Doctoral Dissertation

Development of a Mutual Assistance Evacuation Model Considering the Diversity of Residents' Behavior and Vehicle Ownership: A Case Study in Mount Merapi, Indonesia

住民行動の多様性と車両保有状況を考慮した共助型避難モデルの開発：インドネシア・メラピ山におけるケーススタディ

March, 2023

Faizul Chasanah

Graduate School of Sciences and Technology for Innovation, Yamaguchi University

ABSTRACT

Indonesia has extreme risk of natural disasters because of its position at the confluence of four tectonic plates: the Asian Continent, the Australian Continent, the Indian Ocean, and the Pacific Ocean. The volcano eruption is one of the geological disasters that frequently occur in this country. Mount Merapi is Indonesia's most active volcano and is famous worldwide. The evacuation crisis in 2010, the last major eruption, led to many fatalities for humans and cattle. Nowadays, the local government developed the "sister village" strategy for mitigation. That means cooperation within or between the local community has been constructed to provide shelter, logistics, and other disaster-related services. In this scenario, the meeting area and shelter have been coordinated. However, people's behavior has not been fully considered yet in the vulnerability assessment and government's contingency plan. On the other hand, evacuation issues in a volcanic disaster such as difficulty in expecting evacuation period, aging population, missed communication and risk perception, limited private vehicles in the community, and limited evacuation transport and supporters by the government need to be addressed for better mitigation. This situation led some people to walk to the meeting area, and low walking speeds by vulnerable persons may increase the risk and delay during an emergency.

The objective of this study is to find the effectiveness of the evacuation process, especially for the vulnerable community in the Mount Merapi area. Especially, this study purposes to develop a "mutual assistance" model for vulnerable people in the affected regencies with the people's behavior and vehicle ownership as a viewpoint. The first goal is an assessment of the mutual assistance strategy and social vulnerability index (SoVI) of pedestrian evacuation. I conducted the surveys and then analyzed the data using a multicriteria method to obtain the SoVI values for communities. The second goal is the development of the assembly model to support safer and faster evacuation for vulnerable people. The AnyLogic software was selected for model simulation using input parameters from field surveys.

In conducting a survey, I measured the walking speed directly of the evacuation drills in four affected regencies. I also investigated the people's behavior and eruption characteristics using an interview process with stakeholders and group discussions with local communities. After that, I used the multicriteria method and focused on two factors, social and age structure (young, vulnerable, and mutual assistance between them), and risk perception (work, rain, night, alert, and evacuation map). The index reflects the distribution of actual walking speed, mutual assistance, and the government's plan. The result showed that mutual assistance groups have a higher walking speed than vulnerable people but lower than young people. Mutual assistance coordination is crucial to support the vulnerable in shorter evacuation times. The social and age structure of the social vulnerability index has a stronger risk influence than the perception factor in the evacuation process.

The successful evacuation of vulnerable people during emergencies is a significant challenge. In this study, a mutual assistance strategy is proposed to support vulnerable people by evacuating them with young people. This strategy was simulated using AnyLogic software with the agent-based model concept. Pedestrians and vehicles played the roles of significant agents in this experiment. Evacuation departure rate, actual walking speed, group size, route, and coordination were crucial agent parameters. Residents' attitudes, distribution of each agent, and actual walking speed were obtained from surveys. Then, I developed three scenarios and three models for the evacuation process. Scenarios considered traffic conditions of evacuation routes and models represented behavior approach. The results revealed that this mutual assistance model is effective for the rapid evacuation and risk reduction of vulnerable communities where successful evacuation rates have improved. As for mutual assistance behavior, Model 3, where young people are matched with vulnerable people in advance, has shown better results than Model 2. Additionally, Scenario C, where pedestrians have separate lanes from vehicles during the evacuation process, has resulted in more number of vulnerable people reaching the shelter than Scenario B in Model 3. The highest arrival rate was obtained by the combination of scenario C and Model 3. These findings are a novelty in the volcano context and reflect all categories of vulnerable behavior involving the elderly, disabled, children, and pregnant mothers. The model will benefit disaster management studies and authorities' policies for sustainable evacuation planning and aging population mitigation.

概要

インドネシアは、アジア大陸、オーストラリア大陸、インド洋、太平洋の 4 つのプレートの合流点に位置しており、自然災害のリスクが非常に高い。火山噴火は、この国で頻繁に発生する災害の 1 つである。メラピ山はインドネシアで最も活動的な火山として世界的に著名である。直近では 2010 年の大噴火における避難危機により、人間と家畜に多くの犠牲をもたらした。現在、現地の自治体は減災のために「姉妹村」戦略を開発している。これは、避難所、ロジスティクス、その他の災害関連サービスを提供するために、地域コミュニティ内または地域コミュニティ間に協力関係を構築することを意味する。このシナリオでは、避難のための集合場所と避難所が整備されている。しかし、人々の行動は、脆弱性評価と政府の緊急時対応計画において十分に考慮されていない。一方で、よりよい減災のためには、避難期間の予測の困難性、人口の高齢化、コミュニケーションとリスク認識の欠如、対象地域において私有交通手段が限られること、政府による避難輸送と支援の限界等の課題に取り組む必要がある。この状況下で、住民は集合場所まで徒歩移動の必要があり、脆弱な人々の歩行速度が遅い場合、緊急時のリスクと遅延が増加する可能性がある。

本研究は、特にメラピ山地域の脆弱なコミュニティに対して、避難プロセスの有効性を見出すことを目的としている。 特に本研究では、人々の行動と車両の所有権を視野に、影響を受ける地域の脆弱な人々のための「共助」モデルを開発することを目的としている。 最初の目標は、歩行者避難の共助戦略と社会的脆弱性指数（SoVI）の評価である。 調査を実施した後、多基準法を使用してデータを分析し、地域コミュニティの SoVI 値を得た。 2 番目の目標は、脆弱な人々のより安全で迅速な避難をサポートするためのアセンブリモデルの開発である。 現地調査で得られた入力パラメータを使用し、AnyLogic ソフトウェアによりモデルシミュレーションを実施した。

調査を実施するにあたり、火山の影響を受ける 4 つの県で避難訓練の歩行速度を直接測定した。また、利害関係者へのインタビューや、地域コミュニティとのグループディスカッションに基づいて、人々の行動や火山災害の特徴を調査した。その後、社会的・年齢構成とリスク認識（仕事中、雨天時、夜間、警報発令時、避難路）の 2 つの要素に注目して多基準評価を適用した。この指数は、実際の歩行速度の分布、共助、および自治体の計画を反映している。調査の結果、共助グループは災害弱者よりも歩行速度が速いが、若年層よりは遅いことが示された。災害弱者をより短時間で避難できるよう支援するには、相互支援の調整が不可欠である。社会的脆弱性指数において、社会的・年齢構成は、リスク認識よりも強い影響を及ぼすことが示された。

緊急時に災害弱者の避難を成功させることは重要な課題である。本研究では、脆弱な人々を若者と一緒に避難させることによって支援する、共助戦略を提案する。エージェントベースのモデルコンセプトを備えたAnyLogic ソフトウェアを使用して、この共助戦略のシミュレーションを実行した。この実験では、歩行者と車両が主要なエージェントの役割を果たす。避難出発率、実際の歩行速度、グループのサイズ、ルート、および調整をパラメータとした。住民の態度、各エージェントの分布、および実際の歩行速度は、調査から得られた。そのうえで、避難プロセスのための3 つのシナリオと 3 つのモデルを開発した。シナリオは避難路の交通状況を考慮し、モデルは共助行動の形態を反映している。その結果、共助モデルは、災害弱者の避難率の向上をもたらし、脆弱なコミュニティにおける迅速な避難とリスク軽減に効果的であることが明らかとなった。共助行動に関しては、若者を災害弱者と事前にマッチングするモデル 3 の結果はモデル 2 よりも最も高い集合場所への到着率を達成した。それに加えて、モデル 3 において、歩行者と車両の走行空間を分離するシナリオ C はシナリオ B より集合場所に到達する災弱者の数が多い結果となった。以上より、シナリオ C とモデル 3 の組み合わせで最良の結果を得ることができた。以上の研究結果は、高齢者、障害者、子供、妊娠中の母親が関与する脆弱な行動のすべてのカテゴリを反映しており、火山の文脈では新規性を有する。このモデルは、持続可能な避難計画と高齢化社会における減災に関する防災研究と行政当局の対策に有益であると考えられる.

ACKNOWLEDGEMENT

The current study was conducted in the Regional Development and Planning Laboratory, Environmental Engineering Department, Graduate School of Sciences and Technology for Innovation, Yamaguchi University from 2019-2023. Alhamdulillah, I thank to my Almighty God, Allah SWT for health and His protection during this study.

Firstly, I would like to extend my sincere and deepest gratitude to my supervisor, Professor Hiroyuki Sakakibara, for his kindness, guidance, and support. I have learned so many things during the time I studied under his supervision. I gratefully acknowledge the Next Generation Researcher Challenging Research Program of the Japan Science and Technology Agency (JST) for providing part of my research fund.

Secondly, my deepest appreciation to my graduate committee, Professor Motoyuki Suzuki, Professor Koichi Yamamoto, Associate Professor Hirotoshi Mori, and Associate Professor Haruna Suzuki who have helped me so much to improve the quality of my work with their constructive suggestions.

Thirdly, I would like to thank my family, first to my husband, Imron Rosyadi, for her love, care, and spiritual and physical support during my studies. And also, to my two beloved daughters, Maryam Aqila Rosyadi and Michiko Asma Rosyadi, for being my motivation during my studies. I also thank my dear parents, Achmad Chadziq and RIP Sri Intowati; my father and mother-in-law, Sudirman and Faizatun for their support and prayers.

Lastly, all of the members of the Regional Development and Planning Laboratory, stakeholders in the Regional Disaster Management Agency, my Indonesian and Malaysian friends in Japan, and my colleagues in the Civil Engineering Department, Universitas Islam Indonesia have my sincere thanks for their help and cooperation during my study.

TABLE OF CONTENTS

ABSTRACT ii

概要 iv

ACKNOWLEDGEMENT vi

TABLE OF CONTENTS vii

LIST OF TABLES x

LIST OF FIGURES xi

LIST OF ABBREVIATIONS xiv

CHAPTER I: INTRODUCTION

1.1. Background Information 1

1.2. Dissertation Objectives 3

1.3. Dissertation Structure 3

CHAPTER II: LITERATURE REVIEWS

2.1. Characteristics of Volcano Disaster 6

2.2. Risk of Volcano Eruption on Transportation 8

2.3. Challenges in Evacuation Process for Vulnerable People 10

2.4. Vulnerability Assessment Method 11

2.5. Agent-Based Simulation Approach 12

2.5.1. Agent-based model structure 12

2.5.2. Application overview 13

2.5.3. AnyLogic software 14

2.6. Previous Studies on Mount Merapi Evacuation 15

2.7. Related Studies on Mutual Assistance Evacuation 17

CHAPTER III: ASSESSMENT OF SOCIAL VULNERABILITY IN THE EVACUATION PROCESS FROM MOUNT MERAPI

3.1. Introduction 22

3.2. Data Collection and Methods 23

3.2.1. Data collection 23

3.2.2. Data analysis 25
3.2.3. Social vulnerability index 25
3.3. Results and Discussion 29
3.3.1. Characteristics of the local communities and population 29
3.3.2. Pedestrian evacuation speed 31
3.3.3. Mutual assistance impact 35
3.3.4. Social vulnerability index 37
3.3.5. Comparison with previous studies 39
3.4. Summary 40
CHAPTER IV: DEVELOPMENT OF MUTUAL ASSISTANCE EVACUATION MODEL TO REDUCE THE VOLCANIC RISK FOR VULNERABLE SOCIETY
4.1. Introduction 43
4.2. Related Studies 45
4.2.1. Mount Merapi evacuation 45
4.2.2. Existing evacuation simulation model 47
4.3. Material and Methods 47
4.3.1. Study area 47
4.3.2. Methodological approaches 49
4.3.3. Data used for simulation parameters 50
4.3.4. Agent-based evacuation model 53
4.3.4.1 Anylogic simulation principle 53
4.3.4.2 Evacuation route model 54
4.3.4.3 Logic structure model 54
4.3.4.4 Analysis structure model 56
4.4. Results 57
4.4.1. Simulation performance 57
4.4.2. Effectiveness of the assembly model and the traffic phenomenon 58
4.4.2.1 Effect of mutual assistance on pedestrian evacuation 58
4.4.2.2 Effect on traffic phenomenon 59
4.4.3. Evacuation time analysis 61
4.4.4. Density map evaluation 62

4.4.5. Validation of the results 63
4.5. Discussion and Recommendation 64
4.5.1. Mutual assistance model for Merapi eruption: a successful evacuation? 65
4.5.2. Effective mitigation for an aging population 68
4.5.3. Applicability for various natural disasters 69
4.5.4. Limitations and future research 70
4.6. Summary 71
CHAPTER V: CONCLUSIONS AND FUTURE WORKS
5.1. Conclusions 76
5.2. Future works 76
APPENDIX
A. Result of Scenario B and C 78
B. Result of Modeling Simulation 79
C. List of Publications 106
D. List of Presentation 106

LIST OF TABLES

Table 2.1	Warning levels for Merapi volcano eruptions	6
Table 2.2	Transportation damage and disruption from the volcano hazard in the word (x=road, o=rail, Δ=maritime, ◊=airport)	9
Table 3.1	Detail of survey sites	23
Table 3.2	Scoring criterion design of the social and age structure factor	27
Table 3.3	Scoring criterion design of the risk perception factor	27
Table 3.4	Pedestrian evacuation speed in Boyolali Regency	32
Table 3.5	Pedestrian evacuation speed in Klaten Regency	32
Table 3.6	Pedestrian evacuation speed in Magelang regency	33
Table 3.7	Pedestrian evacuation speed in Sleman Regency	33
Table 3.8	Recapitulation of ANOVA result in each category	34
Table 3.9	The speed comparison of young and vulnerable people according to the independent samples T-test	35
Table 3.10	The speed comparison of mutual assistance and vulnerable people according to the paired samples T-test	37
Table 3.11	A common score of the social and age structure (all affected regencies)	37
Table 3.12	A common score of the risk perception (all affected regencies)	38
Table 3.13	Weight of vulnerability in the subjective and objective view	38
Table 3.14	Social vulnerability index comparison	39
Table 4.1	Evacuation distance and distribution of evacuees	52
Table 4.2	Detailed shelter locations	55
Table 4.3	Simulation results in Scenario A	59
Table 4.4	Data comparison between real and model output using a One-Way ANOVA test. The results show that *p* value (sig) > 0.05 in all scenarios. It indicates that the populations of real and model outputs match	64

LIST OF FIGURES

Figure 1.1	Structure of dissertation	4
Figure 2.1	The detailed explanation of VEI	7
Figure 2.2	The case of volcano eruptions with a high VEI scale. Mount Merapi is categorized as a large eruption with a VEI of 4	7
Figure 2.3	Mount Merapi hazard map and material impact	8
Figure 2.4	Classification of vulnerable factors in disaster risk assessment	11
Figure 2.5	Agent-based model structure	13
Figure 3.1	Documentation of interview, forum group discussion, and simulation	24
Figure 3.2	The assessment framework	26
Figure 3.3	The proportion of the local community risk perception	30
Figure 3.4	Conceptual of regency population	31
Figure 3.5	The mean walking speed comparison between young people and mutual assistance	36
Figure 3.6	The mean walking speed comparison between vulnerable people and mutual assistance	36
Figure 4.1	Map of Merapi volcano hazard zone (KRB I, II, III) and evacuation area at Level 3 within a radius of 5–6 km in Klaten and Sleman Regencies. The inset maps show the location of Mount Merapi on Java Island and in Indonesia	49
Figure 4.2	Research framework, including four methods that involve measuring walking speed, surveying stakeholders and the local community, the simulation model, and an evaluation	50
Figure 4.3	AnyLogic software simulation design of Merapi evacuation	53
Figure 4.4	Three evacuation models: In M1, all residents evacuate independently; in M2, some young and vulnerable evacuees assemble at the meeting point; in M3, evacuees' group at their homes	55
Figure 4.5	A logic scheme for M2 in Kalitengah Lor. The green chart indicates pedestrian flow, and the black chart indicates vehicle flow. Group D, Group E, Group C, and Group PM are assembled between young people and vulnerable people	56
Figure 4.6	Mutual assistance model visualization of Scenario A in Sidorejo village with code AM2. The result shows the young and vulnerable	57

people form a pedestrian group at the meeting point. In Petung Lor (PL) children meeting point case, 21 people arrive at the meeting point consisting of 11 children and 10 young people, 1 child waits for the matching, and 20 people left. Finally, 56 people arrived by groups comprising 28 young and 28 vulnerable individuals, and 146 young people reach the temporary shelter

Figure 4.7 Animated model of Scenario C in Umbulharjo (Pangukrejo). CM1 illustrates self-evacuation in Model 1. CM2 shows Model 2 in 3D, with the young and vulnerable coordinating at the intersection and traveling in pairs. CM3 shows Model 3 in 2D, with the group that forms at homes 58

Figure 4.8 Simulation results in Scenario B and C for Klaten and Sleman regencies. The results show that not all of them were successful in evacuating for one hour. M3 ranks highest for the number of vulnerable people arriving in all locations except for Balerante, where the highest score was observed with M2. The best result is scenario CM3 60

Figure 4.9 The people's arrival time distribution in the temporary shelter at the last minute of the simulation in the case of Scenario C in Tegalmulyo village. All population left to evacuate with a distribution of 119 young people using vehicles, 24 young people self-evacuate, and 82 young and vulnerable evacuate together. The vertical axis shows the arrivals number and the horizontal axis represent the interarrival time of each person in seconds. The green line is the vehicle arrival time flow, the blue line shows the arrival time of young people, and the red line describes vulnerable people's arrival in independently or grouping. Panel (a) presents the results of M1 with approximately 3 min of interarrival time and 58.81 min for the last vulnerable person to arrive. Panel (b) displays the results of M2 with an interarrival time of 1 min (57.83 min of the last person). Panel (c) presents the results of M3 with an interarrival time in sec (58.33 min of the last person). Overall, M3 had the best evacuation time for vulnerable people based on the interval between arrivals and total arrivals 62

Figure 4.10 Density map of Scenario C in Glagaharjo. Panel (a) present the evacuation route according to the GIS map in AnyLogic. Panel (b) shows that M3 leads to more congestion than the other models. Evacuees walking in pairs from their homes to the temporary shelter increases road density 63

Figure 4.11 Comparison between Scenarios A (all evacuees walk) and B and C (vehicles are used). Scenarios B and C are effective for increasing the successful evacuation rates of young and vulnerable people. M2 and M3 are effective for improving the successful evacuation rates of vulnerable people 67

Figure 4.12 Phenomenon of the decreasing arrivals in young people 67

Figure 4.13 Correlation between percentage of vulnerable people and number of arrivals. Increased distribution of vulnerable people leads to more effective mutual assistance models 68

LIST OF ABBREVIATIONS

ABS	Agent-Based Simulations
AM1	Scenario A Model 1
AM2	Scenario A Model 2
AM3	Scenario A Model 3
ANOVA	Analysis of Variance
BM1	Scenario B Model 1
BM2	Scenario B Model 2
BM3	Scenario B Model 3
BNPB	Badan Nasional Penanggulangan Bencana
BPBD	Badan Penanggulangan Bencana Daerah
CDPMs	Community-Based Disaster-Prevention Meetings
CM1	Scenario C Model 1
CM2	Scenario C Model 2
CM3	Scenario C Model 3
CSSD	Computational Social Science of Disasters
ESVs	Emergency Service Vehicles
HCM	Highway Capacity Manual
H_i	Different Hazards
IRC	Indian Roads Congress
KRB	Kawasan Rawan Bencana
km	Kilometer
km^3	Cubic Kilometer
LOS	Level of Service
MATSim	Multi-Agent Transport Simulation
MCE	Multi-Criteria Evaluation
M1	Model 1
M2	Model 2
M3	Model 3

m	Meter
m^3	Cubic Meter
m/s	Meter per Second
min	Minute
R	Risk
SOM	Self Organizing Map
SoVI	Social Vulnerability Index
Sta	Stationing
STDMR	Spatio-Temporal Dynamics Model of Risk
TRANSIMS	Transportation Analysis and Simulation System
UNESCO	United Nations Educational, Scientific and Cultural Organization
VEI	Volcanic Explosivity Index
V	Vulnerability
V_{ij}	Different Vulnerabilities
v_i	Criterion Score for Vulnerability Factor *i*
WHO	World Health Organization
w_i	Weight of a Hazard
w_j	Weight of Importance of a Selected Vulnerability Factor
α_{ijk}	Social Factor Parameter
%	Percentage

CHAPTER I
INTRODUCTION

1.1 Background Information

Natural disasters are a complex combination of natural hazards and human action (Wisner *et al.*, 2003). These catastrophes occur when a danger overwhelms a particularly sensitive community, frequently resulting in mortality and morbidity. Over the last decade, over 300 natural catastrophes have occurred each year throughout the world, impacting millions and costing billions (Prasad and Francescutti, 2017). Indonesia is a country that faces a significant risk of natural disaster due to its location at the meeting point of four tectonic plates: the Asian Continent, the Australian Continent, the Indian Ocean, and the Pacific Ocean. Republic of Indonesia law No. 24 of 2007 defined a disaster as an incident that threatens and disrupts people's lives and livelihoods. It is produced by natural and or non-natural factors, as well as human factors, and results in human casualties, environmental damage, property losses, and psychological impacts (President of the Republic of Indonesia, 2007).

Indonesia has twelve disasters which are categorized into geological disasters (earthquakes, tsunami, volcanoes, and landslides), hydrometeorological disasters (floods, flash floods, drought, extreme weather, extreme waves, forest, and land fires), and anthropogenic disasters (epidemic diseases and industrial-accident technology failures). According to the Indonesian Disaster Risk Index data in 2013, 205 million people were living in disaster-prone areas. Data shows that the incidence of disasters has increased significantly in the past decade. During that period, Indonesia was afflicted by 11,274 disasters, which killed 193.240 lives and resulted in a total loss of Rp 420 trillion. Volcanic eruptions are one of the most impactful natural disasters. The eruptions danger consists of hot clouds, material bursts, heavy ash rain, lava, toxic gas, tsunami, and lava floods. Indonesia has more than 500 volcanoes with 127 of them active. Based on the risk assessment, the total number of people exposed to the risk of a volcanic eruption in Indonesia is 2,396,761 in all provinces in Indonesia with a potential loss of Rp. 13.6 trillion (National Disaster Management Agency, 2014).

Mount Merapi is the most active volcano in Indonesia. This volcano is popular and interesting in world research. It is located in the provinces of Yogyakarta and Central

Java. There are four disaster-prone areas including the Regency of Sleman, Magelang, Boyolali, and Klaten. In the last major eruption in 2010, more than 400,000 people evacuated, and over 50,000 people kept staying in the high-risk zona (Mei *et al.*, 2013). A congestion and evacuations delay were found. Confusion of population in the evacuation process leads to many fatalities for humans and cattle. The impact of the 2010 Merapi eruption is ranked 3 in the world (Guha-Sapir, Hoyois and Below, 2016). Therefore, a disaster mitigation plan is critical for a successful evacuation. Mitigation is defined as any sustained effort undertaken to reduce a hazard risk through the reduction of the likelihood and/or the consequence component of that hazard's risk (Coppola, 2007).

