layers of the modeling layer are introduced in this step. The first level represents the higher-level desires and primary emotions related to the goals through the ROADMAP goal model. The goals provide an overview of the functionalities that an agent system should achieve. The goals can be divided into sub-goals. There are two types of goals: functional goals and quality goals representing nonfunctional requirements for a system. In the emotion-oriented methodology, the modeler can model the primary emotion associated with every goal in the first level. The goals related to a role indicate the actor or agent involved in achieving the goal.

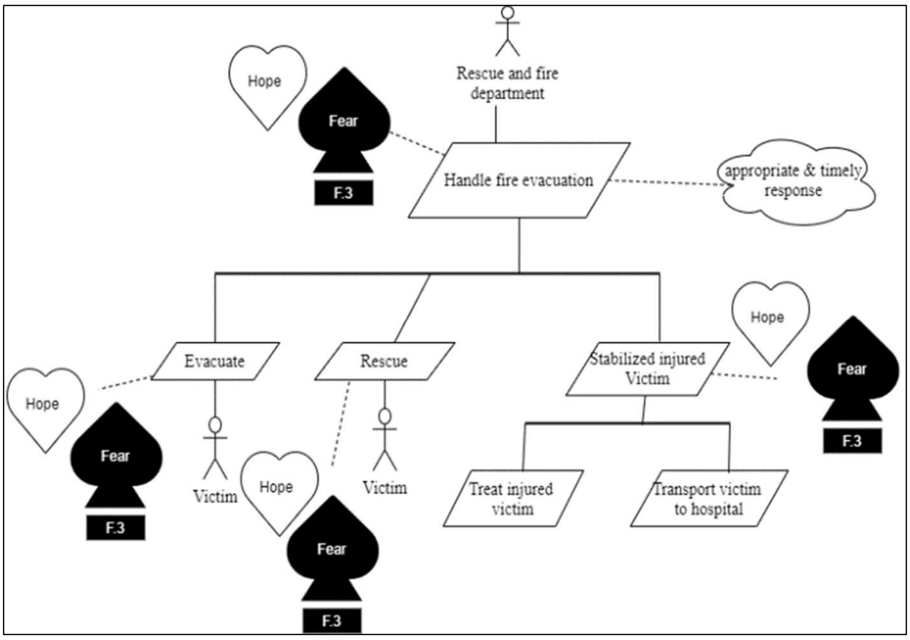

Fig. 4 Emotion-oriented ROADMAP goal model

Using the OCEAN personality type [14], we can model the decision-making based on human behavior as listed above. OCEAN personality models are made up of five main factors: openness, conscientiousness, extraversion, agreeableness, and Neuroticism. Different personality types will have different behavior and emotions during evacuation [29]. Hence, the Tropos i* goal model is used the model every personality type with the possible emotions involved with the desires and intentions.

Using the OCEAN personality trait and behaviors during evacuation [14], [30], the personality analysis and descriptions can create the agent behavior. The notation will be shown in Fig. 5, and behaviors are listed below:

- O+N- Follow Prudently-These people are open-minded and calm. They will follow the crowd prudently according to the surrounding environment.
- O-N+ Follow Blindly-These people are conservative, dependent, and sensitive. They will follow the crowd blindly without considering whether the leader's behavior is reasonable.
- O-C-E-A-N+ Irrational behavior-These people are sensitive, introverted, solitary, negative, and give up easily. They may express irrational behavior during evacuation.
- O+C+E+A+N- Leading behavior-These people have their own opinions and stable emotions. They are independent and maybe a leader in the evacuation.

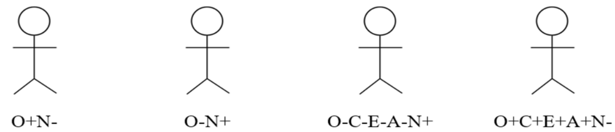

Fig. 5 Personality behavior notation

Fig. 6 shows the second level of goal modelling which is represented by the i* goal model to represent the desire and intention for handling fire evacuation. The emotion-oriented i* goal model in Fig. 6 represents more detailed goal decomposition, roles of firefighters and the secondary emotion which involved the different levels of fear emotions. The models also represent the belief of the actor. Besides, in the emotion-oriented i* goal model, the task is affected by the emotional state of every subgoal as shown in Fig. 6. This means the task is updated based on the emotional state of the goal or desire. In this situation, the number of victims, victim position and victim status are the belief that represents the firefighter's knowledge information towards evacuating the victims. Furthermore, the model can be further extended to represent the common goals that are shared by different actors as shown in Fig. 8. The goal to evacuate is achieved by both the victims (of the four personality types) and the firefighters when they have interactions.

