



Faculty of Computer Science and Information Technology

**An Emotion-based Belief-Desire-Intention Methodology for Fire
Evacuation Simulation**

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**Master of Science
2025**

An Emotion-based Belief-Desire-Intention Methodology for Fire Evacuation Simulation

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A thesis submitted

In fulfillment of the requirements for the degree of Master of Science

(Software Engineering)

Faculty of Computer Science and Information Technology

UNIVERSITI MALAYSIA SARAWAK

2025

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.


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ACKNOWLEDGEMENT

Taking this master's research was a decision that I would never regret. Throughout the journey, I have learned a lot of things and gained a lot of experience. However, it was nearly impossible for me to complete this research without the help of my supervisor Dr Cheah Wai Shiang. Therefore, I want to express my gratitude to my supervisor who is always there to help me in my research studies and for the opportunity that he has given me.

Besides that, to my family especially my parents Paschal Anak Dagang and Serdi Ajang who are always patiently supporting my master's journey and are always there to encourage me and not give up.

Furthermore, to my fellow friends and research mates, I'm also truly grateful for your support and help through this journey.

To all the other lecturers and staff of the Faculty of Computer Science and Information Technology, UNIMAS thank you for your support and guidance.

Finally, I would also like to thank the Centre of Graduate Studies and the administration of UNIMAS for the support and guidance which allowed me to complete this research journey successfully. Thank you all.

ABSTRACT

This research aims to extend the Belief-Desire-Intention (BDI) methodology by incorporating emotions to provide a more authentic simulation of complex human behaviour in fire evacuation scenarios. Emotions play a vital role in decision-making processes, making their accurate representation necessary for realistic simulations. Building upon these findings, two experiments were conducted: Experiment 1 compares the effectiveness of the emotion-based BDI methodology against the extended BDI methodology in modelling agent behaviour during fire evacuations. Experiment 2 employs the System Usability Scale (SUS) score to assess the usability of the emotion-based BDI methodology. The outcomes of both experiments demonstrate the potential of the proposed approach to create more accurate and insightful simulations. This study expands the understanding of the relationship between emotions and behaviour and contributes to the refinement of the emotion-based BDI methodology, making the way for improved simulations across diverse scenarios. Through this research, the potential of enhancing computer simulations with emotions, offering a more authentic representation of human behaviour and decision-making in critical situations, can be observed. This research contributes to extending the BDI methodology by incorporating emotional factors to improve decision-making during fire evacuations. By designing an emotion-oriented BDI framework and evaluating key emotional properties, the study enhances the realism and reliability of evacuation simulations. The integration of emotions leads to more accurate decision-making patterns, resulting in better safety outcomes and more realistic simulations that closely mirror real-world human behaviour in emergencies. Hence, from the results of the analysis, the emotion-based BDI methodology can be used to present human responses, providing a valuable framework for future advancements in simulation technology and applications.

Keywords: Emotion, emotion-based BDI methodology, BDI methodology, fire-evacuation simulations, emotion modelling

Metodologi BDI Berasaskan Emosi untuk Simulasi Pemindahan Kebakaran

ABSTRAK

Penyelidikan ini bertujuan untuk memperluas metodologi 'Belief-Desire-Intention (BDI)' dengan menggabungkan emosi, bertujuan untuk menyediakan simulasi yang lebih tulen bagi tingkah laku manusia yang kompleks dalam senario pemindahan kebakaran. Emosi memainkan peranan penting dalam proses membuat keputusan, menjadikan perwakilan tepatnya penting untuk simulasi realistik. Berdasarkan penemuan ini, dua eksperimen telah dijalankan: Eksperimen 1 membandingkan keberkesanan metodologi BDI berasaskan emosi terhadap metodologi BDI lanjutan dalam memodelkan tingkah laku ejen semasa pemindahan kebakaran. Eksperimen 2 menggunakan skor 'System Usability Scale' (SUS) untuk menilai kebolegunaan metodologi BDI berasaskan emosi. Hasil kedua-dua eksperimen menunjukkan potensi pendekatan yang dicadangkan untuk mencipta simulasi yang lebih tepat dan berwawasan. Kajian ini memajukan pemahaman kita tentang interaksi antara emosi dan tingkah laku dan menyumbang kepada penghalusan metodologi BDI berasaskan emosi, membuka jalan untuk simulasi yang lebih baik merentas pelbagai senario. Melalui penyelidikan ini kita dapat melihat potensi mempertingkatkan simulasi komputer dengan emosi, menawarkan gambaran yang lebih tulen tentang tingkah laku manusia dan membuat keputusan dalam situasi kritikal. Penyelidikan ini menyumbang penyelidikan yang meluaskan metodologi BDI dengan memasukkan faktor emosi untuk menambah baik pembuatan keputusan semasa pemindahan kebakaran. Dengan mereka bentuk rangka kerja BDI berorientasikan emosi dan menilai sifat emosi utama, kajian ini meningkatkan realisme dan kebolehpercayaan simulasi pemindahan. Penyepaduan emosi membawa kepada corak membuat keputusan yang lebih tulen, menghasilkan hasil keselamatan yang lebih baik dan simulasi yang lebih realistik yang mencerminkan tingkah

laku manusia dunia sebenar semasa kecemasan. Oleh itu, daripada hasil analisis, metodologi BDI berasaskan emosi boleh digunakan untuk membentangkan respons manusia, menyediakan rangka kerja yang berharga untuk kemajuan masa depan dalam teknologi simulasi dan aplikasi.

Kata kunci: *Emosi, metodologi BDI berasaskan emosi, metodologi BDI, simulasi pemindahan kebakaran, permodelan emosi*

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LIST OF ABBREVIATIONS

BDI	Belief, Desire and Intention
OCC	Ortony, Clore & Collins
EBDI	Emotion, Belief, Desire, Intention
AOM	Agent-Oriented Modelling
CA-SIRS	Cellular Automata- Susceptible, Infected, Recovered, Susceptible

CHAPTER 1

INTRODUCTION

1.1 Study Background

A fire evacuation drill is essential to disseminate and practice a fire evacuation procedure to the public. The fire evacuation procedure is required to ensure people understand how to behave in an emergency when an unpredictable fire incident occurs. (Tomar, 2019). The fire evacuation is a set of procedures which is taken to transfer people from a place affected by the fire to another safer place (Abdul Aziz et al., 2019).

To simulate a fire evacuation process, a real drill is implemented. However, evacuation drill results are limited or inaccurate due to the lack of the element of fear emotion; the number of participants may be inaccurate and unrealistic experiment (Zinke et al., 2014). To overcome the real fire drill practice, fire evacuation simulation is introduced.

Fire evacuation simulation is a valuable tool for determining the safety of a building or premises and the efficiency of the evacuation process in the event of a fire. Besides, fire evacuation simulation is used to determine the evacuation behaviour such as the time needed to evacuate an affected area. On the other hand, fire evacuation simulation is an effective approach to reproducing evacuation behaviours of people during fire accidents (Ding et al., 2024).

Several simulation techniques have been introduced for fire evacuation simulation. They are mathematical model which uses mathematical representation to develop the fire behaviour to run the simulation (Mutthulakshmi et al., 2020). An agent-based simulation is introduced to study how people react during fire evacuation. The modelling is used to give

a clearer insight into the complex evacuation process. To support agent-based fire evacuation simulation, an extended BDI methodology is introduced (Wai et al., 2021). When modelling human evacuation during a fire, the main goal is to ensure that everyone has evacuated the affected areas in time and there will be fewer casualties are expected when the evacuation is done.

Although an agent is modelled with human cognitive architecture (Wai et al., 2021), it is still missing the notion of emotion when simulating the fire drill evacuation. Emotion is a mental response such as fear or anger, which can be affected by surrounding events. Emotion can also be the cause of a person's behavioural changes and decision making. Emotion has affected human decisions during a fire evacuation (Moore-Petinak et al., 2020). For example, fear and emotion during a fire evacuation can lead to panic which will cause an undesirable decision that can bring harm to the person and the people surrounding. Hence, adding emotion into the BDI agent simulation is needed to enhance its ability to mimic human behaviour and decision-making processes more accurately.

Hence, in this research, the proposed methodology aim to improve the extended BDI methodology to be able to model the complex emotional properties of human behaviour in decision making focusing on a fire evacuation case study. The proposed methodology aim to investigate the ability to adopt the existing BDI methodology to represent the emotional properties as described throughout this research.

In this research, the proposed methodology adopt the state of the art of the (Openness, Conscientiousness, Extroversion, Agreeableness, Neurotism) model (Durupinar et al., 2011) by integrating OCEAN model in the BDI methodology to enhance the emotional intelligence and behavioural realism of the BDI agent simulation. The OCEAN model, also known as the Big Five personality traits model, provides a comprehensive framework for

understanding human personality based on five key dimensions: Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Durupinar et al., 2011).

1.2 Research Problem and Questions

Simulating believable human behaviour during fire evacuation is challenging, as emotions like fear, panic, and stress significantly affect decision-making, often leading to irrational behaviours such as herding and freezing (Kinatader & Ronchi, 2019). These emotional responses complicate evacuation simulations, highlighting the need for models incorporating psychological factors to improve safety and predict crowd dynamics more accurately. Although work has been introduced to simulate agents in fire evacuation through extended BDI methodology (Wai et al., 2021), explicitly incorporating emotional elements into the BDI framework for evacuation scenarios remains largely unexplored. Emotions significantly enrich simulations by adding depth, complexity, and realism, ensuring a more accurate reflection of human behaviours in real-world situations (Ortony & Turner, 1990). Emotion is a complex and multifaceted psychological state that plays a vital role in human behaviour and decision-making (Şahin et al., 2019). Without emotion, simulations and models of human actions and choices can become detached from reality, resulting in simulations that lack authenticity and fail to represent accurately the differences in human responses and interactions.

Based on this problem, this study aims to answer the following research questions:

- i. How can the BDI methodology be extended to incorporate emotional states and decision-making processes?
- ii. What emotional properties and mechanisms are essential for successfully developing and implementing an emotion-based BDI methodology?

- iii. How do these emotional enhancements impact the realism, effectiveness, and believability of fire evacuation simulations using the BDI methodology?

1.3 Research Aim and Objectives

This research aims to extend the BDI methodology into an emotion-oriented BDI methodology to model human emotion during a fire evacuation. The complete emotion-oriented BDI methodology will serve as a systematic guide to designing realistic and believable human behaviour in fire evacuation simulation. This is important to ensure that the evacuation simulation can guarantee the avoidance of casualties and economic damage during a fire evacuation. The objectives of this research are the following:

- i. To design and implement a method to incorporate emotion-oriented human decision-making into fire evacuation simulations through an extension of the BDI methodology.
- ii. To evaluate the emotional properties used in developing the emotion-based BDI methodology.

1.4 Research Scope

This research focuses on extending the BDI methodology towards modelling agent emotion during a fire evacuation. The extended Agent-Oriented Modelling (AOM) begins with the requirements elicitation step. From elicitation, the modeller will proceed with the modelling process, which involves a goal model, organisation model, emotion-oriented goal model, emotion-oriented role model, emotion-oriented organisation model, emotion-oriented Tropos goal model, emotion-oriented domain model, emotion-oriented knowledge model, emotion-oriented scenario model, emotion-oriented interaction model, and emotion-oriented behaviour model. Finally, the model is simulated using the BDI simulation tool to

examine and analyse the various dynamics, behaviours, and outcomes that emerge within the simulated environment. This simulation process allows us to gain insights into the intricate interactions and patterns of the modelled system, providing a deeper understanding of its functioning and potential implications in real-world scenarios.

1.5 Thesis Organizations

This thesis consists of six chapters. An overview of every chapter is described as follows:

Chapter 1 describes the introduction of the research, which includes the research background, research aim, research objective and research scope.

Chapter 2 provides an overview of human behaviour modelling, personality models, emotion models, and BDI-based agent behaviour simulations. It emphasizes the importance of BDI methodology in understanding agent decision-making and explores its architecture. The chapter also discusses various emotion theories and techniques for modelling emotions in emergencies like evacuations. It concludes by examining the integration of emotion into the BDI architecture and its connection with personality traits, offering insights into human behaviour within agent simulations.

Chapter 3 presents the research methodology. Each step has been meticulously documented and elaborated upon comprehensively.

Chapter 4 presents the extension of BDI methodology with emotion. This section introduces the extension of the BDI (Belief-Desire-Intention) methodology through the integration of emotion. Building upon the foundational principles of BDI, this extension incorporates the intricate dimensions of human emotion, enriching the modelling framework.

Chapter 5 describes the walkthrough of the Emotion-Based BDI Methodology and offers a detailed exploration of its core components and operational framework.

Chapter 6 describes the evaluation of the proposed methodology. It is a crucial aspect of this research, aimed at assessing its effectiveness, usability, and potential contributions. Through a series of well-designed experiments and analyses, the methodology's performance is rigorously examined.

Chapter 7 includes a summary of this thesis, which provides a summary of its key points, highlights the research's contributions, and suggests potential directions for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reviews human behaviour modelling, the general human personality model, and the emotion model. Section 2.2 reviews BDI-based agent modelling and simulations. Section 2.3 elaborates on the theory of emotion. Section 2.4 presents the emotional development in the agent system. The chapter concludes in Section 2.5.

2.2 BDI-Based Agent Behaviour Modelling and Simulations

Fire evacuation simulation through Belief Desire Intention (BDI) was developed by Wai et al. (2021) to model human cognition and decision making in fire evacuation simulation. The Belief-Desire-Intention (BDI) model is known as a theory of practical reasoning which describes human reasoning with three mental attitudes: belief, desire, and intention (Velleman & Bratman, 1991). The BDI model was proposed by Bratman in the 1980s and closely follows the Practical Reasoning System (PRS) (Sterling & Taveter, 2009). In a PRS system, an agent holds five main components. The sets of facts that hold knowledge about the world are the first component of an agent in the PRS system (Sterling & Taveter, 2009). As the agent gains more experience in the world, these facts or knowledge will also be updated. Therefore, in the BDI architecture, belief represents the facts and knowledge that an agent has about the environment. According to Sterling and Traveter (2009), the facts and knowledge of an agent will be obtained during the system design layer.

The next component is the set of goals that the agent must achieve. These achievements of goals lead to the next attitude of the BDI architecture which is known as desires (Sterling & Taveter, 2009). The desires represent the purpose and motivation of

agents which are obtained from the events and rules in the system design layer. After the sets of goals are derived, the next component is the intentions. Intentions describe what the agents are currently doing to achieve the set of goals determined earlier. Besides, the structure of the intention components is the mechanism for instantiating, scheduling, executing, and monitoring plans for the agents (Sterling & Taveter, 2009).

The fourth component involved in PRS is the library of plans. This library holds the sets of concrete actions according to the sets of goals each agent holds (Sterling & Taveter, 2009). The plans will help agents to adapt to the changes happening in the environment or the world more attentively. Finally, the last component is the interpreter or the reasoner. The reasoner plays the role of combining the overall behaviour of an agent, managing sensing and acting, informing the agent on the changes in beliefs about the world and choosing which plan to take place (Sterling & Taveter, 2009).

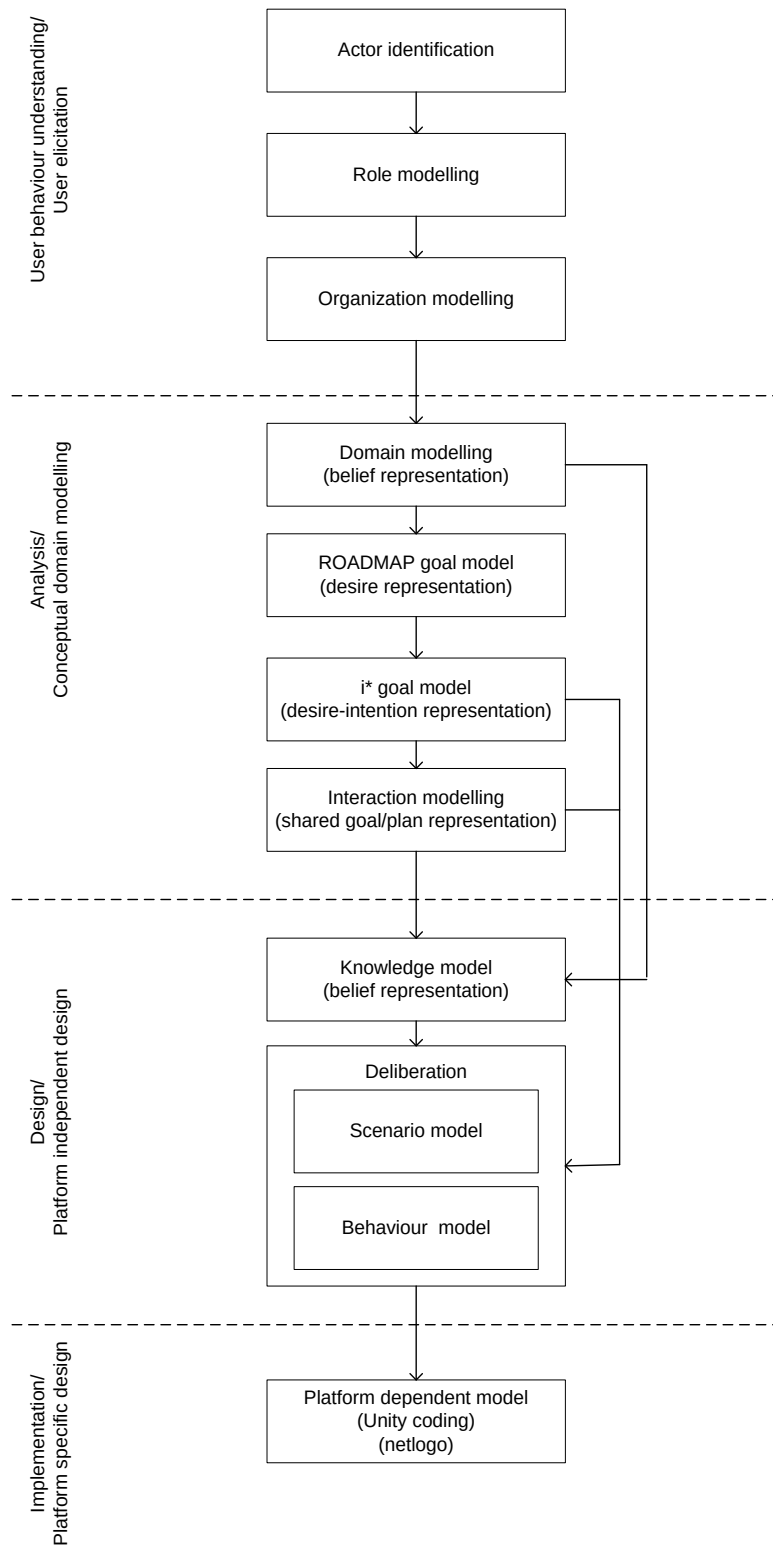


Figure 2.1: The BDI Methodology adopted from (Wai et al., 2021)

To engineer the BDI agent, BDI methodology is developed. The BDI methodology is a theory used in software modelling and artificial intelligence to create an intelligent agent that can react in a complex environment. BDI methodology is known for its ease and effectiveness in designing human behaviour based on the beliefs, desires and intention (Sánchez-López & Cerezo, 2019). The methodology supports the development of the BDI agent into four phases. Figure 2.1 shows the phases of the BDI methodology. The first phase is understanding the user behaviour and the elicitation of user information. The next phase is the conceptual design. Followed by the design phase and implementation phase. The detailed steps of modelling are as follows:

Step 1: Actor identification

During cognitive modelling, the modeller can model the cognition with one actor. On the other hand, the modeler can model the problem-solving with the involvement of two to more actors. This is known as goal delegation. In this step, actor identification involves locating the staff(s) in solving the problem at hand. From the actor identification, the proposed methodology will proceed to role modelling and organisation modelling. The organisation model represents the interaction of the actors within an organisation.

Step 2: Belief modelling

This step involves modelling facts or general beliefs of actors. The domain model is adopted for belief modelling. The domain model describes the relationship between different entities when an event has occurred.

Step 3: Modelling desire and intention

This step models the desire and intention of BDI cognitive architecture. Here the proposed methodology introduce two layers of modelling level. The first level presents the higher-level desire through the ROADMAP goal model. The notion of goal provides an

overview of the functionalities that should be achieved by an agent system. Goals can be divided into sub-goals. In addition to functional goals, there are quality goals that represent non-functional requirements for the system. Achieving a goal consumes resources, and a goal is related to a role, which indicates the actor or agent that is involved in achieving the goal. The second level of modelling in this step is modelling the desire through the Tropos i* goal model. Here, the models present in more detail the goal decomposition and capabilities for the entire actor. Meanwhile, this step also models the shared goal or shared plan. On the other hand, the sharing policy can be further modelled through the interaction model.

Step 4: Deliberation modelling

Deliberation is also known as a strategy that is used by an individual for desire consideration and plan reconsideration. During the deliberation, the context needs to be modelled in detail. The deliberation modelling is based on JASON's cognitive architecture (Bordini et al., 2007). When modelling the deliberation, the proposed methodology first model the contextual details through the knowledge model. As deliberation is determined based on beliefs and events, the triggering parameters should be captured in detail. The knowledge model will represent the knowledge about the agents and objects in its environment or the agent itself. Upon the knowledge model, the scenario model is adopted to describe how the agents of the system can achieve the goal set for the system. A goal-based scenario model will model various strategies or deliberation mechanisms. Then the behaviour model is used to model the details of deliberation through graphical representation.

Step 5: Platform-specific design and modelling

In this step, the agent models will transform into a simulation platform by using a

Unity tool. For instance, the contextual detail modelled in the knowledge model is used to identify the knowledge about the agent itself or agent objects in the stated environment. Then, based on the deliberation modelling in the previous step, the agent model is translated to the simulation model. Although the BDI agent can simulate human behaviour and decisions during an evacuation, the simulation lacks realistic elements like emotion.