In the Merapi volcano mitigation plan, the Regional Disaster Management Agency (Badan Penanggulangan Bencana Daerah or BPBD) develop a sister village scenario for handling this crisis management. The cooperation concept is implemented through an agreement between the affected village and the sister village to provide shelter, logistics, and others. However, there is a potential conflict in the emergency response process covering relief, rescue, and need assessment. The first is the meeting area and shelter have been coordinated, but people's behavior has not been fully considered yet in the vulnerability assessment. Second, the local community must self-evacuate from home to the shelter. The government will prioritize the evacuation of the vulnerable people from the meeting area to the shelter (sister village). The third is the limitation of the government evacuation transport and community vehicle ownership will lead some people to walk to the meeting area, and a slow walking speed for vulnerable people will potentially increase the risk and delay. In addition, the difficulty of evacuating cattle caused most of the livestock will stay at home. This situation led the breeders may return home in the daytime to feed the cattle during the refuge period. The four, Human resource capacity and expert volunteers are limited. Especially, the limitation of trainers for children and elderly trauma, medical staff, and evacuation volunteers from the local government. All issues were reported by key informants and contingency plan documents at the BPBD and the village office (Magelang Regional Disaster Management Agency, 2017; Klaten Regional Disaster Management Agency, 2018; Boyolali Regional Disaster Management Agency, 2019; Sleman Regional Disaster Management Agency, 2019).

Overall, the evacuation issue will increase the delay time and risk for vulnerable people when they walk slowly to the meeting area or still rely on volunteers from the government to pick them up from home. Therefore, the best strategy is to support the vulnerable people to evacuate with the young people (mutual assistance). This study purposes to develop an effective evacuation model for vulnerable people using an agent-based simulation method. This model can contribute to reducing the risk and increasing safety for vulnerable people. Thus, the finding can be applied by the government in contingency plans for effective evacuation in the future. The proposed concept has also been in line with the government's policy on increasing community capacity through the establishment of a resilient village to disasters (National Disaster Management Agency, 2014).

1.2 Dissertation Objectives

This study aims to develop an effective evacuation model for vulnerable people in affected regencies with the people's behavior and vehicle ownership as a viewpoint. Specifically, four sub-objectives have been formulated to obtain the goal mentioned above:

1. To investigate the local community behavior in four affected regencies.
2. To measure the walking speed of the evacuation drills in four affected regencies.
3. To assess the mutual assistance strategy and social vulnerability index of pedestrian evacuation.
4. To develop the mutual assistance model to support safer and faster evacuation for vulnerable people.

1.3 Dissertation Structure

This dissertation is divided into five chapters described in Figure 1.1 and explained as follows:

1. **Chapter I** states the background, objectives, and structure of the dissertation.
2. **Chapter II** explores the extensive background of the theories, methods, and summary of previous studies.
3. **Chapter III** collect the walking speed and people's behavior data and assess the social vulnerability in evacuation process.
4. **Chapter IV** develops the agent-based evacuation model for vulnerable people.
5. **Chapter V** recapitulates the study results and offers suggestions for future studies.

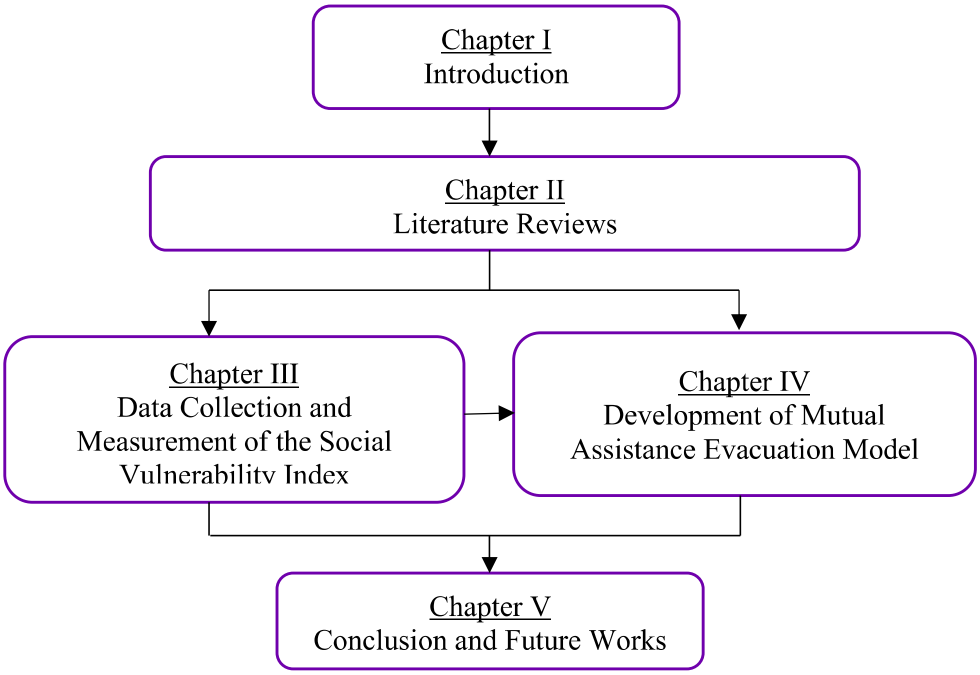

Figure 1.1 Structure of dissertation.

References

Boyolali Regional Disaster Management Agency (2019) *Penyusunan Rencana Kontinjensi Erupsi Gunung Merapi*. Boyolali Regency, Indonesia.

Coppola, D. P. (2007) *Introduction to International Disaster Management*. Oxford: Elsevier Inc.

Guha-Sapir, D., Hoyois, P. and Below, R. (2016) *Annual Disaster Statistical Review 2015: The numbers and trends Centre for Research on the Epidemiology of Disasters (CRED), Centre for Research on the Epidemiology of Disasters (CRED) Institute of Health and Society (IRSS) Université catholique de Louvain – Brussels, Belgium*. Available at: https://reliefweb.int/report/world/annual-disaster-statistical-review-2015-numbers-and-trends.

Klaten Regional Disaster Management Agency (2018) *Rencana Kontingensi Menghadapi Ancaman Erupsi Gunung Merapi di Kabupaten Klaten*. Klaten Regency, Indonesia.

Magelang Regional Disaster Management Agency (2017) *Rencana Kontingensi Erupsi Gunung Merapi Kabupaten Magelang Tahun 2017 – 2020*. Magelang Regency, Indonesia. Available at: http://bappeda.magelangkab.go.id/home/detail/musrenbang-wilayah-eks-karesidenan-kedu-tahun-2019-di-kabupaten-magelang/159.

Mei, E. T. W. *et al.* (2013) 'Lessons learned from the 2010 evacuations at Merapi volcano', *Journal of Volcanology and Geothermal Research*, 261, pp. 348–365. doi: 10.1016/j.jvolgeores.2013.03.010.

National Disaster Management Agency (2014) *Rencana Nasional Penanggulangan*

Bencana 2015-2019. Jakarta: Republic of Indonesia. Available at: https://www.bnpb.go.id//uploads/renas/1/BUKU RENAS PB.pdf.

Prasad, A. S. and Francescutti, L. H. (2017) 'Natural Disaster', *International Encyclopedia of Public Health*. Second. Elsevier. doi: https://doi.org/10.1016/B978-0-12-803678-5.00519-1.

President of the Republic of Indonesia (2007) *Undang-Undang Republik Indonesia No 24 Tahun 2007 Tentang Penanggulangan Bencana*. Republic of Indonesia. Available at: https://bnpb.go.id/ppid/file/UU_24_2007.pdf.

Sleman Regional Disaster Management Agency (2019) *Rencana Kontijensi Erupsi Gunungapi Merapi*. Sleman Regency, Indonesia.

Wisner, B. *et al.* (2003) *At Risk: natural hazards, people's vulnerability and disasters Second edition*, *AT RISK*. doi: 10.4324/9780203428764.

CHAPTER II
LITERATURE REVIEWS

2.1 Characteristics of Volcano Disaster

Differences in characteristics between natural disasters can be evident from the early warning system, duration of the disaster, size, damage, affected area, and others. There is one significant difference between volcanic eruptions and other crises: the disaster duration and evacuation period are uncertain (Gaudru, 2004). In the 2010 Mount Merapi eruption, the disaster lasted for more than two months. The first eruption occurred in October and decreased emergency state in December (Mei *et al.*, 2013). In November 2020, the local government reported an emergency state increase from Level II to Level III and started to evacuate inhabitants living within a radius of 5 km from the peak mountain (the Republic of Indonesia, Ministry of Energy and Mineral Resources and Center for Volcanology and Geological Hazard Mitigation, 2020). This warning status has not changed until 2022 because it still erupts frequently. The case of this Merapi volcano shows the uncertain duration of the disaster. Early warning systems for volcanic disasters worldwide are available both manually and automatically. Table 2.1 is warning levels for Mount Merapi in Indonesia.

Table 2.1 Warning levels for Merapi volcano eruptions (Sayudi, DS, Nurnaning A, Juliani Dj, Muzani, 2010; Magelang Regional Disaster Management Agency, 2017; Klaten Regional Disaster Management Agency, 2018; Boyolali Regional Disaster Management Agency, 2019; Sleman Regional Disaster Management Agency, 2019).

Status	Description
Level I (Normal activity)	There is no magma pressure activity, and the local communities' activity is normal
Level II (On guard)	There is an increase in seismic, magma, and other volcanic activity, the local community activities must be outside the 3 km radius of Mount Merapi
Level III (Prepare)	Intensive increase of seismic activities, magma activities continue and will cause disaster, evacuation process, especially in hazard zone 3 (vulnerable people priority)
Level IV (Beware)	The eruption will occur, and all the local community population in the disaster-prone area must have been evacuated

Volcanoes exist in many forms and sizes, and they exhibit a wide range of eruptive behaviors. Hazardous volcanic flows may be highly influenced by topography, whereas ash dangers are influenced by meteorological conditions. The size, intensity, and duration of eruptions vary by order of magnitude. The mass or volume of erupting material is conventionally used to determine size (Sparks *et al.*, 2013). The volcanic explosivity index (VEI) is widely used as a metric of eruption scale. VEI is a relative measure of the explosiveness of volcanic eruptions. In 1982, it was developed by Chris Newhall of the United States Geological Survey and Stephen Self at the University of Hawaii. The detailed description of the VEI is shown in Figure 2.1. Mount Merapi has a VEI in the range of 4 (see Figure 2.2).

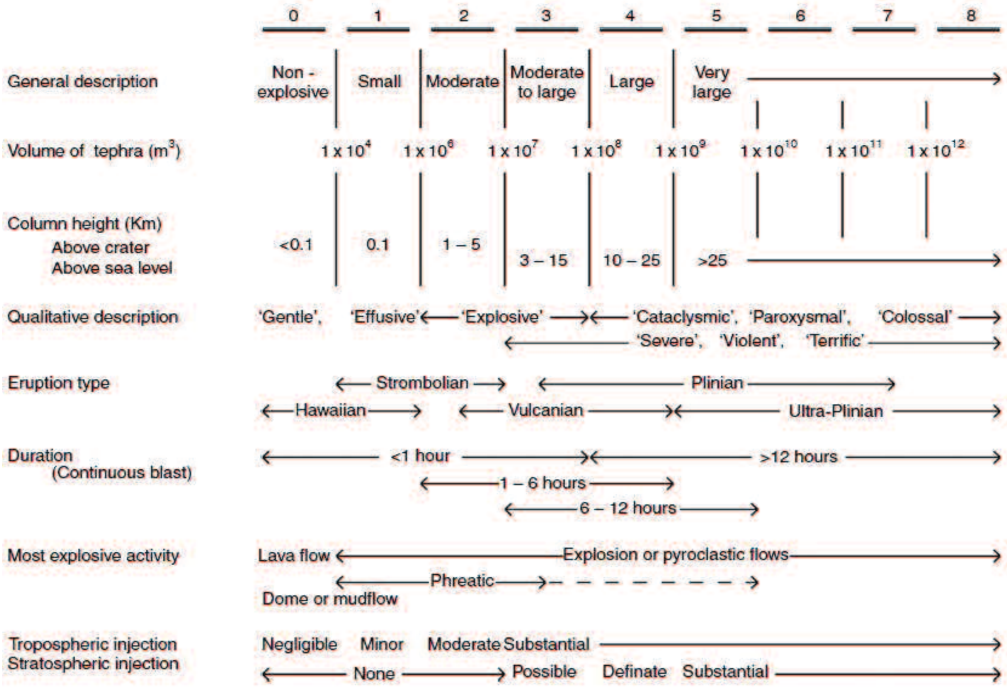

Figure 2.1 The detailed explanation of VEI (Newhall and Self, 1982).

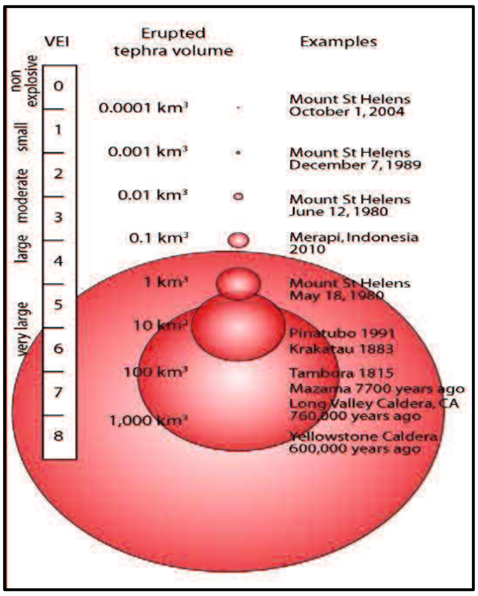

Figure 2.2 The case of volcano eruptions with a high VEI scale. Mount Merapi is categorized as a large eruption with a VEI of 4 (USGS, 2016).

For a volcano mitigation plan, the risk is commonly stated in terms of loss of life and the primary tactic in most volcano emergencies is to relocate people out of harm's way by evacuation. In a normal activity period, the risk reduction can be promoted through land-use planning, evacuation planning, and raising awareness of hazards and associated risks in potentially impacted regions (Sparks *et al.*, 2013). In Mount Merapi case, the local government developed the contingency plan based on the hazard zone. There are three hazard zone of Merapi volcano. Hazard zone I is low risk and hazard zone III is high risk. Detail of the affected area shown in Figure 2.3.

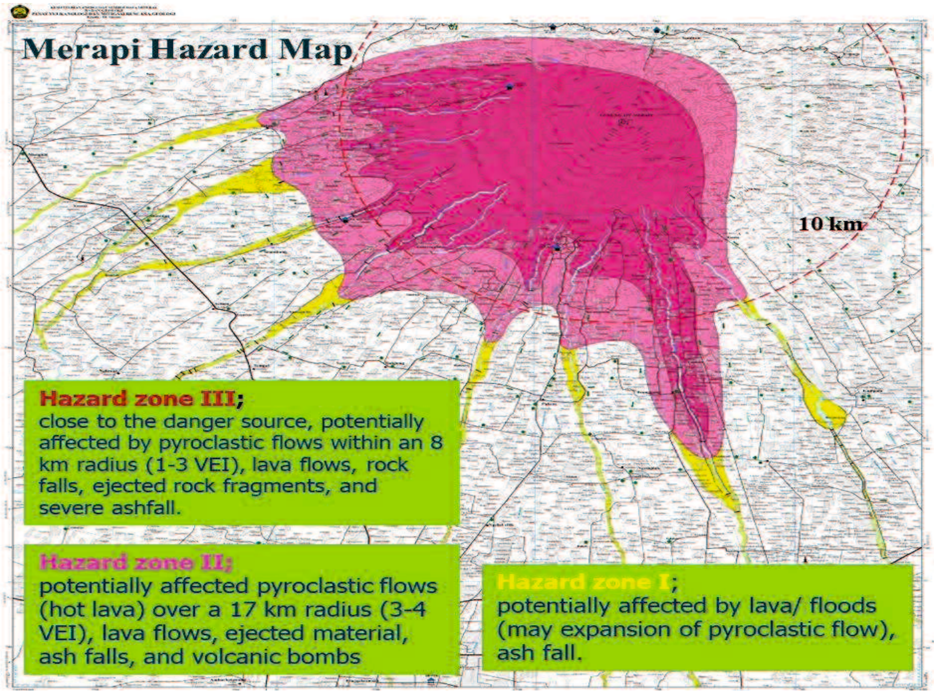

Figure 2.3 Mount Merapi hazard map and material impact (Sayudi, DS, Nurnaning A, Juliani Dj, Muzani, 2010).

2.2 Risk of Volcano Eruption on Transportation

Transportation networks are critical infrastructures in urban and rural environments. The volcano activities have the potential to reduce the level of service (LOS) for transportation involving evacuation zone. All transportation modes and infrastructures such as roads, railways, and airports may be disrupted. The loss of infrastructure functionality can have serious consequences for governments and local authorities, such as considering shutting down parts of a network (Daniel Mark Blake *et al.*, 2017). The previous study revealed that most physical damage to the transportation network is caused by pyroclastic surges during the earliest phases of the eruption. However, the service has been reduced since the evacuation process before the eruption. Tephra distribution and deposition patterns can cause significant differences in LOS, which has implications for transportation management. Some cases of transportation damage and disruption from the volcano disaster are mentioned in Table 2.2. Mount Merapi eruption is also included in the list and has an impact on road infrastructure (Daniel M. Blake *et al.*, 2017).

On the other hand, congestion and evacuations delay may occur during an emergency period. Congestion during evacuation not only decreases the efficacy of evacuations but also increases the risk of traffic accidents. One of the major causes of traffic chaos is the confusion and inability to detect Emergency Service Vehicles (ESVs) including ambulances, police cars, trucks, and others. This condition led to slow progress and even accidents involving the ESVs moving to their destinations. As a result, they are more likely to be involved in accidents and face unpredictable delays in reaching the afflicted region (Rizvi *et al.*, 2007). Eruptions with big explosions and fire hazards have produced the risk materials for a long time. Therefore, waste management and sustainable improvement are also necessary (Ostad-Ali-Askari, 2022).

Table 2.2 Transportation damage and disruption from the volcano hazard in the word (x=road, o=rail, Δ=maritime, ◊=airport) (Daniel M. Blake *et al.*, 2017).

Volcano and country	Year	Physical damage from proximal hazards					Disruption from volcanic ash					
		Pyroclastic density current	Lava flow	Lahar	Tsunami	Deformation or degassing	Reduced skid resistance	Visibility issues	Marking coverage	Closure or obstruction	Vehicle or engine issues	Derailment (tram)
Tavurvur and Vulcan, Papua New Guinea	1994	x		x			x			x Δ◊	x	
Sakurajima, Japan	1995						x		x			
Ruapehu, New Zealand	1995–96			x			x	x	x	x◊		
Popocatepetl, Mexico	1997									◊		
Soufrière Hills, U.K. (overseas territory)	1997	◊					x					
Reventador, Ecuador	1999									◊		
Pichincha, Ecuador	1999									◊		
Miyakejima, Japan	2000–08					◊						
Etna, Italy	2002–03		x				x	x		x◊		
Reventador, Ecuador	2002						x		x	x◊	x	
Nyiragongo, Democratic Republic of Congo	2002		◊									
Popocatepetl, Mexico	2003									◊		
Anatahan, Mariana Islands	2003–05									◊		
Merapi, Indonesia	2006	x										
Home Reef, Tonga (submarine)	2006									Δ	Δ	
Etna, Italy	2006									◊		
Chaitén, Chile	2008			x			xo	x		xΔ◊	xΔ	
Okmok, U.S.A.	2008										Δ	
Redoubt, U.S.A.	2009										x	
Merapi, Indonesia	2010			x			x					
Pacaya, Guatemala	2010						x	x	◊	◊	x	
Tungurahua, Ecuador	2010									◊		
Cordón Caulle, Chile	2011			x			x	x		Δ◊	x	
Sakurajima, Japan	2011						x		x	o◊	x	
Shinmoedake, Japan	2011						x	x		o	xo	
Etna, Italy	2013									◊	x	
San Cristóbal, Nicaragua	2013							x				
Kelud, Indonesia	2014			x			◊	x◊		◊	◊	
Sakurajima, Japan	2014								x			
Sinabung, Indonesia	2014						x					
Tungurahua, Ecuador	2014									◊		
Calbuco, Chile	2015							x				
Villarrica, Chile	2015			x								

2.3 Challenges in Evacuation Process for Vulnerable People

Vulnerable people have different definitions in each country, it depends on what the community considers to be a decent life as guaranteed by the constitution. Vulnerable people is defined as people who have characteristics and live in circumstances that make them more susceptible than others in a community to the damaging effects of a hazard, despite measures to avoid disasters or to recover from disasters taken on behalf of the entire population (Vink and Takeuchi, 2013). Behavior of them is frequently less likely to evacuate before a crisis. They lack personal transportation, have health impairments that make movement difficult, or have misperceptions about their level of danger. Individuals and families in these places require extra attention during the evacuation planning stage to ensure they are both prepared and willing to leave (MDC, 2006).

In volcanic rural areas, the communities usually still maintain a spiritual connection with active volcanoes. This culture makes some people especially the elderly reluctant to evacuate during the eruption. In the case of Mount Yasur, there is an area called Sulfur Bay, Tanna Island, Vanuatu, which has high vulnerability, but no evacuation process and any science-based volcano risk reduction plan has ever been implemented. A traditional belief system had organized this village, which sees Mount Yasur as their ancestor and has resisted the introduction of external ontologies (Niroa and Nakamura, 2022). This cultural challenge needs to be considered by all local governments in the volcano area for effective mitigation. Besides that, it is crucial to recognize that stigmatizing beliefs occur in disaster-response situations, with repercussions for those who are already more vulnerable than others. Therefore, the appropriate education and training need to be implemented for vulnerable groups (Blake, Pooley and Lyons, 2020).

There is strategy that apply to almost any kind of catastrophe. The older adults and their families are recommended as follows (Benson, 2013).

1. Create a family communication plan to ensure that the locations and well-being of each family member are reported to a key person(s) during a disaster.
2. Plan how to stay informed of developments in the crisis scenario through telephone, mobile phone, internet, radio, television, or newspaper.
3. Choose a meeting location away from home that is reasonably familiar and convenient for all family members.

4. Stock up on personal, health, and home supplies, such as a two-week supply of prescription medications, enough ready-to-eat food and water to last three days, first-aid supplies, candles and matches or flashlights, a waterproof container for important documents, and items needed by older adults and people with disabilities.
5. Prepare a to-go kit that contains a flashlight, additional batteries, a battery-operated radio, a first-aid kit, contact lenses or eyeglasses, medications, copies of prescriptions, picture identification, copies of crucial documents, and a small amount of cash.