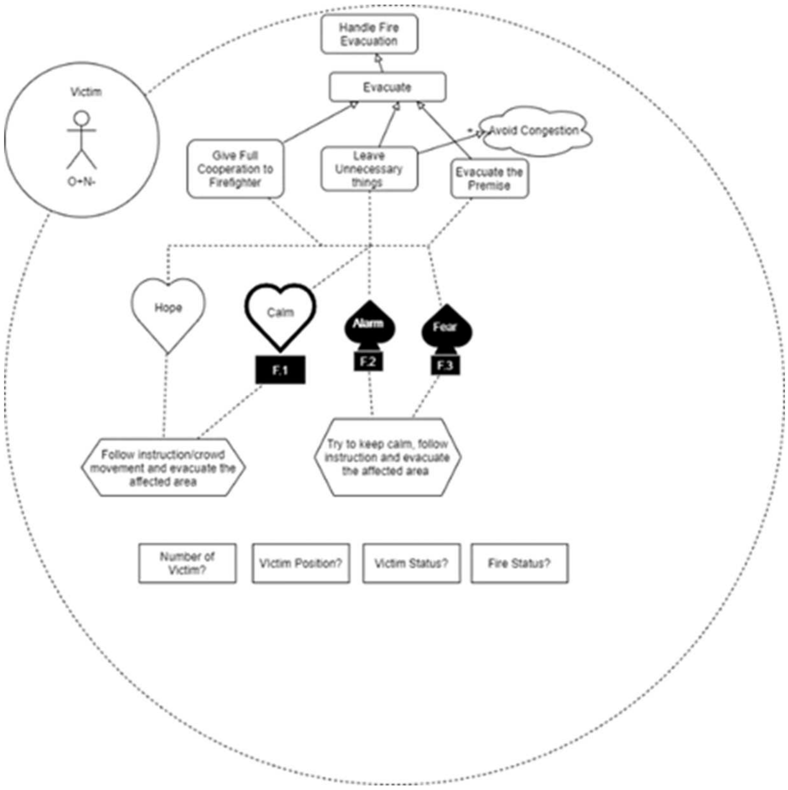

Fig. 6 Level 2: Emotion-oriented i* goal model for the victim with personality type: O+N-