2.3 Theory of Emotion

Emotion, a multifaceted psychological phenomenon encompassing subjective experiences, physiological responses, and expressive behaviours, plays a fundamental role in human cognition, behaviour, and social interaction (Ekman, 1992; Levenson, 2014). Emotion is also an important element in human behaviour.

Various theories of emotion were examined by (P S & G S, 2017) There is the physiological James-Lange Theory of Emotion, the Cannon-Bard Theory of Emotion, the Neurological Facial-Feedback Theory of Emotion, and the Cognitive Appraisal Theory. These theories offer differing explanations for the mechanisms underlying emotional experiences and expressions. The James-Lange Theory suggests that physiological responses precede emotional experiences, while the Cannon-Bard Theory proposes that physiological responses and emotional experiences occur simultaneously but independently. The Facial-Feedback Theory posits that facial expressions influence emotional experiences, and the Cognitive Appraisal Theory emphasizes the role of cognitive evaluations in shaping emotional responses.

Among these theories, the cognitive appraisal theory stands out as being extensively studied, as noted by Huangfu et al. (2013). This theory focuses on how individuals interpret and evaluate situations, events, or stimuli, leading to specific emotional reactions based on their subjective appraisals. The Cognitive Appraisal Theory highlights the importance of

cognitive processes in understanding the nature and dynamics of emotions, contributing significantly to the comprehension of emotional experiences and behaviours.

Furthermore, the review study highlights the OCC (Ortony, Clore, and Collins) theory as a prominent framework for incorporating emotions into computational systems, as noted by Huangfu et al., (2013). The OCC theory provides a structured framework for representing emotions in computational models, emphasizing the role of three components: objects (the entities that trigger emotions), agents (the individuals experiencing emotions), and appraisal variables (the criteria used to evaluate objects). By employing the OCC theory, computational systems can effectively model and simulate emotional responses in various contexts, offering a valuable tool for understanding and integrating emotions into artificial intelligence and multi-agent systems.

2.4 Emotion Development in Agent Systems

Stamatopoulou et al. (2012) use the emotion fear levels as the emotional element in an emergency evacuation simulation study. By considering the different personalities of an agent, some agent reaches a state of panic more easily compared to others who are calm or alert for a longer period (Stamatopoulou et al., 2012). From the study, the levels of emotion will start with the first level, which is calm, and the level of emotion will increase to another level if the agent does not find an exit during the evacuation process.

Farooqi and Mesgari (2015) investigate how the level of emotion affects the random movement of every agent to reach a different exit during evacuation. The researchers use the general level of emotion, Calm-Alarm- Fear-Terror- Panic- Hysteria, to model the action of each agent. In this case, every agent has a different number of levels of emotion, and they all start with different levels of emotion. The adult agents have all six levels of emotion, child agents have two out of six levels of emotion, calm and hysteria, while security has only

one level of emotion, which is calm (Faroqi & Mesgari, 2015). In the experiment, the agents are all set to a calm level and every time the agents do not find an exit, the level of emotion increases to another level. For adults, the level will increase from calm to alarm. The security agent must show direction to the people who are near him. The security agent is modelled with only one level of emotion: calm.

The fear level dynamic model is implemented in the GAMA agent-based simulations platform (Ta et al., 2017) to simulate the behaviour of the agents in response to fear-inducing stimuli. The emotion of fear is divided into different levels. The levels are low level and high level of fear. The fear level is influenced by the distance to fear-inducing stimuli, which is fire. The level changes according to the distance of the agent and the fires. According to Ta et al. (2017), the emotion level will decay with time if there are no triggers, for example, fire, warning alarms, smoke or any other element that can impact the emotion. Emotion is formulated into certain values using a mathematical function.

Liu et al. (2018) use Delaunay Triangular Representations to model a crowd evacuation route by taking emotion into account. Emotion is represented as a value that affects the group's movement during evacuation. In this case, the agents with positive emotions will move faster towards the exit while those with negative emotions will move slower.

Integrating cognitive and emotional behaviours into agent-based evacuation simulations significantly improves their realism (Zakaria et al., 2019). By employing Lazarus's cognitive appraisal theory combined with fuzzy logic, the model captures how emotional states such as fear, panic, and anxiety dynamically evolve within agents as they continuously evaluate their environment and coping strategies.

The emotion component is introduced in BDI architecture by Jiang et al. Embedding

emotion into the BDI (Belief-Desire-Intention) architecture involves seamlessly integrating emotional components into each aspect of the framework (Jiang et al., 2007). Jiang et al. introduce the primary and secondary emotions into the BDI framework. This aims to create agents that are rational and capable of emotional responses. This enhanced emotional BDI (EBDI) architecture allows for more realistic simulations of human-like behaviour, particularly in scenarios where emotions impact decision-making and actions. Furthermore, In the belief component, emotions influence how agents perceive and interpret the world, biasing attention towards emotionally salient stimuli and shaping the interpretation of sensory information. For example, fear might lead an agent to focus on potential threats in its environment. In the desire component, emotions drive the agent's goals and preferences, guiding its decision-making process. Fear may prioritize safety-related desires, while joy may prioritize desires related to pleasure or reward. Lastly, emotions affect the agent's commitment and motivation to act in the intention component. Sadness may decrease motivation, while contentment or determination may increase it. By considering emotion in each component, agents can exhibit more detailed and human-like behaviour in their interactions and decision-making processes within the BDI framework.

Mao et al. (2019) extended the BDI architecture with the emotion model by combining the BDI Architecture with the OCEAN personality model and OCC emotion model. OCEAN, also known as the Five-Factor Model or the Big Five Personality Traits, is a widely recognized framework for describing and categorizing human personality (Costa & McCrae, 1999). It consists of five key dimensions (Costa & McCrae, 1999):

1. Openness to Experience: This dimension reflects a person's curiosity, creativity, and willingness to explore new ideas and experiences.
2. Conscientiousness: Conscientious individuals tend to be organized, responsible,

and goal-oriented. They value planning and self-discipline.

3. Extraversion: Extraverts are outgoing, sociable, and energetic. They enjoy interacting with others and often seek stimulation from external sources.
4. Agreeableness: Agreeable individuals are friendly, compassionate, and cooperative. They prioritize getting along with others and tend to be empathetic.
5. Neuroticism: Neuroticism refers to emotional stability. People high in neuroticism may experience mood swings, anxiety, and stress more frequently.

The OCEAN model provides a structured way to assess and describe various personality traits and behaviours, aiding researchers, psychologists, and professionals in understanding and predicting human behaviour across different contexts.

OCC emotion model is an emotion model proposed by Ortony, Clore and Collins in 1988 (Mao et al., 2019). The OCC model contains three main branches representing different responsive modes of a real human, and each mode includes a specific emotion (Mao et al., 2019). Furthermore, according to Mao et al. (2019) the OCC model also includes a whole set of variables that affect human emotion intensity. However, the OCC model is further improved by modifying the emotion module with the CA-SIRS model, which stands for the cellular automaton-based SIRS model, while considering the effects of the Yerkes-Dodson Law during the decision-making phase (Mao et al., 2019). Yerkes-Dodson law states that every kind of human behaviour has an ideal level of motivations (Mao et al., 2019). For example, a high or low stressor level will not guarantee a good performance, which means that the stressor level or motivations must be at an ideal level to ensure the quality of the performance is guaranteed. CA-SIRS model helps simulate the emotional contagion in a dynamic crowd (Mao et al., 2019).

Furthermore, emotion contagion in crowds shows various ways researchers have

simulated how emotions spread among individuals, affecting their behaviour in group situations (Van Haeringen et al., 2023). Additionally, Islas-Toski and colleagues (2024) proposed an agent-based evacuation model that considers human behaviours such as panic, accidents, and confusion during emergencies, helping create more accurate and realistic simulations (Islas-Toski et al., 2024). Current methods successfully capture basic emotional interactions but often struggle to represent subtle or rapidly changing emotions. This research aims to improve these methods by integrating emotion contagion into the Belief-Desire-Intention (BDI) methodology. This integration will help create more realistic simulations of human behaviours, especially in emergency situations.

2.5 Discussion

Emotions are essential in human decision-making and behaviour, influencing how individuals perceive, process, and respond to situations. Emotion modelling offers a means to capture this intricate interplay between cognitive processes and affective states, enhancing the realism and depth of agent behaviour simulation.

Upon reviewing related emotion techniques, several key findings emerge as potential requirements to enhance the BDI methodology. These include incorporating cognitive appraisal theory, which provides a structured approach to understanding how individuals evaluate and react to emotional stimuli. Additionally, the OCC theory offers a well-established framework for representing emotions computationally.

Furthermore, exploring various techniques for modelling human emotions during evacuation processes underscores the complexity of capturing emotional dynamics in simulations. Each approach brings a unique perspective, addressing different aspects of human emotional responses in evacuation scenarios. The transition diagram method

emphasizes emotional progression, while the mathematical representation of Delaunay Triangular Representations introduces a geometric dimension to emotions' impact on evacuation routes (Liu et al., 2018). The Fear level dynamic model offers insights into fear-based behaviours (Ta et al., 2017).

Incorporating personality traits and emotions through flowcharts highlights a simplified yet tangible approach. The fusion of Lazarus's theory and fuzzy logic provides a computationally accessible means of representing emotion-driven behaviours (Zakaria et al., 2019). Notably, Mao et al. (2019) comprehensive technique combines multiple emotion models, enhancing the extended BDI Architecture with OCEAN personality traits, OCC emotion modelling, CA-SIRS contagion dynamics, and the Yerkes-Dodson law.

Moreover, Sterling's work on integrating emotional aspects into the BDI framework further highlights the importance of embedding psychological and emotional states into agent behaviours (Lopez-Lorca et al., 2014; Sterling & Taveter, 2009). Sterling's approach emphasizes emotional adaptability and realistic decision-making processes, providing a valuable reference for advancing emotion-based agent simulations. Furthermore, previous works have been done, such as the "Modelling Emotion-Oriented Approach through Agent-Oriented Approach" (Zulkifli et al., 2020), proposing enhancements to AOM by integrating emotional components grounded in psychological theories, thereby creating realistic and believable agent simulations. Similarly, "Autonomous Agents in 3D Crowd Simulation Through BDI Architecture" (Wai et al., 2021) provides a plugin for Unity3D to support autonomous agents using the BDI architecture. However, this approach does not explicitly incorporate emotional dynamics into agent behaviours, setting it apart from the emotion-focused methodologies.

In contrast, the proposed methodology in this research significantly improves upon existing methods by explicitly incorporating emotional dynamics into the BDI architecture, focusing specifically on the OCEAN personality traits and their emotional implications. By doing so, this approach aims to provide a more comprehensive and realistic representation of human emotional responses and decision-making processes.

This research aims to integrate the OCEAN personality model (Liu et al., 2019) into the BDI architecture and map it with emotional states and dynamics. By incorporating the emotional aspects of the OCEAN model, such as affective tendencies and responses, into the BDI methodology, the proposed methodology aims to create more emotionally intelligent agent simulations. This means that agents will not only exhibit personality traits but also experience and express emotions in a manner consistent with their personality profiles. By mapping personality traits onto emotional states and dynamics within the BDI framework, the proposed methodology can better understand how personality influences emotional responses and decision-making processes in agents, which will be presented in Chapter 4 of this thesis. This integrated approach will provide insights into the complex interplay between personality and emotion, ultimately leading to more realistic and immersive agent simulations.

2.6 Chapter Summary

This chapter reviews human behaviour modelling, focusing on the BDI (Belief-Desire-Intention) agent architecture and its role in simulating human cognition and decision-making, particularly in fire evacuation scenarios. While the BDI model effectively models rational behaviour, it lacks emotional realism. The chapter explores various emotion theories, emphasizing the Cognitive Appraisal and OCC theories as key frameworks for incorporating emotions into computational systems. It reviews studies that simulate agent

behaviour under emotional influences, particularly fear, during emergency evacuations. The integration of emotions into BDI, along with the OCEAN personality model, is proposed to create more emotionally intelligent and realistic agent simulations. This approach will be further explored in Chapter 4, mapping personality traits onto emotional dynamics within the BDI framework.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

This chapter consists of three sections that describe the research methodology used for this research. Section 3.1 provides an overview of the methodology. Section 3.2 includes details of the research methodology steps. Section 3.3 provides an overall summary of the chapter.

3.2 Introduction to Research Methodology

The research methodology of this research consists of four steps, which are:

Step 1: Explore the related topics within the research area.

- a) Review the works on emotion-based human decision making during an evacuation process.
- b) Conduct a literature review on existing techniques for modelling emotion during evacuation.
- c) Analysis of the properties of emotion used in human decision making.
- d) Defined the problem and research objectives.

Step 2: Investigate the adoption of BDI methodology to model emotion in a fire evacuation case study.

- a) A case study on how emotion affects human decisions during fire evacuation will be created.
- b) Investigate whether current software notation can model human emotion explicitly.

- c) Finding the suitable modelling method to model a decision with emotion orientation.

Step 3: Proposed methodology

- a) Proposed an emotion-based BDI methodology by introducing the notation to represent emotion.
- b) Use a fire evacuation case study.
- c) Present a detailed guideline on how to use the newly proposed emotion-based BDI methodology.

Step 4: Validation of the proposed methodology through a case study.

- a) Used fire evacuation as a case study.
- b) Implement the case study into Unity3d.
- c) Compare the simulation results with related works.

Step 5: Evaluating the proposed methodology.

- a) Conducting two experiments to evaluate the methodology.
- b) Experiment 1 aimed to investigate the practical application of both the existing extended BDI methodology and the newly proposed emotion-based BDI methodology in the context of modelling emotion-oriented decision-making.
- c) Experiment 2 focused on assessing the usability and user experience of the proposed emotion-based BDI methodology, building upon the findings from Experiment 1.
- d) Analyse the results in experiments 1 and 2.

3.2.1 Step 1: Explore the related topics within the research area

The initial phase of this research is to explore the issues within the software engineering areas of modelling human emotion during fire evacuation through a literature review. There are few techniques found in works that have been done to model human emotion or where the element of emotion is involved in the modelling or simulation evacuation process. However, it was found that the existing techniques cannot model human decision making such as human strategy and interruptible behaviours that include a clear representation of the element of human emotion. Hence, this research aims to fill the gap between the modelling of human emotion in the fire evacuation process by extending the BDI methodology into an emotion-oriented BDI methodology to model human emotion during a fire evacuation.

Next, an analysis of the properties of emotion used in human decision making during a fire evacuation scenario was done to understand the impact of emotion in the evacuation. This will help to understand better what are the properties of emotion that are involved during a fire evacuation process and how it can affect the evacuation process. Furthermore, analysing the properties of emotion in a fire evacuation will help in choosing the emotion properties and will give a great understanding to fill in the research problem. Besides, an introduction to BDI and extended AOM was also included in this phase as it will be used to create the proposed solution.

Journals, website articles and books were the three types of sources used in the literature review. Hence, through the review and findings, it can be concluded that the element of emotion has a clear impact on the evacuation process and there are gaps to be considered in modelling the human emotion involved in decision making during a fire evacuation. Moreover, most of the techniques to model emotion involve mathematical

representation which is complex and hard to understand. Therefore, appropriate objectives were defined to extend the BDI methodology with the emotion model.

3.2.2 Step 2: Investigate the adoption of BDI methodology to model emotion in fire evacuation

The proposed methodology adopted the emotion models from the revisited version of the OCC (Ortony, Clore & Collins) Emotion model (Steunebrink et al., 2009). The current notation available to model emotion, which represents personal emotional goals and context-specific emotional goals by Miller et al. (2015), shown in Table 3.1, can be used to model the emotional goals that address people's feelings towards the current goal. A new notation will be introduced to model the emotion itself.

Table 3.1: Personal Emotional Goal and Context-specific Emotional Goals

Types of emotional goals	Personal emotional goal	Context-specific emotional goals
Representation/Symbol		
Description	A personal emotional goal refers to emotions an individual experiences or desires internally (Miller et al., 2015). For example, a person may wish to feel happy, secure, or satisfied as a general personal aspiration.	Emotions are specifically linked to interactions or experiences with systems, technologies, or external situations. (Miller et al., 2015). For example, feeling trust when using a technological application.

The emotional properties represented by the proposed methodology will be introduced according to the analysis of human emotion properties involved during a fire evacuation scenario through a literature review, such as the involvement of positive or negative emotion and the level of fear.

Through the review done in the previous Chapter 2, there are two properties of human emotion included in producing the proposed emotion-oriented BDI methodology which are:

1. OCEAN model of personality. Different personality types will have different behaviours and emotions during evacuation (Zhan et al., 2013) . Using the OCEAN personality type by Liu et al., (2019), the proposed methodology can model decision making based on human behaviour. For example, if the victim has a leading behaviour, they will appear to be calmer and guide the others to the nearest exit (Liu et al., 2019; Şahin et al., 2019). Hence, personality types are one of the properties of emotions that will be considered in the emotion-oriented BDI methodology as they can help model the emotion along with the decision-making process.
2. Level of fear emotion during evacuation (Cao et al., 2017; Faroqi & Mesgari, 2015; Mao et al., 2019; Mao et al., 2020; Parrott, 2001; Stamatopoulou et al., 2012). Generally, during a fire evacuation event, the main emotion involved is the emotion of fear. Hence, the proposed methodology will focus emotion of fear. The six general fear levels (Calm-Alarm- Fear-Terror- Panic- Hysteria) (Faroqi & Mesgari, 2015a) are used in this research to explicitly represent human emotion during a fire evacuation. The level of fear or fear intensity will be affected according to the evacuation situation. For example, the fear intensity or fear level

will increase, if the victim is close to the fire or cannot find an exit (Faroqi & Mesgari, 2015; Liu et al., 2019).

3.2.3 Step 3: Proposed Methodology

In this step, the proposed methodology, emotion-based BDI methodology, is described in detail. This step will be further explained in Chapter 4 of this thesis.

3.2.4 Step 4: Validation of proposed methodology through a case study

The proposed methodology is validated by applying the fire evacuation in a bushfire case study. The fire evacuation case study is used in the proposed emotion-based BDI methodology, which will be implemented in Unity3D. Then, the result of the simulation will be compared with related work to validate the model and to see whether the proposed model can be used in modelling human emotion, human behaviours and human decision making during a fire evacuation scenario.

3.2.5 Step 5: Evaluating the proposed methodology

Experiment 1 involved students from the Bachelor of Software Engineering program modelling emotion-oriented decision-making using both the extended BDI methodology and the newly introduced emotion-based BDI methodology. In the first part, participants employed the extended BDI methodology to represent emotions in a fire evacuation scenario, highlighting its challenges and limitations. The second part introduced the emotion-based BDI methodology, tasking participants with modelling the same scenario and assessing its effectiveness in addressing emotional complexities.

Experiment 2 focused on usability, where participants who completed Experiment 1 evaluated the emotion-based BDI methodology's user-friendliness through questionnaires based on the System Usability Scale (SUS). This assessment aimed to gather insights into

users' perceptions of the methodology's ease of use, efficiency, and overall usability, guiding improvements for practical implementation. These experiments collectively aimed to evaluate the application and usability of the emotion-based BDI methodology in emotion-rich decision-making scenarios.

3.3 Chapter Summary

This chapter outlined the research methodology in five key steps. First, a literature review explored emotion-based human decision-making during fire evacuations, identifying gaps in existing modelling techniques and defining research objectives. Next, the study investigated the adoption of the BDI methodology for modelling emotions, incorporating relevant emotion models such as OCC and OCEAN, with a focus on fear levels. The proposed emotion-based BDI methodology extended the traditional BDI framework by explicitly representing emotions in decision-making. Validation was conducted through a fire evacuation case study implemented in Unity3D, comparing simulation results with related works. Finally, the methodology is evaluated through two experiments, one assessing its practical application and the other focusing on usability using the SUS.

CHAPTER 4

EMOTION-BASED BDI METHODOLOGY

4.1 Overview

This section presents the extension of the BDI methodology with emotion. Wyai et al. (2020) adoption of BDI theory in human cognitive modelling through AOM is extended by adding the element of human emotion. To add the element of emotion, Jiang et al.'s (2007) EBDI (Emotion, Belief, Desire, Intention) architecture is adapted. Section 4.2 presents the adoption of EBDI architecture to the extended BDI methodology. Finally, Section 4.3 summarises the chapter.

4.2 Extended BDI Methodology with Emotion

As mentioned in Chapter 3, section BDI methodology, when modelling the BDI agent, the modeller initiates Phase 1, which encompasses understanding the user cognition, elicitation, and emotional state. This phase emphasizes comprehending how users think, process information, and make decisions (user cognition), gathering information about their needs and preferences (user elicitation), and understanding their emotional states and reactions (user emotional state). By exploring these aspects, designers can develop BDI agents that effectively mimic human-like decision-making processes, considering agents' cognitive abilities, preferences, and emotional responses. Besides, in the first phase, actor identification, goal modelling, role modelling and organisation modelling are used.

In Phase 2, the primary emotional state and belief representation are integrated into the domain modelling process, along with analysis and computational domain modelling. This involves incorporating roadmap goal modelling to represent desires and primary

emotional states and utilizing i* goal model to depict secondary emotional states alongside behaviour and personality representation. Additionally, interaction modelling is employed to represent shared goals and secondary emotional state representation, providing a comprehensive framework for guiding the behaviour and decision-making of the BDI agent.

Furthermore, in Phase 3 of BDI agent modelling, belief representation is structured through a knowledge model, organizing the agent's understanding of the environment and entities within it. This model forms the basis for the agent's decision-making process. Deliberation during this phase involves scenario modelling, where the agent considers various situations while incorporating personality and emotional representation. The agent can determine appropriate actions aligned with its internal state and objectives by simulating scenarios and accounting for its personality traits and emotional states. Additionally, the behaviour model in this phase integrates personality and emotional representation to define the agent's responses in diverse situations, enhancing its adaptability and mirroring human-like behaviour more effectively.