2.4 Vulnerability Assessment Method

Disaster risk is a product that is directly affected by hazard and vulnerability factor. Vulnerability refers to the characteristics of individuals, households, or economies that raise the chance of suffering damage because of a hazard occurrence. It is thought to be a combination of several elements, including exposure, capacity, resilience, livelihood stress, susceptibility, sensitivity, and or weakness (Lowe, 2010). When estimating risk, it is necessary to distinguish between exposure and vulnerability. When the volcano becomes active, an exposed population may be living normally in an area with a potentially high risk. Besides this exposure, the vulnerability also determines the community risk. A variety of physical, economic, cultural, and social elements, as well as the existence of a well-thought-out evacuation strategy will impact a vulnerability (Sparks *et al.*, 2013). Figure 2.4 is classification of vulnerable factors.

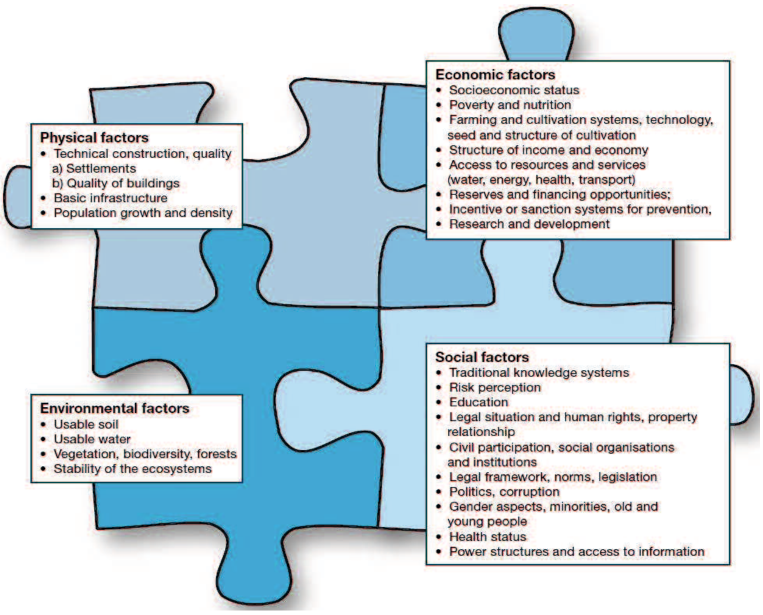

Figure 2.4 Classification of vulnerable factors in disaster risk assessment (Kohler, Jülich and Bloemertz, 2004).

In the current study, social factors were optioned to evaluate. There are several methods to assess the social vulnerability in volcano disaster. The Self Organizing Map (SOM) and Social Vulnerability Index (SoVI) methods have been applied in the Mount Merapi case, especially in Sleman affected area. SOM is known as an excellent platform for identifying sites based on their similarity and determining the most relevant factors to define the social vulnerability in each cluster. Whereas SoVI is utilized for the generation of vulnerability indexes to quantify the amount of vulnerability. The result showed the parameters referred to the number of migrants and the number of females had the greatest influence on social vulnerability (Maharani, Lee and Ki, 2016). The social vulnerability assessment method is also clearly described in the reference (Velasquez, 2003). This procedure was selected for analysis in the current research and explained in Chapter 3.

2.5 Agent-Based Simulation Approach

2.5.1 Agent-based model structure

Gilbert defined agent-based modeling as a computational tool that allows a researcher to create, analyze, and experiment with models made up of agents that interact within an environment. Agents, environments, and timescales are crucial points in this simulation. In the first point, agents have to describe three characteristics in perception, performance, and memory. They can see their environment, conduct a set of behavior, and have a memory that preserves their perception of prior states and activities. Second, the environment will comprise a passive object, such as landscape barriers, road or link down which agents can go, and resources to provide agents with energy, food, and other necessities. These can be programmed similarly to agents, but more simply since they do not need to be able to react to their environment. The third point is about randomness and time. When designing agent-based models, three aspects must be considered: synchronization, event-driven simulation, and time calibration (Gilbert, 2008).

There are three elements of an agents based model structure (Taylor, 2014):

1. A set of agents, their attributes and behaviors.
2. A set of agent relationship and interaction methods: an underlying topology of connectivity governs how and with whom agents interact.
3. The agents' environment: agents interact with their surroundings in addition to other agents.

Huang et al. also explained the agent-based model structure for transport system involving four steps. The first is pre analysis to determines the application scenario, the model purposes, the scale, and the simulation system resolution. Second step, an agent is defined to identify and classify heterogeneous things in the transport system environment based on their categories. Third step, a significant rule is applied to models the behavior and interaction of agents. Last step is model tuning where model of verification, calibration, and validation are necessary. Figure 2.5 is agent-based model structure for transport system.

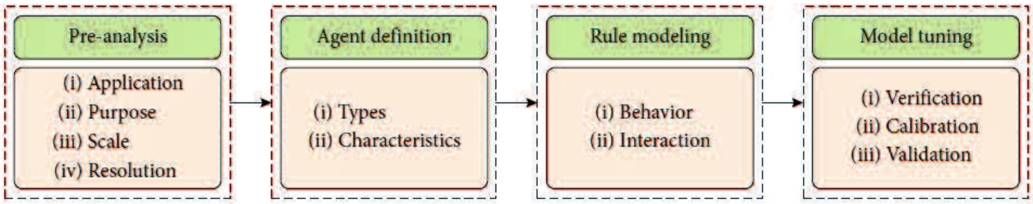

Figure 2.5 Agent-based model structure (Huang *et al.*, 2022).

2.5.2 Application overview

Almost every area of the physical, biological, social, economic, management science, and technological spheres has been simulated using agent-based models (Taylor, 2014). One such application of the transportation model and related human behavior produced results that are dependent on one or more assumptions. A review of the literature revealed that the potential of agent-based modeling is far greater than ever before due to ever-improving computing speeds and capabilities, whereas understanding complex human behavior will remain a challenge for simulations and automation techniques developed thus far (El-Amine *et al.*, 2017). The following are some of the benefits of using an agent-based model method in transportation modeling and analysis: (1) consideration of the interactive elements and rule configurations in the study of heterogenicity and emergent dynamics in the form of different time scale models; (2) investigation of modeling the adaptability, beliefs, and desires of individual entities to create a more robust system; and (3) potential of being integrated with optimization to achieve realistic and reliable results (Huang *et al.*, 2022).

Kagho et al. presented an overview of the existing agent-based model software and its application in the transport planning field. This application included Aimsun, Sumo, Albatross, Feathers, TRANSIMS, MATSim, SimMobility, Polaris, and others. An

Aimsun software focused on reproducing traffic situations in an urban network, whereas Sumo is a multi-modal simulation of road traffic. Albatross and Feathers were unable to integrate the various aspects of transport modeling or provide a comprehensive agent-based modeling structure. The general approach was then to 'loosely' combine these models. The TRANSIMS tool is the Los Alamos National Institute's first major fully integrated large-scale agent-based model simulation, and it is used for disaggregate modeling of travel behavior on large-scale transportation networks. MATSim is a dynamic traffic assignment mesoscopic traffic flow simulator. By tracing synthetic travelers' daily schedules and decisions, MATSim delivers a fully integrated agent-based model of traffic flow and associated congestion. SimMobility is a multi-scale simulation platform that models millions of agents to simulate land use, transportation, and communication interactions. Polaris provides a plug-and-play solution for older software in its framework, attempting to alleviate the interoperability challenges that TRANSIMS and MATSim experience when combining disparate models (Kagho, Balac and Axhausen, 2020).

In a disaster evacuation case, the Paramics tool was applied to model a microscopic simulation system on a road network in San Marcos City, Texas. The crucial structures of the network involve a grid road, a ring road, and a real road (Chen and Zhan, 2008). The AnyLogic software was also used to create the evacuation model. The average evacuation time for each individual and the overall exit time, as well as the intensity of the people flow at the building's entry and exit, are computed (Avdeeva, Uzun and Borodkina, 2020). In the current study, a microscopic analysis in which the details of mutual assistance interactions and behavior of agents were addressed. AnyLogic simulation capabilities in this large-scale pedestrian simulation approach are encouraging to be selected.

2.5.3 AnyLogic software

AnyLogic was the first tool to provide multimethod simulation modeling, and it is currently the only application that does so. Dynamic business simulation models are built using three crucial methodologies consist of system dynamics, discrete event modeling, and agent-based modeling. Agents in this model can represent a wide range of objects including people in various roles, units of equipment, vehicles, projects, products, ideas, investments, companies, and so on (Grigoryev, 2018). AnyLogic software package is a robust platform with a built pedestrian library and several techniques for collecting statistical findings from simulations, making it simple to fully apply the agent behavior (Avdeeva, Uzun and Borodkina, 2020). In addition to transportation and road traffic, this simulation tool is used in various industrial fields such as supply chains, manufacturing, warehouse operations, rail logistics, mining, oil and gas, ports and terminals, passenger terminals, healthcare, business processes, asset management, marketing, social processes, and defense (AnyLogic Company, 2022).

In this application, there are six library products called the Process Modeling Library, Material Handling Library, Pedestrian Library, Rail Library, Road Traffic Library, and Fluid Library. The Process Modeling Library is a powerful tool for analysts to model operations in transportation, healthcare, finance, manufacturing, and other dynamic business processes and services. The Material Handling Library makes complicated manufacturing processes and operations easier to simulate. It may be used to create comprehensive models of manufacturing and storage facilities as well as control material operations inside four walls. The Pedestrian Library is a pedestrian simulation and crowd analysis tool that allows users to precisely model, display, and evaluate how crowd flows operate in a real setting, as well as reduce any inefficiencies that may exist. The Rail Library enables users to quickly model, simulate, and visualize rail yard and rail transportation processes of any complexity and size. Users can use the Road Traffic Library to plan, design, and simulate traffic flows at a comprehensive physical level. This library is useful for modeling each driver's behavior explicitly as well as expressing transportation flow dynamics. The final product is the Fluid Library, which enables users to simulate the transportation and storage of bulk commodities, fluids, and gas, as well as pipeline operations, mining activities, and the generation and transportation of gas and fuel (AnyLogic Company, 2022). In the present study, we use a combination between Process Modeling Library, Pedestrian Library, and Road Traffic Library.

2.6 Previous Studies on Mount Merapi Evacuation

During the 2010 Merapi eruption, several lessons were acquired that might be applied in future Merapi mass evacuations. The evacuation experience during this eruption demonstrated that evacuation went off without a hitch for the first several days. However, as the eruption activities grew in size, the evacuation procedure became problematic due to a lack of preparation on the part of the government and its inhabitants. It will be necessary for the future to build a complete new contingency plan as well as public education (Mei *et al.*, 2013). Jumadi et al. created a model for determining individual evacuation decisions during a crisis. This agent-based model investigated the emergence of reluctance during times of crisis. The decision of whether or not to evacuate an agent is based on an assessment of the severity of the driving variables utilizing threshold-based criteria (Jumadi *et al.*, 2018). In affected Sleman Regency, AnyLogic software was used to analyze the evacuation scenarios of a simultaneous and staged Merapi volcanic eruption. According to the findings, a staged scenarios is more suited to lowering possible traffic congestion during peak hours. However, some limitations were identified, including the variety of population behavior, which was not extensively investigated in this preliminary simulation study (Jumadi, Carver and Quincey, 2019).

In the case of the volcano risk study, the Spatio-Temporal Dynamics Model of Risk (STDMR) approach was also applied. The STDMR includes a Multi-Criteria Evaluation (MCE) based on an individual risk model into an Agent-Based Model simulation, which may show the impact of the evacuation process on the risk reduction outcome. The success or failure of this model is dependent on the actual interaction of agents, which necessitates validation improvement of the destination choice rule (Jumadi *et al.*, 2020). Maharani et al. used the SOM method to determine the vulnerable cluster and the most significant related variable. Their findings demonstrated that the factors of migrate-in population number and number of women had the greatest influence on social vulnerability (Maharani, Lee and Ki, 2016). Meanwhile, Nugraha et al. conducted a risk assessment of Mount Merapi focusing on mapping eruption risk in the Sleman Regency. The results revealed that there is still a significant hazard to this area. Therefore, a strategy improvement for mitigation planning is necessary (Nugraha *et al.*, 2019). However, no previous research has considered the government contingency that was updated in 2019. The authority created a sister-village scenario with a combination of staged and simultaneous evacuation under the new legislation. In this present study, we build a model based on the most recent policy approach and include the local community to investigate their behavior.

2.7 Related Studies on Mutual Assistance Evacuation

In Japan, the Miracle of Kamaishi was an actual successful model by the mutual assistance evacuation program during the 2011 earthquake and tsunami disaster. That means is Junior high school students supported elementary school students for evacuation together to the shelter. This strategy was highly effective and successful to rescue the vulnerable people especially for children (Alalouf-Hall, 2019). Karashima and Ohgai confirmed that the mutual assistance activities between resident and vulnerable is important in earthquake disaster mitigation. A methodology was developed based on the quantitative evaluation of mutual assistance abilities. GIS and Multi-Agent System tools were used to examine and demonstrate this purpose in case study of Toyohashi City, Aichi prefecture, Japan. The findings show that this method is effective at Community Disaster Management Plan (CDMP) revision and resident awareness on the essential of mutual assistance (Karashima and Ohgai, 2021). On the other hand, the mutual assistance is also recommended for industrial disasters. A fires, chemical spills and radiation are disaster that are often solved through internal protocols in company. However, the best rescue strategy needs to be addressed to save the low costs and time. A framework proposal was presented in the humanitarian logistics context for A Brazilian case. The rescue process is characterized by the flow of materials and people within the limited time. Coordination analysis and the integration of all the agent's humanitarian were involved. The finding indicated that logistics preparedness and response strategy by mutual assistance concept can guarantee faster and more effective output compared with the usual procedure of companies (Moura, Cruz and Chiroli, 2020).

In the flood disaster case, a mutual aid evacuation model was evaluated for vulnerable people in urban community, China. An agent-based modeling framework was developed to analyze the community properties, residents' psychological attributes, and mutual aid mechanisms of the evacuation process. The agent-based model was applied in a synthetic community design, which was constructed based on the urban communities' structure and the community grid management in China. The result shows that a mutual aid mechanism can reduce evacuation time in low-density residents, and the impact was more pronounced with a higher distribution of vulnerable people agents in the community (Wang *et al.*, 2020). A proposal for mutual-aid-type distributed evacuation in the hilly and mountainous areas in Japan context was also presented. Typhoons and heavy rains usually lead to landslides and flooding disasters in the mountains area. These selected study areas have unique evacuation challenges where the population is potential quickly aging. The semi-structured interviews using open-ended questions method were conducted with almost all communities in the research area. The result of the survey showed that a mutual-aid-type distributed evacuation rule can effectively utilize the limited community resources available as supporters in hilly locations (Takahashi *et al.*, 2022). However, the mutual assistance idea for the specific disaster from volcanic eruptions in the previous study has not been found. Therefore, the current study was concerned to examine an eruption context, especially in Indonesia country.

References

Alalouf-Hall, D. (2019) '"The Kamaishi miracle": Lessons learned from the 2011 tsunami in Japan', *Alternatives Humanitaires/Humanitarian Alternatives*, (March), pp. 1–6. Available at: http://alternatives-humanitaires.org/en/2019/03/25/kamaishi-miracle-lessons-learned-2011-tsunami-japan/.

AnyLogic Company (2022) *AnyLogic*. Available at: https://www.anylogic.com/ (Accessed: 19 July 2022).

Avdeeva, M., Uzun, O. and Borodkina, Y. (2020) 'Simulation of the evacuation process at various economic facilities using the Anylogic software product', in *E3S Web of Conferences*. doi: 10.1051/e3sconf/202017511031.

Benson, W. F. (2013) 'Disaster Planning Tips for Older Adults and their Families', *CDC Healthy Aging Program, Atlanta*.

Blake, Daniel Mark *et al.* (2017) 'Improving volcanic ash fragility functions through laboratory studies: example of surface transportation networks', *Journal of Applied Volcanology*, 6(1), p. 18. doi: 10.1186/s13617-017-0066-5.

Blake, Daniel M. *et al.* (2017) 'Investigating the consequences of urban volcanism using a scenario approach II: Insights into transportation network damage and functionality', *Journal of Volcanology and Geothermal Research*, 340, pp. 92–116. doi: 10.1016/j.jvolgeores.2017.04.010.

Blake, D., Pooley, S. and Lyons, A. (2020) 'Stigma and disaster risk reduction among vulnerable groups: Considering people receiving opioid substitution treatment', *International Journal of Disaster Risk Reduction*, 48(June 2019), p. 101588. doi: 10.1016/j.ijdrr.2020.101588.

Boyolali Regional Disaster Management Agency (2019) *Penyusunan Rencana Kontinjensi Erupsi Gunung Merapi*. Boyolali Regency, Indonesia.

Center for Volcanology and Geological Hazard Mitigation (2020) *Peningkatan Status Aktivitas Gunung Merapi dari Level II ke Level III*. Yogyakarta, Indonesia. Available at: https://vsi.esdm.go.id/index.php/kegiatan-pvmbg/download-center/doc_download/5673-peningkatan-status-aktivitas-g-merapi-tanggal-5-november-2020.

Chen, X. and Zhan, F. B. (2008) 'Agent-based modelling and simulation of urban evacuation: Relative effectiveness of simultaneous and staged evacuation strategies', *Journal of the Operational Research Society*, 59(1), pp. 25–33. doi: 10.1057/palgrave.jors.2602321.

El-Amine, S. *et al.* (2017) 'Demand for Agent-Based Transportation Models & Social Behavioral Challenges', in *Procedia Computer Science*. Elsevier B.V., pp. 210–216. doi: 10.1016/j.procs.2017.08.351.

Gaudru, H. (2004) 'Overview of potential impact of eruptions on volcanic islands: Global approaches for volcanic risk mitigation', *European Volcanological Society*, (December 1995). Available at: https://www.preventionweb.net/publication/overview-potential-impact-eruptions-volcanic-islands.

Gilbert, N. (2008) *Agent Based Models, Series: Quantitative Applications in the social sciences*. UK, London: SAGE Publications.

Grigoryev, I. (2018) *AnyLogic 8 in Three Days*. fifth edit.

Huang, J. *et al.* (2022) 'An Overview of Agent-Based Models for Transport Simulation and Analysis', *Journal of Advanced Transportation*, 2022, p. 17. doi: 10.1155/2022/1252534.

Jumadi *et al.* (2018) 'Modelling individual evacuation decisions during natural disasters: A case study of volcanic crisis in Merapi, Indonesia', *Geosciences (Switzerland)*, 8(6), pp. 1–30. doi: 10.3390/geosciences8060196.

Jumadi, J. *et al.* (2020) 'Estimating spatio-temporal risks from volcanic eruptions using an agent-based model', *Jasss*, 23(2). doi: 10.18564/jasss.4241.

Jumadi, J., Carver, S. J. and Quincey, D. J. (2019) 'An agent-based evaluation of varying evacuation scenarios in Merapi : Simultaneous and staged', *Geosciences*, 9, pp. 1–19. doi: 10.3390/geosciences9070317.

Kagho, G. O., Balac, M. and Axhausen, K. W. (2020) 'Agent-Based Models in Transport Planning: Current State, Issues, Expectations', in *Procedia Computer Science*. Elsevier B.V., pp. 726–732. doi: 10.1016/j.procs.2020.03.164.

Karashima, K. and Ohgai, A. (2021) 'A methodology of workshops to explore mutual assistance activities for earthquake disaster mitigation', *International Journal of Environmental Research and Public Health*, 18(7), pp. 1–26. doi: 10.3390/ijerph18073814.

Klaten Regional Disaster Management Agency (2018) *Rencana Kontingensi Menghadapi Ancaman Erupsi Gunung Merapi di Kabupaten Klaten*. Klaten Regency, Indonesia.

Kohler, A., Jülich, S. and Bloemertz, L. (2004) 'Risk analysis – a basis for disaster risk management', in *Risk Management*. Federal Ministry for Economic Cooperation and Development, pp. 18–67.

Lowe, C. J. (2010) *Analysing vulnerability to volcanic hazards: application to St. Vincent*. Department of Geography University College London. Available at: http://eprints.ucl.ac.uk/20466/.

Magelang Regional Disaster Management Agency (2017) *Rencana Kontingensi Erupsi Gunung Merapi Kabupaten Magelang Tahun 2017 – 2020*. Magelang Regency, Indonesia. Available at: http://bappeda.magelangkab.go.id/home/detail/musrenbang-wilayah-eks-karesidenan-kedu-tahun-2019-di-kabupaten-magelang/159.

Maharani, Y. N., Lee, S. and Ki, S. J. (2016) 'Social vulnerability at a local level around the Merapi volcano', *International Journal of Disaster Risk Reduction*, 20(October), pp. 63–77. doi: 10.1016/j.ijdrr.2016.10.012.

MDC (2006) 'When Disaster Strikes: Promising Practice', pp. 1–10. Available at: https://www.mdcinc.org/wp-content/uploads/2017/08/When-Disaster-Strikes-Promising-Practices-Evacuation.pdf.

Mei, E. T. W. *et al.* (2013) 'Lessons learned from the 2010 evacuations at Merapi volcano', *Journal of Volcanology and Geothermal Research*, 261, pp. 348–365. doi: 10.1016/j.jvolgeores.2013.03.010.

Moura, E. H. de, Cruz, T. B. R. e and Chiroli, D. M. D. G. (2020) 'A framework proposal to integrate humanitarian logistics practices, disaster management and disaster mutual assistance: A Brazilian case', *Safety Science, ELSEVIER*, 132. doi: https://doi.org/10.1016/j.ssci.2020.104965.

Newhall, C. G. and Self, S. (1982) 'The volcanic explosivity index (VEI): an estimate of explosive magnitude for historical volcanism.', *Journal of Geophysical Research*, 87(C2), pp. 1231–1238. doi: 10.1029/jc087ic02p01231.

Niroa, J. J. and Nakamura, N. (2022) 'Volcanic disaster risk reduction in indigenous communities on Tanna Island, Vanuatu', *International Journal of Disaster Risk Reduction*, 74(March), p. 102937. doi: 10.1016/j.ijdrr.2022.102937.

Nugraha, A. L. *et al.* (2019) 'Analysis of risk assessment of Mount Merapi eruption in settlement area of Sleman Regency', *IOP Conference Series: Earth and Environmental Science*, 313(1). doi: 10.1088/1755-1315/313/1/012003.

Ostad-Ali-Askari, K. (2022) 'Management of risks substances and sustainable development', *Applied Water Science*, 12(4), pp. 1–23. doi: 10.1007/s13201-021-01562-7.

Rizvi, S. R. *et al.* (2007) 'A novel approach to reduce traffic chaos in emergency and evacuation scenarios', *IEEE Vehicular Technology Conference*, pp. 1937–1941. doi: 10.1109/VETECF.2007.407.

Sayudi, DS, Nurnaning A, Juliani Dj, Muzani, M. (2010) 'Peta Kawasan Rawan Bencana Gunung Api Merapi Jawa Tengah dan Daerah Istimewa Yogyakarta 2010 (Merapi Hazard Map, Central Java and Yogyakarta Special Region Provinces).' Kementerian Energi dan Sumber daya Mineral, Badan Geologi, Pusat Vulkanologi dan Mitigasi Bencana Geologi, Bandung. Available at: https://merapi.bgl.esdm.go.id/pub/page.php?idx=358.