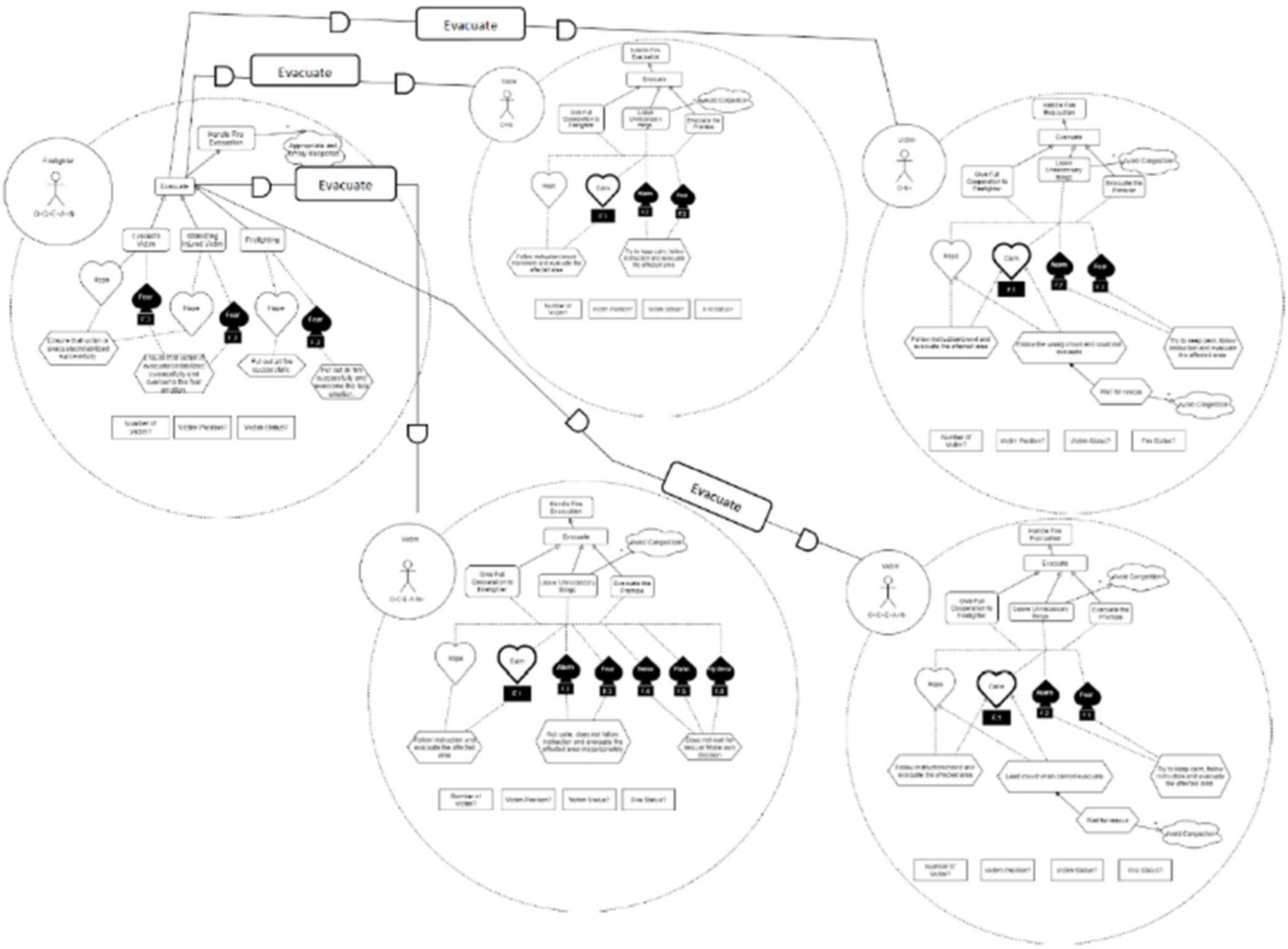

Fig. 7 Level 2: Modelling shared goal

Hence, these steps also model the shared goal or shared plan and sharing policy through the interaction model. Fig.8 shows an emotion-oriented interaction model, representing the interaction between firefighters and Victims with personality types: O+N-, O-N+ and O+C+E+A+N- during a fire evacuation event secondary emotional states involved during the interaction. For example, when the victim informs the firefighter about the incidents, both the victim and the firefighter will feel hopeful.

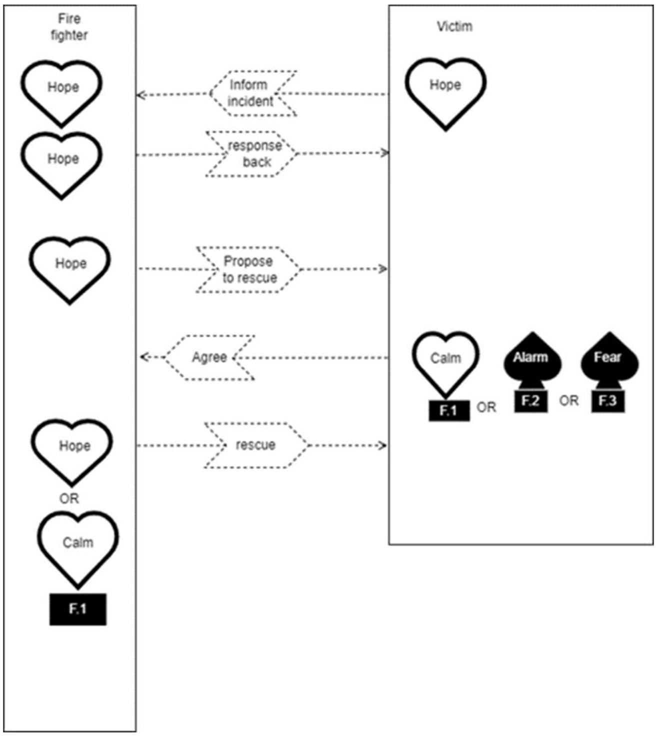

Fig. 8 Emotion-oriented interaction model for the victim with personality type: O+N-, O-N+ and O+C+E+A+N-

E. *Step 5 Deliberation Modelling*

In this step, deliberation is the strategy to choose the best options by considering the desire and plan. Hence, in this emotion-oriented BDI methodology, emotion will also be one of the factors used by an individual for desire consideration and plan reconsideration. The context during deliberation needs to be modeled in detail. Therefore, based on the JASON cognitive architecture, when modeling deliberation, first, the contextual details. Deliberation is determined based on belief and events. Hence, the triggering parameters such as emotion, behavior, and personality properties need to be captured in detail. Knowledge model will represent the knowledge about the agents and objects in its environment or agent itself.

