Faculty of Information and Communication Technology

ENHANCED MULTI-AGENT APPROACHES FOR EFFICIENT EVACUATION AND RESCUE OPERATIONS IN MANAGING DISASTERS

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ENHANCED MULTI-AGENT APPROACHES FOR EFFICIENT EVACUATION AND RESCUE OPERATIONS IN MANAGING DISASTERS

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DECLARATION

I declare that this thesis entitled “Enhanced Multi-Agent Approaches for Efficient Evacuation and Rescue Operations in Managing Disasters” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

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Date : 29 January 2025 ……..

DEDICATION

With heartfelt gratitude to my God for granting me the strength and perseverance to complete my Ph.D., I dedicate this work to my beloved parents, my wife, my precious sons, my dear brothers, and my loving sister. Their unwavering love, endless prayers, steadfast support, and boundless kindness have been my guiding light throughout this journey. I am forever grateful and deeply appreciative of their presence in my life.

ABSTRACT

This study addresses disaster management within Multi-Agent System (MAS) environments, focusing on two critical phases: evacuation and rescue. The study tackles two primary challenges: the Emergency Route Planning (ERP) problem, which involves determining optimal evacuation routes within capacity-constrained transportation networks, and the Winner Determination Problem (WDP) in reverse combinatorial auctions, which pertains to effective task allocation and coordination among rescue agents. The research progresses through four stages: problem definition, approach design, implementation and evaluation, and simulation. For the evacuation phase, a Dynamic Real-Time Capacity Constrained Routing (DRTCCR) algorithm is introduced to address ERP challenges. The algorithm aims to generate optimal evacuation routes considering the complexity, capacity constraints, and scale of evacuees in the transportation network. Analytical evaluation against existing algorithms, specifically Multiple-Route Capacity Constrained Planner (MRCCP) and Max-Flow Rate Priority (MFRP), demonstrated that the DRTCCR significantly improves performance in terms of Total Evacuation Time (TET) and Weighted Average Time (WAT). Compared to MRCCP, DRTCCR reduced TET by 14.95% and WAT by 1.7%, while against MFRP, it decreased TET by 17.25% and WAT by 9.18%. In the rescue phase, two innovative approaches are proposed to enhance task allocation for WDP in reverse combinatorial auctions. These approaches were rigorously evaluated against Andrea's algorithm and a Genetic Algorithm, revealing competitive advantages. Notably, as the number of bidders increased, the execution time of competing approaches escalated exponentially, while the proposed approaches exhibited a steady increase. Building on the proposed algorithm and approaches, Agent-Based Simulation (ABS) models were developed to evaluate both evacuation and rescue operations in Al-Aqsa Mosque (AM) scenarios in Palestine. The ABS evacuation model demonstrated superior performance compared to the Random, Kasereka, and Nearest Neighbor Search (NNS) models, achieving a 0% Total Deaths (TD) rate, outperforming Kasereka 1%, Random 5.5%, and NNS 14%. It also achieved a 99.5% Total Alive Evacuees (TA) rate, compared to 98.7% for Kasereka, 94.9% for Random, and 87.6% for NNS, along with an Average Health of Alive Agents (ATA) improvement of 52.4% over Kasereka, 82.1% over Random, and 93% over NNS. Similarly, the ABS rescue model outperformed both the Nearest Neighborhood Rescuing (NNR) model and the Hooshangi and Alesheikh model, reducing the duration of rescue operations by 49.2% compared to NNR and 32.6% compared to the Hooshangi and Alesheikh model, while also decreasing the number of casualties by 10.6% relative to NNR and 2.4% relative to the Hooshangi and Alesheikh model. These results highlight the model's significant improvements in both efficiency and effectiveness in managing evacuation and rescue scenarios.