Sleman Regional Disaster Management Agency (2019) *Rencana Kontijensi Erupsi Gunungapi Merapi*.

Sparks, R. S. *et al.* (2013) *Risk and uncertainty assessment of volcanic hazards*, *Risk and Uncertainty Assessment for Natural Hazards*. Cambridge University Press. doi:

10.1017/CBO9781139047562.012.

Takahashi, K. *et al.* (2022) 'A proposal for mutual-aid-type distributed evacuation based on residents' evacuation intentions in a hilly and mountainous area of Japan', *International Journal of Disaster Risk Reduction, ELSEVIER*. doi: https://doi.org/10.1016/j.ijdrr.2022.103366.

Taylor, S. J. (2014) *Agent-Based Modeling and Simulation*. UK, London: Palgrave Macmillan.

USGS (2016) *Volcano Hazards Program: Glossary - VEI*. Available at: https://volcanoes.usgs.gov/vsc/glossary/vei.html.

Velasquez, G. T. (2003) *Quantifying the Social Aspect of Disaster Vulnerability*.

Vink, K. and Takeuchi, K. (2013) 'International comparison of measures taken for vulnerable people in disaster risk management laws', *International Journal of Disaster Risk Reduction*, 4, pp. 63–70. doi: 10.1016/j.ijdrr.2013.02.002.

Wang, Z. *et al.* (2020) 'Analysis of flood evacuation process in vulnerable community with mutual aid mechanism: An agent-based simulation framework', *International Journal of Environmental Research and Public Health*, 17(2), pp. 1–21. doi: 10.3390/ijerph17020560.

CHAPTER III
ASSESSMENT OF SOCIAL VULNERABILITY IN THE EVACUATION PROCESS FROM MOUNT MERAPI

3.1 Introduction

Mount Merapi is the most active volcano in Indonesia, and the impact of the 2010 eruption was ranked third in the world (Guha-Sapir, Hoyois and Below, 2016). During the last major eruption, more than 400,000 people evacuated, and over 50,000 people kept staying in the high-risk zona (Mei *et al.*, 2013). In this disaster, crisis management problems such as congestion and evacuations delay were found. Congestion during evacuation not only reduces the effectiveness of evacuations but also leads to traffic accidents (Rizvi *et al.*, 2007). Risk analysis is essential to develop efficient and adequate strategies for implementing the various components of development-oriented emergency aid and reconstruction planning to less vulnerable and more sustainable development measures (Kohler, Jülich and Bloemertz, 2004). Following UNESCO practice, Risk can be defined as = "Hazard x Vulnerability", with hazard referring to the physical events produced by an eruption and vulnerability including a consideration of the consequences for people, buildings, infrastructure, and economic activity (Blong, 1996).

There are four affected regencies in the Merapi eruption, and each Regional Disaster Management Agency has mitigation and prevention plans for handling this disaster. All maps about the hazard, vulnerability, and evacuation have become available and contingency plans documents have been updated by 2020. The regency governments are always improving development cooperation and the cooperation of the local community is a key strategy for effective evacuation. In the "sister village" scenario, the pair of meeting areas and shelter has been coordinated. The governments prioritize to evacuate vulnerable people from the meeting area to shelter, and young people need to evacuate from their houses to the meeting area or shelter by themselves (Magelang Regional Disaster Management Agency, 2017; Klaten Regional Disaster Management Agency, 2018; Boyolali Regional Disaster Management Agency, 2019; Sleman Regional Disaster Management Agency, 2019). Nakamura et al. confirmed that an effective relationship and communication with local communities is an essential factor in Community-based disaster-prevention meetings (CDPMs). It is crucial to improve not only understanding of disaster but also human communication and interaction between different generations (Nakamura, Umeki and Kato, 2017). The risk perception is also one of the important factors in people's behavior during the evacuation process. The poor risk perception is characterized by an approximate personal representation of the volcanic processes, an excess of trust in concrete countermeasures, the presence of physical-visual obstructions, or cultural beliefs related to former eruptions (Lavigne *et al.*, 2008). In this case, the community's behavior has not been fully considered yet by our government in vulnerability assessment. Therefore, the objective of this study is to observe the walking speed of the evacuation simulation, to analyze the people's behavior and mutual assistance, and to assess the social vulnerability index of social and age factor and risk perception factor.

3.2 Data Collection and Methods

3.2.1 Data collection

This study focuses on hazard zone III of Mount Merapi. This means that the vulnerability and risk are extremely high and the priority to evacuate is highest. The area is located within a radius of 10 km from Mount Merapi. Administratively, this volcano is located on the border between Yogyakarta Special Province (Sleman Regency) and Central Java Province (Boyolali, Klaten, and Magelang Regencies). Data collection was done through a survey. The total of survey locations is 4 regencies involving 11 villages in Boyolali, 5 villages in Klaten, 19 villages in Magelang, and 7 villages (24 hamlets) in Sleman. These spots were determined according to the government contingency scenario and hazard map. Especially, the village area in Sleman is exceptionally large so the regency government maps the risks according to the hamlet. Table 3.1 is a description of the survey sites.

Table 3.1 Detail of survey sites

Regencies	Research Location
Boyolali (11 villages)	Tlogolele, Klakah, Jrakah, Lencoh, Samiran, Surotoleng, Wonodoyo, Jombong, Cluntang, Mriyan, and Sanggup
Klaten (5 villages)	Balerante, Tegalmulyo, Sidorejo, Panggang, and Bawukan
Magelang (19 villages)	Kaliurang, Nglumut, Ngablak, Ngargosoko, Tegalrandu, Mranggen, Srumbung, Kemiren, Kapuhan, Wonolelo, Ketep, Ngargomulyo, Sewukan, Sumber, Kalibening, Keningar, Sengi, Krinjing, and Paten
Sleman (24 hamlets)	Ngandong, Nganggring, Tunggularum, Gondoarum, Sempu, Manggungsari, Turgo, Ngepring, Kemiri, Boyong, Ngipiksari, Kaliurang Timur, Kaliurang

Regencies	Research Location
	Barat, Pelemsari, Pangukrejo, Jambu, Kopeng, Batur, Pagerjurang, Kepuh, Manggong, Kalor, Kalkid, and Srunen

The purposive sampling method was used to collect the data. As secondary data, contingency plan documents from the Regional Disaster Management Agency in each regency and contingency plan documents from the village offices were checked. Primary data was obtained from the interviews with 50 stakeholders, forum group discussion with 658 local communities, and the walking speed of 518 volunteers was measured. The distribution of these respondents and volunteers already represented all affected villages. Interviews were conducted with the village leader and several stakeholders at the Regional Disaster Management Agency. The local communities participating in forum discussions and simulations consist of young and vulnerable people. Young people are defined as the group having ages 12 to 59 years old. While vulnerable people consist of breastfeeding mothers, pregnant women, children, elderly, and people with disabilities. People aged 0 to 11 years old are categorized as children and aged more than 60 years old are categorized as elderly. The questionnaire instrument used was tested for validity and reliability using SPSS software. The test is done at a 5% level of significance. The walking speed was measured directly where volunteers were asked to walk through a route for about 250 m to 500 m distance. The observer used a walking measure tool, timer, and handy cam to record the data. The actual evacuation distance from homes to the meeting areas of each affected village is different, but the average distance is about 1-3 km. It is obtained according to the evacuation map of each village by measuring the distance from the hamlets center to the meeting areas and confirmed by the village leader. Figure 3.1 illustrates how the survey was conducted.

Figure 3.1 Documentation of interview, forum group discussion, and simulation

3.2.2 Data analysis

Walking speed data and mutual assistance impact are analyzed with descriptive statistics such as mean, standard deviation, and others. The Analysis of Variance (ANOVA) is also used to analyze this data. The Evacuation group and location were categorized into different groups according to their levels. The evacuation group was categorized as young without baggage, young with baggage, young and children, young and pregnant mother, young and elderly, young and disabled, breastfeeding mother and baby, pregnant mother, children, elderly, and disability. While the location was categorized as Boyolali, Klaten, Magelang, and Sleman regencies. All tests were done at a 5 % level of significance. Furthermore, the social vulnerability index was assessed with a multicriteria method.

3.2.3 Social vulnerability index

The risk analysis, risk evaluation, and risk management are part of the holistic concept of risk assessment (Bell and Glade, 2004). There are two essential elements in risk assessment namely hazard and vulnerability. The probability of occurrence of a harmful natural event is defined as a hazard (Kohler, Jülich and Bloemertz, 2004). While the meaning of vulnerability is the characteristics of people, households, or economies that increase the likelihood to suffer damage given a hazard event. It is considered a formulation of many factors such as exposure, capacity, resilience, livelihood stress, susceptibility, sensitivity, and/or weakness (Lowe, 2010). Velasquez confirmed that in case many vulnerability factors contribute to a hazard or a set of hazards, the total risk can be expressed as (Velasquez, 2003):

$$R = \sum_{i=1,j=1,k=1}^{n\ \ n\ \ n} w_i H_i * (\alpha_{ijk}) w_j V_{ij} \tag{1}$$

Where R represents the total risk, H_i represents the different hazards, V_{ij} represents the different vulnerabilities corresponding to these hazards, α_{ijk} is the social factor parameter that increases or decreases the hard vulnerability, w_j is the weight of importance of a selected vulnerability factor, and w_i is the weight of a hazard.

Kohler et al. explained that vulnerability factors have four classifications. They are economic vulnerability factors, physical vulnerability factors, social vulnerability factors, and environmental vulnerability factors. Especially, the variable of social vulnerability factor consists of the traditional knowledge system, risk perception, education, legal situation and human rights, civil participation, social organizations and institutions, legal framework, politics, social and age factor, health status, power structures and access to information (Kohler, Jülich and Bloemertz, 2004). There are five top categories for the most useful social vulnerability. They are gender, public health condition, public infrastructure, and migration. Previous studies have been limited to measure the social vulnerability index in a natural disaster. Consequently, additional research is needed to develop the social vulnerability index and to develop appropriate variable weighting schemes and valid indices (Fatemi *et al.*, 2017). Therefore, an assessment of the social vulnerability index is purposed in this research. The community behavior analysis and mutual assistance strategy are our concern to get more effective pedestrian evacuation. In this case, people behavior variable is divided into two factors consisting of social and age structure and risk perception. Young people, vulnerable people, and mutual assistance groups are classification of social and age factors. While risk perception factor considers various conditions of working, rain, night, alert, and destination understanding. The assessment method is carried out in 3 stages including decision framework, criterion design, and multicriteria evaluation. The decision framework is shown in Figure 3.2.

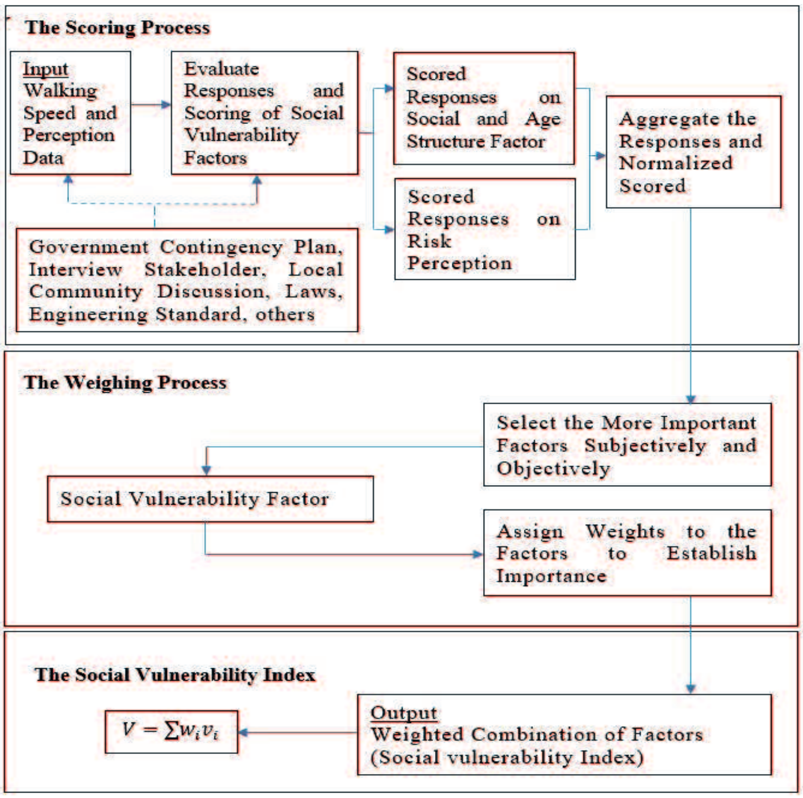

Figure 3.2 The assessment framework

Criterion design of the social and age structure factor is very dependent on walking speed data from the simulation. Truong et al. confirmed that the average speed and 15th percentile crossing speed from all survey sites and crossing types are 1.49 m/s and 1.25 m/s, respectively (Truong *et al.*, 2018). The overall 15th percentile speed of 1.25 m/s is close to the normal walking speed of 1.2 m/s often adopted for both green walk and flashing red do not walk time design (Austroads, 2019). According to Highway Capacity Manual (HCM) and Indian Roads Congress (IRC) method, pedestrian speed results in Level of Service (LOS) varies with gender, age group, group size, and trip purpose (Sangeeth and Lokre, 2019). LOS of walkways and sidewalks is classified as high if the speed is above 1.3 m/s (Transportation Research Board, 2000). Each country has a different pedestrian mean speed. Pedestrian speed in developed countries is higher than in developing countries. Pedestrians of developing countries have a free flow mean walking speed of 1.2 m/s (Rahman *et al.*, 2012). Also, Yosritzal *et al*. confirmed that the average walking speed during the simulation of tsunami evacuation in Indonesia was 1.419 m/s. It is varied by age and gender of the evacuee (Yosritzal *et al.*, 2018). Based on the previous study, criterion design in the current study were determined by 1.40 m/s standard because of the evacuation case approach and location of the same country. We consider the similarity of people's behavior in developing countries (Indonesia) and emergency response because studies about the pedestrian evacuation of volcanic eruptions are still limited. Meanwhile, the criterion design of risk perception factors depends on the questionnaire data from local communities. Table 3.2 and Table 3.3 clarify the scoring criteria for both factors.

Table 3.2 Scoring criterion design of the social and age structure factor

Categories	Score	Description	Description to Consider (values)
Young People Vulnerable People	0	Not Vulnerable	Faster than the mean walking speed standard (≥ 1.4 m/s)
Mutual Assistance Group	1	Vulnerable	Slower than the mean walking speed standard (< 1.4 m/s)

Table 3.3 Scoring criterion design of the risk perception factor

Score	Description	Description to Consider (values)
Work condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Returned home to meet family
Rain condition		
0	Not Vulnerable	Direct evacuation to the waiting area

Score	Description	Description to Consider (values)
Work condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Delay until the rain stop
Night condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Delay until morning
Alert condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Delay until seeing an eruption
Understanding of destination		
0	Not Vulnerable	Understand the waiting area
1	Vulnerable	Do not understand the waiting area

The next step is to assess the social vulnerability index using the multicriteria method. Based on the guidelines of quantifying the social aspects of disaster vulnerability, Velasquez explained about equation form as follow (Velasquez, 2003):

$$V = \sum w_i v_i \tag{2}$$

Where V is vulnerability, w_i is weight of factor i, v_i is criterion score for vulnerability factor i.

The detailed assessment is described into four processes.

1. Determine the relative weight

   Evaluate all respondent data and scoring based on the average delay evacuation categorized as vulnerable. The score of delayed evacuation is 1 and the score of direct evacuation is 0. Where R = raw score.

2. Normalized the score

   Normalize the factors to 0-1 (0 not vulnerable, 1 = vulnerable).

   Where $Xi = (Ri\text{-}Rmin)/(Rmax\text{-}Rmin)$.

3. Calculate the criterion weights

   Subjectively, the factor weights and normalized weight of important reveal are decided. Assigning criteria uses a simple pairing procedure utilizing at nine-step scale. This value indicates the relative scale of importance including 1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, and 9. The meaning of 1/9 is less important, 1 is standard, and 9 is more important.

4. Reveal the weighted linear combination of factors

   Social vulnerability index = $w1v1 + w2\ v2 + \ldots. + w_n v_n$

3.3 Results and Discussion

3.3.1 Characteristics of the local communities and population

We collaborated with the affected village offices to invite the members of local communities to fulfill the population proportion and people's behavior. Volunteers from local communities are fully recommended by the village leader or hamlet leader. These volunteers represent 8 types of people's behavior including young people, children, pregnant mothers, breastfeeding mothers, elderly, disability, driver, and breeder. The children were represented by ages 5 to 11 years old, the young were represented by ages 12 to 59 years old, and the elderly were those aged 60 years old or more. While breastfeeding mothers are mothers carrying babies and toddlers. The volunteers who own private cars and trucks are categorized as drivers and having cattle and or goats are categorized as breeders. Each type of volunteers consisted of both female and male. We organized 16 volunteers in each village or hamlet to conduct focus group discussions and then measured the walking speed directly. However, at the execution time, some volunteers exceeded the number of the invitation, and some lacking. This condition was caused by situations such as rain, night, and limited disabled people.

The local communities in the four affected regencies have similar characteristics. The results of the primary and secondary data collection show that the population is dominated by young people with details for the Boyolali and Klaten Regency at 64%, Magelang Regency at 81%, and Sleman Regency at 72%. The majority of the local community's livelihoods are agriculture and livestock farming. Data of students and workers outside the residence village for the affected regencies of Boyolali, Klaten, Magelang, and Sleman are about 5%, 10%, 20%, and 25%, respectively. It means that many residents stay in the villages during the daytime. This condition will influence the evacuation plan scenario if a disaster occurs at the time. As for single elderly data, the proportion of the population is exceedingly small, and elderly people usually live with their family or their homes nearby. Social culture with neighbors in these regencies is good and residents help each other. Therefore, the concept of "Mutual Assistance" between young people and vulnerable people in this evacuation case is possible to conduct. We also survey about evacuation experience in the last major eruption in 2010 and evacuation plans in the future. The result of risk perception showed that most people will immediately leave for evacuation. The proportion of the local community perception in disaster emergency plan is shown in Figure 3.3.

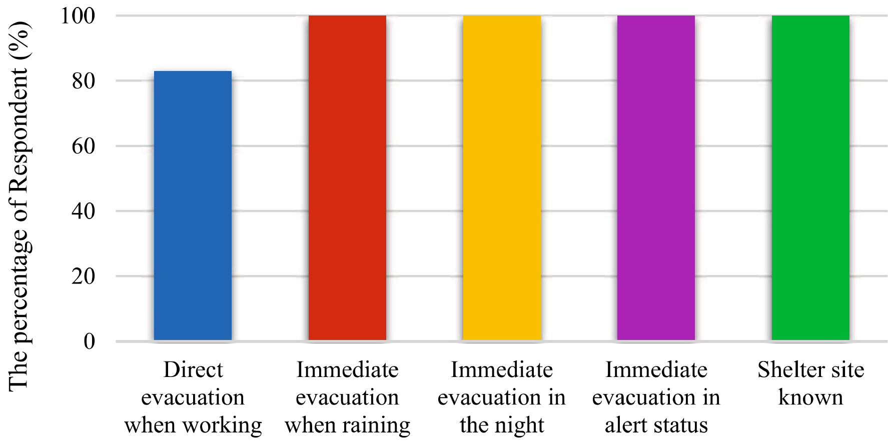

Figure 3.3 The proportion of the local community risk perception

The "sister village" scenario is a key strategy in mitigation development by the government. The cooperation concept is implemented through an agreement between the affected village and the sister village. The agreement includes the role of handling disaster emergencies such as providing shelter, logistics, and others. Sister village can be specified from the villages within the same regency or other regencies. On the other hand, evacuation transportation is the responsibility of the regency government and the affected communities. At level 3 status, the government will appeal to all residents for evacuation. Residents are expected to evacuate independently and simultaneously using their private vehicles from their homes to the meeting area and shelter in the sister village based on the evacuation map. The government will support staged evacuation from the meeting area to the shelter. In the first stage, the government will focus to evacuate vulnerable people and then young people without a private vehicle. Therefore, the effectiveness of pedestrian evacuation time from the house to the meeting area is crucial because of the uncertainty on the interval for changing from level 3 to 4 (eruption) status. A mutual assistance concept is being developed in this study to assess its effect. In the future, the government can also support this concept by conducting data collection and training for young and vulnerable people who have the status of family or neighbors. This strategy is essential for increasing public awareness, safety, and effective evacuation.

The population distribution of evacuation groups from home to the meeting area is divided into 3 groups namely young people, mutual assistance, and vulnerable people.

Young people use a private vehicle and young people bring baggage are also included in the young group. The total number of people carrying baggage is represented by the percentage of young men population. Information about the population of young and vulnerable people and data of the local community's vehicle is obtained from the village contingencies plans and interviews with the village leader. We formulated the proportion of mutual assistance and single vulnerable people by 50% and 50%. This assumption is determined according to the highest potential risk that will be handled by the government. Figure 3.4 is a detail of the regency population concept in the pedestrian evacuation process.

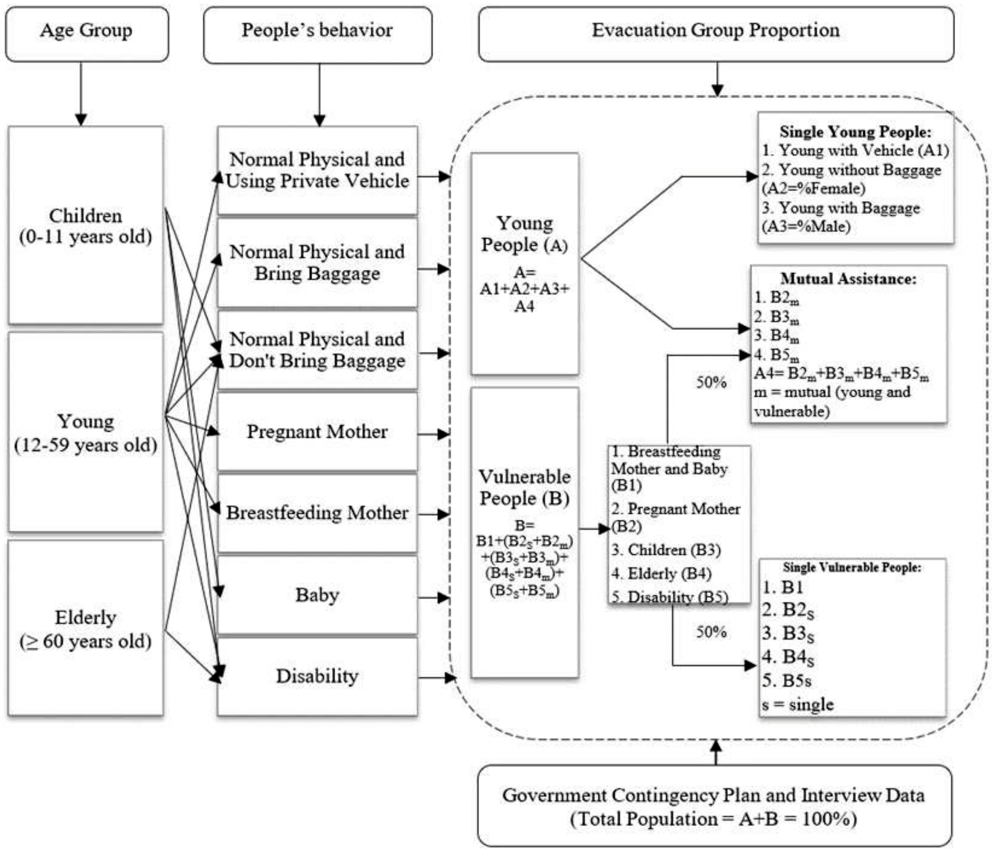

Figure 3.4 Conceptual of regency population

3.3.2 Pedestrian evacuation speed

The mean of young people's evacuation speed is 1.48 (m/s) for Boyolali Regency, 1.7 (m/s) for Klaten Regency, 1.25 (m/s) for Magelang Regency, and 1.23 (m/s) for Sleman Regency. Klaten Regency has the highest mean speed due to the downhill road conditions and good pavement. Whereas Magelang and Sleman Regencies have a combination of surfaces between flat, uphill, and downhill which cause slower speeds. Boyolali Regency has a relatively flat and descending surface. These three regencies also have access roads from good to moderate damage. Overall, the result indicates that mutual assistance groups have a median speed between vulnerable and young people. For example, the mean speeds of young, mutual assistance (young and elderly), and elderly people in Boyolali are 1.48 (m/s), 1.22(m/s), and 0.99 (m/s), respectively. This relationship is common in all regencies. The details of the mean walking speed and standard deviation in four affected regencies are shown in Table 3.4, Table 3.5, Table 3.6, and Table 3.7.