Finally, phase 4, which focuses on platform-dependent modelling and implementing emotion-oriented simulation within BDI tools, builds upon the foundations laid in the previous phases. In Phase 1, the understanding of user cognition, elicitation, and emotional states provides insights into the design requirements for the BDI agent's emotional simulation. Phase 2, involving the analysis and computational domain modelling, informs the development of the emotional simulation algorithms and models within the BDI tools. Phase 3, which encompasses belief representation, deliberation, and behaviour modelling with personality and emotional representation, influences the design of the emotional simulation mechanism to align with the agent's decision-making processes. By integrating emotion-oriented simulation into BDI tools, Phase 4 enables real-time testing and refinement

of emotional responses, thus completing the iterative design process initiated in Phase 1 and refined through Phases 2 and 3.

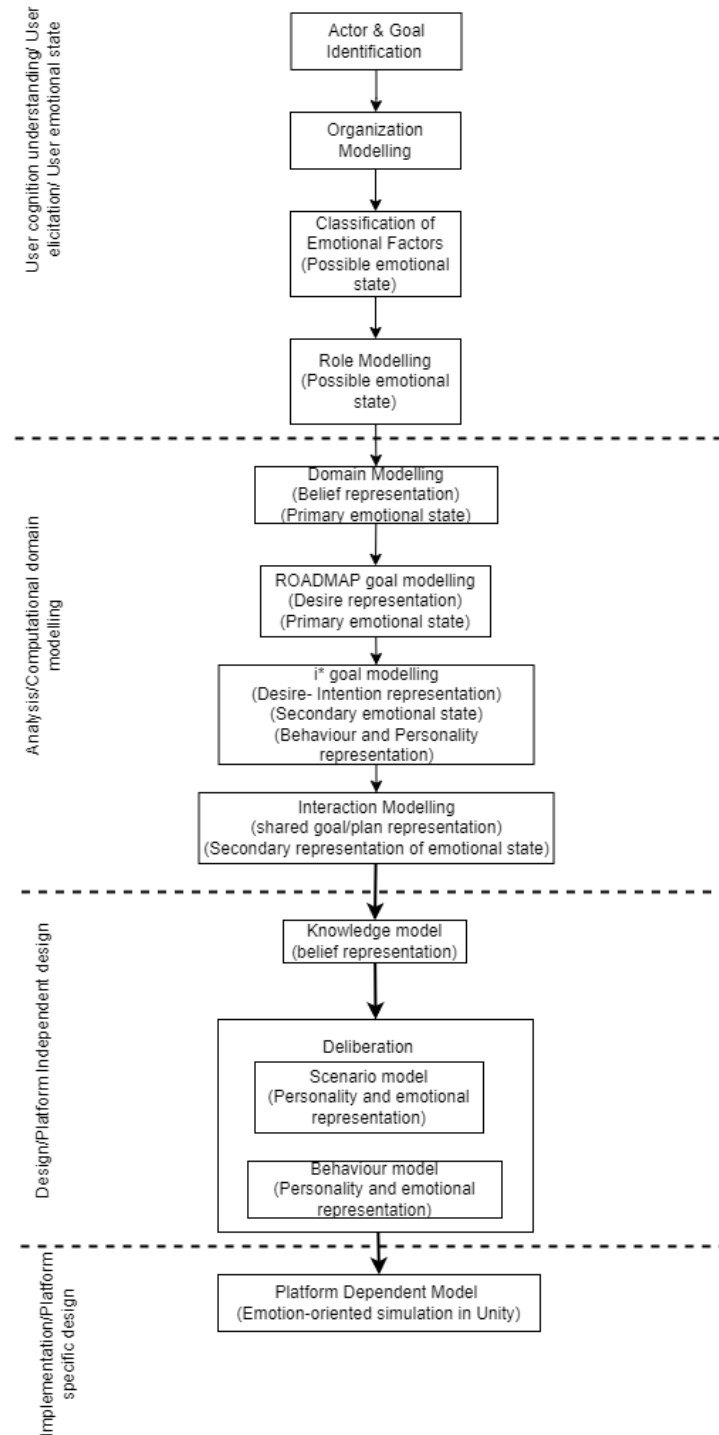


Figure 4.1: Overview of the Emotion-Based BDI Methodology

Figure 4.1 shows the proposed steps on emotion-based BDI methodology. The proposed emotion-oriented BDI methodology consists of four phases and ten steps. The phases are user cognition understanding, conceptual domain modelling, platform independent design, and platform-specific design.

Phase 1: User Cognition Understanding

Step 1: Actor and Goal Identification

Adapting the work of Sterling and Taveter (2009), by taking the “organisation” as a metaphor actor identification involves locating staff(s) to solve the current problem. This step helps to determine the types of actors needed to accomplish the goal of the organisation. Actor identification is a critical step in this methodology to identify the actors (autonomous agents) that will play a role in the system. Besides, this process is important to understand the dynamics of the system and to develop an effective simulation.

After identifying the actor, the goals that the actor aims to achieve within the system can be identified by using the goal model described by Sterling and Taveter (2009). The modeller can model both the goals and roles with the goal model. Goal models outline the hierarchical structure of the system’s objectives, beginning with the system's overall purpose. Furthermore, goal identification is closely related to actor identification because the goals of the system or agent are often derived from the roles and responsibilities of these actors. When the actors are identified, their specific goals and objectives can be expressed. These goals define what the actors aim to achieve within the system, guiding the design and behaviour of the agent that represents them.

Step 2: Organisation Modelling

Organisation modelling represents the interaction of actors within the organisation. This step involves structuring the relationships, responsibilities, and communication channels among individuals or entities within the organisation to facilitate effective problem-solving and decision-making processes. Organisation modelling seeks to capture the hierarchical structure, reporting lines, workflow processes, and collaboration mechanisms within the organisation. By defining roles, authority levels, and information flow patterns, organisation modelling helps identify how actors interact, cooperate, and coordinate their efforts to address challenges and achieve common goals.

Step 3: Classification of Emotional Factors

In the third step of the emotion-based BDI methodology, it is crucial to thoroughly list and understand these emotional properties as they form the foundation for modelling how emotions drive agent behaviour and decision-making. By identifying these emotional factors, researchers and practitioners can develop comprehensive models that integrate emotions into the BDI framework, allowing for more refined and human-like behaviour in agents. The emotion factor derived from Steunebrink et al. (2009) It is important to note that this step of the emotion-based BDI methodology is likely to be the identification and categorization of basic emotional properties. These properties encompass a wide range of emotions that influence agents' behaviour and decision-making process.

Step 4: Primary Emotion Modelling with Role Model

In this step, the process will proceed with role modelling. The primary emotion is introduced during the role modelling. The primary emotion is the first emotion felt by an agent or actor during an event or situation. The modeller can list all possible emotions according to each responsibility of the role. After role modelling, organisation modelling is

done which represents the interaction of the actors within the organisation. People have roles and responsibilities in solving the problem at hand. In serving those responsibilities, people may think rationally or emotionally. To model human emotions within the context of roles and responsibilities in problem-solving scenarios, the extension of the role model with emotional elements involves incorporating various components that capture the emotional aspect of decision-making.

In the context of modelling human behaviour within roles and responsibilities, emotional properties such as emotional states, triggers, and goals/motivations play pivotal roles. Emotional states encapsulate the diverse range of feelings individuals experience, influencing their perceptions and responses within problem-solving scenarios. Emotional triggers denote stimuli or events that evoke specific emotional responses, shaping individuals' reactions and decision-making processes. Furthermore, individuals' goals and motivations are deeply intertwined with their emotional experiences, as emotions can drive their desires and priorities in problem-solving events. For instance, the fear of failure may motivate someone to approach a problem cautiously, while the anticipation of success may energize them to pursue innovative solutions. By incorporating these emotional properties into role-based models, the proposed methodology gain a richer understanding of how emotions influence human behaviour, enabling more sophisticated and empathetic decision-making processes for agents or systems.

Every emotion has its own opposite emotion because emotion normally refers to a specific form of mental experience that will cause a certain feeling of either pleasure or displeasure (Robinson, 2008). The modeller can use the emotion list taken from the revisited version of the OCC (Ortony, Clore & Collins) Emotion model (Steunebrink et al., 2009) as shown in Figure 4.2 and the specifications in Figure 4.3 to model the primary emotion. From

the OCC emotion model, emotion can be divided into two categories, which are positive and negative emotions. This means that the emotion can either bring positive or negative effects towards something. Regarding an event, the positive means pleasure and the negative means displeasure. For example, for the pair of emotions fear and hope, the positive emotion hope will bring pleasure during an event, while the negative emotion will bring displeasure.

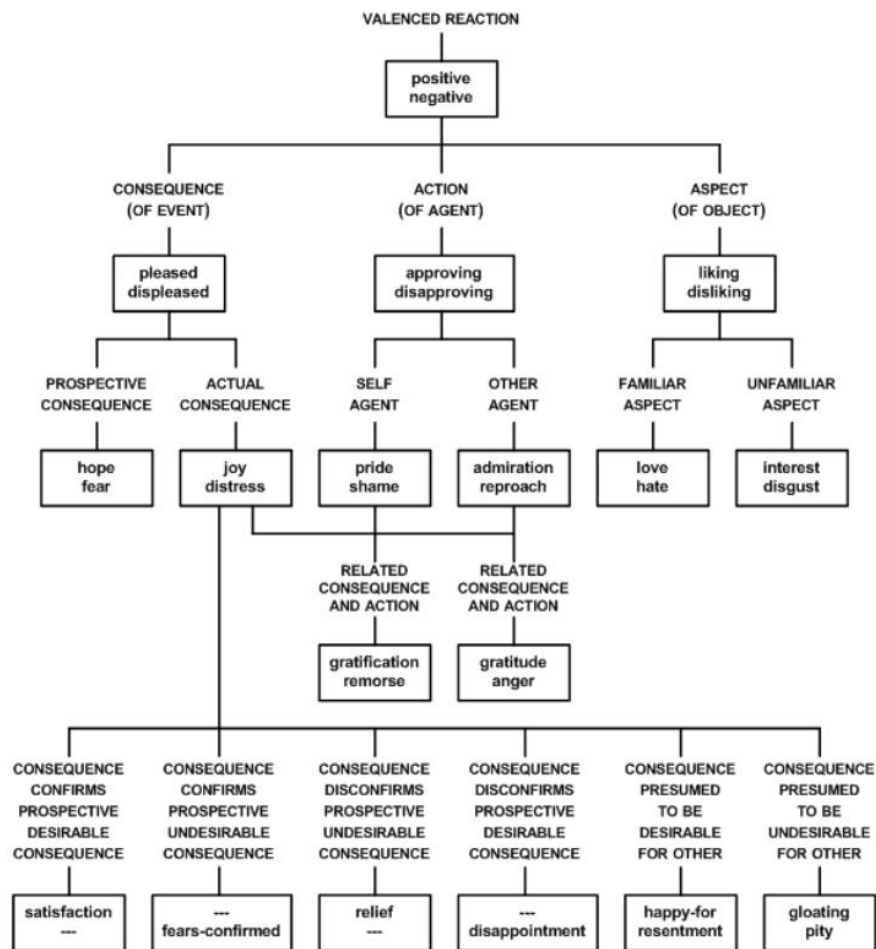


Figure 4.2: Hierarchy of emotions of the OCC model Adopted from Steunebrink et al. (2009)

<i>positive</i>	and <i>negative</i> are valenced reactions (to "something")
<i>pleased</i>	is being <i>positive</i> about a consequence (of an event)
<i>displeased</i>	is being <i>negative</i> about a consequence (of an event)
<i>hope</i>	is being <i>pleased</i> about a prospective consequence (of an event)
<i>fear</i>	is being <i>displeased</i> about a prospective consequence (of an event)
<i>joy</i>	is being <i>pleased</i> about an actual consequence (of an event)
<i>distress</i>	is being <i>displeased</i> about an actual consequence (of an event)
<i>satisfaction</i>	is <i>joy</i> about the confirmation of a prospective desirable consequence
<i>fears-confirmed</i>	is <i>distress</i> about the confirmation of a prospective undesirable consequence
<i>relief</i>	is <i>joy</i> about the disconfirmation of a prospective undesirable consequence
<i>disappointment</i>	is <i>distress</i> about the disconfirmation of a prospective desirable consequence
<i>happy-for</i>	is <i>joy</i> about a consequence (of an event) presumed to be desirable for someone else
<i>resentment</i>	is <i>distress</i> about a consequence (of an event) presumed to be desirable for someone else
<i>gloating</i>	is <i>joy</i> about a consequence (of an event) presumed to be undesirable for someone else
<i>pity</i>	is <i>distress</i> about a consequence (of an event) presumed to be undesirable for someone else
<i>approving</i>	is being <i>positive</i> about an action (of an agent)
<i>disapproving</i>	is being <i>negative</i> about an action (of an agent)
<i>pride</i>	is <i>approving</i> of one's own action
<i>shame</i>	is <i>disapproving</i> of one's own action
<i>admiration</i>	is <i>approving</i> of someone else's action
<i>reproach</i>	is <i>disapproving</i> of someone else's action
<i>gratification</i>	is <i>pride</i> about an action and <i>joy</i> about a related consequence
<i>remorse</i>	is <i>shame</i> about an action and <i>distress</i> about a related consequence
<i>gratitude</i>	is <i>admiration</i> about an action and <i>joy</i> about a related consequence
<i>anger</i>	is <i>reproach</i> about an action and <i>distress</i> about a related consequence
<i>liking</i>	is being <i>positive</i> about an aspect (of an object)
<i>disliking</i>	is being <i>negative</i> about an aspect (of an object)
<i>love</i>	is <i>liking</i> a familiar aspect (of an object)
<i>hate</i>	is <i>disliking</i> a familiar aspect (of an object)
<i>interest</i>	is <i>liking</i> an unfamiliar aspect (of an object)
<i>disgust</i>	is <i>disliking</i> an unfamiliar aspect (of an object)

Figure 4.3: Emotion Type Specifications Adopted from Steunebrink et al. (2009)

Phase 2: Analysis/ Computational Domain Modelling

Step 5: Domain Modelling with Primary Emotion Modelling

The domain model is adopted to model the primary emotion and the belief further. In domain modelling, incorporating beliefs alongside primary emotions represents how individuals' beliefs about themselves, others, and the world influence their emotional responses and subsequent behaviour. Beliefs encompass cognitive constructs such as attitudes, perceptions, expectations, and attributions, shaping individuals' interpretations of events and emotional reactions to them. For example, if someone believes they are competent, they may experience positive emotions like confidence and pride when completing a task. On the contrary, if individuals believe they are incompetent or unworthy, they may experience negative emotions such as self-doubt or shame in similar circumstances.

In domain modelling, primary emotions are represented based on the different entities and the relationships between them when an event occurs. This involves mapping out how various entities within the domain interact and how these interactions trigger emotional responses. For instance, consider a scenario in a workplace where a team member receives recognition for their contributions to a project. In the domain model, this event may be represented by depicting the team member (entity) receiving acknowledgement from their supervisor (another entity). The emotional response to this event could be represented by a heart shape (positive emotion), symbolizing feelings of pride, satisfaction, or gratitude.

Conversely, imagine a situation where a team member is unfairly criticized by their colleagues during a meeting. In the domain model, this event could be represented by showing the team member (entity) being confronted or surrounded by their colleagues (other entities), triggering a negative emotional response. This negative emotional response could be represented by a spade shape (negative emotion), symbolizing feelings of anger, frustration, or disappointment.

By integrating beliefs and primary emotions into the domain model using visual symbols such as heart shapes and spade shapes, modellers can gain a clearer understanding of how emotional responses are influenced by individuals' perceptions, interpretations, and relationships within the domain. This holistic representation facilitates the identification of key emotional triggers and belief systems that impact decision-making and behaviour, enabling modellers to devise strategies for managing emotions and fostering positive outcomes within the domain. Primary emotions are the emotions that is felt first as a response to any kind of situation (Jiang et al., 2007). For example, fear may be felt first in a fire evacuation situation. In this case, the domain model captures the positive and negative emotions related to the current context.

The domain modelling models the fact or general belief of actors which is mapped with the belief modelling in BDI. The domain model represents the primary emotional state of the actor. Table 4.1 presents the notation for the emotion-oriented domain model. The positive emotion is a model with a love shape. Meanwhile, the negative emotion is modelled with the “Ace of Spades” shape.

Table 4.1: 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)

Step 6: Road Map Goal Modelling

In this step of the emotion-oriented BDI methodology, the modelling process delves into secondary emotions, desires, and intentions within the cognitive architecture. Secondary emotions arise after primary emotions and may either supplement or replace them. For instance, in a fire evacuation scenario, a victim may initially experience a sense of calm, but upon witnessing the fire's spread, this calm emotion may be replaced by fear, which is considered a secondary emotion. This modelling process introduces two layers: the first level

focuses on goals and emotional goals, while the second level addresses secondary emotions, desires, and personality representation.

At the first level of modelling, the ROADMAP goal model is utilized to represent higher-level desires and primary emotions associated with goals. Goals serve as a roadmap outlining the functionalities to be achieved by an agent system, which can be further subdivided into functional and quality goals, representing functional and non-functional requirements, respectively. In this context, each goal can be linked to a primary emotion, providing insight into the emotional aspect of goal pursuit. Additionally, the actor or agent involved in achieving each goal is identified, aligning roles with goal attainment.

Step 7: i* Goal Modelling

Moving to the second level of modelling, the Tropos i* goal model is employed to represent secondary emotions, detailed goal decomposition, capabilities, and personality traits for the entire actor. This level provides a brief view, explaining the specific emotional responses and desires associated with each goal. Furthermore, personality representation, which influences human decision-making, is integrated into this level of modelling, enhancing the understanding of how individual differences shape behaviour and emotional responses. Incorporating the Ocean model (Liu et al., 2019) into these steps further enriches the modelling process by capturing personality traits such as openness, conscientiousness, extraversion, agreeableness, and neuroticism, which contribute to the variability in emotional responses and decision-making tendencies among individuals.

In the second level, the secondary emotion is introduced by including the elements of fear level to model the emotion. Secondary emotion comes from the result of further considerations and can replace the primary emotion (Jiang et al., 2007). The level of fear is

adopted for this research to further represent human emotion during an evacuation process (Cao et al., 2017; Faroqi & Mesgari, 2015; Mao et al., 2019; Mao et al., 2020; Stamatopoulou et al., 2012). Hence, a new notation is introduced to model the fear level, as shown in Table 4.2 and Figure 4.4. The general level of fear (Calm-Alarm- Fear-Terror- Panic- Hysteria) is adapted from Faroqi and Mesgari (2015) and Stamatopoulou et al. (2012), and every level will be represented by numbers as shown in Table 4.2. The six levels of the fear emotion are related to the feeling of horror. The emotion can transition to the next level depending on the situation. In other words, the surrounding situations affect the fear level or intensities. For example, in a fire situation, a human may feel fear or panic when the situation is uncontrollable, the fire spread worsens, or the victim is close to the fire.

Table 4.2: Notation for fear level

Notation	Meaning
	Role/Agent
	Positive emotion goal (i.e Hope)
	Negative emotion (i.e Fear) Fear Level Notation: $F.n \sim \text{Fear}$, $n = (1,2,3,4,5,6)$, Where 1=Calm, 2=Alarm, 3=Fear, 4=Terror, 5= Panic, 6=Hysteria

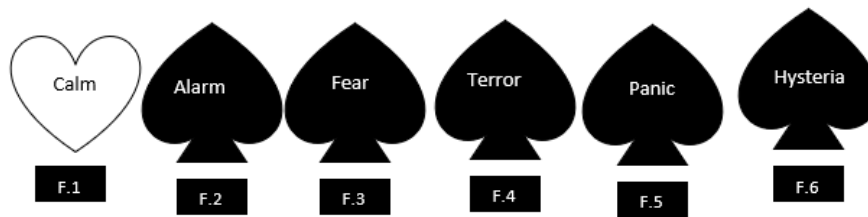


Figure 4.4: Emotion Fear level

Figure 4.4 illustrates the notation of fear levels used in the proposed methodology. The heart shape, representing a positive emotional goal, signifies a calm emotion and is labelled as “F.1” since it is part of the fear emotion but remains positive. The next level, “alarm,” is represented by a spade shape and labelled as “F.2,” as it follows calm in the emotional hierarchy. The remaining fear-related emotions are shown in Figure 4.4. The OCEAN personality test or inventory is adopted to further model the decision making of an agent or actor based on the personality trait and behaviours. The OCEAN personality test was created by Goldberg in 1993 to measure the Big Five (Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism) personality framework (Goldberg, 1990). A person’s behaviour, mental traits and emotional states can be determined by their personality (Durupinar et al., 2011). Hence, the OCEAN model is chosen to determine the possible human personality type.

Using the OCEAN personality type described by (Liu et al., 2019) as explained in Chapter 4, the proposed methodology can model decision-making based on human behaviour, as listed above. In the second level of goal modelling with the emotion-oriented i* goal Tropos goal model, for this case study, the proposed methodology includes three personality types, which are type-N(O+C+E+A+N-), type-C(O-N+) and type-AEO(O-C-E-A-N+). Based on the bushfire case study, the behaviour of the three types of personalities is listed below:

- Type-C(O-N+) Have their ideas - These people are conservative, dependent and sensitive. They will evacuate or defend blindly without considering the surrounding environment.
- O-C-E-A-N+ Irrational behaviour- These people are sensitive, introverted, solitary, negative, and give up easily. They may express irrational behaviour during evacuation. In the case study, this type of personality will keep trying to escape when they perceive fire without consideration of surroundings and do not defend their home.

O+C+E+A+N- Leading behaviour - These people have their own opinions and stable emotions. They are independent and may be a leader in the evacuation. They can decide based on the surrounding environment and are often calm.