Fig. 10 shows the deliberation of agents towards the goals through graphical representations based on the scenario model. It also models the entire agent's belief and intentions to achieve its desires. Furthermore, from the behavior model, we can see how the entire architecture of the emotion-based BDI methodology and how the emotions and personalities affected the decision making.

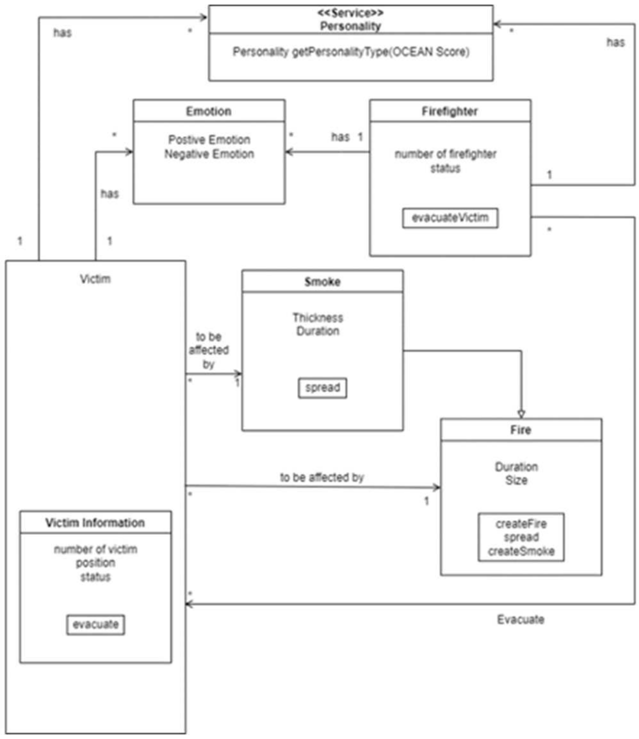

Fig. 9 Knowledge model

TABLE IIII
THE EMOTION-ORIENTED SCENARIO MODEL FOR ACHIEVING THE GOAL "HANDLING FIRE EVACUATION" FOR PERSONALITY TYPE: O-N+

Plan	Evacuate Premise			
Initiator	Victim with personality type O-N+			
Trigger	fireIsNear=true/ smoke =true			
		Description		
Belief	**Step**	**Desire**	**Plan**	**Soft goal/ Goal or plan**
hasFire	1 1.1	Evacuate Give Full cooperation to firefighter	Hope or Calm	Follow instruction/ crowd movement Evacuate affected area
hasFire	2	Leave unnecessary things	Hope or Calm	
fireSpread noClearExit	3	Find another exit	Alarm or Fear	Try to keep calm Follow instruction Evacuate affected area
	4	Evacuate the premise	Hope or Calm	
hasFire	1 1.1	Evacuate Give Full cooperation to firefighter	Hope or Calm	Follow instruction/ crowd movement Evacuate affected area