Table 3.4 Pedestrian evacuation speed in Boyolali Regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range	
			High	Low
Young without Baggage	18	1.48 ± 0.43	2.19	1.04
Young with Baggage	6	1.28 ± 0.23	1.51	0.97
Young and Children	5	1.45 ± 0.37	1.96	1.07
Young and Pregnant Mother	9	1.21 ± 0.29	1.67	0.83
Young and Elderly	9	1.22 ± 0.35	2.02	0.84
Young and Disability	3	0.86 ± 0.17	1.04	0.67
Breastfeeding Mother and Baby	8	1.23 ± 0.30	1.79	0.90
Pregnant Mother	8	1.25 ± 0.38	1.81	0.84
Children	4	1.22 ± 0.42	1.84	0.96
Elderly	5	0.99 ± 0.11	1.15	0.86
Disability	2	1.12 ± 0.18	1.25	1.00

Table 3.5 Pedestrian evacuation speed in Klaten Regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range	
			High	Low
Young without Baggage	9	1.70 ± 0.62	2.56	1.00
Young with Baggage	2	2.58 ± 0.07	2.63	2.53
Young and Children	3	1.46 ± 0.72	2.18	0.74
Young and Pregnant Mother	4	1.09 ± 0.23	1.32	0.77
Young and Elderly	4	1.45 ± 0.48	2.13	1.00
Young and Disability	2	1.44 ± 0.15	1.54	1.33
Breastfeeding Mother and Baby	4	1.60 ± 0.52	2.10	0.99
Pregnant Mother	3	1.25 ± 0.19	1.39	1.04
Children	3	1.39 ± 0.07	1.47	1.34
Elderly	2	1.38 ± 0.21	1.52	1.23
Disability	1	0.46 ± 0.00	0.46	0.46

Table 3.6 Pedestrian evacuation speed in Magelang regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range	
			High	Low
Young without Baggage	75	1.25 ± 0.26	1.85	0.79
Young with Baggage	2	0.80 ± 0.42	1.10	0.50
Young and Children	12	1.78 ± 0.38	2.33	1.25
Young and Pregnant Mother	9	1.02 ± 0.43	1.52	0.44
Young and Elderly	9	1.10 ± 0.46	1.39	0.40
Young and Disability	7	1.05 ± 0.51	1.79	0.55
Breastfeeding Mother and Baby	18	0.90 ± 0.39	1.45	0.55
Pregnant Mother	15	0.87 ± 0.39	1.45	0.40
Children	11	1.36 ± 0.33	1.83	1.05
Elderly	15	0.95 ± 0.44	1.94	0.39
Disability	11	0.88 ± 0.45	1.47	0.39

In Table 3.5, it is found that young with baggage has a significantly higher speed than young people because the topographic contours tend to decrease, baggage capacity only contains important documents, and running action. Besides, the disabled person in Klaten Regency has the lowest speed (0.46 m/s) due to leg defects and old age. There are many types of disability in this case including autism child, deaf, and limp legs with or without a wheelchair. When compared to disability speed in Boyolali Regency, it has a normal walking speed because of deaf, and mild leg defect condition. While Table 3.6 describes that the mutual assistance group between young and children has a dramatically higher speed than young people due to the children walked faster and the assistant followed them.

Table 3.7 Pedestrian evacuation speed in Sleman Regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range	
			High	Low
Young without Baggage	56	1.23 ± 0.18	1.64	0.99
Young with Baggage	14	0.95 ± 0.16	1.23	0.67
Young and Children	6	1.08 ± 0.16	1.25	0.81
Young and Pregnant Mother	11	1.02 ± 0.15	1.28	0.73
Young and Elderly	14	1.01 ± 0.11	1.15	0.80
Young and Disability	5	0.84 ± 0.24	1.26	0.69
Breastfeeding Mother and Baby	30	1.04 ± 0.28	1.56	0.37
Pregnant Mother	22	0.98 ± 0.33	1.43	0.32
Children	14	1.07 ± 0.26	1.57	0.63
Elderly	41	0.87 ± 0.26	1.38	0.55
Disability	7	1.11 ± 0.30	1.35	0.64

In this paper, the One-Way ANOVA and Independent Samples T-Test are also used to analyze the speed data. Table 3.8 summarizes the result of the One-way ANOVA in SPSS Statistics. The test of normality and homogeneity of variances were fulfilled. At a 1% - 5 % level of significance, the result of the test implies that the mean walking speed in four regencies is not significantly different except in the category of young with baggage. It means the four affected regencies have similar community behavior in the pedestrian evacuation.

While in Table 3.9, the walking speed of young and vulnerable people are compared using the independent samples T-test. The vulnerable people group consists of breastfeeding mothers, pregnant mothers, elderly, and disabled people. Children are not included in each group because they sometimes walk faster than young people. The total of samples in this test was 158 for young people and 191 for vulnerable people. The result shows that p-value (sig) < 0.05. It indicates that the mean walking speed between these groups has a significant difference at a 5 % level of significance.

Table 3.8 Recapitulation of ANOVA result in each category (comparison between regencies)

Categories		Sum of Squares	df	Mean Square	F	Sig.
Young People	Between Groups	.033	1	.033	1.715	.202
	Within Groups	.484	25	.019		
	Total	.518	26			
Young with baggage	Between Groups	.554	3	.185	18.076	.000
	Within Groups	.204	20	.010		
	Total	.759	23			
Young and Children	Between Groups	.318	3	.106	4.296	.016
	Within Groups	.542	22	.025		
	Total	.860	25			
Young and Pregnant Mother	Between Groups	.056	3	.019	.851	.477
	Within Groups	.640	29	.022		
	Total	.697	32			
Young and Elderly	Between Groups	.140	3	.047	1.246	.310
	Within Groups	1.161	31	.037		
	Total	1.301	34			
Young and Disability	Between Groups	.121	3	.040	1.184	.354
	Within Groups	.444	13	.034		
	Total	.565	16			
Breastfeeding Mother	Between Groups	.254	3	.085	3.338	.026
	Within Groups	1.418	56	.025		
	Total	1.672	59			
Pregnant Mother	Between Groups	.955	3	.318	2.526	.070
	Within Groups	5.544	44	.126		
	Total	6.499	47			
Children	Between Groups	.614	3	.205	2.263	.103
	Within Groups	2.533	28	.090		

Table 3.8 Recapitulation of ANOVA result in each category (comparison between regencies)

Categories		Sum of Squares	df	Mean Square	F	Sig.
	Total	3.148	31			
Elderly	Between Groups	.133	3	.044	1.591	.201
	Within Groups	1.645	59	.028		
	Total	1.778	62			
Disability	Between Groups	.485	3	.162	1.050	.396
	Within Groups	2.618	17	.154		
	Total	3.103	20			

Table 3.9 The speed comparison of young and vulnerable people according to the independent samples T-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Speed (m/s)	Equal variances assumed	3.205	.074	8.277	347	.000	.30197	.03648	.23022	.37373
	Equal variances not assumed			8.375	345.512	.000	.30197	.03606	.23105	.37289

3.3.3 Mutual assistance impact

Figure 3.5 shows the effects of mutual assistance on walking speed. Mutual assistance means that young people evacuate with vulnerable people. For young people, evacuation with vulnerable people generally means the decline of walking speed. However, the mutual assistance between young and children in Magelang Regency reaches the top speed at 1.78 m/s. This result may occur due to a lack of coordination between them. Effective evacuation time is an important goal but avoiding high risk is also essential. Therefore, mutual assistance coordination is crucial for vulnerable people's safety. Figure 3.5 explains that the mean speed of young people decreases sharply in four affected regencies. The biggest drop is in the young and disability group at intervals of 0.20 m/s – 0.62 m/s. On the other hand, the group speed of young and children, young and pregnant mothers, and young and elderly have a slight deflation.

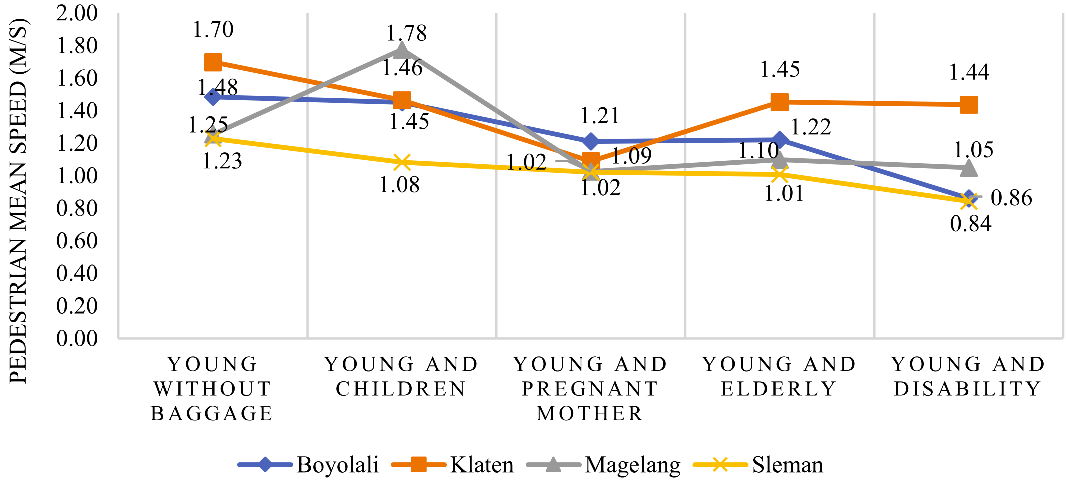

Figure 3.5 The mean walking speed comparison between young people and mutual assistance

In Figure 3.6, there is a clear difference in the walking speed between vulnerable dan mutual assistance in four affected regencies. Children, elderly, and disabled people have a significant impact on this mutual assistance action. In the case of disability, the mean walking speed is increased from 0.89 m/s to 1.05 m/s. The SPSS software is also used to confirm a speed comparison of mutual assistance and vulnerable people. Test of normality and homogeneity of variances were fulfilled. The paired samples T-test result shows that p-value (sig) < 0.05. It describes that pedestrian evacuation speed of mutual assistance and vulnerable have a significant difference at a 5 % level of significance (Table 10). Especially, this vulnerable group is the elderly and disabled people.

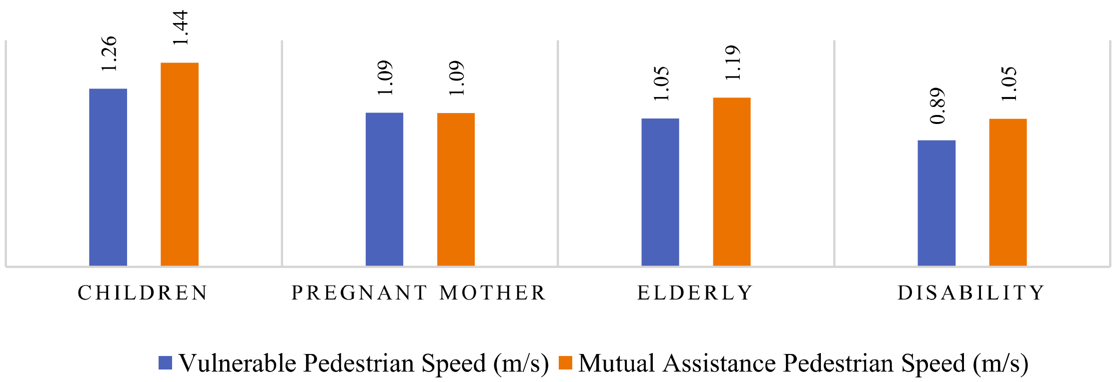

Figure 3.6 The mean walking speed comparison between vulnerable people and mutual assistance

Table 3.10 The speed comparison of mutual assistance and vulnerable people according to the paired samples T-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Speed (m/s)	Equal variances assumed	.088	.768	2.637	135	.009	.15968	.06056	.03990	.27946
	Equal variances not assumed			2.587	103.801	.011	.15968	.06173	.03727	.28209

3.3.4 Social vulnerability index

The social vulnerability index is assessed from two points of view, subjectively and objectively. Then both are compared by focusing on two people's behavior factors namely social and age structure, and risk perception. We use the normalized weight of importance reveal based on a group evaluation by stakeholders and the local community to get subjective results. All affected regencies have the same weight of vulnerability. Regional characteristics involving topography, livelihoods, and community culture are similar so the calculation of criteria score each regency can be represented by a common score. Consequently, the social vulnerability index in four affected regencies is subjectively the same. In contrast to objectively, we use the weight of importance based on the total population so a different index in each regency is obtained. Detailed results of common score, vulnerability weight, social vulnerability index is referred from Table 3.11, Table 3.12, Table 3.13, and Table 3.14.

Table 3.11 A common score of the social and age structure (all affected regencies)

Categories	Number	Pedestrian Speed (m/s)		Common Score (Normalized)
		Mean	Standard Deviation	
Young without Baggage	158	1.42	0.37	0.484
Young with Baggage	24	1.40	0.22	0.496
Young and Children	26	1.44	0.41	0.460
Young and Pregnant Mother	33	1.09	0.27	0.875
Young and Elderly	36	1.19	0.35	0.722
Young and Disability	17	1.05	0.27	0.908

Categories	Number	Pedestrian Speed (m/s)		Common Score (Normalized)
		Mean	Standard Deviation	
Breastfeeding Mother and Baby	60	1.19	0.37	0.709
Pregnant Mother	48	1.09	0.32	0.834
Children	32	1.26	0.27	0.699
Elderly	63	1.05	0.25	0.919
Disability	21	0.89	0.23	0.985

Table 3.12 A common score of the risk perception (all affected regencies)

Categories	Criterion Score				Common Score
	Boyolali	Klaten	Magelang	Sleman	
Work Condition	0.900	0.733	0.815	0.727	0.794
Rain Condition	0.080	0.117	0.103	0.061	0.090
Night Condition	0.040	0.017	0.011	0.029	0.024
Alert Condition	0.040	0.017	0.011	0.025	0.023
Understanding of Destination	0.600	0.317	0.130	0.108	0.289

Based on Table 3.14, the subjective and objective assessment shows that the social and age structure factor has a higher index than the risk perception factor. It means that the social and age structure factor has strong risk influence in the pedestrian evacuation process. Overall, the subjective social vulnerability index is higher than the objective index. This phenomenon occurs because the subjective view focuses on the evacuation problem of vulnerable people and the objective view depends on the group population in the communities. The objective index in the four regencies is low due to the elderly people proportion is not large. Magelang Regency represents the highest objective index for the social and age structure factor, and Sleman Regency reflects the highest objective index for the risk perception factor. Nevertheless, both factors have a low objective index. It indicates a minor impact on social vulnerability to the total population.

Table 3.13 Weight of vulnerability in the subjective and objective view

No	Categories	Weight of Vulnerability (Subjective)	Regency Weight (Objective)			
			Boyolali	Klaten	Magelang	Sleman
Social and Age Structure Factor						
1	Young with Vehicle	0.000	0.488	0.432	0.130	0.439
2	Young without Baggage	0.010	0.003	0.032	0.306	0.083
3	Young with Baggage	0.029	0.003	0.032	0.301	0.082
4	Young and Children	0.087	0.200	0.200	0.025	0.144
5	Young and Pregnant Mother	0.029	0.010	0.010	0.007	0.002
6	Young and Elderly	0.087	0.070	0.070	0.104	0.083

No	Categories	Weight of Vulnerability (Subjective)	Regency Weight (Objective)			
			Boyolali	Klaten	Magelang	Sleman
7	Young and Disability	0.087	0.010	0.010	0.010	0.008
8	Breastfeeding Mother and Baby	0.087	0.070	0.070	0.043	0.040
9	Pregnant Mother	0.146	0.005	0.005	0.004	0.002
10	Children	0.087	0.100	0.100	0.013	0.072
11	Elderly	0.146	0.035	0.035	0.052	0.042
12	Disability	0.204	0.005	0.005	0.005	0.004
Risk Perception Factor						
1	Work Condition	0.310	0.012	0.026	0.048	0.048
2	Rain Condition	0.034	0.247	0.244	0.238	0.238
3	Night Condition	0.034	0.247	0.244	0.238	0.238
4	Alert Condition	0.517	0.247	0.244	0.238	0.238
5	Understanding of Destination	0.103	0.247	0.244	0.238	0.238

Table 3.14 Social vulnerability index comparison

Regencies	Index of Age Structure Factor		Index of Risk Perception Factor	
	Subjective	Objective	Subjective	Objective
Boyolali	0.806	0.324	0.292	0.115
Klaten	0.806	0.352	0.292	0.124
Magelang	0.806	0.494	0.292	0.139
Sleman	0.806	0.338	0.292	0.147

3.3.5 Comparison with previous studies

Yosritzal *et al.* observed the walking evacuation speed of tsunami disaster in Padang, West Sumatera, Indonesia. They involved 9 volunteers, 6 observers, 1 route with 5 segments in their simulation. In conclusion, the mean walking speed during the evacuation was 1.419 m/s. The group of age 20-40 years was found to walk 11% faster than children and 7 % faster than elderly people. Male was discovered 10 % faster than female in the same group (Yosritzal *et al.*, 2018). Jumadi *et al.* compared the evacuation scenario with an agent-based model between simultaneous and staged of Merapi Volcano in Sleman Regency, Yogyakarta, Indonesia. The results confirm that the staged scenario has a better ability to reduce the potential traffic congestion during the peak time. The time interval between the stage was divided into 5 districts namely Cangkringan, Ngemplak, Pakem, Tempel, and Turi. The average travel time to reach a major road was 23.8 minutes. However, the simultaneous strategy has better performance regarding the speed of reducing the risk. This study has several limitations such as the variability of population behavior that has not been involved in this initial simulation development, and the government contingency plans have not yet been considered (Jumadi, Carver and Quincey, 2019). Meanwhile, Nugraha *et al.* confirmed the risk assessment of Mount Merapi in the settlement area of Sleman Regency and concern on the mapping of eruption risk. The result shows that there is still a large risk in the Regency. Therefore, an appropriate strategy in mitigation planning is needed (Nugraha *et al.*, 2019).

Klein *et al.* presented the four challenging principles for integrated community-based and ecosystem-based disaster risk reduction in mountain systems. They are governance and institutional arrangement that appropriate local needs, empowerment, and capacity-building to strengthen community resilience, discovery and sharing of constructive practices that combine local and scientific knowledge, and oncoming focused on well-being and equity (Klein *et al.*, 2019). Besides, the presence of too many cooperators or defectors in the evacuation group is not conducive to safe evacuation. It is found that heterogeneous pedestrian speeds can increase the evacuation efficiency to a certain extent. The total evacuation time can be reduced if 20% of the pedestrians slow down. The evacuation time is the shortest when the radius is about 4 cells (Zou *et al.*, 2020). In this present research, we focused on the local community behavior in four affected regencies especially the "mutual assistance" study. The index output reflects the distribution of actual walking speed, mutual assistance, and the government's plan updating in 2019. Therefore, this study is a development from previous research to get a more effective and practical evacuation plan for the considered by the government.

3.4 Summary

This chapter presents the influence of local community behavior and mutual assistance in the pedestrian evacuation process. Actual walking speed and risk perception are the main variables. These data collection was carried out by direct surveys in the local community. The statistical analysis results showed that mutual assistance can be effective to reduce any risk during evacuation. Probably, the reduced evacuation time is not so big but vulnerable people may be left if young people do not care about them. The social and age structure of the social vulnerability index has a stronger risk effect than the perception factor. However, these two factors have a minor impact on social vulnerability to the total population. In future work, it is necessary to develop an evacuation model of cattle because they must be evacuated simultaneously at level 3 status according to the government plan. Several factors were not included in this study such as education, politics, income, health, and others. Correlations between all factors are needed to find a comprehensive assessment of the social vulnerability index and total risk.

References

Austroads (2019) *Guide to Traffic Management Part 9: Traffic Operation*. 3.1, *Austroads AGTM09-19*. 3.1. Sydney: Austroads Ltd. Available at: www.austroads.com.au.

Bell, R. and Glade, T. (2004) 'Quantitative risk analysis for landslides - Examples from Bíldudalur, NW-Iceland', *Natural Hazards and Earth System Science*, 4(1), pp. 117–131. doi: 10.5194/nhess-4-117-2004.

Blong, R. J. (1996) 'Volcanic Hazards Risk Assessment', in *Monitoring and Mitigation of Volcano Hazards, Scarpa/Tilling (eds)*. Springer-Verlag Berlin Heidelberg, pp. 675–698. doi: 10.1007/978-3-642-80087-0_20.

Boyolali Regional Disaster Management Agency (2019) *Penyusunan Rencana Kontinjensi Erupsi Gunung Merapi*. Boyolali Regency, Indonesia.

Fatemi, F. *et al.* (2017) 'Social vulnerability indicators in disasters: Findings from a systematic review', *International Journal of Disaster Risk Reduction*, 22, pp. 219–227. doi: https://doi.org/10.1016/j.ijdrr.2016.09.006.

Guha-Sapir, D., Hoyois, P. and Below, R. (2016) *Annual Disaster Statistical Review 2015: The numbers and trends Centre for Research on the Epidemiology of Disasters (CRED)*, *Centre for Research on the Epidemiology of Disasters (CRED) Institute of Health and Society (IRSS) Université catholique de Louvain – Brussels, Belgium*. Available at: https://reliefweb.int/report/world/annual-disaster-statistical-review-2015-numbers-and-trends.

Jumadi, J., Carver, S. J. and Quincey, D. J. (2019) 'An agent-based evaluation of varying evacuation scenarios in Merapi : Simultaneous and staged', *Geosciences*, 9, pp. 1–19. doi: 10.3390/geosciences9070317.