Step 8: Interaction Modelling

Moreover, the modelling process addresses shared goals or plans and shared policies through the interaction model, fostering collaboration and coordination among actors within the organisational context. The sharing policy is further modelled in the interaction model (Wyai et al., 2020). The interaction model describes the interaction between agents which are represented through message passing. By systematically incorporating these elements into the modelling process, stakeholders gain a comprehensive understanding of the interplay between goals, emotions, personality traits, and collaborative dynamics, facilitating the design and implementation of effective agent systems within complex environments.

Phase 3: Design/Platform Independent Design

Step 9: Knowledge Modelling

In this phase, the design aspect of human cognition is presented. The first step of this phase will be like the previous work, which is to model the contextual details through a knowledge model. The knowledge model will represent the knowledge about the agents and objects in its environment or the agent itself. The knowledge model serves as the cognitive backbone of the agents in the simulation. Representing their beliefs about the environment, other agents, and themselves enables them to navigate the simulated world in a way that is consistent with their emotional states and personality traits. This model feeds into more detailed scenario and behaviour models, ensuring that the agent's actions are coherent, contextually appropriate, and emotionally resonant within the broader simulation.

Step 10: Deliberation

In this step, deliberation is the strategy for choosing the best options by considering 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. Deliberation, a strategic process for evaluating desires and reconsidering plans, is significantly influenced by beliefs and events. To accurately model this process, it's essential to capture triggering parameters through a detailed scenario model (Wyai et al., 2020). These parameters include environmental factors such as fire location and intensity, individual characteristics like familiarity with the building and personal traits, and social influences such as the behaviour of others during evacuation. Incorporating these elements into a comprehensive scenario model enhances the realism and effectiveness of evacuation simulations (Wyai et al., 2020).

In the emotion-oriented BDI methodology, the scenario and behaviour models are instrumental in the deliberation process. Starting from the third step, emotional factors are meticulously classified, encompassing a comprehensive list of positive and negative emotions associated with specific activities.

Deliberation involves a detailed modelling of the context in which decisions are made, requiring capturing information about the environment and the agent's internal states. Following the JASON cognitive architecture, this process begins with identifying the agent's beliefs, emotions, behaviours, and personality traits, which serve as key triggers for decision-making.

The scenario model outlines the goals the agent aims to achieve within the system and describes the strategies or deliberation mechanisms that guide its decision-making. It details how the agent can accomplish these goals in various situations.

Separately, the behaviour model provides a visual representation of the deliberation process, illustrating how the agent's goals, beliefs, and contextual details interact to produce specific behaviours. This model ensures that the agent's actions are coherent and aligned with its goals and the surrounding environment. The behaviour model models the deliberation of agents in a holistic view. Hence, it can form the architecture of the BDI agent.

Phase 4: Platform-Specific Design

The agent models developed during the Platform Independent Design phase are then transformed into a simulation platform, where tools like Unity can be utilized for further simulation and testing. This transformation involves translating the abstract, platform-independent models into a concrete implementation that can operate within Unity's environment.

4.3 Chapter Summary

This chapter introduced the emotion-based BDI methodology, which improves the traditional BDI approach by adding human emotions. It includes four phases: understanding user thoughts and emotions, modelling the system, designing without a specific platform, and designing for a chosen platform. The method integrates emotions, personality traits, and fear levels in decision-making, making simulations more realistic. The next chapter will explain this approach in more detail.

CHAPTER 5

WALKTHROUGH OF EMOTION-BASED BDI METHODOLOGY

5.1 Overview

In this chapter, a demonstration of the proposed emotion-based BDI methodology is implemented in the fire evacuation case study. This chapter also includes the representation of how the emotion-based BDI methodology is transformed into the Unity-based simulation model. The next section, which is Section 5.2 will present the case study that is used in this research and the walkthrough of the emotion-based BDI methodology. This section also covers the whole step-by-step process of implementing the proposed methodology. Then, Section 5.3 will include the result from Section 5.2. Finally, this chapter will be concluded in Section 5.4.

5.2 Australian Bush Fire Case Study

In this section, the proposed methodology demonstrates the viability of the proposed methodology by replicating a case study by Adam and Gaudou (2017) and Wai et al. (2021).

The case study is elaborated as follows. Bushfires in Victoria, Australia, in 2007 were a significant instance of destructive wildfires, resulting in the loss of 173 lives (Adam & Gaudou, 2017). To simulate the case, it is elaborated with a residential area surrounded by a forest with 100 houses (Wai et al., 2021). One occupant stays each house. The residential area also consists of two shelters, one on the upper right and one on the lower left. On a normal day, the residents are doing their everyday activities. Suddenly, a bushfire outburst affected the residential area. The occupants begin to defend their homes or escape to a safer area.

5.2.1 Phase 1: User Cognition Understanding

According to Wyai et al. (2020), actor identification, organisation modelling, and role modelling are needed to understand human cognition. Human cognition is the process of obtaining knowledge and understanding through thinking, learning, remembering, judging, and problem-solving (Wyai et al., 2020).

Step 1: Actor and Goal Identification

Given a particular problem, the modeller should identify the goal and actor involved. According to Sterling and Taveter (2009), the proposed methodology can adopt the organisation metaphor concept of hiring staff. The organisational metaphor offers a practical approach to identifying goals and actors in agent-oriented modelling. The proposed methodology can create a structured and comprehensive model by viewing a problem domain as an organisation, hiring staff (actors), and assigning goals to them based on their roles. This approach ensures that all necessary roles are considered, and goals are appropriately assigned, leading to a more effective and practical representation of the problem-solving scenario. For example, in a fire evacuation process, the main goal is to safely evacuate all victims from the affected area. An agent-oriented goal model can be used to model the main goal and the actor involved, as shown in Figure 5.1.

Based on the description of the case study, only one actor, the occupant, is involved in the scene. The main goal is to “Stay Alive,” while the two subgoals are “Defend Home” and “Escape.”

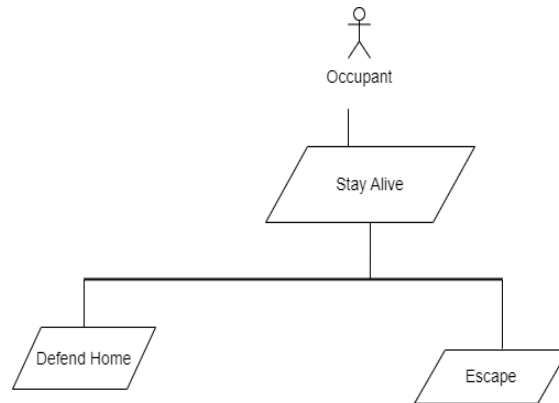


Figure 5.1: Goal Model

Step 2: Organisation Modelling

After the actors are identified, the process continues with organisation and role modelling. The organisation model represents the interaction between the actors within the organisation (Wyai et al., 2020). For example, in a fire evacuation scenario, the evacuation of victims is one of the goals that the firefighter can achieve. Hence, the interaction between firefighters and Victims is unidirectional, which means they are involved in one-way communication. Figure 5.2 shows the organisational model that describes the relationship between the actors.

The description of the case study states that only one actor is involved. The case study focuses solely on the behaviour of occupants during an evacuation and does not include firefighters or rescue personnel. Hence, Figure 5.2 shows the organisation model for this case.

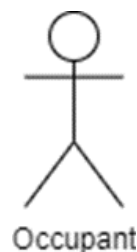


Figure 5.2: Organisation Model

Step 3: Classification of Emotional Properties

This step is a preparation step for proceeding with agent modelling. In this step, the main actions are mapped to the agent's behaviour. This will create a specific classification of the emotional factors used in this methodology to the agent's behaviour, as shown in Figure 5.3. Figure 5.3 outlines the relationship between actions, cognitive attributes, personality types, emotions, and behaviours during a fire emergency. The primary action identified is "Evacuate," driven by the cognitive attribute of "Motivation to Escape." This methodology classifies individuals into three personality types: Type-N (O+C+E+A+N-), Type-C (O-N+), and Type-AEO (O-C-E-A-N+). Each type is associated with distinct emotional responses and behaviours.

For instance, Type-N individuals are independent with stable emotions, capable of leading an evacuation and making rational decisions based on their perception of the fire and potential defence actions. Type-C individuals, who are more conservative and dependent, may not consider their surroundings but can still proceed with evacuation based on external cues. Type-AEO individuals, who are introverted and sensitive, are prone to panic and irrational behaviour, especially in high-stress situations. The emotions experienced during evacuation range from calmness and hope to fear, panic, and even hysteria, depending on the personality type. Figure 5.3 highlights the complexity of human responses in emergencies, highlighting the need for understanding these dynamics to manage evacuation processes effectively. Hence, this step is important to identify the emotional properties involved in any scenario or case study.

Figure 5.3 classifies individuals into three distinct personality types—Type-N (O+C+E+A+N-), Type-C (O-N+), and Type-AEO (O-C-E-A-N+)—and illustrates how these classifications influence their emotional responses and subsequent behaviour during

an Australian bush fire. Type-N individuals are marked by their stable emotions, independence, and strong personal opinions, which typically lead them to approach emergencies with calm or hope. This emotional stability allows them to assess the situation rationally and make informed decisions about whether to defend against the fire or to escape. Their independent nature often makes them potential leaders during evacuations.

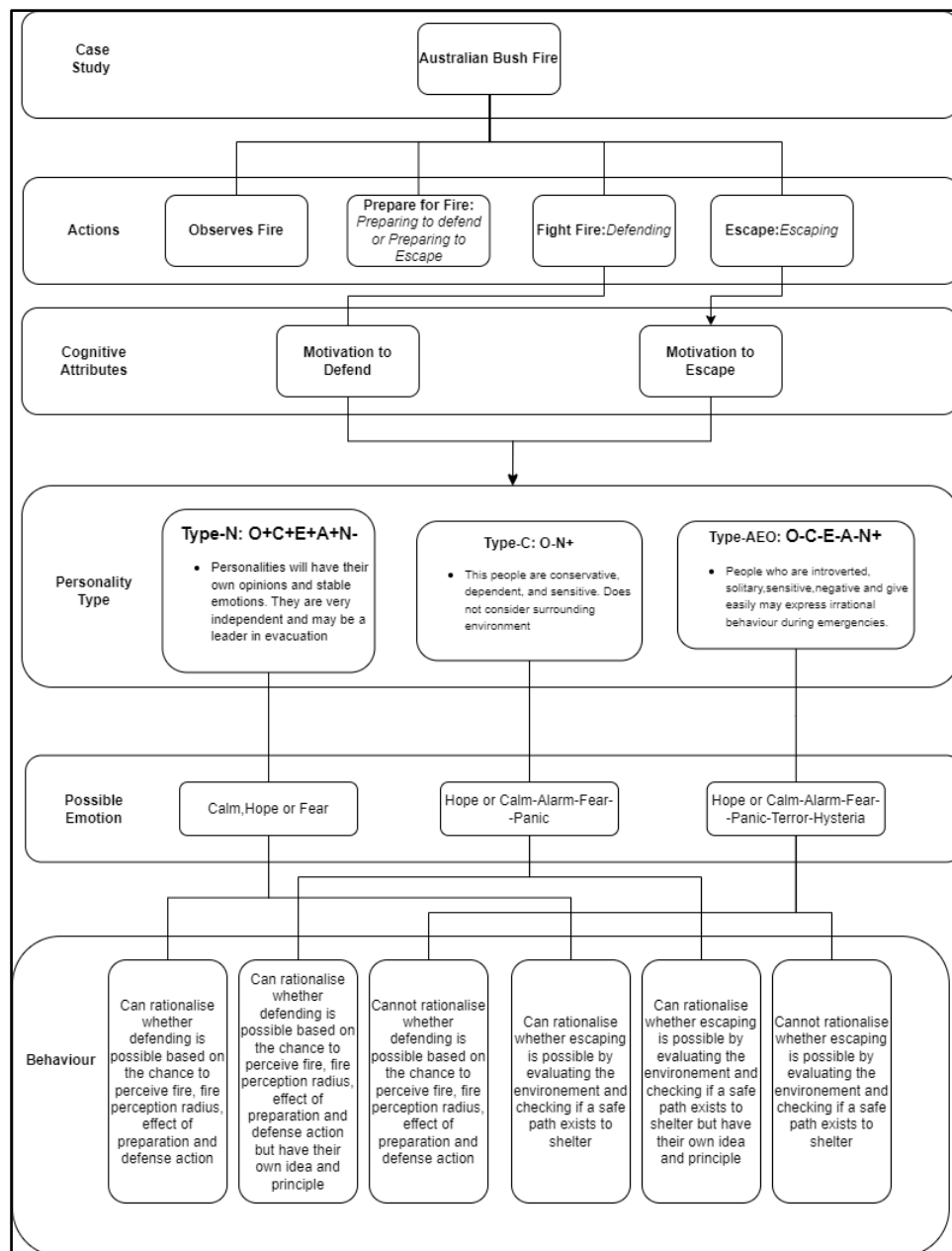


Figure 5.3: Classification of Emotional Properties for Australian Bush Fire Case Study

In contrast, Type-C individuals are conservative, dependent, and sensitive, often struggling to consider the broader environment in a crisis. They may experience a range of emotions, from hope to panic, and their decision-making is heavily influenced by these emotions. While they can rationalize their actions, they tend to follow their principles, which might not always align with the best course of action. Lastly, Type-AEO individuals are characterized by introversion, sensitivity, and negativity, making them prone to extreme emotional responses such as panic, terror, and hysteria during emergencies. This emotional instability can impair their ability to rationalise effectively, leading to irrational behaviours, especially when deciding whether to defend or escape.

Step 4: Primary Emotion Modelling with Role Model

Then, role modelling is derived in this phase. In this emotion-oriented BDI methodology, the emotions are introduced in the role model. Based on the EBDI architecture, this allows the emotional status and any new information, together with the current goals to become a guide for the agent to evaluate its beliefs later (Jiang et al., 2007; Puică & Florea, 2013). During modelling the role, the modeller can list all possible emotions of the role in the role model.

Primary emotion modelling involves modelling the first emotion felt by an agent or actor during an event or situation. The modeller can list all possible emotions according to each responsibility of the role. The role model is adopted to model the primary emotion of the actor. Table 5.1 shows the role model for the occupant the responsibilities of the Occupant are to “defend home, evacuate, avoid fire, avoid obstacles”.

The constraints are “fire can’t be controlled, have an obstacle, fire can’t be controlled, obstacle can’t be controlled”. The possible emotion which relates to the responsibilities and

negative emotions that relate to the constraints are listed in Table 5.1 For example, in the responsibility of “defend home”, the occupant might have the fear emotion or the opposite of fear emotion which is the hope emotion. This means the occupant can either feel hopeful or fearful when defending their home. The determination of positive emotion will be related to the responsibilities and what the actor might feel when fulfilling the responsibility respectively. The negative emotion will represent what the actor feels when the constraints happen or when the responsibility is not met.

Table 5.1: The Role Model for The Role Occupant

Role	Occupant		
Description	Respond to Fire		
Responsibilities	Positive Emotion	Constraints	Negative Emotion
Defend home	Hope	Fire can't be controlled	Fear
Evacuate	Hope	Have an obstacle	Fear
Avoid fire	Hope	Fire can't be controlled	Fear
Avoid obstacles	Hope	Obstacles can't be controlled	Fear

This step involves modelling the primary emotion, fact or general belief of actors. The domain model is adopted to further model the primary emotion together with the belief.

In domain modelling, 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 a spade shape (negative emotion) as described in the previous Chapter 4.

5.2.2 Phase 2: Analysis/Conceptual Domain Model

Step 5: Belief Modelling with Primary Emotion Modelling

As shown in Figure 5.4, there are domain entities in the case study of the fire evacuation during a bushfire. The agent with the role of the occupant is situated in a residential area. The “residential area layout” consists of “Physical objects” of the types “Shelter”, “Fire” and “House”.

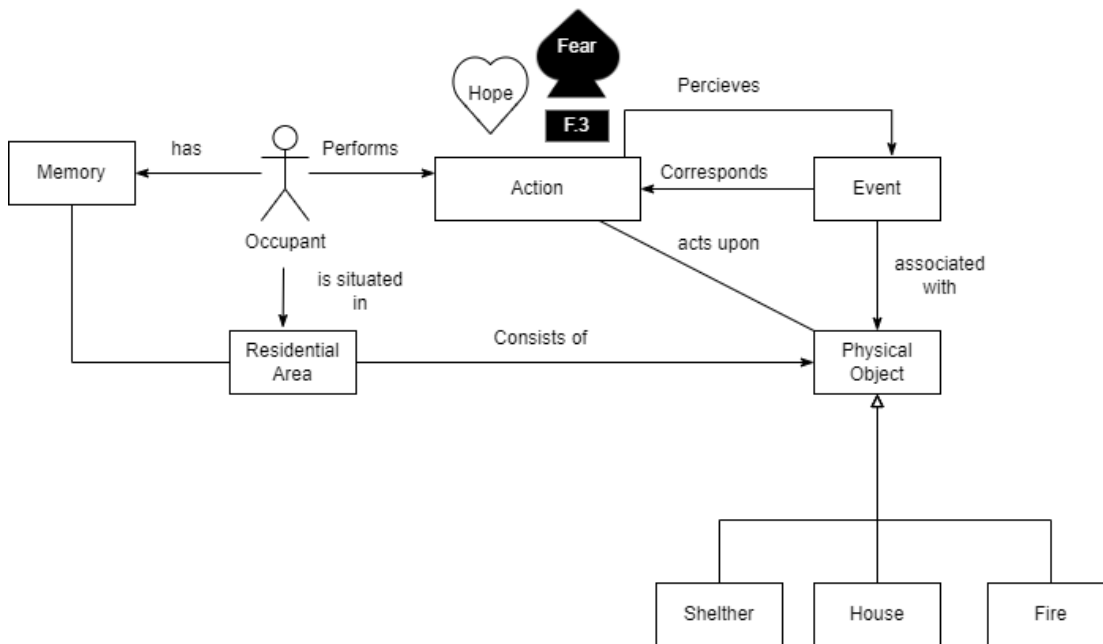


Figure 5.4: Emotion-Oriented Domain Model

The agent with the role of occupant perceives events and performs actions on physical objects. Decision-making for the agent’s action is affected by the emotion of hope or fear. Then, “Memory” will update the agent's belief whenever the agent perceives an

event. The “Memory” and “Residential Area” are connected through the Occupant. The occupant, who resides in the residential area, has a memory that influences their actions and decisions during an evacuation. Memory stores past experiences, which shape how the occupant perceives and responds to events like fire. While memory does not directly interact with the residential area, it indirectly affects the occupant’s behaviour.

The possible emotion felt by the Occupant 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 (Robinson, 2008). Hope is classified as a positive emotion as it is an expectation of a positive outcome, and humans can respond positively if the hope emotion is felt (Robinson, 2008). In this scenario, both actors can feel either the fear emotion first or the hope emotion. uncontrollable

Step 6: Road Map Goal Modelling

After the belief is modelled in the domain model, the next step is to model the desire and intention of BDI architecture (Wyai et al., 2020). Desires represent the goal of the actors while intention describes the plan selected to fulfil the desires according to the intended goals. Two levels of modelling level are introduced, where the first level presents the higher-level desire modelling through the ROADMAP goal model and the second level desire modelling through the Tropos i* goal model. In the first level, as shown in Figure 5.5, the primary emotion is modelled.

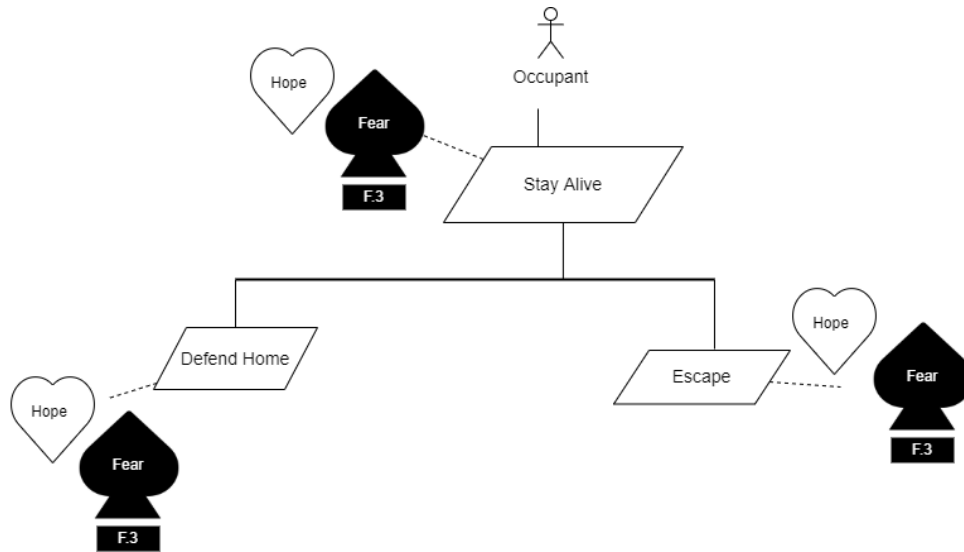


Figure 5.5: Emotion-Oriented ROADMAP Goal Model

Figure 5.5 shows an example of the emotion-oriented ROADMAP goal model for the Australian Bushfire case study. The main goal is to ‘Stay Alive’. According to the emotion-oriented ROADMAP goal model in Figure 5.5, the goal is achievable by one actor which is the Occupant as stated in Phase 1. There are two subgoals which are “Defend Home” and “Escape” to support “Stay Alive”. The possible primary emotions are also represented in the emotion-oriented ROADMAP goal model.

Step 7: i* Goal Modelling

This step models the secondary emotions, desires and intentions of the emotion-oriented BDI cognitive architecture. The secondary emotions are the emotions that appear 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 to become fear which is considered the secondary emotion. Hence, two layers of the modelling 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 should be achieved by an agent system. The goals can be divided into sub-goals. There are two types of goals which are functional goals and quality goals that represent non-functional requirements for a system. In the emotion-oriented methodology, at the first level, the modeller can model the primary emotion associated with every goal. The goals related to a role indicate the actor or agent that is involved in achieving the goal.