PENDEKATAN PELBAGAI AGEN YANG DIPERTINGKATKAN UNTUK OPERASI PEMINDAHAN DAN MENYELAMAT YANG CEKAP DALAM MENGURUS BENCANA

ABSTRAK

Kajian ini menangani pengurusan bencana dalam persekitaran Sistem Pelbagai-Agen (MAS), dengan memberi tumpuan kepada dua fasa kritikal: pemindahan dan penyelamatan. Kajian ini mengatasi dua cabaran utama: masalah Perancangan Laluan Kecemasan (ERP), yang melibatkan penentuan laluan pemindahan yang optimum dalam rangkaian pengangkutan yang terhad kapasitinya, dan Masalah Penentuan Pemenang (WDP) dalam lelongan kombinatorial terbalik, yang berkaitan dengan peruntukan tugas yang berkesan dan koordinasi antara agen penyelamat. Penyelidikan ini melalui empat peringkat: definisi masalah, reka bentuk pendekatan, pelaksanaan dan penilaian, serta simulasi. Untuk fasa pemindahan, algoritma Penghalaan Terhad Kapasiti Masa Nyata Dinamik (DRTCCR) diperkenalkan untuk menangani cabaran ERP. Algoritma ini bertujuan untuk menghasilkan laluan pemindahan yang optimum dengan mengambil kira kerumitan, kekangan kapasiti, dan skala penghuni dalam rangkaian pengangkutan. Penilaian analitik terhadap algoritma yang sedia ada, khususnya Perancang Terhad Kapasiti Laluan-Pelbagai (MRCCP) dan Keutamaan Kadar Arus-Maksimum (MFRP), menunjukkan bahawa algoritma DRTCCR meningkatkan prestasi secara signifikan dari segi Jumlah Masa Pemindahan (TET) dan Purata Masa Tertimbang (WAT). Dalam fasa penyelamatan, dua pendekatan inovatif dicadangkan untuk meningkatkan peruntukan tugas bagi WDP dalam lelongan kombinatorial terbalik. Pendekatan ini dinilai secara teliti berbanding dengan algoritma Andrea dan Algoritma Genetik, menunjukkan kelebihan kompetitif. Terutama, apabila bilangan pembida meningkat, masa pelaksanaan pendekatan tersebut meningkat secara eksponen, manakala pendekatan yang dicadangkan menunjukkan peningkatan yang stabil. Berdasarkan algoritma dan pendekatan yang dicadangkan, model Simulasi Berasaskan Agen (ABS) telah dibangunkan untuk kedua-dua operasi pemindahan dan penyelamatan. Model pemindahan ABS, yang berpandukan algoritma DRTCCR, dinilai secara kritikal berbanding dengan model Rawak, Kasereka, dan Pencarian Jiran Terdekat (NNS). Keputusan menunjukkan hasil yang lebih baik dari segi Jumlah Penghuni Hidup (TA), Jumlah Kematian (TD), Purata Kesihatan Penghuni Hidup (ATA), Purata Masa Pemindahan (ATE), dan Diagram Kepadatan. Begitu juga, berdasarkan pendekatan peruntukan tugas yang dipertingkatkan, model ABS untuk operasi penyelamatan telah dibangunkan dan dinilai berbanding model Penyelamatan Jiran Terdekat (NNR) dan model Hooshangi dan Alesheikh. Keputusan adalah memuaskan, menunjukkan penambahbaikan yang ketara dalam tempoh operasi penyelamatan dan bilangan korban.

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LIST OF ABBREVIATIONS

MAS	-	Multi-Agent System
ERP	-	Emergency Route Planning
WDP	-	Winner Determination Problem
ABS	-	Agent-Based Simulation
CCRP	-	Capacity Constraint Route Planner
GA	-	Genetic Algorithm
MFRP	-	Max-Flow Rate Priority
DRTCCR	-	Dynamic Real-Time Capacity Constrained Routing
MRCCP	-	Multiple-Route Capacity Constrained Planner
AM	-	Al-Aqsa Mosque
CSAR	-	Crowd Search and Rescue

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1. Abusalama, J., Razali, S. and Choo, Y. H., 2022. An enhanced approach for solving winner determination problem in reverse combinatorial auctions. *Indonesian Journal of Electrical Engineering and Computer Science*, 28(2), pp. 934-945.

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2. Abusalama, J., Razali, S., Choo, Y.H., Momani, L. and Alkharabsheh, A., 2020. Dynamic real-time capacity constrained routing algorithm for evacuation planning problem. *Indonesian Journal of Electrical Engineering and Computer Science*, 20(3), pp. 1388-1396.

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2. Abusalama, J., Razali, S. and Choo, Y. H. and Ali, Attajer, 2025. Agent-Based Simulation Model for Evacuation Operations in Crowd Mass Disasters. *International Journal of Simulation and Process Modelling*.
3. Abusalama, J., Razali, S. and Choo, Y. H. and Ali, Attajer, 2025. Agent-Based Simulation Model for Rescuing Operations in Crowd Mass Disasters. *Modelling and Simulation in Materials Science and Engineering*.

CHAPTER 1

INTRODUCTION

1.1. Introduction

This chapter gives an overview of the research conducted in this study. The explanations include research background, problem statement, research questions, research objectives and thesis outlines. The research background introduced the most issues related to the research phases in general. Moreover, the gap analysis and research motivation have been discussed. Research problem described the research problem and the suggested solving methods in this study, followed by research questions and objectives, and finally the thesis structure has been introduced at the end of this chapter.

1.2. Research background

Disaster management has become an important issue in the last few years due to the large number of disasters occurring and other recent catastrophes (Huang et al., 2022), and these catastrophes result in the death of many people in crowded mass area. Managing the disaster involves coordinating a large number of emergency responders to evacuate and rescue victims in possibly hazardous environments where ambiguity about events is prevalent (Masys, 2015). In this study, the aim was targeted at coping with managing the disaster, specially managing the evacuation and rescuing operations during the disaster in Multi-Agent System (MAS) environments. Whereas, MAS are dynamic environments, which are composed of intelligent