Klaten Regional Disaster Management Agency (2018) *Rencana Kontingensi Menghadapi Ancaman Erupsi Gunung Merapi di Kabupaten Klaten*. Klaten Regency, Indonesia.

Klein, J. A. *et al.* (2019) 'An integrated community and ecosystem-based approach to disaster risk reduction in mountain systems', *Environmental Science and Policy*, 94(January), pp. 143–152. doi: 10.1016/j.envsci.2018.12.034.

Kohler, A., Jülich, S. and Bloemertz, L. (2004) 'Risk analysis – a basis for disaster risk management', in *Governance Nad Democracy*. Eschborn: Deutsche Gesellschaft fur, Technische Zusammenarbeit (GTZ) GmbH, pp. 1–73. Available at: https://www.preventionweb.net/files/1085_enriskanalysischs16.pdf.

Lavigne, F. *et al.* (2008) 'People's behaviour in the face of volcanic hazards: Perspectives from Javanese communities, Indonesia', *Journal of Volcanology and Geothermal Research*, 172(3–4), pp. 273–287. doi: 10.1016/j.jvolgeores.2007.12.013.

Lowe, C. J. (2010) *Analysing vulnerability to volcanic hazards: application to St. Vincent*. Department of Geography University College London. Available at: http://eprints.ucl.ac.uk/20466/.

Magelang Regional Disaster Management Agency (2017) *Rencana Kontingensi Erupsi Gunung Merapi Kabupaten Magelang Tahun 2017 – 2020*. Magelang Regency, Indonesia. Available at: http://bappeda.magelangkab.go.id/home/detail/musrenbang-wilayah-eks-karesidenan-kedu-tahun-2019-di-kabupaten-magelang/159.

Mei, E. T. W. *et al.* (2013) 'Lessons learned from the 2010 evacuations at Merapi volcano', *Journal of Volcanology and Geothermal Research*, 261, pp. 348–365. doi: 10.1016/j.jvolgeores.2013.03.010.

Nakamura, H., Umeki, H. and Kato, T. (2017) 'Importance of communication and knowledge of disasters in community-based disaster-prevention meetings', *Safety Science*, 99, pp. 235–243. doi: 10.1016/j.ssci.2016.08.024.

Nugraha, A. L. *et al.* (2019) 'Analysis of Risk Assessment of Mount Merapi Eruption in Settlement Area of Sleman Regency', in *IOP Conference Series: Earth and Environmental Science*. doi: 10.1088/1755-1315/313/1/012003.

Rahman, K. *et al.* (2012) 'Analysis of pedestrian free flow walking speed in a least developing country: A factorial design study', *Research Journal of Applied Sciences, Engineering and Technology*, 4(21), pp. 4299–4304.

Rizvi, S. R. *et al.* (2007) 'A novel approach to reduce traffic chaos in emergency and evacuation scenarios', *IEEE Vehicular Technology Conference*, (June 2014), pp. 1937–1941. doi: 10.1109/VETECF.2007.407.

Sangeeth, K. and Lokre, A. (2019) 'Factors influencing Pedestrian Speed in Level of Service (LOS) of pedestrian facilities', *Transportation Research Interdisciplinary Perspectives*, 3, p. 100066. doi: 10.1016/j.trip.2019.100066.

Sleman Regional Disaster Management Agency (2019) *Rencana Kontijensi Erupsi Gunungapi Merapi*.

Transportation Research Board (2000) *Highway Capacity Manual*, *National Research Council, Washington, DC*. Washington DC.

Truong, L. T. *et al.* (2018) 'Walking speeds for timing of pedestrian walk and clearance intervals', in *ATRF 2018 - Australasian Transport Research Forum 2018, Proceedings*, p. 11.

Velasquez, G. T. (2003) *Quantifying the Social Aspect of Disaster Vulnerability*.

Yosritzal *et al.* (2018) 'An observation of the walking speed of evacuees during a simulated tsunami evacuation in Padang, Indonesia', in *IOP Conference Series: Earth and Environmental Science*, pp. 1–8. doi: 10.1088/1755-1315/140/1/012090.

Zou, B. *et al.* (2020) 'Effect of pedestrian judgement on evacuation efficiency considering hesitation', *Physica A: Statistical Mechanics and its Applications*, 547. doi: 10.1016/j.physa.2019.122943.

CHAPTER IV
DEVELOPMENT OF MUTUAL ASSISTANCE EVACUATION MODEL TO REDUCE THE VOLCANIC RISK FOR VULNERABLE SOCIETY

4.1 Introduction

Volcanic eruptions are among the most catastrophic natural disasters: Their effect is not only casualties during an eruption, but the material risk of a large explosion might have an impact on the sustainable hazard (Ostad-Ali-Askari, 2022). Indonesia has more than 500 volcanoes, 127 of which are active (National Disaster Management Agency, 2014). Mount Merapi is the country's most active volcano and is famous worldwide. It ranked third in terms of eruption impact in 2010 (Guha-Sapir, Hoyois and Below, 2016), when a paroxysmal eruption occurred with an ash column reaching an altitude of 17 km and a pyroclastic density spread 16 km from the volcano's peak in the Gendol River (Surono *et al.*, 2012). The Center for Volcanology and Geological Hazard Mitigation enlarged the danger zone to 20 km around the summit and urged residents to evacuate (Mei *et al.*, 2013). However, the large-scale evacuation was uncontrolled, and many casualties occurred due to this management crisis. The national disaster management agency (Badan Nasional Penanggulangan Bencana, or BNPB) assists in relocating residents to a safe place as a mitigation strategy (National Disaster Management Agency, 2014). In addition, each regional disaster management agency (Badan Penanggulangan Bencana Daerah, or BPBD) is developing its cooperation with sister villages. This strategy was implemented through an agreement between the affected area and these sister villages; the agreement covers responsibilities such as providing shelter, logistics, and other disaster-related services. Another eruption response technique is establishing a staged and simultaneous evacuation system, with priority given to vulnerable populations. Vulnerable communities are first made to evacuate independently, and the local government picks them up when they have difficulties. The government focuses on supporting the evacuation process from the meeting point to the shelter, and the movement is carried out at Level 3, which is expected to reduce risk (Klaten Regional Disaster Management Agency, 2018; Liu *et al.*, 2022). However, self-evacuation from the house to the meeting point is difficult to control because of human behavior factors.

As a result, the efficacy of this evacuation stage must be evaluated, particularly in terms of the risk to vulnerable persons.

In this case, there are various critical evacuation issues that must be addressed for mitigation management. The first is the indefinite eruptive evacuation period (Gaudru, 2004). Umbulharjo village officials stated that the 2006 eruption was sluggish, whereas the 2010 eruption was quick. Around 50–70 percent of internally displaced persons returned to the hazard zone during the crisis despite evacuation orders (Mei *et al.*, 2013). During the 2020 evacuation period, the secretary of the Boyolali District Disaster Management Agency stated that several inhabitants also returned to farm the land during the day and went to shelters at night. The uncertainty of a volcano's hazardous period may cause inevitable difficulties for authorities. Second, Indonesia will be ranked 5th in the world for aging populations in 2025, according to a World Health Organization (WHO) report (Hakim, 2020). Consequently, the evacuation of vulnerable people is a topic of concern. Third, the community's behavior has not been fully considered yet in the government's contingency plan. Even if the meeting points and shelters have been coordinated appropriately, the physical constraints of vulnerable people and misperceptions of risk during an emergency can result in casualties. Fourth, there is a lack of an opportunity for cross-sector communication. Consequently, the inhabitant rescue may be delayed. Fifth, evacuation transport provided by the local government and vehicle ownership in the community was limited. This condition leads some people to walk and makes them vulnerable due to their low speeds, which can cause hazards and delays. Issues 3 to 5 were highlighted by key informants at the BPBD and the village office.

Consequently, there are still significant challenges for evacuation management, and research and development are necessary. We propose a mutual assistance approach or assembly model to improve successful evacuation procedures and protect vulnerable people. The ideal solution is to enlist the help of young people in assisting the vulnerable. Alalouf-Hall confirmed that an assembled evacuation model was successfully implemented in the earthquake and tsunami in Japan. However, this strategy has only been carried out to save the children. Grouping for the elderly and other vulnerable people has not been examined (Alalouf-Hall, 2019). Ma et al. also examined the influence of group behaviors and crowd dynamics during pedestrian evacuation. The result revealed that increased group sizes and numbers can promote crowd cooperation but prolongs the duration of the evacuation. Specific impacts on pedestrian interactions have not been considered and variations in people's walking speed have not been included (Ma, Liu and Huo, 2022). In the current study, we focused on the small group model and represent walking speed for all categories of vulnerable people. There are limited previous studies and implementations regarding the grouping interaction and vulnerable people concerns in disaster mitigation plans. Our original idea is a concept of mutual assistance that is well controlled and registered by the government to reduce risk. Our novelty is a simulation model that reflects the actual walking speed data in the field representing all categories of people such as young people, the elderly, the disabled, children, and pregnant mothers (Chasanah and Sakakibara, 2021). Actual emergency data is hard to measure. However, the survey has been conducted using an emergency approach in the affected areas by considering people's perceptions, carrying baggage, using the actual evacuation route, representing rainy and summer weather, and other environmental factors. After that, the concept of interaction and grouping is developed in software to confirm the purpose. We also simulated the model with the actual evacuation distance approach. We generated and tested numerous scenarios using an agent-based evacuation model in a volcano context. The results are presented in Section 4.4, Section 4.5 discusses the results, and Section 4.6 presents our summary.

4.2 Related Studies

4.2.1 Mount Merapi evacuation

Several lessons were learned during the 2010 Merapi eruption that could be used in future Merapi mass evacuations. The evacuation experience during this eruption revealed that evacuation proceeded smoothly during the first few days. However, when the eruption became much larger, the evacuation process encountered difficulties owing to the lack of preparation by the government and residents. In the future, it is critical to developing a comprehensive new contingency plan and public education (Mei *et al.*, 2013). Hardiansyah et al. developed an evacuation model using SATURN version 11.3.12 W to minimize casualties. The findings of the study confirmed an increase in the flow and travel times of the road network in the Sleman Regency in both Ring 2 and Ring 3 and the road network beyond the rings. However, an evacuation simulation in Rings 2 and 3 is required to broaden the coverage of the impacted region and the extent of the influence of performance changes in the existing road networks (Hardiansyah *et al.*, 2018).

Jumadi et al. also developed a model for individual evacuation decision-making during a disaster. This agent-based model was concerned with the emergence of hesitancy during times of crisis. The evacuation choice of an agent to stay or depart is based on an assessment of the intensity of the driving factors using threshold-based criteria (Jumadi *et al.*, 2018). AnyLogic was used to compare the evacuation scenario between a simultaneous and staged Merapi volcano eruption scenario in Sleman Regency. The results revealed that a staged scenario is more capable of reducing potential traffic congestion during peak hours. However, several limitations were noted, such as the variability of population behavior, which was not fully examined in this initial simulation development (Jumadi, Carver and Quincey, 2019). Maharani et al. used the self-organizing map method to determine the vulnerable cluster and the most significant related variable. Their findings demonstrated that the factors of migrate-in population number and number of women had the greatest influence on social vulnerability (Maharani, Lee and Ki, 2016). Meanwhile, Nugraha et al. conducted a risk assessment of Mount Merapi in the Sleman Regency habitation area, focusing on mapping eruption risk. The results showed that there is still a significant danger to this regency (Nugraha *et al.*, 2019). The Spatio-Temporal Dynamics Model of Risk (STDMR) method was also applied in this volcano risk analysis. The STDMR incorporates the Multi-Criteria Evaluation (MCE) based on an individual risk model into an Agent-Based Model simulation and may demonstrate the influence of the evacuation process on the risk reduction outcome. The possibility of success or ignoring of this model depends on the actual interaction of agents, which requires validation improvement of the destination choice rule (Jumadi *et al.*, 2020). Therefore, an appropriate strategy for mitigation planning is needed. However, no previous studies have considered the government contingency that was revised in 2019. In the new regulation, the government developed a sister-village scenario and a combination of staged and simultaneous evacuations. In the present study, we develop a model based on this latest policy approach and directly involve the community to determine its perceptions, aiming to strengthen the resilience and reduce the risk for vulnerable people.

4.2.2 Existing evacuation simulation model

In recent decades, several methodologies for evacuation dynamics simulations have been proposed. The Miracle of Kamaishi was a successful evacuation model employed during the 2011 earthquake and tsunami in Japan. Junior high school students supported elementary school students, which was highly effective and allowed them to miraculously survive the earthquake and tsunami evacuation (Alalouf-Hall, 2019). The computational social science of disasters (CSSD) was introduced as the systematic study of disasters' social behavioral dynamics using computer methodologies. The CSSD provides new theoretical grounds to investigate the complexities and the interacting processes involving traditional social sciences of disasters, computational social science, and crisis informatics. However, there is still a challenge in the collection and handling of human subject data (Burger *et al.*, 2019). Hawe et al. revealed that Agent-based simulations (ABS) have become the de-facto technique for determining the best way to respond to a large-scale emergency. The ABS can be employed for either preparedness or real-time response. This simulation reflects four perspectives: usage, environment implementation, agent implementation, and scalability (Hawe *et al.*, 2012). An experimental model has also been developed using the AnyLogic simulation tool, which offers a novel approach for simulating the evacuation of complex environments (Liu *et al.*, 2022). Avdeeva et al. conducted a simulation of the evacuation process at various economic facilities. The study computed the average evacuation time for each individual and the overall exit time, as well as the intensity of people's flow at the buildings' entry and exit points (Avdeeva, Uzun and Borodkina, 2020). Previous research has also adopted modeling with AnyLogic in a variety of cases, including the evaluation and optimization of pedestrian evacuation in high-density urban areas (Zuo *et al.*, 2021) and microscopic simulation-based pedestrian decision-making models in urban rail stations (Liu and Chen, 2021).

4.3 Material and Methods

4.3.1 Study area

Mount Merapi is on the Indonesian island of Java. This volcano serves as the administrative border between the Central Java Province (Boyolali, Klaten, and Magelang Regencies) and Yogyakarta Special Province (Sleman Regency). In the event of a Merapi eruption, four regencies would be affected. The government divides the danger zones

(Kawasan Rawan Bencana, or KRB) into three levels: KRB III is high-risk, and KRB I is low risk. Hazard zone III is close to the danger source and is regularly impacted by pyroclastic flows (maximum range of 8 km with a VEI of 1–3), lava flows, rock falls, ejected rock fragments, and severe ashfall. Hazard zone II is potentially affected by pyroclastic flows (a range of over 17 km with a VEI of 3–4), lava flows, ejected material, ash falls, and volcanic bombs. Hazard zone I may be affected by lava/floods, as well as the expansion of pyroclastic and lava flows (Sayudi, DS, Nurnaning A, Juliani Dj, Muzani, 2010; Purnomo and Sunartono, 2011).

In the 1994 eruption, a lava dome grew on the south bank, and pyroclastic flows entered the Boyong and Bedog Rivers (Abdurrachman, 1998; Abdurachman, Bourdier and Voight, 2000). Another explosive eruption occurred in 2010, and pyroclastic flows were dominant in the south and southeast (Sayudi, DS, Nurnaning A, Juliani Dj, Muzani, 2010). In 2021, the Geological Disaster Technology Research and Development Center reported that the potential hazards in the south-southwest sector reached a maximum of 3 km to the Woro River and 5 km to the Gendol, Kuning, Boyong, Bedog, Krasak, Bebeng, and Putih Rivers (Geological Disaster Technology Research and Development Center, 2021). The government also determined 12 villages within a radius of 5 km in four affected regencies to evacuate as the situation reached Level 3 status in 2020 (Center for Volcanology and Geological Hazard Mitigation, 2020). Therefore, the current study focuses only on hazard zone III, within a radius of 5–6 km from the peak of Merapi, and the evacuation process for alert Level 3 in rural areas in the Sleman and Klaten Regencies. The simulation covers 6 villages and 14 hamlets in both regencies. The hazard zone map is depicted in Figure 4.1.

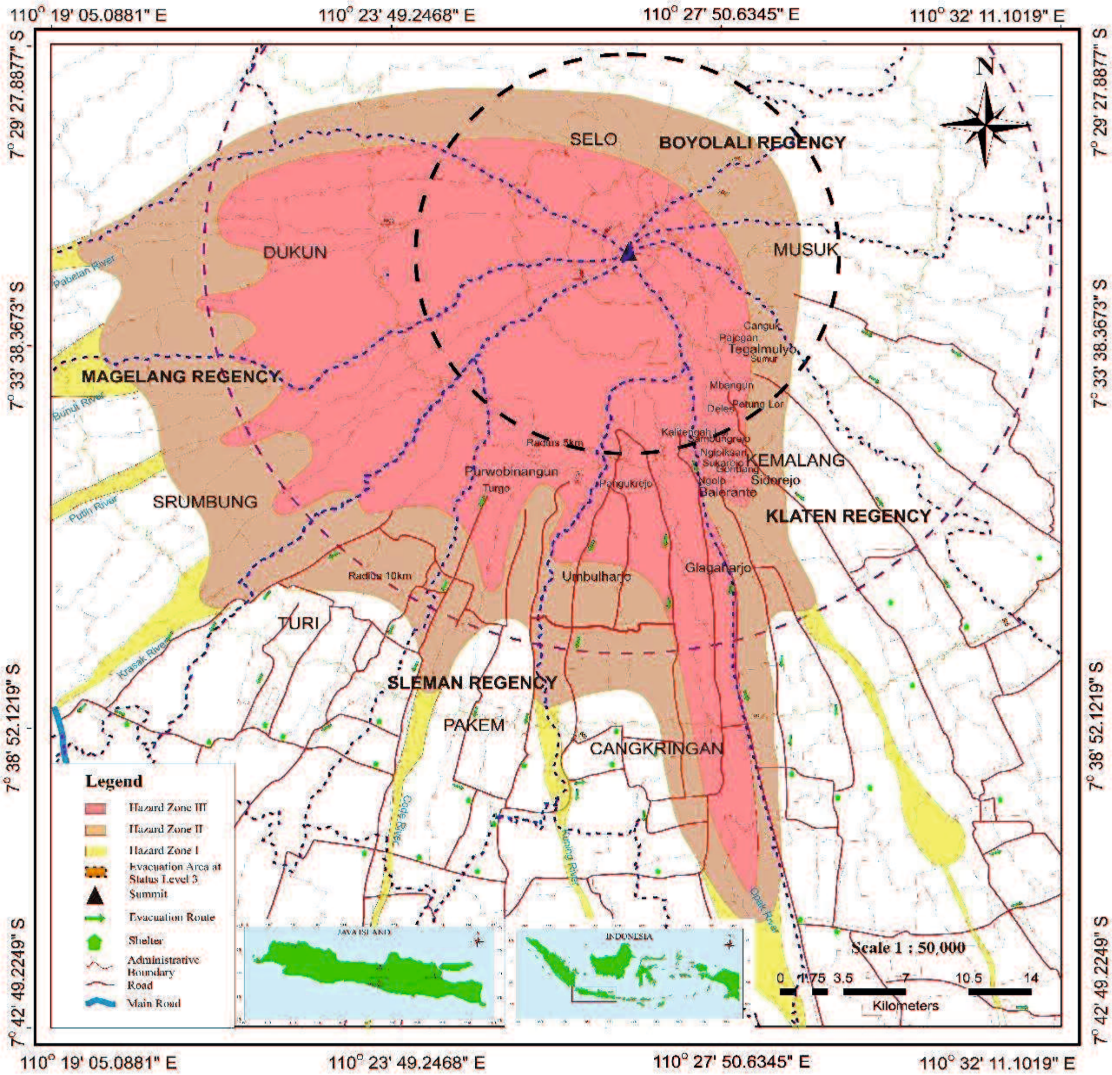

Figure 4.1 Map of Merapi volcano hazard zone (KRB I, II, III) and evacuation area at Level 3 within a radius of 5–6 km in Klaten and Sleman Regencies. The inset maps show the location of Mount Merapi on Java Island and in Indonesia.

4.3.2 Methodological approaches

We used an agent-based technique to model volcano evacuation flows. An actual walking speed was assessed in the first stage to determine people's behavior regarding various emergency speeds. Second, interviews and group discussions were conducted to explore the most recent regulations, crucial issues, and community characteristics. The implementation details of both research stages can be found in (Chasanah and Sakakibara, 2021). The final step was an agent-based evacuation model simulation, which is a testing approach for the people interaction of mutual assistance strategy. Several scenarios and models were developed to find the best evacuation for vulnerable people. Figure 4.2 presents an overview of the study's framework.

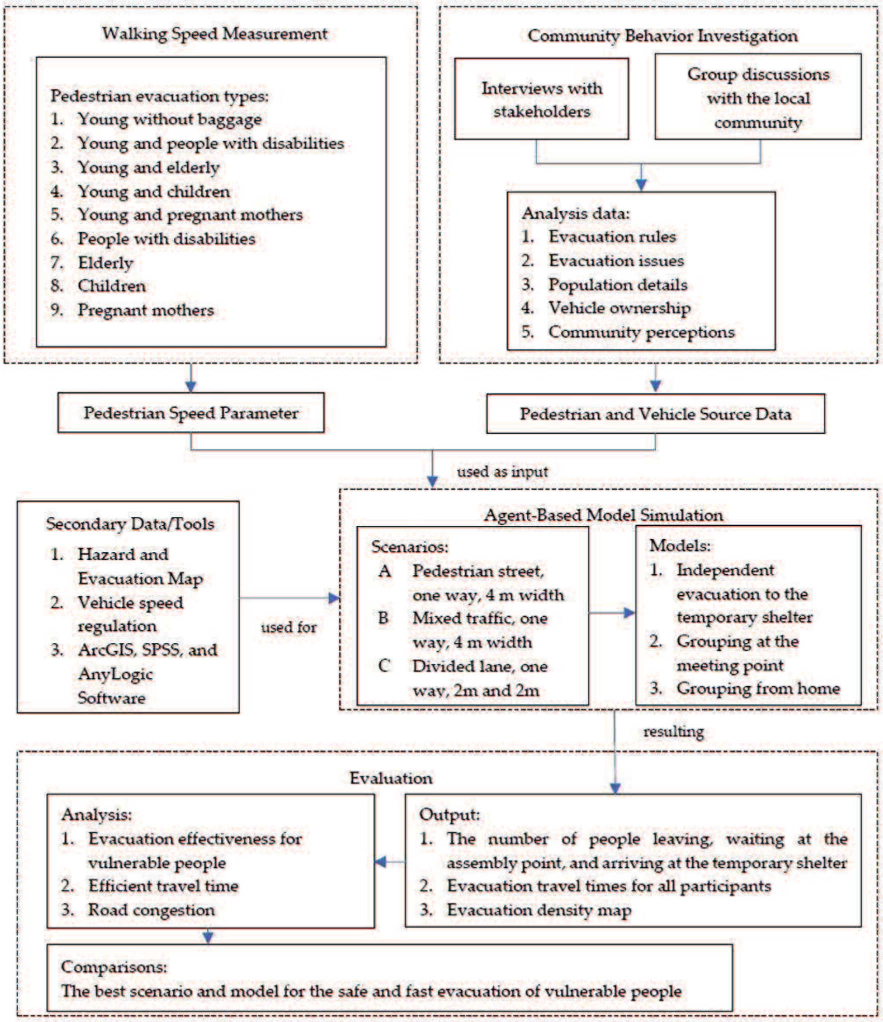

Figure 4.2 Research framework, including four methods that involve measuring walking speed, surveying stakeholders and the local community, the simulation model, and an evaluation.