Desire is modelled through the Tropos i* goal model in the second level of modelling (Wyai et al., 2020). Figures 5.6, 5.7, and 5.8 show the i* goal model representing the desire and intention for handling fire evacuation. Figures 5.7 and 5.8 represent the details of how different types of personality can affect emotions and the decision-making process, as the emotion-oriented i* goal model has modelled the individual emotions, behaviours, desires, and intentions.

Furthermore, the second level of goal modelling will be done according to the different types of personality. Based on the previously modelled emotion-oriented ROADMAP goal model, the main goal is 'Handling Fire Evacuation' and consists of a subgoal 'Evacuate'. The soft goal 'Appropriate and Timely Response' is considered for the firefighters to evacuate the victims.

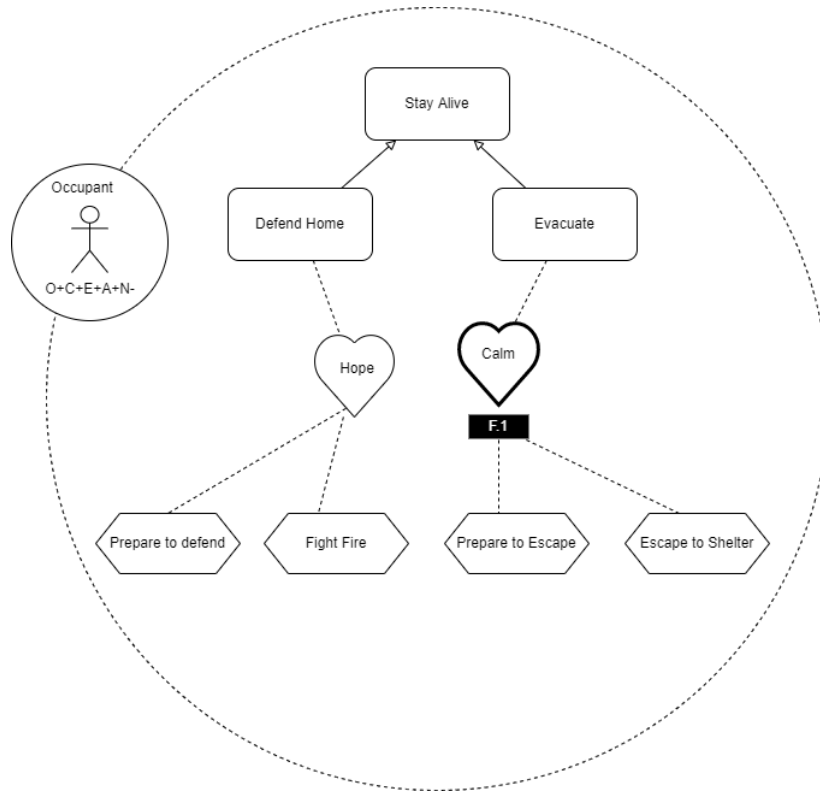


Figure 5.6: Level 2: Emotion-oriented i* goal model for Victim with Personality Type-N (O+C+E+A+N-)

The emotion-oriented i* goal model in Figure 5.6 represents a more detailed goal decomposition of an agent with personality type-N (O+C+E+A+N-), roles of the occupant and the secondary emotion, which involved the different levels of fear emotions. The models also represent the beliefs of the actor. Besides, in the emotion-oriented i* goal model, the task is affected by the emotional state of every subgoal according to the different types of agents' personalities described previously.

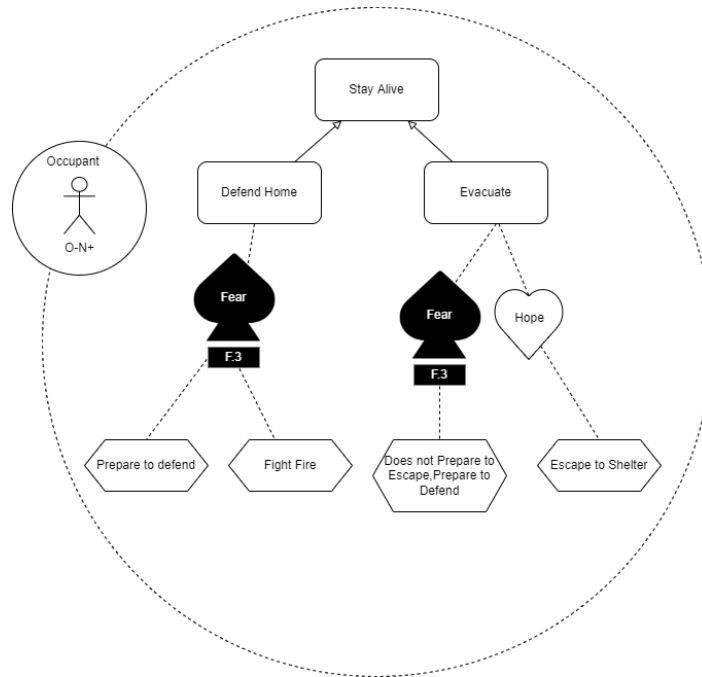


Figure 5.7: Level 2: Emotion-oriented i* goal model for Victim with Personality Type-C (O-N+)

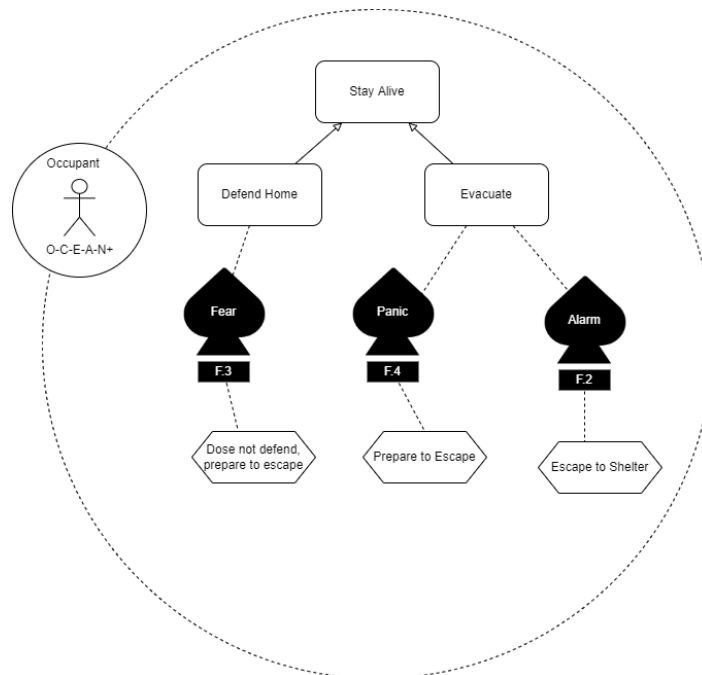


Figure 5.8: Level 2: Emotion-oriented i* goal model for Victim with Personality Type-AEO (O-C-E-A-N+)

5.2.3 Phase 3: Design/Platform Independent Design

Step 7: Knowledge Modelling

In this phase, the design aspect of human cognition is presented. The first step of this phase will be like the previous work, which is to model the contextual details through a knowledge model. The knowledge model describes the knowledge about the agents and objects in its environment or the agent itself, as shown in Figure 5.9. Furthermore, the knowledge model further elaborates on the beliefs that are used by firefighters and Victims (Wyai et al., 2020).

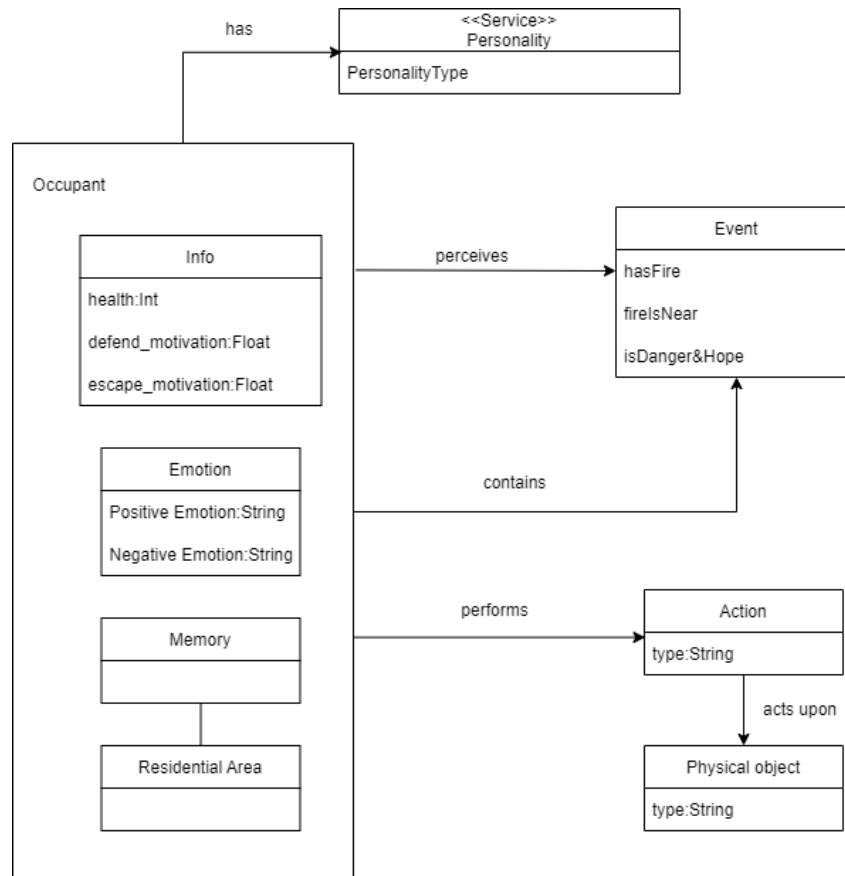


Figure 5.9: Belief details representation through the Knowledge model

The knowledge model represents how an “Occupant” perceives events, processes information, and acts based on their personality, emotions, memory, and motivations. The

occupant in a residential area has attributes like health, escape motivation, and defend motivation, which influence decision-making. When an event occurs (e.g., fire presence or danger), the occupant perceives it and responds based on their emotional state and personality traits. Their actions then impact physical objects in the environment, shaping the evacuation process. Table 5.2 shows the instantiation of the knowledge model. The knowledge model is used for deliberation modelling and further elaborates and expands the belief.

Table 5.2: Instantiation of Knowledge Model

Knowledge Item	Knowledge Attribute	Type
Info(health,	health	int
defend_motivation,	defend_motivation	float
escape_motivation,	escape_motivation	float
emotion)	emotion	string

Step 8: Deliberation

Deliberation, a strategic process for evaluating desires and reconsidering plans, is significantly influenced by beliefs and events. To accurately model this process, it's essential to capture triggering parameters through a detailed scenario model (Wyai et al., 2020). In the emotion-oriented BDI methodology, both the scenario model and behaviour model are instrumental in the deliberation process. Starting from the third step, emotional factors are meticulously classified, encompassing a comprehensive list of positive and negative emotions associated with specific activities.

The information gathered in step 3 serves as a foundation for outlining both the

scenario model and behaviour model. By incorporating personality types into the emotion-oriented scenario model, the proposed methodology can further enhance the model's accuracy. This allows for a better understanding of how individual differences can shape deliberation and decision-making. In the emotion-oriented scenario modelling, all possible emotions are listed with the activity, which includes both the positive and negative emotions as modelled in the i* goal model based on the different personality types respectively as shown in Table 5.3, Table 5.4 and Table 5.5.

Table 5.3: Scenario model for achieving the goal “Stay Alive” for personality Type N: (O+C+E+A+N-)

Goal	Stay Alive				
Initiator	Occupant with personality type O+C+E+A+N-				
Trigger	Has Fire				
Description					
Belief	Step	Desire	Emotion	Plan	Softgoal/ goal or plan
hasFire	1	Defend Home	Hope	<Prepare to defend>	hasFire
				Fight the fire	fireIsNear
hasFire	2	Evacuate	Calm	<Prepare to escape> Escape to shelter	isDanger&Hope

Table 5.4: Scenario model for achieving the goal “Stay Alive” for personality Type C: (O-N+)

Goal	Stay Alive				
Initiator	An occupant with personality type O-N+				
Trigger	Has Fire				
Description					
Belief	Step	Desire	Emotion	Plan	Softgoal/ goal or plan
hasFire	1	Defend Home	Fear	<Prepare to defend> Fight the fire	hasFire fireIsNear
hasFire	2	Evacuate	Fear	<Prepare to escape> ~ <Prepare to Defend	
			Hope	Keep defending if the first attempt is <prepare to defend> Escape to shelter	isDanger&Hope

Table 5.5: Scenario model for achieving the goal “Stay Alive” for personality Type AEO: (O-C-E-A-N+)

Goal	Stay Alive					
Initiator	Occupant with personality type O-C-E-A-N+					
Trigger	Has Fire					
Description						
Belief	Step	Desire	Emotion	Plan	Softgoal/ or plan	goal
hasFire	1	Defend Home	Panic	<Prepare defend> <Prepare Escape> <i>Keep trying to escape, never defending</i>	hasFire	
			Alarm	Fight the fire~ Escape to shelter.	fireIsNear	
hasFire	2	Evacuate	Panic	<Prepare escape> <i>Keep trying to escape when perceiving fire</i>	hasFire	
			Alarm	Escape to shelter	isDanger&Hope	

From the scenario model, the proposed methodology continues to model the deliberation model for agents through the behaviour model, as shown in Figure 5.10.

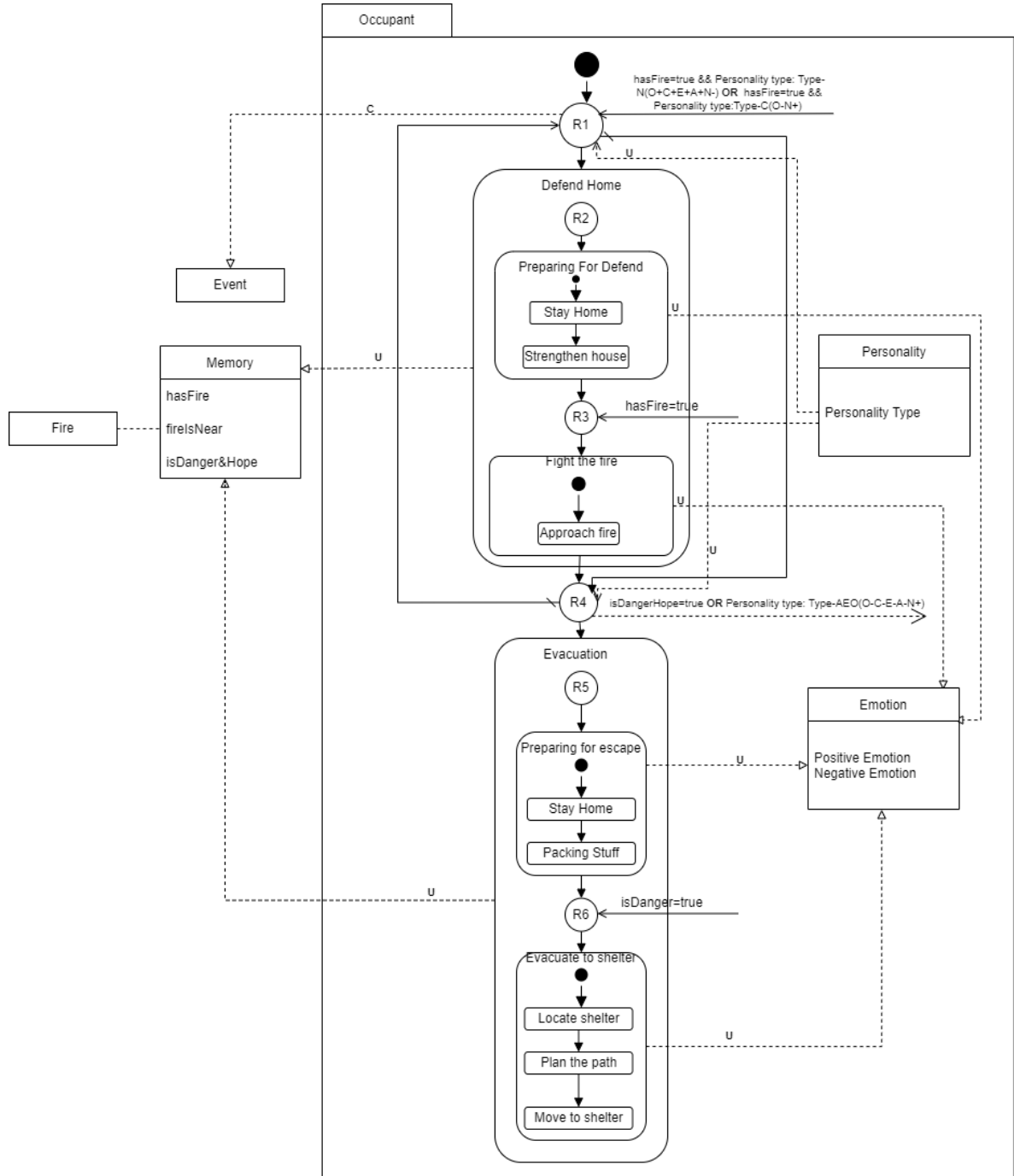


Figure 5.10: Behaviour Model for Occupant

Figure 5.10 shows agents' deliberation towards the goals through graphical representations based on the scenario model. It also models the entire agent's beliefs and intentions to achieve its desires. The dotted lines represent influences and dependencies, while straight lines indicate decision-making steps and actions in response to the situation. Furthermore, from the behaviour model, the proposed methodology can see how the entire architecture of the emotion-based BDI methodology decision-making process is affected by the emotions and personalities that affect decision-making.

5.2.4 Phase 4: Implementation/Platform Specific Design

In this phase, an emotion-oriented simulation of a fire evacuation case study will be done by extending the BDI plugin with an emotion component through Unity. The fire evacuation in an office building is used to study the adoption of the proposed emotion-oriented BDI methodology in designing an emotion-oriented fire evacuation model simulation.

Step 10: Implementation/Platform Specific Design

The knowledge model is mapped into the Unity construct. In Unity 3D, the agent behaviour and attributes are scripted using C# by defining various states, goals and actions. For example, an agent's beliefs can be modified through the 'ModifyState' method, which adjusts the internal state based on the key-value pairs. If a specific state already exists, its value is incremented or decremented, and if the state falls below a certain threshold, it is removed. An agent's attributes, such as its starting behaviour, can be set in the 'Start()' method, where different personalities may dictate various goals or actions. For example, a personality type like 'FollowPrudently' might prioritize evacuation as a goal, while a 'LeadingBehaviour' might involve a randomised decision-making process to either lead or follow, altering the agent's belief state accordingly. The Unity3D syntax uses common C#

constructs like ‘if-else’ statements, invoking methods with parameters, and adding subgoals to a goal list, which all contribute to the dynamic behaviour of agents within a Unity3D environment.

As illustrated by the scenario model and behaviour model, in Unity3D, agent desires and intentions are modelled through procedures and state management within an update loop. For example, in a C# script, the ‘Update()’ method is used to continuously monitor and adjust the agent’s beliefs, emotions and actions based on its environment and internal states. Depending on the agent’s personality type, different emotions and actions are triggered when certain conditions, modifying states such as ‘hasFire’ or fireSpread’ and setting emotional responses like “Hope”, “Calm”, or “Panic” based on random chance or specific thresholds. This dynamic adjustment allows the agent to exhibit varied behaviours adjustment allows the agent to display varied behaviours, aligning with its desires and intentions as dictated by its personality and environmental cues. The use of constructs like ‘Gworld.Instance.GetQueue()’ to check the environment and ‘beliefs.ModifyState()’ to change internal states is key in enabling this interactive and responsive behaviour in Unity3D.

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 the previous work (Wai et al., 2021). A BDI plugin tool has been created by (Wai et al., 2021) Developing the BDI simulation model using the programming language provided by Unity3D. Hence, the same Unity3D tools will be used to implement the proposed methodology and develop the emotion-based fire evacuation simulation through the emotion-based BDI methodology.

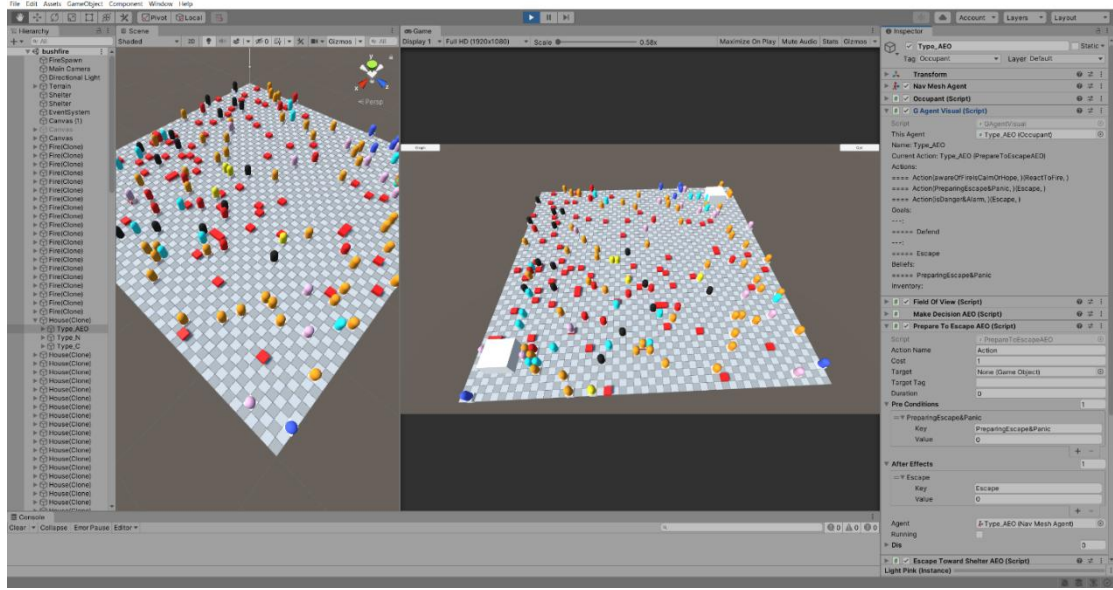


Figure 5.11: The interface of the fire evacuation simulation in Unity3D

Figure 5.11 shows the Unity interface for a fire evacuation simulation based on case study 1. The interface contains the simulation’s settings like the settings described by (Wai et al., 2021). In the emotion-based BDI agent simulation settings, the difference is the action is considered based on the personality type. Hence, there are three types of agents “Occupants” which are Occupant Type N: (O+C+E+A+N-), Type-C: (O-N+) and Type-AEO: (O-C-E-A-N+). For example, as shown in Figure 5.12 for the settings of Occupant Type-AEO: (O-C-E-A-N+), based on the modelling deliberation, this type of agent never attempts the defending action; hence, the “Prepare to defend” and “Fight fire” action is not included for this agent.