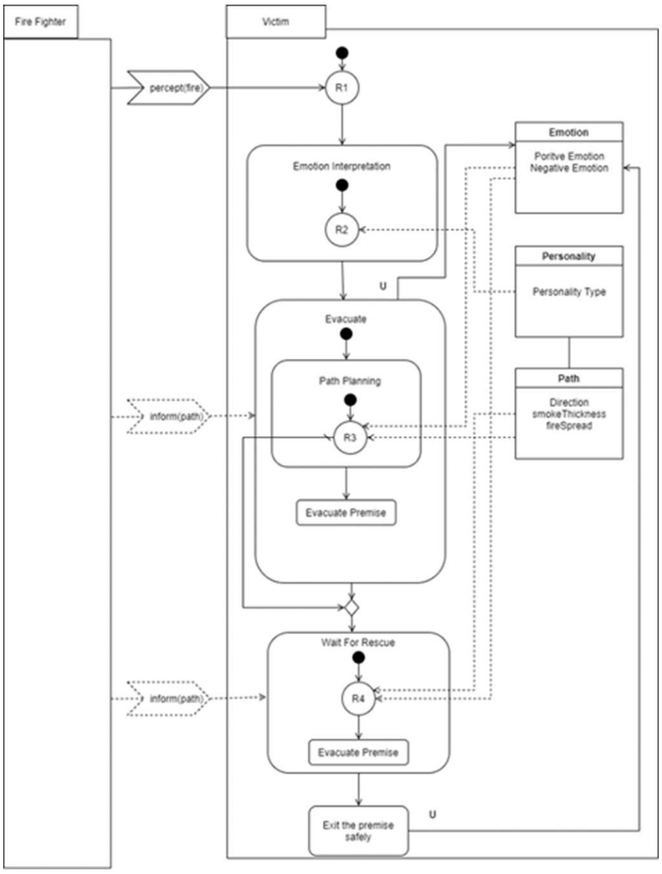

Fig. 10 Behavior model for the victim

F. Step 6 Platform Specific Design and Modelling

The agent models are transformed into a BDI based simulation Unity platform. The emotion-based BDI methodology can be transformed into the emotion-based BDI simulation by adopting our previous work [18]. A BDI plugin tool has been created 18] using the programming language provided by Unity3D to develop the BDI simulation model. Hence, to develop the emotion-based fire evacuation simulation through emotion-based BDI methodology, the same Unity3D tools will be used to implement the proposed methodology. For example, based on previous work in [18] Table 6 shows the mapping of the scenario model into Unity3D construct.

TABLE IIIV
MAPPING OF EMOTION-BASED SCENARIO MODEL INTO UNITY3D CONSTRUCT

Model context	**Unity3D construct**	**Example of Unity3D syntax**

Agent desires and intention type	Procedure	private void Update ()
		{
		//do something
		//for example, update the belief(emotions)
		}

Agent interaction activity	Void OnTriggerEnter(Collider other)	private void OnTriggerEnter(Collider other)
		{//do something
		}

Rule and condition	The "if" or "if else" logic operator	if condition{
		//do something
		}

III. RESULTS AND DISCUSSION

From the modeling of the behavior model, we can transform design models into an emotion-based BDI simulation platform, as reported in this section. This section presents the human reaction in response to fire evacuation. Fig. 11 shows the interface of the fire evacuation simulation through emotion-based BDI. It showcases the transformed models into the Unity3D tool. The right part of the interface shows an example of how the personalities are set up, and the emotions are set as a precondition(belief) to determine the success(desires) of the evacuation(intentions) process.

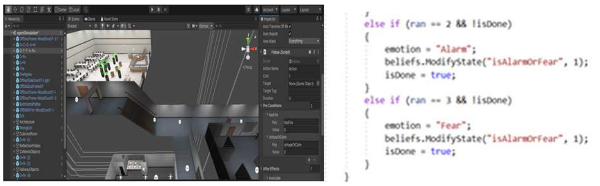

Fig. 11 Prototype of the fire evacuation simulation

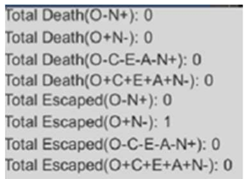

Fig. 12 Sample result from the fire evacuation simulation

Fig. 12 shows that the agent with personality type O+N- where they are calmer and more open-minded, is the first agent that managed to evacuate the premise compared to the other personality type. The total death and total escape can be observed according to the different personality types from the simulation. Hence, personality is one factor that triggers human emotion during a fire evacuation. Besides, Fig. 11 shows part of the emotion-based BDI decisions in fire evacuation simulations. This showcases how the emotions(belief) is updated for the decision-making of the emotion-based fire evacuation simulation. Therefore, the fire evacuation simulation can be developed as real as possible through the emotion-based BDI methodology.

IV. CONCLUSION

Fire evacuation simulation systems have played a big role in improving the evacuation procedure due to cost-effectiveness and flexibility. Results from the simulation can be obtained faster than the actual fire drills, and the requirements can be changed accordingly. As emotion modeling is a complex process, the introduction of emotion-based BDI methodology has eased the process of modeling emotions involved during a fire evacuation. Besides, adding emotions as a requirement or conditions for developing a fire evacuation is a stepping stone to improve the fire evacuation simulation to be as real as possible. In future work, this research can be extended to understand the role of third parties, such as interactions between other victims or firefighters, and how it can affect the decision-making or the emotions between them, which is much closer to the real situations. This is important to design realistic human behavior in fire evacuation simulation.

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