4.3.3 Data used for simulation parameters

There are two essential parameters in this model development. They are the speed parameter and data distribution of vehicle ownership and pedestrian. The first step is walking speed measurement. Speed is a fundamental measure of traffic performance, and mean travel speed is used as a measure of effectiveness for arterials, rural highways, and more extensive facility assessments (Transportation Research Board, 2000). In this study, walking speed was measured manually. Travel time and speed studies have used the methods described in (Roess, Prassas and McShane, 2011) and (Wiley, 2016). Collaboration with the affected village office was arranged to organize pedestrian volunteers. The pedestrians were asked to walk the evacuation route, which was recorded by the observer. Measurements were taken individually and in groups of young and vulnerable individuals. The details of conducting the survey and data results are described in Chapter III.

The model involved nine types of agents or pedestrians, and the pedestrian evacuation included groups of young people, children, the elderly, individuals with disabilities, pregnant mothers, and mutual assistance groups. The children were aged 5 to 11 years, the young were aged 12 to 59 years, and the elderly were those aged 60 years or older (World Health Organization, 2022). The results showed a significant difference in walking speed between the vulnerable and mutual assistance groups. The speed values are fully explained in (Chasanah and Sakakibara, 2021). Subsequently, the actual walking speed was entered into the simulation model as a pedestrian agent parameter. Vehicle speed was not directly measured; instead, we set a vehicle speed of 30 km/h as a behavioral parameter and applied it to all vehicle types. This decision was based on the speed limit in rural areas of Indonesia (Ministry of Transportation, 2015).

The second stage is community behavior investigation. Data were collected using a purposive sampling approach. This method is commonly used in qualitative research to identify and select information-rich instances connected to the phenomena of interest (Palinkas *et al.*, 2015). The method can also be applied using both qualitative and quantitative research techniques (Tongco, 2007). Interviews with stakeholders and focus group discussions with local communities were conducted in the study area (see Chapter III), and the contingency plans of the BPBD and village offices for both regencies were examined. Information about the affected population, evacuation map and shelter, evacuation transport scenarios, and other details are comprehensively described in (Glagaharjo Village Authority, 2019; Purwobinangun Village Authority, 2019; Sleman Regional Disaster Management Agency, 2019; Tegalmulyo Village Authority, 2019; Umbulharjo Village Authority, 2019; Center for Volcanology and Geological Hazard Mitigation, 2020). Policymakers also confirmed the latest regulations on disaster management, issues and obstacles, and future challenges. These key informants included the secretary and staff of the Klaten District Disaster Management Agency, the head of the Search and Rescue Sector in Klaten Regency, the head of the Quick Reaction Team, the head of the Early Warning System of the Sleman District Disaster Management

Agency, the head of the Search and Rescue for Community Protection in Kaliurang, and all the village heads in the affected area.

The results of the group discussions confirmed that 83% of residents would evacuate directly to the meeting point when working, 100% would evacuate soon when raining, 100% of people would evacuate even if it were at night, 100% would evacuate immediately in an alert status scenario, and 100% already knew the shelter destination. These results indicate that the possibility of a long evacuation delay is low. The community's perspective was that it would not refuse to evacuate or adhere to the rules of the government's contingency plan. Therefore, the assumption that everyone would evacuate within one hour of the Level 3 alert status was used in this simulation. The total population and vehicle ownership data are available in (Glagaharjo Village Authority, 2019; Purwobinangun Village Authority, 2019; Sleman Regional Disaster Management Agency, 2019; Tegalmulyo Village Authority, 2019; Umbulharjo Village Authority, 2019; Center for Volcanology and Geological Hazard Mitigation, 2020) and conceptual of the community population available in Chapter III. In this simulation, only one young person drove a vehicle; therefore, the pedestrian population distribution could be estimated. Table 4.1 presents the quantity comparison between young individuals driving, young pedestrians, and vulnerable pedestrians. Overall, these data comprised the sources for pedestrian and vehicle agents.

Table 4.1 Evacuation distance and distribution of evacuees.

Villages	Hamlets	Width (m)	Distance (km)	Young people with vehicle	Young pedestrians	Vulnerable pedestrians	Total population
Klaten Regency							
Tegalmulyo	Canguk	4	2	44	22	18	84
	Pajegan	4	2	20	14	15	49
	Sumur	4	1.5	55	29	8	92
	Total			119	65	41	225
Balerante	Sambungrejo	4	4.7	42	38	38	118
	Ngipiksari	4	4	45	34	34	113
	Sukarejo	4	3.7	23	22	22	67
	Gondang	4	3.4	90	30	30	150
	Ngelo	4	3.6	16	5	5	26
	Total			216	129	129	474
Siderejo	Mbangan	4	2.5	44	21	10	75
	Deles	4	2.4	63	30	22	115
	Petung Lor	4	2.7	73	46	29	148
	Total			180	97	61	338
Sleman Regency							
Umbulharjo	Pangukrejo	4	1.5	268	247	247	762
Glagaharjo	Kalitengah Lor	4	0.5	158	216	175	549
Purwobinangun	Turgo	4	1.2	122	185	185	492

4.3.4 Agent-based evacuation model

4.3.4.1 AnyLogic simulation principle

Agent-based modeling is a computational method for modeling complex system dynamics (Taylor, 2014) that enables researchers to create, analyze, and test models composed of agents that interact within an environment (Gilbert, 2008). In this study, we used the AnyLogic simulation to build a model because it allows the observation of system behavior over time at any level of detail, provides for increased accuracy and more precise forecasting, and can be animated in 2D/3D so that it can be more easily verified. The AnyLogic software package is a powerful platform that has a developed pedestrian library and many methods to collect the statistical results of a simulation so that it is easy to implement the agent approach completely (Avdeeva, Uzun and Borodkina, 2020). The process modeling and pedestrian and road traffic libraries were used in this study's experiment. Further, a traffic simulation interaction between vehicles and pedestrians was developed using this model (Karaaslan *et al.*, 2018). The process design of the AnyLogic simulation is shown in Figure 4.3.

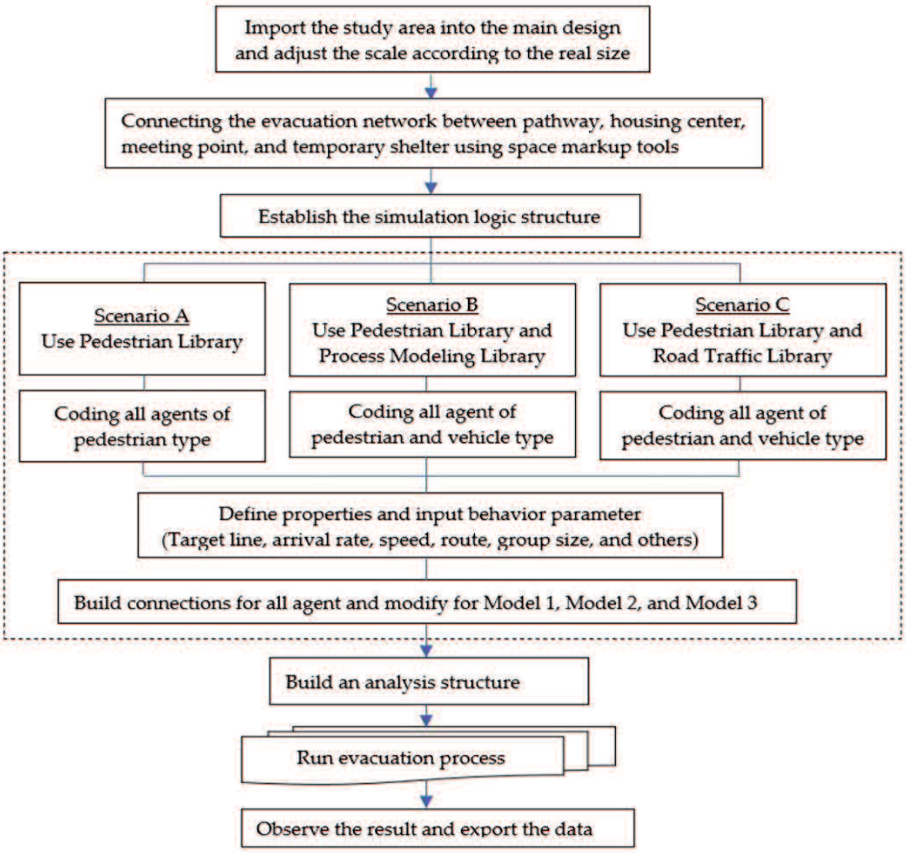

Figure 4.3 AnyLogic software simulation design of Merapi evacuation.

4.3.4.2 Evacuation route model

In this study, we focus on microscopic simulations in which the details of group interactions and behavior of agents can be observed clearly, and the number of people successfully evacuated can be obtained. Therefore, macroscopic simulations using the road network zone were not applied. The simulation uses a scalable pathway animation with actual distance addressed to create an evacuation route. The visualization results do not display location details graphically, but the location and distance of the route segment observed can be known by using the movable camera tools on the software. The evacuation route distance was created by importing a GIS map to AnyLogic software and converting them into pathway designs based on the real condition of each of the village evacuation maps. The scale was defined graphically with a ruler length corresponding to 5 m (1 m = 10 pixels). A space markup was selected and connected to create a comprehensive route. The target line and rectangular node were used to draw the housing center, assembly point, and temporary shelter. All points were coordinated according to the actual conditions. In this case, the intersection was set as an assembly point before evacuees moved to a temporary shelter. To calculate the evacuation distance shown in Table 4.1, we also used the Google Maps distance matrix application programming interface to confirm the distance.

4.3.4.3 Logic structure model

Blocks elected and connected in a certain sequence create an algorithm or scheme for people's behavior when various events occur (Jumadi, Carver and Quincey, 2019). We developed three scenarios using the three models applied in each scenario. Scenario A involved the population walking in the pedestrian evacuation lane. Scenario B involved pedestrians and vehicles moving in the same lane. Scenario C involved pedestrians and vehicles moving in different lanes. In the design of software, the difference in scenarios A, B, and C lies in the road design and logic structure. First, the road design is different because each scenario has a variant agent distribution and lane width. Scenario A only involves pedestrians, so it uses a Pedestrian Library to select a Pathway in Space Markup with 4 m of width. Scenario B involves pedestrians and vehicles with mixed traffic at a width of 4 m, which uses a Pathway in the Pedestrian Library and a Path in the Process Modeling Library. Scenario C chooses a Pathway in the Pedestrian Library and a Road in the Road Traffic Library with a width of 2 m each. Second, there are differences in the logic structure in Blocks selection. Scenario A uses Ped Source, scenario B uses Ped Source and Source, and scenario C uses Ped Source and Car Source. The input data in this logic structure must be connected to the road design tools.

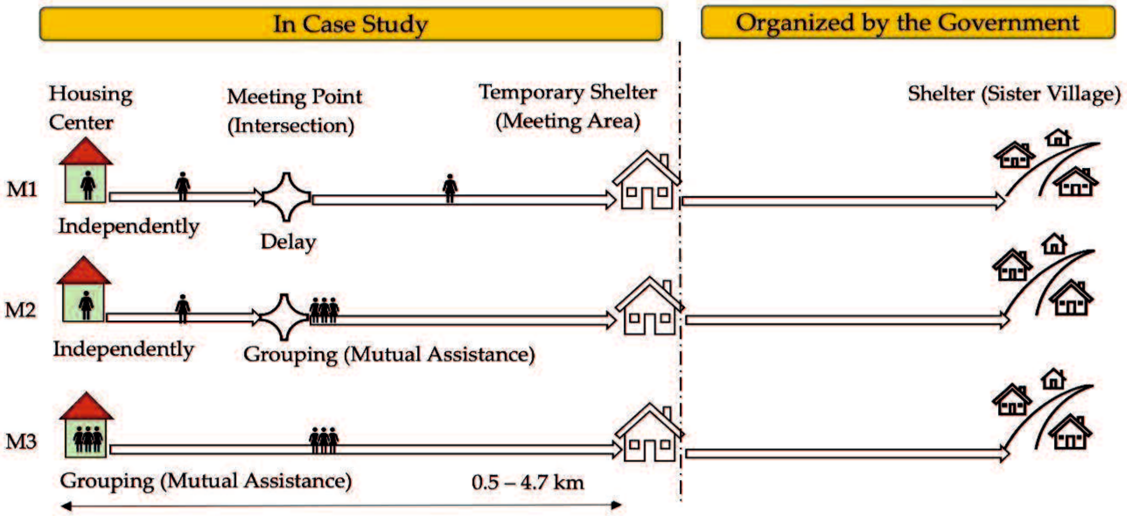

Figure 4.4 Three evacuation models: In M1, all residents evacuate independently; in M2, some young and vulnerable evacuees assemble at the meeting point; in M3, evacuees' group at their homes.

Table 4.2 Detailed shelter locations.

Village	Hamlets	Meeting point	Temporary shelter	Shelter/ Sister village
Klaten Regency				
Tegalmulyo	Canguk	Intersection	Tegalmulyo Village Office	Demak Ijo Village
	Pajegan	Intersection	Tegalmulyo Village Office	Demak Ijo Village
	Sumur	Intersection	Tegalmulyo Village Office	Demak Ijo Village
Balerante	Sambungrejo	Intersection	Balerante Village Office	Kebondalem Lor Village
	Ngipiksari	Intersection	Balerante Village Office	Kebondalem Lor Village
	Sukarejo	Intersection	Balerante Village Office	Kebondalem Lor Village
	Gondang	Intersection	Balerante Village Office	Kebondalem Lor Village
	Ngelo	Intersection	Balerante Village Office	Kebondalem Lor Village
Siderejo	Mbangan	Intersection	Sidorejo Village Office	Menden Village
	Deles	Intersection	Sidorejo Village Office	Menden Village
	Petung Lor	Intersection	Sidorejo Village Office	Menden Village
Sleman Regency				
Umbulharjo	Pangukrejo	Intersection	Merapi Garden Cangkringan	Plosokerep Barrack, Umbulharjo
Glagaharjo	Kalitengah Lor	Intersection	Security Post, Kalitengah Lor	Gayam Barrack, Argomulyo
Purwobinangun	Turgo	Intersection	Tritis Field, Turgo	Purwobinangun Barrack,Watuadeg

Currently, M1 is the approach to the latest evacuation scenario adopted by the local government. M2 and M3 were model developments. In M1, a two-minute delay was designed to allow for possible discussion with other people using Ped Wait agent of Blocks. The specific M2 behavior involved coordination and grouping events at the meeting points. Ped Group Assemble and Ped Enter were used to arrange a group size of two people and the mutual assistance group speed. M3 involved a group formation of two to three people to assist children and the elderly and two people per group to assist individuals with disabilities and pregnant mothers. The important parameters in Ped Source and Car Source are arrival rate, speed, and group size. We defined the arrival rate of the agent as the average number of people or vehicles leaving their homes to evacuate. The departure rate distribution of people and vehicles is very complex and differs for each model. A matrix should be created for all models and scenarios in all villages. The type of agent must be made according to the categories of young, the elderly, disabled, children, pregnant mothers, cars, trucks, and motorcycles with their respective speeds as agent parameters. Overall, the difference in the model is only in the logic structure. M1 and M3 have simple structures. M3 does not use the assembled group tool, but the number of people in a group is defined in the group size on Ped Source. The total input arrival rate is listed in Table 4.1. An example logic chart for scenario CM2 is shown in Figure 4.5.

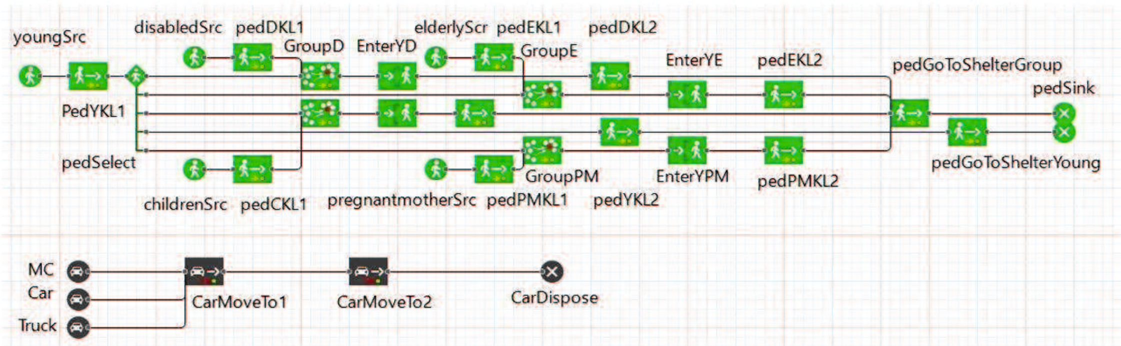

Figure 4.5 A logic scheme for M2 in Kalitengah Lor. The green chart indicates pedestrian flow, and the black chart indicates vehicle flow. Group D, Group E, Group C, and Group PM are assembled between young people and vulnerable people.

4.3.4.4 Analysis structure model

Data sets and time plots were applied to compute the evacuation travel time for successfully evacuated people. The code was executed when a pedestrian or vehicle entered a block in a temporary shelter. This function was crucial for connecting the total agent to the dataset. The dataset, scale, and time axis were also arranged on a time plot. AnyLogic enables the collection of statistics on the density of moving units in the simulated space and displays this information in animated form as a density map. The density map on the space markup is commonly used to detect critical density areas. At the model runtime, if the density values of the area are equal to or greater than the critical density, then the red color appears: The color changes logarithmically from the "minimum" (blue) color to the "maximum" (red) color. The critical density value was 1.5 units/m2; the units were either pedestrians or transporters.

4.4 Results

4.4.1 Simulation performance

Running AnyLogic provided details of the number of people in each block, along with the evacuation flow. People's movements of leaving home, staying on the road, and arriving at the temporary shelter were displayed. There were 54 simulated models, covering six villages in both regencies. Each village tested nine models, from AM1 to CM3. A visualization of the mutual assistance model is shown in Figure 4.6. The numbers in the block structure show the people number at a specific location during the evacuation process. The input block number is people arriving in the given area, the output block number is people leaving the given area, and the top block number is people waiting or moving within the given area. The input and output block value at the temporary shelter represents the number of successfully evacuated people. The animation at a random point in time for the 2D and 3D images is shown in Figure 4.7 and confirmed that grouping was formed after the matching process at the meeting point in M2. The movement of mutual assistance is also shown from the start of departure in the M3 animation. Overall, the basic performance results for this simulation are the number of people reaching the temporary shelter so that the effectiveness of a model can be interpreted. The position and number of people moved and delayed on the road can also be identified with this logical structure. Detailed results of scenarios A, B, and C are shown in Section 4.4.2 and Appendix A.

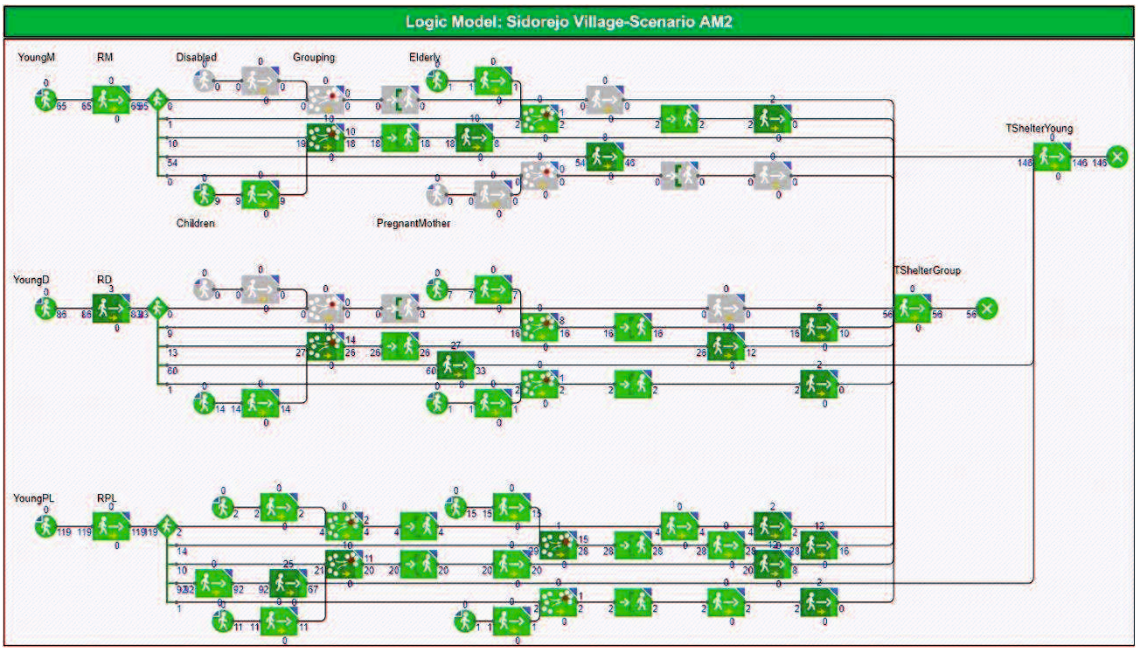

Figure 4.6 Mutual assistance model visualization of Scenario A in Sidorejo village with code AM2. The result shows the young and vulnerable people form a pedestrian group at the meeting point. In Petung Lor (PL) children meeting point case, 21 people arrive at the meeting point consisting of 11 children and 10 young people, 1 child waits for the matching, and 20 people left. Finally, 56 people arrived by groups comprising 28 young and 28 vulnerable individuals, and 146 young people reach the temporary shelter.

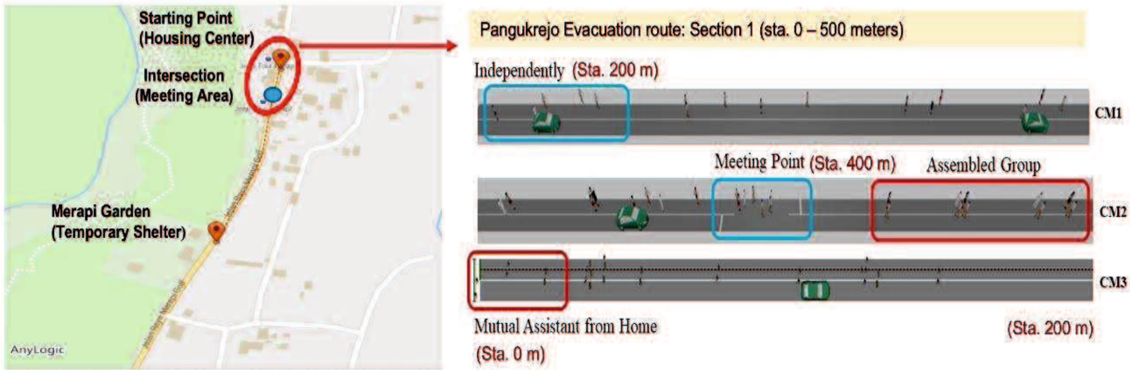

Figure 4.7 Animated model of Scenario C in Umbulharjo (Pangukrejo). CM1 illustrates self-evacuation in Model 1. CM2 shows Model 2 in 3D, with the young and vulnerable coordinating at the intersection and traveling in pairs. CM3 shows Model 3 in 2D, with the group that forms at homes.