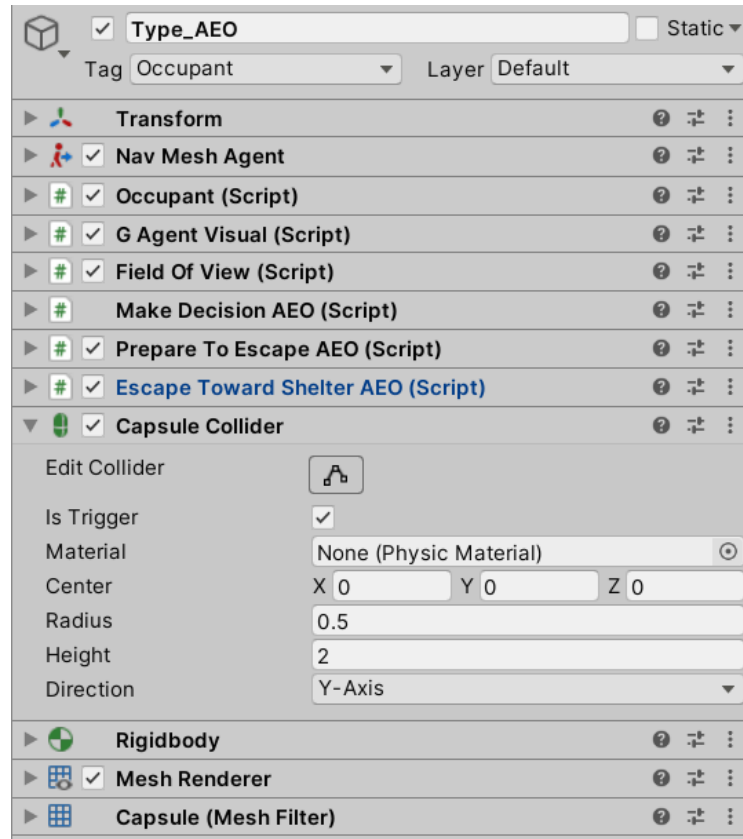


Figure 5.12: The settings for Occupant Type-AEO: (O-C-E-A-N+)

General Settings	
Max_health	300
Nb_people	100
Fire Settings	
Fire_proba_grow	0.5
Fire_proba_ungrow	0.1
Fire_proba_propag	0.4
Fire_initial_intensity	3
Fire_max_intensity	15
Fire_damage_factor	1
Fire_injury_factor	3
Fire_init_number	20
Fire_max_number	70
Building Settings	
Building_max_resistance	300
Building_protection_factor	0.001
Building_min_protection	1
Building_fire_ready	150
Occupant Settings	
People_further_awareness	7
Proba_detection	1
People_defense_radius	1
People_preparation_factor	10
People_fighting_factor	15
People_overconfidence_bi	0.7
Motivation_update_rate	0.2
Ability_update_rate	0.01
People_proba_decide	0.1
People_proba_act	0.1

Figure 5.13: Parameters Used

Figure 5.13 shows the parameters used in the proposed methodology experiment. The parameters, formulas, and calculations are like those of Wai et al. (2021) and Adam and Gauduo (2017), as the proposed methodology extended the simulation tool created by Wai et al. (2021). The simulation parameters have defined maximum and minimum limits for fire, people, and buildings. Fire-related parameters include probabilities for fire growth, propagation, and de-growth (ranging from 0 to 1), as well as intensity levels (0 to 100) and fire impact factors on buildings and people (0 to 1). People-related parameters cover awareness radius (0 to 10), fire detection and response probabilities (0 to 1), motivation and confidence updates (0 to 1), and decision-making tendencies (0 to 1). Building parameters include the number of buildings (0 to 500), resistance levels (0 to 500), and protection factors (0 to 1). These ranges allow users to simulate different fire scenarios, occupant behaviours, and structural resistances for realistic evacuation and defence strategies.

```
void perceive_fires()
{
    Random.InitState(System.DateTime.Now.Millisecond);
    for (int i = 0; i < fov.fires.Count; i++)
    {
        if (Random.value < (fireSpawn.proba_detection * objective_ability))
        {
            if (!known_fires.Contains(fov.fires[i]))
            {
                known_fires.Add(fov.fires[i]);
            }
        }

        if (fov.fires[i].transform.parent.GetComponent<FirePropagation>().intensity <= 0)
        {
            known_fires.Remove(fov.fires[i]);
        }
    }

    if (known_fires.Count > 0 && !isPerceived)
    {
        beliefs.ModifyState("awareOfFireIsCalmOrHope", 1);
        GetComponent<MeshRenderer>().material.SetColor("_Color", new Color32(230, 160, 200, 255));
        fireSpawn.indecisiveNumber++;
        fireSpawn.unawareNumber--;

        isPerceived = true;
    }
}
```

Figure 5.14: Code Snippet for Decision Making in Fire Evacuation

Figure 5.14 shows what the Occupant perceives. If there is fire around the agents' sight, the occupant will update their beliefs and emotions depending on their personality type. For example, at the first counter of fire or if 'hasFire=True', the occupants start to update their beliefs, which also contain the agent's emotions. They will start to achieve their goals and plan their actions based on their motivations, which are affected by personality type.

```

if (GetComponent<Occupant>().number_of_heatCell == 0)
{
    //target = null;
    GetComponent<Occupant>().state = State.STATE_PREP_DEFEND;
    //target = transform.parent.gameObject;
    fireSpawn.defendNumber--;
    fireSpawn.prepareDefendNumber++;
    beliefs.RemoveState("fireIsNear");
    beliefs.ModifyState("PreparingDefend&Fear", 1);
    GetComponent<MeshRenderer>().material.SetColor("_Color", new Color32(255, 137, 0, 255));

    return true;
}

if (GetComponent<Occupant>().escape_motivation > GetComponent<Occupant>().defend_motivation)
{
    //keep defending although escape motivation high
    GetComponent<Occupant>().state = State.STATE_DEFEND;
    fireSpawn.defendNumber--;
    fireSpawn.defendNumber++;
    beliefs.RemoveState("fireIsNear");
    beliefs.ModifyState("fireIsNear", 1);
    GetComponent<MeshRenderer>().material.SetColor("_Color", Color.red);
    return true;
}
else {
    //Cant' decide whether to escape thinking of defending, back to indecisive state, this personality have their own idea and does not take into account the surrounding
    GetComponent<Occupant>().state = State.STATE_INDECISIVE;
    beliefs.ModifyState("awareOfFireIsCalmOrHope", 1);
    beliefs.RemoveState("fireIsNear");
    fireSpawn.defendNumber--;
    fireSpawn.indecisiveNumber++;
    return true;
}

```

Figure 5.15: Code Snippet for personality Type-C:(O-N+)

Figure 5.15 shows how the deliberation works for personality Type-C:(O-N+). If the fire is near the occupant while achieving the goal “Defend Home”, then the occupant needs to reconsider the goal and replan actions. As shown in the code, no matter what the surrounding environment on motivation, since they are now showing panic emotion, this type of agent is set to always plan to defend and keep defending although the escape motivation is high.

```

if (GetComponent<Occupant>().number_of_heatCell == 0 )
{
    //target = null;
    GetComponent<Occupant>().state = State.STATE_PREP_DEFEND;
    //target = transform.parent.gameObject;
    fireSpawn.defendNumber--;
    fireSpawn.prepareDefendNumber++;
    beliefs.RemoveState("fireIsNear");
    beliefs.ModifyState("PreparingDefend&Hope", 1);
    GetComponent<MeshRenderer>().material.SetColor("_Color", new Color32(255, 137, 0, 255));

    return true;
}

if (GetComponent<Occupant>().escape_motivation > GetComponent<Occupant>().defend_motivation)
{
    GetComponent<Occupant>().state = State.STATE_ESCAPE;
    beliefs.ModifyState("isDanger&Hope", 1);
    beliefs.RemoveState("fireIsNear");
    fireSpawn.defendNumber--;
    fireSpawn.escapeNumber++;
    GetComponent<MeshRenderer>().material.SetColor("_Color", new Color32(0, 255, 255, 255));
    return true;
}

```

Figure 5.16: Code Snippet deliberation personality Type-N-:(O+C+E+A+N-)

Figure 5.16 shows how the deliberation works for personality Type- N-:(O+C+E+A+N-). This type of personality can rationalise their action and plan based on the surrounding environment.

5.3 Results and Discussion of the Australian Bush Fire Case Study

According to the case study elaborated in the previous chapter, the proposed methodology will compare the results with an existing study. (Adam & Gaudou, 2017; Wai et al., 2021). Figure 5.17 shows the percentage of causes of death in the simulation. The results obtained are as follows: 69% of the occupants died while still passive (indecisive); 15% died while escaping; 6% died while defending; 6% died while preparing to defend; 4% died while escaping. The percentage of death is calculated by the formula below:

$$\frac{\text{Number of people died}}{\text{Total number of death}} \times 100\% = \text{Percentage of death} \quad \text{Equation 5.1}$$

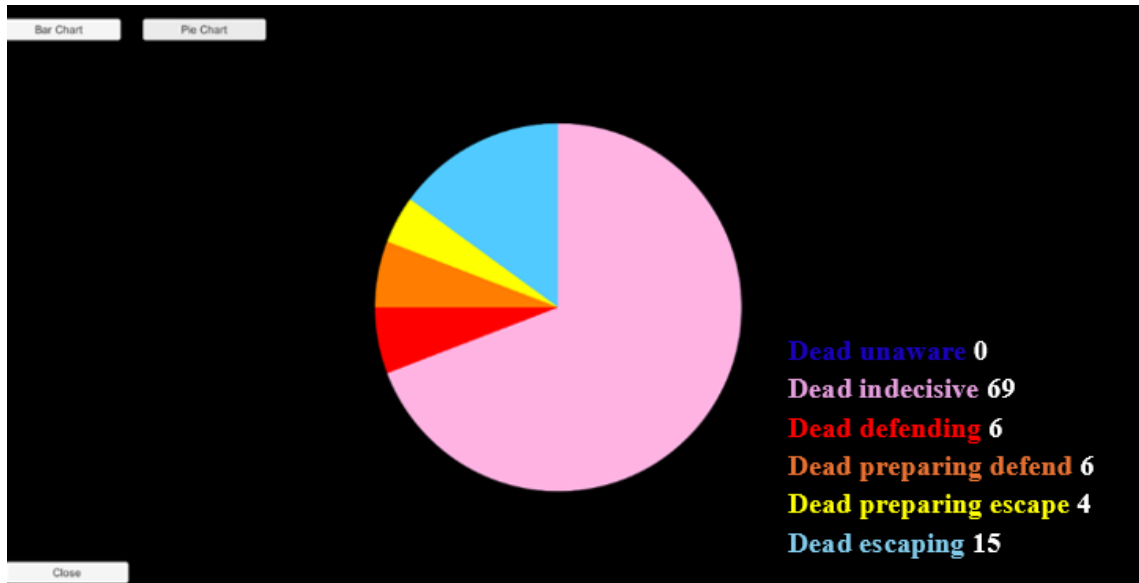


Figure 5.17: Causes of Death in the Proposed Methodology Experiment

It shows that, from the simulation, the highest percentage of deaths are caused by dying while indecisive. This shows that the occupant does not know how to respond to fire or is still making decisions.

To evaluate the correctness of the model, the proposed methodology compared to the results from Figure 5.17 with those from Figure 5.18. From the comparison, the proposed methodology found that both results share almost similar patterns. The results show “dead while still unaware” (0% vs 0%), “dead while deciding what to do” (69% vs 48%), “dead while defending” (6% vs 8%), and “dead while preparing to defend” (6% vs 28%), “dead while preparing to escape” (4% vs 0%) and “dead while escaping” (15% vs 20%). The results show that in the simulation, there is a death related to preparing to escape (4% vs 0%). However, the other causes of death have an almost similar percentage of death causes. Hence, based on the comparison, it is considered adequate to support and validate the emotion-oriented simulation model.

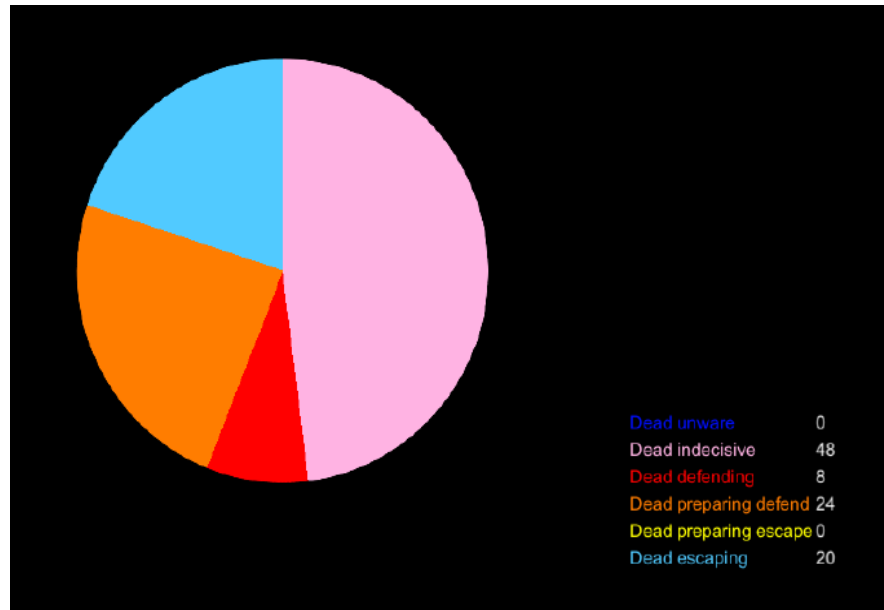


Figure 5.18: The Simulation results from (Wai et al., 2021)

The result is then compared with statistics from the 2009 Australian bushfire, as described by Adam and Gaudou (2017), to validate the model and the simulation result further. Figure 5.19 shows the comparison of actual death rates, simulation with BDI death rates, and simulation with emotion-based BDI death rates.

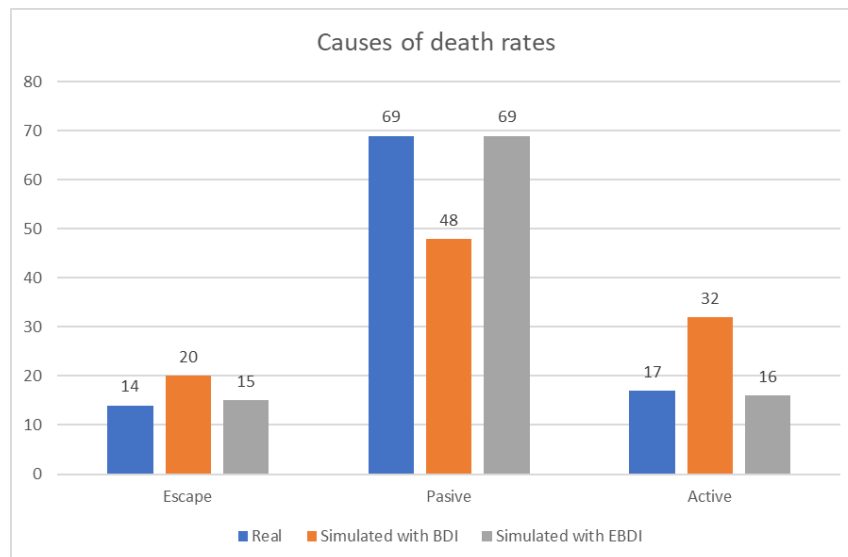


Figure 5.19: Comparison between real, simulated with BDI and simulated with EBDI rates of death causes

The proposed methodology discovered that the simulation done with it shows very similar

death rates to the actual death rate compared to the simulation done only with BDI. The comparison shows that in the simulation the “passive” death rate is like the actual results (69% vs 69%). This is because the action and plan of the agent are obtained based on the different personality types, which then portray the emotion of the agent, allowing the agent to go back to being passive or indecisive (deciding on what to do). Meanwhile, in the experiment done with extended BDI methodology, the agent can’t go back into a passive state. Once the agent is instructed to prepare actively, it cannot revert to a passive state (Wai et al., 2021). This shows how the personality and emotional factors added have affected the decision-making and allowed the simulation to be closer to the real situation. This means the proposed method can be used to model human emotion during evacuation to create an emotion-oriented simulation model that can replicate actual situations.

Hence, in this case study, the proposed methodology have shown how to model a complex fire evacuation simulation while considering the emotional properties and converting the models into Unity. This emotion-based BDI methodology can systematically reproduce human cognition and emotion.

5.4 Summary

This chapter applies an emotion-based BDI methodology to a fire evacuation case study in Victoria, Australia, using Unity-based simulation. The methodology accurately replicates human behaviour during emergencies by modelling different occupant personalities and their emotional responses. The simulation results show that incorporating emotional and personality factors closely aligns with real-life outcomes, particularly in capturing indecisiveness during evacuations. This approach effectively simulates human emotions and cognition, offering a more realistic model of behaviour in crises.

CHAPTER 6

USABILITY STUDY OF THE PROPOSED METHODOLOGY

6.1 Overview

The evaluation of the proposed methodology is presented in this chapter. The evaluation focuses on the study of the usability of the Emotion-based methodology. Section 6.2 explains the experiment settings. Section 6.3 presents the background of the participants participating in the experiments. Then, Section 6.4 presents the details for experiment 1. Experiment 1 involves evaluating the incorporation of emotional properties into decision-making through both the Extended BDI Methodology and the Emotion-based BDI Methodology. Section 6.5 covers the details of experiment 2. Experiment 2 is conducted to evaluate the usability of the proposed methodology. The outcomes of the experiments will be presented in Section 6.6. Section 6.7 explains the threats to the validity of the experiments. Finally, Section 6.8 presents the chapter summary.

6.2 Experiment Setting

Quantitative analysis is used to investigate whether the proposed methodology can be used to model emotion-oriented decision making in a fire evacuation scenario. The proposed methodology conducted two experiments in this research. Through these experiments, the research aims to determine the effectiveness of the emotion-based methodology in modelling emotion-centric decisions and to evaluate its user-friendliness. The combined results from both experiments contribute to a comprehensive understanding of the methodology's applicability and usability in the context of emotion-oriented decision modelling for fire evacuation case study. The experiments were formulated to assess the validity of the following hypotheses:

Hypothesis 1: The Emotion-based BDI methodology can represent emotion-oriented decision making better than the extended BDI methodology.

Despite the presence of numerous modelling techniques as detailed in Chapter 2, the central problem persists: these approaches for emotion management lack a basis in any psychological theory, and none of them is widely adopted (Bourgais et al., 2018). Therefore, the proposed methodology believes that the emotion-based BDI methodology offers a systematic approach to modelling emotion-oriented decision-making.

Hypothesis 2: The usability of the Emotion-based BDI methodology is acceptable.

The hypothesis suggests that individuals who engage with or employ the Emotion-based BDI methodology will perceive it as effective and practical for modelling a fire evacuation case study. It posits that users or participants interacting with this methodology will view it as a suitable and functional tool to represent and analyse emotion-oriented decision-making processes related to a fire evacuation scenario. The hypothesis anticipates that the methodology's design and implementation will result in a level of usability and functionality that aligns with the specific context of modelling a fire evacuation case study.

Experiment 1 seeks to investigate the application of both the extended BDI methodology and the emotion-based BDI methodology for modelling decision-making centred around emotions. In experiment 1, the participants are required to use the extended BDI methodology to model emotion-oriented decision making using the same case study as elaborated in Chapter 5. A scoring system has been developed based on the ability to model the emotional properties to assess participants' proficiency in employing both methodologies to model the given case study. The scoring systems for both methods are shown in Table 6.1 and Table 6.2.

Table 6.1: Scoring System for Extended BDI Methodology

Mark Scoring (Total 20)	Criteria		
	Model not used or wrong interpretation.	Able to use the modelling method accurately.	Able to present the properties of emotion in the extended BDI methodology
1. Actor Identification (2 %)	0	1	2
2. Role Modelling (2%)	0	1	2
3. Organisation Modelling (2%)	0	1	2
4. Domain Modelling (2%)	0	1	2
5. Roadmap Goal Model (2%)	0	1	2
6. I* Goal Modelling (2%)	0	1	2
7. Interaction Modelling (2%)	0	1	2
8. Knowledge Model (2%)	0	1	2
9. Scenario Model (2%)	0	1	2
10. Behaviour Model (2%)	0	1	2

Table 6.2: Scoring System for Emotion-based BDI Methodology

Mark Scoring (Total 20)	Criteria		
	Model not used or wrong interpretation.	Able to use the modelling method accurately.	Able to present the properties of emotion in the Emotion-based BDI methodology
1. Actor Identification (2 %)	0	1	2
2. Emotion-Based Role Modelling (2%)	0	1	2
3. Emotion-Based Organisational Modelling (2%)	0	1	2
4. Emotion-Based Domain Modelling (2%)	0	1	2
5. Emotion-Based Roadmap Goal Model (2%)	0	1	2
6. Emotion-Based I* Goal Modelling (2%)	0	1	2
7. Emotion-Based Interaction Modelling (2%)	0	1	2
8. Emotion-Based Knowledge Model (2%)	0	1	2
9. Emotion-Based Scenario Model (2%)	0	1	2
10. Emotion-Based Behaviour Model (2%)	0	1	2

On the other hand, experiment 2 is conducted to evaluate the usability of the proposed methodology. The System Usability Scale (SUS) is a straightforward, ten-item scale that provides an overall perspective on subjective evaluations of usability. Experiment Participants' Background

6.3 Experiment Participants' Background

The study was carried out with students enrolled in the Bachelor of Software Engineering program at Universiti Malaysia Sarawak, specifically those taking the course TME4093, Advanced Topics in Software Engineering, during the second semester of the academic year 2021/2022. A total of 31 students took part in the experiments. Notably, the same group of students participated in both Experiment 1 and Experiment 2, as these two experiments share a related context and subject matter.

The participants are familiar with the extended BDI methodology due to their exposure to it during the mentioned course. However, their understanding of the Emotion-based BDI methodology is entirely lacking, as they have not been introduced to it previously.

6.4 Experiment 1: The Usage of Emotion-based BDI Methodology and Extended BDI Methodology

The primary objective of this experiment is to assess the practical implementation of both methodologies for modelling emotion-oriented decision making within a fire evacuation case study. The outcomes of this experiment are expected to provide validation for hypothesis one which states the following:

Hypothesis 1: The Emotion-based BDI methodology can represent emotion-oriented decision making better than the extended BDI methodology.

This experiment is divided into two distinct parts. In the initial part, due to their foundational understanding of the extended BDI methodology, students were assigned the

task of modelling emotion-oriented decision making utilizing this methodology. The task necessitated the comprehensive modelling of all the specified requirements. Subsequently, in the second part, the students were introduced to the emotion-based BDI methodology. Following this introduction, they were presented with an identical task, replicating the task assigned in the first part of the experiment.

6.4.1 The Walkthrough of The Fire Evacuation Case Study for Experiment 1

The case study is adapted from the Australian Bush Fire (Adam & Gaudou, 2017), similar to the one elaborated in Chapter 5. There are 100 houses in a residential area surrounding the forest. Each house contains 1 occupant. There are 2 shelters located on the upper right and bottom left. The occupants are doing their daily routine. Suddenly, there was a bushfire that started to spread over the residential area. The list below shows requirements that should be modelled with the extended BDI methodology and the emotion-based BDI methodology:

1. The occupants are doing their daily routine. Suddenly, there was a bushfire that started to spread over the residential area.
2. The occupants will start to react by defending their home or evacuating to a safe place.
3. While defending their home or evacuating there will be an emotion that is involved which can affect the decision-making process.
4. When the bushfire starts to spread at first the residents may feel calm but as it gets worse from being calm, they will become alarmed and from there can feel fear or worse depending on the situation. Although they feel fear, they can still decide to defend their home and find the right exit (follow instructions and wait for rescue).

5. Let's say when the fire spread becomes worse and the residents are near the fire, they will feel fear and some might feel terror, panic, or even hysteria. This might affect the evacuation process, and the residents might be stuck in their current position.
6. Furthermore, when they can't find the exit as the fire is spreading, their fear level will increase making it hard to make decisions. For those who are calm, they will wait for rescue, wait for instruction or try to follow the crowd to find the exit. However, those who are feeling, fear, terror, panic or hysteria, might not follow instructions and can make irrational decisions which can cause harm, such as they go to the wrong exit (which will disrupt the evacuation process). Furthermore, they can also make extreme decisions such as jumping from a high place, which will cause harm during the evacuation process.

Hence, from the requirements and scenario stated in the case study, the students need to produce the models accordingly.

6.4.2 Experiment 1 Setup

Experiment 1 was conducted on the 13th of June 2022 with a group of 33 students who were enrolled in the second semester of 2022 for the course TME4093, Advanced Topics in Software Engineering. As previously mentioned, the experiment was structured into two distinct parts.

In the initial part, students were instructed to utilize the extended BDI methodology to model emotion-oriented decision making within a fire evacuation case study. Although they possessed prior knowledge of the extended BDI methodology, they were not provided explicit guidance on the specific techniques for modelling emotions. This part of the

experiment aimed to highlight the necessity of developing an alternative emotion-oriented methodology that can effectively manage the complexities of emotions, particularly in decision-making situations related to fire evacuation scenarios.

Transitioning to the second part of the experiment, students were initially briefed on the emotion-based BDI methodology. Subsequently, they were presented with the identical case study as in the first part of experiment 1. In this segment, their task involved employing the emotion-based BDI methodology to model emotion-oriented decision making within the same fire evacuation case study. The primary objective of the second part of experiment 1 was to assess whether students could successfully model emotion-oriented decision making in a fire evacuation scenario, adhering to the requirements specified in the case study.

6.4.3 Data Analysis for Experiment 1

Table 6.3 and Figure 6.1 show the mean score of the experiment.

Table 6.3: Experiment 1 Results

Methodology	Extended BDI Methodology	Emotion-based Methodology
Average Score	5.24	15.67

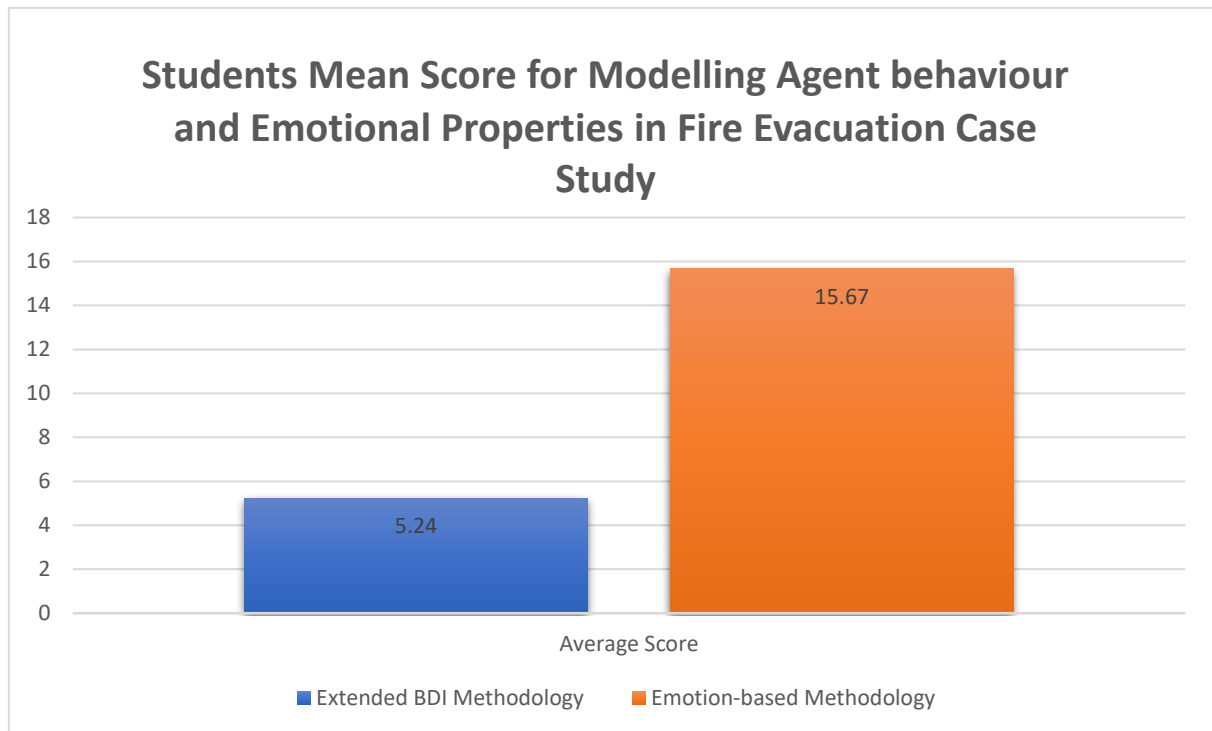


Figure 6.1: Experiment 1 Result

An analysis of the data from Table 6.3 and Figure 6.1 reveals distinct differences in the mean scores between the extended BDI methodology and the emotion-based BDI methodology. Specifically, the average score for utilizing the extended BDI methodology is comparatively lower at 5.24, while the emotion-based BDI methodology demonstrates a substantially higher mean score of 15.67. The possible score range for the Extended BDI Methodology is between 15 and 55, while the Emotion-Based BDI Methodology has a score range between 35 and 100. The threshold value (Average of Extended BDI score – Average of Emotion-based BDI score) to indicate the effectiveness of the Emotion-Based BDI Methodology is 52.12, representing the difference between the average scores of both methodologies. This threshold suggests that if the Emotion-Based BDI methodology consistently achieves a score improvement beyond this value, it demonstrates a significant enhancement in decision-making effectiveness by incorporating emotions.

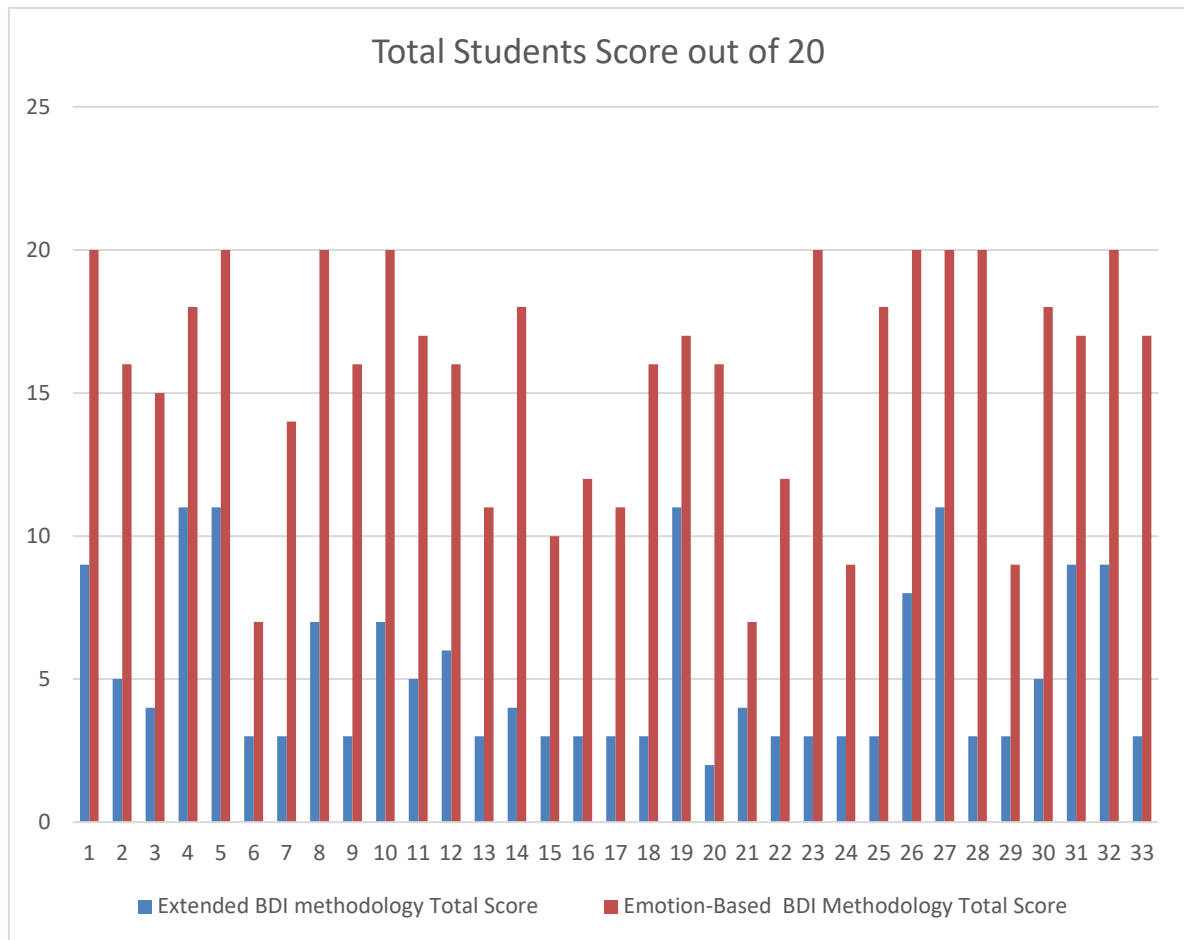


Figure 6.2: The Overview of Students Score

Furthermore, a closer examination of the score distribution reveals an interesting pattern as shown in Figure 6.2. The bar chart compares the total scores of 33 students using two different methodologies: the Extended BDI methodology and the Emotion-Based BDI Methodology. The x-axis represents the individual students, numbered from 1 to 33, while the y-axis indicates the total score each student received out of 20 points. The red bars, representing the Emotion-Based BDI Methodology, are consistently higher than the blue bars, which represent the Extended BDI methodology. This suggests that students generally performed better using the Emotion-Based BDI Methodology. Overall, the data underscores the potential efficacy of the Emotion-Based BDI methodology, hinting at its ability to capture and integrate emotional dimensions more successfully than the Extended BDI.

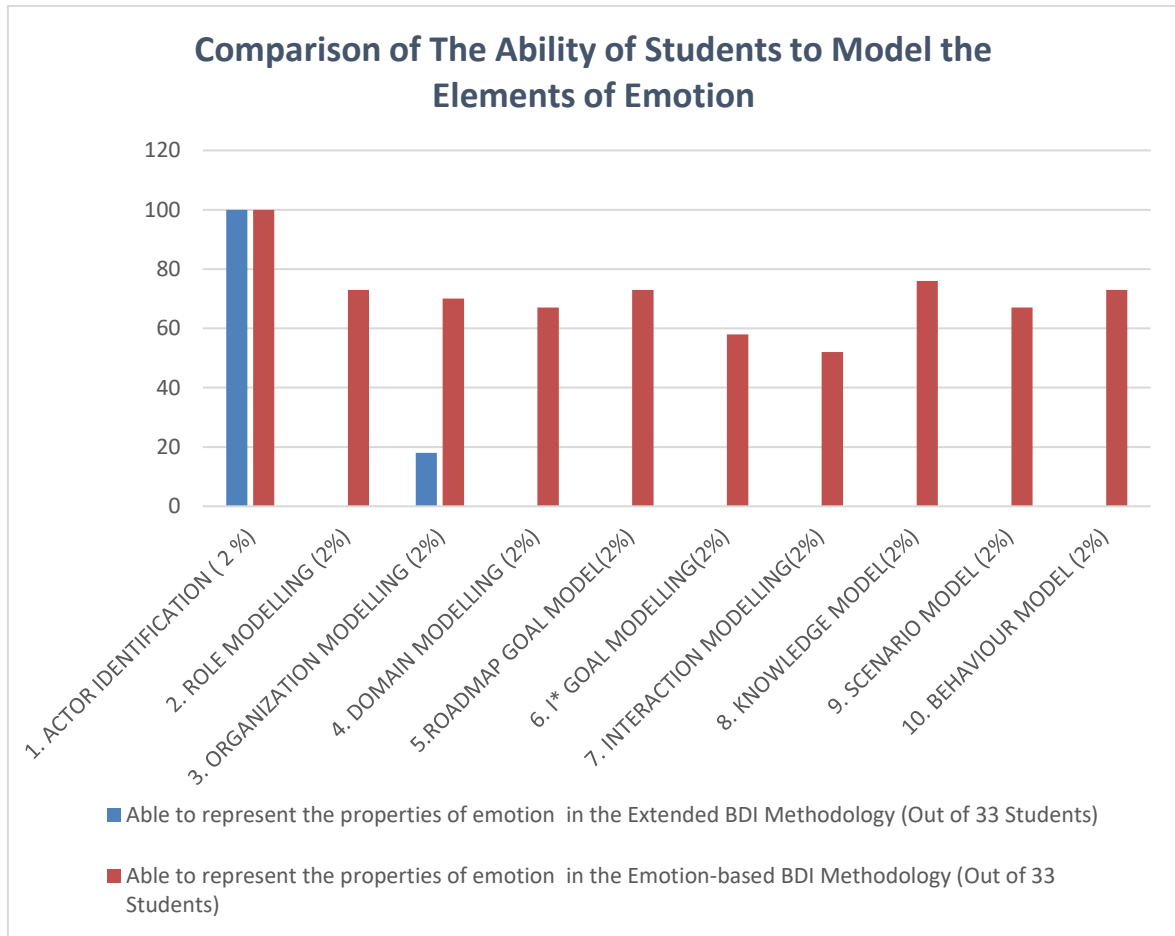


Figure 6.3: Comparison of The Ability of Students to Model the Elements of Emotion.

Figure 6.3 represents a bar chart that illustrates the comparison of students' ability to model various elements of emotion using the Extended BDI Methodology and the Emotion-Based BDI Methodology. For “Actor Identification”, both methodologies achieved a 100% success rate, with all students successfully identifying actors. In “Role Modelling” and “Organization Modelling”, the Emotion-Based BDI Methodology outperformed the Extended BDI Methodology, as indicated by taller red bars. “Domain Modelling” showed a significant disparity, with the Extended BDI Methodology performing poorly compared to the Emotion-Based BDI Methodology. This trend continued in “Roadmap Goal Modelling”, “Goal Modelling”, “Interaction Modelling”, “Knowledge Modelling”, “Scenario Modelling”, and “Behaviour Modelling”, where the Emotion-Based BDI Methodology

consistently resulted in higher success rates among students. Overall, the Emotion-Based BDI Methodology was more effective across all modelling elements, as demonstrated by the higher percentages of students successfully representing the properties of emotion in each category.

In the Emotion-based BDI Methodology, a more complex picture emerges. Students continued to excel in representing emotion properties in emotion-oriented Actor Identification, echoing their success in the Extended BDI approach. Interestingly, a notable 73% of students demonstrated proficiency in emotion-based Role Modelling within the Emotion-based BDI Methodology, showcasing its potential effectiveness in this regard. Moreover, emotion-based Organisation Modelling (70%), emotion-based Domain Modelling (67%), emotion-based Roadmap Goal Model (73%), emotion-based i* Goal Modelling (58%), emotion-based Interaction Modelling (52%), emotion-based Knowledge Model (76%), emotion-based Scenario Model (67%), and emotion-based Behaviour Model (73%) also demonstrated varying levels of success.

This comparative analysis highlights the Emotion-based BDI Methodology's advantages in capturing a diverse range of emotion properties, as evidenced by its higher success rates in several categories compared to the Extended BDI Methodology. While both methodologies showed ability in certain aspects, the data suggests that the Emotion-based BDI Methodology may offer a more versatile and effective framework for incorporating emotions across a broader spectrum of modelling components.

However, it's important to note that the challenges encountered within the Extended BDI Methodology, particularly in Role Modelling, provide valuable insights into potential areas for improvement. This data serves as a foundation for further investigation and refinement of both methodologies, aiming to enhance their capacity to comprehensively and

accurately model emotion-related properties in various decision-making contexts. In summary, this analysis offers a glimpse into the dynamic landscape of emotion modelling methodologies and highlights the important interactions between theory and application in decision-making modelling.

6.4.4 Statistical Comparison of Result for Experiment 1

Based on the student scoring as listed in Table 6.4, the t-test is a statistical tool used to determine if the observed differences between two groups are statistically significant or if they could likely have occurred by random chance. In this specific analysis, the t-test is being applied to compare the mean scores of two groups: one using the Extended BDI methodology and the other using the Emotion-Based BDI Methodology. The assumption of unequal variances is considered, which means that the variability of scores in the two groups may not be the same.

Table 6.4: Total Score for Both Methodologies

Extended BDI methodology Total Score	Emotion-Based BDI Methodology Total Score
9	20
5	16
4	15
11	18
11	20
3	7
3	14
7	20
3	16

Table 6.4: continued

7	20
5	17
6	16
3	11
4	18
3	10
3	12
3	11
3	16
11	17
2	16
4	7
3	12
3	20
3	9
3	18
8	20
11	20
3	20
3	9
5	18
9	17
9	20

Table 6.4: continued

3	17
---	----

The hypotheses for this experiment were formulated as follows. The null hypothesis, denoted as H_0 , suggests that there is no significant difference in the mean scores between the groups using the Extended BDI methodology and the Emotion-Based BDI Methodology. In other words, the null hypothesis assumes that the mean scores are expected to be equal regardless of whether the extended BDI methodology or the emotion-based BDI methodology is employed. This null hypothesis is mathematically represented as shown in Equation 6.1.

$$H_1: \mu_{Emotion-based\ BDI} = \mu_{Extended\ BDI} \quad \text{Equation 6.1}$$

The alternative hypothesis H_1 , suggests that the usability of the Emotion-Based BDI Methodology is significantly different from that of the Extended BDI Methodology. In simpler terms, this hypothesis seeks to determine whether the Emotion-Based BDI Methodology is more usable than the Extended BDI Methodology.

The alternative hypothesis H_1 , opens the possibility that the Emotion-Based BDI Methodology could potentially outperform the Extended BDI Methodology in terms of user experience and usability. This could be due to factors such as improved design, better incorporation of emotional considerations, or more intuitive interfaces in the Emotion-Based BDI Methodology. The alternative hypothesis is mathematically represented as shown in Equation 6.2.

$$H_1: \mu_{\text{Emotion-based BDI}} > \mu_{\text{Extended BDI}}$$

Equation 6.2

In this research, the proposed methodology use a Two-sample t-test assuming unequal variances between two groups to further evaluate experiment 1 statistically. The value of t was calculated using the formula shown in Equation 6.3.

$$t = \frac{\bar{\mu}_1 - \bar{\mu}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad \text{Equation 6.3}$$

Table 6.5: T-test Analysis Result

	Extended BDI methodology Total Score	Emotion-Based BDI Methodology Total Score
Mean	5.24	15.67
Variance	8.75	16.98
Observations	33.00	33.00
Hypothesized Mean Difference	0.00	
df	58	
t Stat	-11.80518042	
P(T<=t) one-tail	2.32633E-17	
t Critical one-tail	1.671552762	
P(T<=t) two-tail	4.65266E-17	
t Critical two-tail	2.001717484	

Based on the provided t-test results and the extremely low p-values (both one-tailed and two-tailed), the proposed methodology can confidently reject the null hypothesis. The null hypothesis typically states that there is no significant difference between the groups being compared. In this case, the null hypothesis would state that there is no significant difference between the mean scores of participants using the Extended BDI methodology and the Emotion-Based BDI Methodology.

However, since the p-values are well below the commonly used significance level (such as 0.05 or 0.01), it indicates that the observed differences in mean scores are highly unlikely to have occurred due to random chance. Therefore, the proposed methodology have sufficient evidence to reject the null hypothesis in favour of the alternative hypothesis, which suggests that there is a significant difference between the groups. This aligns with the interpretation that the Emotion-Based BDI Methodology leads to higher mean scores compared to the Extended BDI methodology in the context of the study. Thus, the hypotheses are substantiated, providing empirical evidence for the effectiveness and potential advantages of the Emotion-Based BDI Methodology in modelling emotion-oriented decision making, as anticipated in the study.

6.5 Experiment 2: System Usability Score for Both the Methodology Used in Experiment 1

Experiment 2 is conducted to understand the users' subjective impressions of the methodologies in terms of usability with the same group of students from experiment 1.

The SUS, a widely recognized and validated questionnaire-based instrument, presents a comprehensive framework to capture participants' sentiments towards usability adopted in this experiment. Comprising 10 thoughtfully crafted statements, the SUS probes various facets of usability, ranging from ease of use to overall satisfaction. Participants

provide their responses, which are then meticulously analysed to yield a numerical SUS score—a concise yet powerful metric indicative of perceived usability (Brooke, 1995).

By distributing the SUS form to participants who engaged with both the Extended BDI Methodology and the Emotion-Based BDI Methodology, the proposed methodology intends to derive invaluable insights into the user experience landscape. The SUS scores obtained from these participants will enable a quantitative assessment of the usability of each methodology. A higher SUS score for one methodology than the other would signify a preference for that methodology in terms of user-friendliness and effectiveness. The proposed methodology moving forward with the study on emotion-based decision making in Experiment 2.

This time, the proposed methodology focusing on something different—how easy it is for people to use the two methods. In Experiment 1, participants tried out both the Extended BDI Method and the Emotion-Based BDI Method to make decisions in a fire evacuation situation. Now, the proposed methodology want to know what they thought about using these methods. Were they easy to use? Did they make sense? That's where the System Usability Scale (SUS) comes in.

The SUS is like a set of questions that helps us understand how people feel about using these methods. It asks things like, "Was it easy to use?" or "Did you feel confident using it?" Participants answer these questions, and the proposed methodology use their answers to calculate a score. This score tells us how usable and user-friendly each method is from the participant's point of view. The ten SUS questions used for extended BDI methodology and emotion-based BDI methodology are listed below:

1. The methodology will likely be used frequently in human behaviour modelling.

2. The methodology used for human behaviour modelling, unnecessarily complex.
3. The methodology is easy to use.
4. The support of a technical person is needed to use the methodology.
5. The various functions in the methodology are well integrated.
6. There is too much inconsistency in the methodology.
7. Most people would learn to use the methodology in human behaviour modelling very quickly.
8. The methodology in human behaviour modelling is very cumbersome to use.
9. I felt very confident using the methodology in human behaviour modelling.
10. A lot of learning is required before getting used to the methodology.

The System Usability Scale (SUS) employs a distinctive scoring approach to assess participants' perceptions of the usability of a system or product. As participants respond to the 10 statements within the SUS questionnaire, their selections on the scale, ranging from "Strongly Disagree" to "Strongly Agree" are systematically translated into numerical values. For odd-numbered statements, the response value is subtracted by one, while for even-numbered statements, the response is subtracted from five (Brooke, 1995) as shown in Equation 6.4.

Participant score

Equation 6.4

$$\begin{aligned}
 &= (Q1 - 1) + (5 - Q2) + (Q3 - 1) + (5 - Q4) \\
 &+ (Q5 - 1) + (5 - Q6) + (Q7 - 1) + (5 - Q8) \\
 &+ (Q9 - 1) + (5 - Q10)
 \end{aligned}$$

This conversion process ensures a consistent and standardized representation of participants' feedback. Subsequently, the cumulative converted scores for all 10 statements

yield an individual participant's SUS score, which initially spans from 0 to 40. To enhance interpretability, this score is then scaled to a range of 0 to 100 by multiplying the individual score by 2.5(Brooke, 1995).

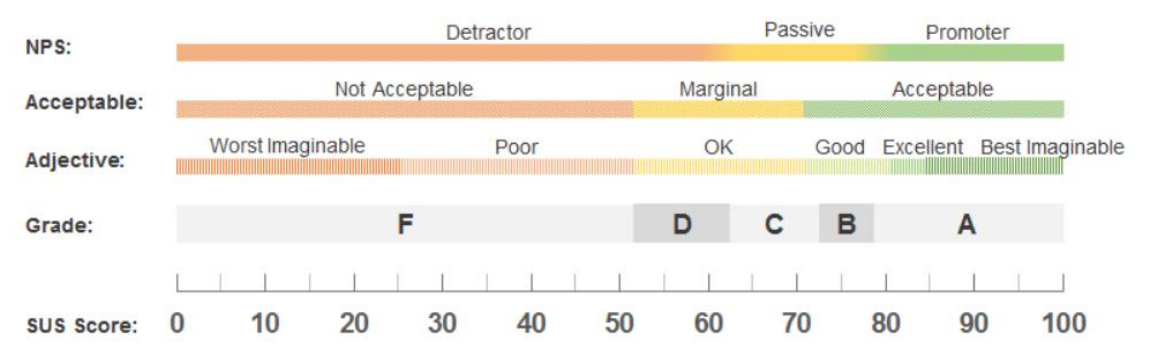


Figure 6.4: Interpretation of SUS Scores Guide Adopted from Sauro (2018)

The resulting SUS score serves as a quantifiable measure of perceived usability, providing insights into the extent to which participants found the system user-friendly. Based on Figure 6.4, this research focuses on evaluating the SUS score based on the grade and adjectives. A higher SUS score correlates with superior perceived usability, with thresholds like 70, 80, and 50 offering reference points for okay, good, excellent, and potentially problematic usability, respectively (Bangor et al., 2009). The average score obtained from the experiment will be evaluated based on Figure 6.4 which was standardised to interpret the SUS score(Brooke, 1995; Parvez et al., 2019; Sauro, 2018). Hence, the SUS score facilitates meaningful comparisons between different methodologies thereby contributing to a comprehensive understanding of user-centred design and interaction experiences.

6.5.1 Result Analysis of Experiment 2

Table 6.6 shows the SUS analysis results for the Emotion-based methodology, whereas Table 6.7 shows the SUS results for the extended BDI methodology.

Table 6.6: SUS for Emotion-based BDI Methodology

No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total Score (/40)	SUS Score (/100)	Grades
1	2	1	1	0	2	0	1	2	1	0	10	25	F
2	2	3	3	1	3	0	1	0	1	1	15	37.5	F
3	2	1	2	1	2	1	2	1	2	1	15	37.5	F
4	4	0	4	0	4	0	2	1	1	0	16	40	F
5	3	2	2	0	3	2	2	0	3	0	17	42.5	F
6	2	2	2	1	3	3	2	1	2	0	18	45	F
7	3	2	2	0	3	2	3	2	2	0	19	47.5	F
8	3	0	2	1	3	2	1	4	2	1	19	47.5	F
9	3	1	2	1	3	1	2	2	3	1	19	47.5	F
10	3	1	3	1	3	2	2	2	2	0	19	47.5	F
11	3	2	3	1	2	1	3	2	2	1	20	50	F
12	3	2	3	0	3	2	2	2	3	0	20	50	F
13	3	2	3	0	4	2	3	1	3	0	21	52.5	D
14	3	2	2	2	3	2	2	2	2	1	21	52.5	D
15	3	2	3	1	3	1	3	2	2	1	21	52.5	D
16	3	2	2	2	2	2	2	2	3	2	22	55	D
17	4	2	2	1	3	2	2	2	3	1	22	55	D
18	3	2	3	1	3	2	3	2	3	1	23	57.5	D
19	3	2	3	1	3	2	2	2	3	2	23	57.5	D
20	3	2	2	2	3	2	3	2	3	1	23	57.5	D
21	4	2	3	1	3	2	3	4	1	2	25	62.5	D
22	3	2	2	1	4	3	4	3	3	0	25	62.5	D
23	3	3	2	3	2	2	3	3	2	3	26	65	C
24	3	3	2	3	3	3	2	2	3	2	26	65	C
25	4	2	3	2	3	3	2	3	3	1	26	65	C
26	3	3	3	3	3	3	3	2	3	1	27	67.5	C
27	3	1	3	3	3	3	3	3	3	3	28	70	C
28	3	3	2	4	3	3	3	3	3	3	30	75	B
29	4	2	3	2	4	3	3	3	4	3	31	77.5	B+
30	4	3	3	3	3	4	3	3	3	3	32	80	A-
Average SUS Score												54.92	D

Table 6.7: SUS for Extended BDI Methodology

No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total Score (/40)	SUS Score (/100)	Grades
1	2	1	2	1	2	2	1	1	1	1	15	37.5	F
2	3	2	3	2	2	3	3	2	3	2	25	62.5	D
3	4	2	3	2	3	2	3	2	3	1	25	62.5	D
4	3	3	3	2	3	3	3	3	3	2	28	70	C
5	4	0	4	0	4	0	4	0	4	0	20	50	F
6	3	2	2	0	3	2	2	2	2	0	18	45	F
7	1	1	1	2	2	1	2	2	1	1	14	35	F
8	0	2	2	4	2	3	0	3	2	4	22	55	D
9	3	2	2	0	3	1	2	1	2	0	16	40	F
10	2	0	4	0	3	1	0	1	0	0	11	27.5	F
11	2	1	3	0	2	2	1	2	1	0	14	35	F
12	3	3	2	1	3	2	2	2	2	1	21	52.5	D
13	3	3	2	2	3	2	3	2	2	1	23	57.5	D
14	3	1	2	0	4	0	4	2	2	0	18	45	F
15	2	2	3	0	3	2	2	2	2	0	18	45	F
16	2	2	2	2	2	2	2	2	2	2	20	50	F
17	1	2	1	1	2	1	2	1	2	0	13	32.5	F
18	3	3	3	2	3	3	2	3	3	1	26	65	C
19	4	4	4	0	4	4	4	4	4	4	36	90	A+
20	4	2	3	2	4	3	4	2	3	1	28	70	C
21	3	2	3	0	4	3	3	3	2	0	23	57.5	D
22	3	1	2	0	3	2	2	1	1	0	15	37.5	F
23	3	1	3	1	3	1	3	1	3	1	20	50	F
24	3	2	2	1	3	2	3	2	3	1	22	55	D
25	3	2	2	0	3	2	3	2	2	0	19	47.5	F
26	3	3	3	1	3	1	3	2	3	1	23	57.5	D
27	3	2	2	0	2	2	1	2	2	0	16	40	F
28	3	3	3	1	2	2	2	3	1	2	22	55	D
29	2	1	2	2	2	2	1	1	2	1	16	40	F
30	1	2	1	0	2	2	1	1	1	0	11	27.5	F
Average SUS Score												49.83	F

Table 6.8: Average SUS Score

	Emotion-based BDI Methodology	Extended BDI Methodology
Average SUS Score	54.92	49.83

The Emotion-Based BDI Methodology received an average SUS score of 54.92, while the Extended BDI Methodology received an average SUS score of 49.83. These scores suggest that participants found the Emotion-Based BDI Methodology to be slightly more user-friendly and easier to use compared to the Extended BDI Methodology.

The scores for the emotion-based BDI methodology are above 50, indicating that participants generally found the methodology to be at least moderately usable, the higher SUS score for the Emotion-Based BDI Methodology suggests that participants had a somewhat better experience using this approach. Whereas the extended BDI is less usable in modelling emotion-oriented decision making.

6.6 Discussion

Experiment 1 was designed to explore the efficacy of two methodologies, namely the Extended BDI Methodology and the Emotion-Based BDI Methodology, in modelling decision-making scenarios centred around emotions. The results of this experiment shed light on participants' ability to apply these methodologies within the context of a fire evacuation scenario.

In experiment 1, participants were tasked with utilizing both methodologies to model decision-making processes. The analysis of the participants based on Figure 6.1, Figure 6.2, Figure 6.3 and the subsequent scoring system provided insights into their ability to capture

emotional properties within the decision-making context. The findings revealed that while both methodologies could address certain aspects of emotion representation, the Emotion-Based BDI Methodology demonstrated more advantage in effectively capturing emotional properties.

The experiment's outcomes revealed inherent complexities associated with modelling emotions in decision-making scenarios. While the Extended BDI Methodology exhibited competence in handling certain facets, it encountered challenges in fully addressing the intricacies of emotional considerations. In contrast, the Emotion-Based BDI Methodology showcased a more refined capacity to encompass emotional attributes, albeit with its own set of limitations.

This experiment highlights the significance of acknowledging emotional dimensions in decision-making models, especially in scenarios as dynamic and critical as fire evacuations. Furthermore, it highlights the need for methodologies that can systematically incorporate these dimensions, as witnessed in the potential demonstrated by the Emotion-Based BDI Methodology.

Experiment 2 shifted the focus from modelling proficiency to user experience by utilizing the System Usability Scale (SUS) to assess the perceived usability of the Extended BDI Methodology and the Emotion-Based BDI Methodology. This phase sought to understand participants' impressions of the methodologies' user-friendliness and effectiveness.

The SUS scores obtained in Experiment 2 provided quantitative insights into participants' perceptions of usability. The average SUS score for the Emotion-Based BDI Methodology (54.92) outperformed that of the Extended BDI Methodology (49.83),

indicating a slightly higher level of perceived usability for the former. This suggests that participants found the Emotion-Based BDI Methodology to be more approachable and user-friendly in the context of decision-making scenarios.

The combination of results from Experiment 1 and Experiment 2 paints a comprehensive picture of the two methodologies. Experiment 1 highlighted the Emotion-Based BDI Methodology's potential to capture emotional attributes, while Experiment 2 reaffirmed its advantage in terms of usability. In summary, these findings provide a strong foundation for considering the Emotion-Based BDI Methodology as a promising avenue for modelling emotion-oriented decision making.

6.7 Threats to Validity

Potential threats to validity revolve around the scope of emotional properties captured by the evaluation criteria, potentially leading to an oversimplified representation. Participants' familiarity with the Extended BDI Methodology might have influenced their approach to the Emotion-Based BDI Methodology, introducing internal validity concerns. The context-specific nature of the fire evacuation scenario could limit the external validity of findings to broader decision-making contexts. Furthermore, the small sample size may restrict the ability to generalise the findings across a wider population. Hence, the result may reflect specific traits or experiences of those individuals rather than the broader group.

6.8 Chapter Summary

In Chapter 6, the proposed methodology conducted experiments to explore the effectiveness and usability of the Emotion-Based BDI Methodology. The proposed methodology set the stage with the experiment's context and participant backgrounds, followed by Experiment 1 where participants used both the Emotion-Based BDI and

Extended BDI methods to solve a scenario, and the proposed methodology analysed their approaches and results. Experiment 2 focused on usability, using the System Usability Score (SUS) to assess participants' perceptions of the methods' user-friendliness. The outcomes of both experiments were discussed, highlighting the EBBDI methodology's potential and usability. The proposed methodology also acknowledged potential limitations and threats to validity, ensuring a comprehensive evaluation of the proposed methodology. This chapter is a crucial bridge between theoretical insights and practical applications, shaping the understanding of emotion-oriented decision making and its modelling methodologies.

CHAPTER 7

CONCLUSION

7.1 Overview

This chapter summarises the research's contributions and limitations. It consists of four sections: the first section outlines the chapter's overview, followed by Section 7.2, which describes the research's contributions. Section 7.3 presents the limitations and future works, and Section 7.4 concludes the thesis.

7.2 Contributions

This research makes a significant contribution to computer science by extending the Belief-Desire-Intention (BDI) architecture to explicitly incorporate emotional states and personality traits, enhancing the realism and effectiveness of agent-based simulations. The introduction of new modelling notations and integration of established psychological theories, such as the OCC model and the OCEAN personality framework, provides a structured computational method for representing complex emotional dynamics. Furthermore, practical implementation, validation, and usability evaluations conducted using Unity3D demonstrate the methodology's effectiveness in modelling emotion-oriented human decision making, significantly advancing agent-oriented software simulation techniques.

The main contribution of this research aligns closely with the research aim, which is to extend the BDI methodology into an emotion-oriented BDI methodology. Specifically, the contributions address the stated objectives:

1. Designing and implementing a method to incorporate emotion-oriented human decision-making into fire evacuation simulations through an extension of the BDI methodology. This novel integration enhances the accuracy and reliability of evacuation decisions by incorporating emotional factors into the BDI framework, directly addressing the first object as stated in Section 1.3.
2. Evaluating the emotional properties essential to developing the emotion-based BDI methodology. This involves systematically assessing the emotional attributes and mechanisms, such as the OCC emotion model and the OCEAN personality framework, which significantly impact evacuation scenarios, thus addressing the research objective of evaluating emotional properties used in the methodology.

7.3 Limitations and Future Work

The emotion-based BDI methodology has shown great potential in modelling human emotion and behaviour during a fire evacuation scenario. However, it is essential to note that while the Emotion-Based BDI Methodology demonstrated advantages, it also possesses unique strengths and limitations. Future work should focus on refining and expanding the Emotion-Based BDI Methodology to further harness its potential while addressing its limitations, ultimately contributing to the evolution of decision-making models that comprehensively integrate emotional considerations. Hence, several limitations can be further improved in the proposed methodology.

1. Area of study. The study only focuses on fire evacuation processes. In the future, this methodology can be further tested with a different case study and scenario.

2. The third-party influence on occupants' emotions and personality. The emotion-based BDI methodology is only able to model a single agent's behaviour by itself and not how other agents can affect them. In the actual evacuation, human personality and behaviour are also affected by their condition at that time (Proulx, 2001). For example, how the role of a firefighter, leader or other occupants affects the emotional factors and reaction of the agents should be further considered to model a fire evacuation scenario which much closer to the real situations.
3. A great systematic modelling methodology also requires a tool that can handle the detailed modelling and simulations. In the future, it would be a great advantage if a suitable tool could be developed along with the emotion-based methodology.

7.4 Conclusions

This research has provided a new vision for modelling human emotion during evacuation. Through the gaps that were found when the literature study was done, by reviewing the existing methodologies, modelling methods and emotional properties during fire evacuation the proposed methodology is then defined. Then, the extended BDI methodology is further improved by adding the emotional modelling factor. The proposed emotion-based BDI methodology is introduced. To evaluate the proposed methodology the experiments were divided into three parts. The first experiment is to test the correctness of the emotion and personality properties in creating the emotion-based methodology. The second part is to compare the implementations of the proposed emotion-based BDI methodology with the existing extended BDI methodology. The result from the second experiment is also compared to the actual Australian bushfire case study. The third part of the experiment is to test the usability and usefulness of the emotion-based methodology which was conducted with a group of students.

As emotion modelling is a complex process, the introduction of emotion-based BDI methodology has eased the process of modelling emotions involved during a fire evacuation. Besides, adding emotions as a requirement or condition for developing a fire evacuation is a stepping stone to improving 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 for designing realistic human behaviours in fire evacuation simulation.

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APPENDICES

Appendix A: Case Study Task for Experiment 1

Question

There are 100 houses in a residential area surrounding the forest. Each house contains 1 occupant. There are 2 shelters located on the upper right and bottom left. The occupants are doing their daily routine. Suddenly, there was a bushfire that started to spread over the residential area. The occupants will start to react by defending their home or evacuating to a safe place. While defending their home or evacuating, an emotion will be involved, which can affect the decision-making process.

When the bushfire starts to spread at first the residents may feel calm but as it gets worse from being calm, they will become alarmed and from there can feel fear or worse depending on the situation. Although they feel fear, they can still decide to defend their home and find the right exit (follow instructions and wait for rescue).

Let's say, that when the fire spread becomes worse and the residents are near the fire, they will feel fear and some might feel terror, panic, or even hysteria. This might affect the evacuation process, and the residents might be stuck in their current position.

Furthermore, when they can't find the exit as the fire is spreading, their fear level will increase making it hard to make decisions. For those who are calm, they will wait for rescue, wait for instruction or try to follow the crowd to find the exit. However, those who are feeling, fear, terror, panic or hysteria, might not follow instructions and can make irrational decisions which can cause harm, such as they go to the wrong exit (which will

disrupt the evacuation process). Furthermore, they can also make extreme decisions such as jumping from a high place, which will cause harm during the evacuation process.

Based on the case study, answer the following questions.

Modelling human cognition and emotion through agent-oriented modelling (AOM) or extended BDI Methodology. Notes: You are required to refer to the document in Appendix A to complete this modelling process. Furthermore, you are required to model the emotion according to the situation based on the six levels of fear emotion as shown below:

Calm → Alarm → Fear → Terror → Panic → Hysteria

- i. Modelling the human cognition and emotion in bush fire evacuation through domain model.
- ii. Modelling the human cognition and emotion in bush fire evacuation through ROADMAP Goal model-desire representation.
- iii. Modelling the human cognition and emotion in bush fire evacuation through Tropos goal model-desire and intention representation.
- iv. Modelling the human cognition and emotion in bush fire evacuation through knowledge model.
- v. Modelling the human cognition and emotion in bush fire evacuation through scenario model.
- vi. Modelling the human cognition and emotion in bush fire evacuation through behaviour model.