4.4.2 Effectiveness of the assembly model and the traffic phenomenon

4.4.2.1 Effect of mutual assistance on pedestrian evacuation

We found that the assembly model is an effective strategy to support the evacuation of vulnerable people. Scenario A was adopted to identify the differences in the results of the three models and evaluate their impact on evacuation. The recapitulation of the experiment output is presented in Table 4.3. The results showed that the mutual assistance approach in M2 and M3 was more effective than in M1, which represents the real condition. The percentage increase of successfully evacuated vulnerable people in M3 was the highest for all areas except Balerante village, where M2 has an improvement of 13.95% while M3 is only 1.55%. This result is possibly due to differences in regional characteristics such as achievable walking speed, population distribution between young and vulnerable evacuees, and evacuation distances since Balerante has the farthest evacuation distance compared to the other villages. Overall, a mutual assistance model is advantageous to vulnerable people during volcano evacuation. However, this idea potentially reduces the number of young people arriving at temporary shelters. Despite the decline in young people, the total of individuals arriving increased, which this model can be categorized as a good evacuation. For example, in the Purwobinangun village, the number of young people successfully evacuated in M1 (229 people) was higher than in

M2 (214 people) and M3 (195 people). On the other hand, the total of the community reached the destination was greater in M2 (334 people) and M3 (344 people) than in M1 (329 people).

Table 4.3 Simulation results in Scenario A.

Area	Model	Population numbers arriving at temporary shelter (people/h)			Percentage increase in arrivals of vulnerable people (%)
		Young	Vulnerable	Total	
Klaten Regency					
Tegalmulyo (Canguk, Pajekan, Sumur)	M1	132	22	154	
	M2	154	24	178	4.88
	M3	144	29	173	17.07
Balerante (Sambungrejo, Ngipiksari, Ngelo, Gondang, Sukarejo)	M1	98	8	106	
	M2	84	26	110	13.95
	M3	80	10	90	1.55
Sidorejo (Mbangan, Ndeles, Petung Lor)	M1	159	26	185	
	M2	174	28	202	3.28
	M3	162	33	195	11.48
Sleman Regency					
Umbulharjo (Pangukrejo)	M1	178	53	231	
	M2	299	119	418	26.72
	M3	266	122	388	27.94
Glagaharjo (Kalitengah Lor)	M1	332	133	465	
	M2	343	160	503	15.43
	M3	314	168	482	20.00
Purwobinangun (Turgo)	M1	229	100	329	
	M2	214	120	334	10.81
	M3	195	149	344	26.49

4.4.2.2 Effect on traffic phenomenon

Traffic on rural roads consists of a mix of vehicles and pedestrians. Scenarios B and C included more accurate representations of the actual scenario on a roadway. Simulation results of Scenario B and Scenario C are shown in Appendix A. The movement behavior of each agent is not considered in the simulation. All agents move in a straight line with constant speed. Agent interaction only happens between young and vulnerable people at the meeting point for M2 and at home for M3. This causes no significantly different agent behavior between B and C. In scenario B, the combination of the library makes it difficult to control the interaction between pedestrians and vehicles. It leads to a potential for conflict (overlap) between pedestrians and vehicles due to differences in agent types that cannot connect. While in scenario C, there is no conflict because pedestrians and vehicles have their own lanes. Vehicles also have no overlap because motorcycles, cars, and trucks have the same speed and depart at different times.

Figure 4.8 illustrates the comparison results for the two regencies. The bar chart (P) shows a population of vulnerable people evacuation. The line chart (M1, M2, M3) indicates the number of vulnerable people successfully evacuated. In the case of Sidorejo village (B-sdr and C-Sdr) with a total of 61 vulnerable people, M3 has the greatest score for vulnerable persons' success, with 35 people in scenario B and 33 in scenario C. Overall, M3 ranked highest in the Klaten Regency for the arrival of vulnerable communities. The exception was in Balerante village, where M2 was most successful, with a score of 16 people in Scenario B and 11 people in Scenario C. The small number of young people in this village may lead to delays in departure for vulnerable people if assembled from home. Because the evacuation distance is also long, the duration of interarrival time for everyone at the temporary shelter is affected, making M3 ineffective. In Sleman Regency, M3 was effective in all areas. This phenomenon is indicated by the M3 line having the highest position among the others.

In Figure 4.8, the impact on vulnerable people can be identified. When the models are compared, M2 and M3 (mutual assistance) are better and more effective than M1 (existing contingency). M3 is the highest rank for vulnerable people successful in all scenarios. In comparison scenarios, B and C (using a vehicle) are more effective than A (all pedestrians). The impact of scenario C is a significant increase in the number of vulnerable people for Model 3. The impact of scenario B is a significant increase in the number of vulnerable people for Model 2. Overall, the best result is scenario CM3.

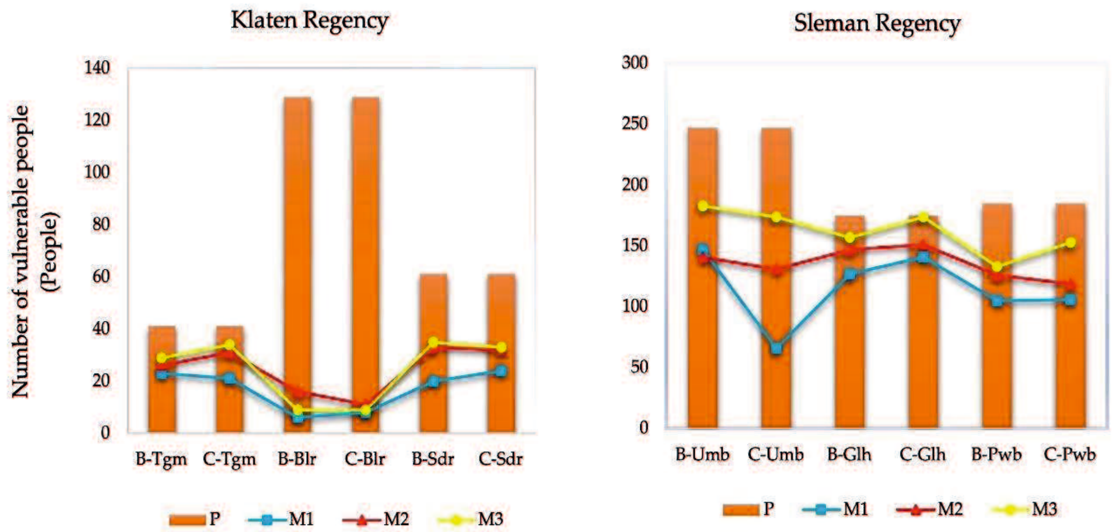

Figure 4.8 Simulation results in Scenario B and C for Klaten and Sleman regencies. The results show that not all of them were successful in evacuating for one hour. M3 ranks highest for the number of vulnerable people arriving in all locations except for Balerante, where the highest score was observed with M2. The best result is scenario CM3.

Based on Appendix A, the impact on total population can be calculated. scenario B has implications for increasing the total population for M2. Scenario C has implications for increasing the total population for M3. It means when choosing implementation M2 then B is the best and if choosing implementation M3 then C is the best. Overall, CM3 is recommended for the success of vulnerable people and the total population.

4.4.3 Evacuation time analysis

Figure 4.9 shows the distributions of arrivals of agents in scenario C at Tegalmulyo village. The arrival time of each person during the one-hour experiment was obtained. The green, blue, and red lines represent the arrivals of the young people using vehicles, walking young people, and vulnerable people/groups of young and vulnerable people, respectively. In all Models, the young people using vehicles arrive first. The best evacuation time is interpreted by the short interarrival time and a large number of successfully evacuated people. Interarrival time is the interval between arrivals of each person according to the type of agent. The intervals of arrivals tend to be shorter in M3 than that in M1 and M2, which means that the group of vulnerable and young people tend to arrive at a similar time. M3 has the possibility of securing the equality of evacuation of vulnerable people. The graph in Figure 4.9 illustrates the case of Scenario C in Tegalmulyo. The arrival time sequence of four vulnerable people randomly at the last time of the simulation for M1, M2, and M3 was 52–58 min (3 min of gap), 54–57 min (1 min of gap), and 56–58 min (seconds of gap), respectively, indicating that the pedestrian interarrival time in M3 was relatively short. In this AnyLogic simulation properties, there is an exponential function for the interarrival time of group members, affecting a few seconds gap between vulnerable and young people in group arrivals. This condition leads the arrival time for everyone to be different, and the graph is relatively flat. Overall, the assembly models were more efficient in terms of the interarrival time and numbers of people arriving.

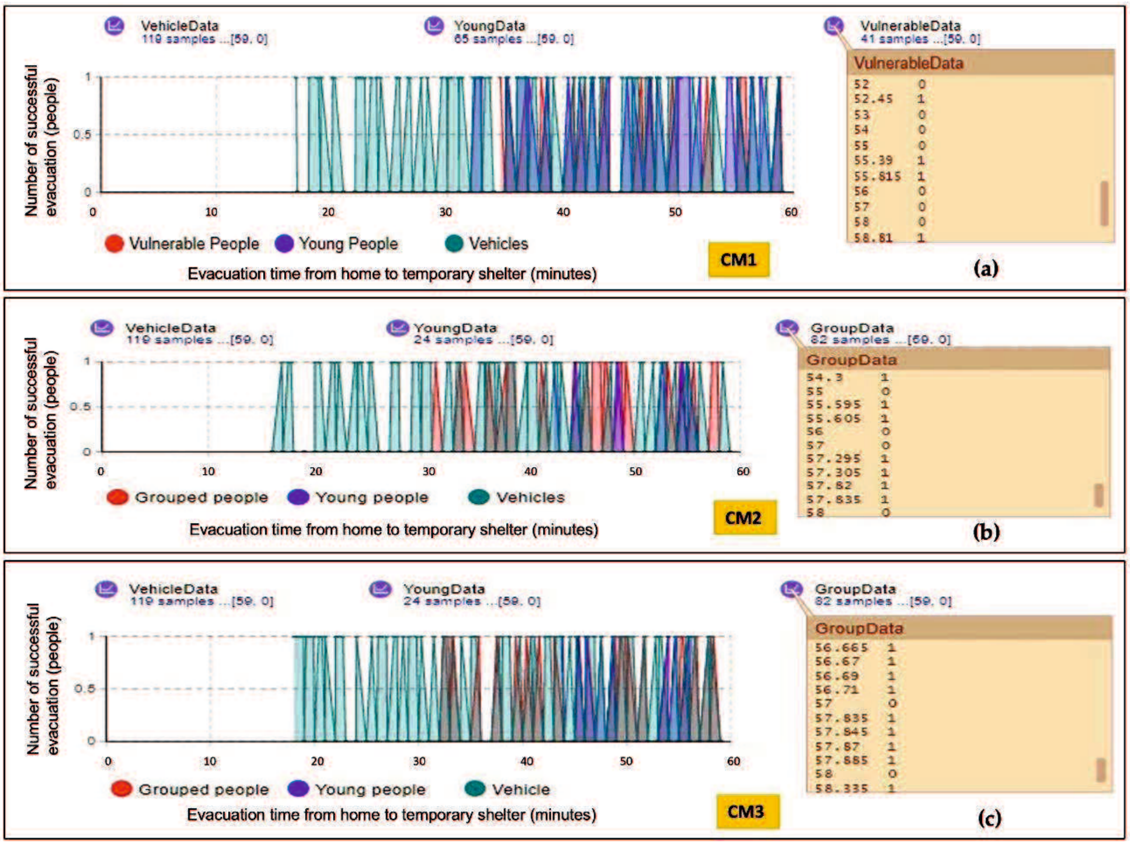

Figure 4.9 The people's arrival time distribution in the temporary shelter at the last minute of the simulation in the case of Scenario C in Tegalmulyo village. All population left to evacuate with a distribution of 119 young people using vehicles, 24 young people self-evacuate, and 82 young and vulnerable evacuate together. The vertical axis shows the arrivals number and the horizontal axis represent the interarrival time of each person in seconds. The green line is the vehicle arrival time flow, the blue line shows the arrival time of young people, and the red line describes vulnerable people's arrival in independently or grouping. Panel (a) presents the results of M1 with approximately 3 min of interarrival time and 58.81 min for the last vulnerable person to arrive. Panel (b) displays the results of M2 with an interarrival time of 1 min (57.83 min of the last person). Panel (c) presents the results of M3 with an interarrival time in sec (58.33 min of the last person). Overall, M3 had the best evacuation time for vulnerable people based on the interval between arrivals and total arrivals.

4.4.4 Density map evaluation

Next, the density of the evacuation process was examined. Most impacted regions do not experience road congestion because the number of vehicles in rural areas is limited to local inhabitants. Traffic delays only appeared around the intersection and assembly point. Glagaharjo village had the highest density map. This congestion was caused by the short evacuation distance of 500 m and the large population of 549 people. Figure 4.10 depicts the density map of this village and illustrates that M3 was verified to be more crowded than M1 and M2. All segments from the housing center to the meeting point, to the temporary shelter, were red, indicating that there was a critical density of more than 1.5 pedestrians per m^2 of road area.

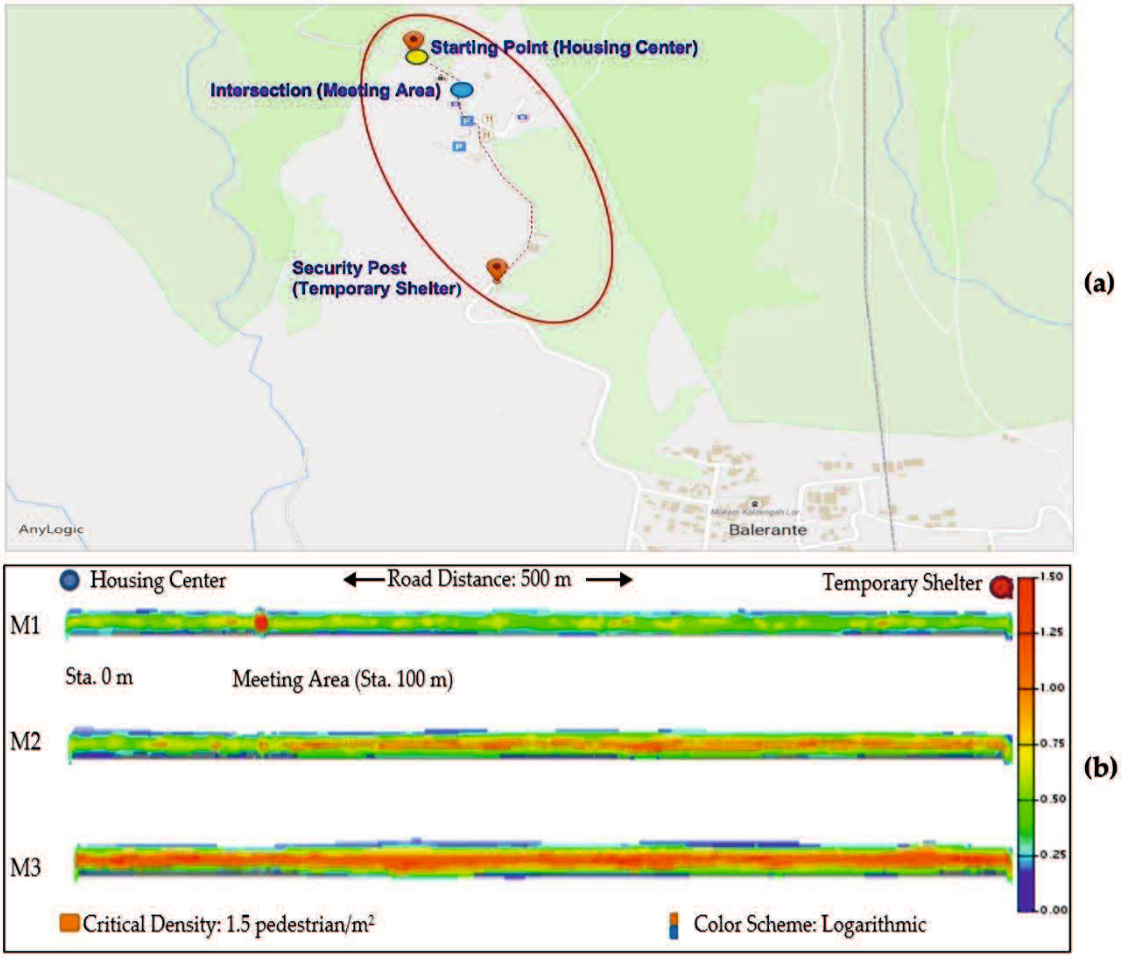

Figure 4.10 Density map of Scenario C in Glagaharjo. Panel (a) present the evacuation route according to the GIS map in AnyLogic. Panel (b) shows that M3 leads to more congestion than the other models. Evacuees walking in pairs from their homes to the temporary shelter increases road density.

4.4.5 Validation of the results

Replicative validity was used to verify this model (Hawe *et al.*, 2012), which requires that the simulation output match the actual data. The retrodiction approach was used as a validation tool (Troitzsch, 2004); thus, the model was tested using historical data. The current data were loaded into evacuation maps and hazard zones (Sayudi, DS, Nurnaning A, Juliani Dj, Muzani, 2010; Glagaharjo Village Authority, 2019; Purwobinangun Village Authority, 2019; Sidorejo Village Authority, 2019; Tegalmulyo Village Authority, 2019, 2020; Umbulharjo Village Authority, 2019; Balerante Village Authority, 2020). The average walking speed parameter was directly assessed (Section 4.3.3), and the maximum and minimum walking speed ranges were calibrated in the model at a comfortable speed. Meanwhile, the average speed and size of the vehicles were provided by the rules (Ministry of Transportation, 2015; Ministry of Public Works and Housing, 2020). The model was designed in real-time with a scale of 1 and a 60-min stop time. A trial was conducted on the variation of the time model, and the results showed a linear correlation. In replicative validation, we use three analyses to ensure a match between model output and real data. First, in the model, the number of agents leaving for evacuation must be equal to the actual population. The model's population function was departure (in) = on (the way) + out (arrival). The departure input was the average of the real population; therefore, it has an impact on the simulation outcomes, which may be lower or higher. SPSS software was used to confirm the data comparison for all regions. The one-way ANOVA test results showed a p-value (sig) > 0.05, indicating that the real and simulated evacuation data had no significant difference at the 5% level. Table 4.4 shows all the scenario results of population validation in reality and in the model. For example, in Scenario AM2 Sidorejo village (Figure 4.6), the difference between the real data and the model departure was 338 versus 331 people, respectively, with a validation percentage of 2% and a p-value (sig) of 0.934 in all regency's analysis. Second, the group sizes in M2 and M3 were consistent with the group design. The animated display demonstrated that there was a grouping of two people between young and vulnerable people at the meeting point and a grouping of two to three people from the agent source. All the scenarios of the model visualization output have been checked and confirmed well-coordinated, Figure 4.7 is one example. Third, the evacuation time was calculated manually (Transportation Research Board, 2010). The real evacuation time approach is obtained by dividing the evacuation distance (m) by the actual walking speed (v m/s). Comparison between real-time and model results showed no significant difference. The one-way ANOVA test results showed a p-value (sig) > 0.05.

Table 4.4 Data comparison between real and model output using a One-Way ANOVA test. The results show that p value (sig) > 0.05 in all scenarios. It indicates that the populations of real and model outputs match.

Scenarios		Sum of Squares	df	Mean Square	F	Sig.
AM1	Between Groups	494.083	1	494.083	0.015	0.904
	Within Groups	323,302.833	10	32,330.283		
	Total	323,796.917	11			
AM2	Between Groups	234.083	1	234.083	0.007	0.934
	Within Groups	328,746.833	10	32,874.683		

Scenarios		Sum of Squares	df	Mean Square	F	Sig.
	Total	328,980.917	11			
AM3	Between Groups	10.083	1	10.083	0.000	0.987
	Within Groups	343,120.167	10	34,312.017		
	Total	343,130.250	11			
BM1	Between Groups	1121.333	1	1121.333	0.034	0.857
	Within Groups	325,729.333	10	32,572.933		
	Total	326,850.667	11			
BM2	Between Groups	720.750	1	720.750	0.021	0.887
	Within Groups	341,238.167	10	34,123.817		
	Total	341,958.917	11			
BM3	Between Groups	456.333	1	456.333	0.012	0.915
	Within Groups	378,832.667	10	37,883.267		
	Total	379,289.000	11			
CM1	Between Groups	588.000	1	588.000	0.017	0.898
	Within Groups	338,922.667	10	33,892.267		
	Total	339,510.667	11			
CM2	Between Groups	330.750	1	330.750	0.010	0.923
	Within Groups	333,582.167	10	33,358.217		
	Total	333,912.917	11			
CM3	Between Groups	126.750	1	126.750	0.004	0.953
	Within Groups	339,792.167	10	33,979.217		
	Total	339,918.917	11			

4.5 Discussion and Recommendation

4.5.1 Mutual assistance model for Merapi eruption: a successful evacuation?

The ratio of saved people to fatalities dictates whether an evacuation has succeeded or failed. However, determining evacuation effectiveness is dependent not only on the number of lives saved but also on how individuals act and their vulnerability throughout the evacuation time (Mei *et al.*, 2013). In the existing evacuation contingency for Mount Merapi eruptions, the local government has developed a combination of stages and simultaneous evacuation. However, the government still needs to make a significant effort for the early evacuation step at Level 3 status. Volcano features that must be considered include unpredictable eruption durations since long evacuation periods may lead some people to return home. Moreover, the limited ownership of vehicles and the difficulty of government control present potential risks for vulnerable groups. If a large eruption occurs quickly, inhabitants will be caught off guard, resulting in numerous casualties. A lack of information and hoaxes are also frequent occurrences during emergencies; therefore, a mutual assistance strategy is critical because young people generally receive up-to-date information more quickly and can transfer it to vulnerable people.

This study is the first to consider the government contingency revised in 2019 and focuses on the evacuation of vulnerable groups. The results in all scenarios showed an increase in the number of successfully evacuated vulnerable people when the assembly was modeled. Figure 4.11 compares Scenarios A, B, and C for both regencies. When several young individuals use vehicles in Scenarios B and C, BM1 is the best in increasing the number of young and vulnerable people. When the mutual assistance in Model 2 and Model 3 is introduced, CM3 is the best in increasing the number of the vulnerable group. Mutual assistance affected decreasing number of young people arriving in the temporary shelter with a percentage less than 10%. Figure 4.12 explains in more detail the phenomenon of the decline of young people. The paired sample's T-test result shows that the p-value (0.08) > 0.05. It means the changes are not significantly different (5 % level of significance) and the number of young people is almost the same. Overall, mutual assistance by walking led to changes in the proportions where the vulnerable people rise and young people down. However, the total population success between the existing model and the mutual assistance model is almost the same. The mutual assistance model by walking is effective because of its success implications for vulnerable people and the total population. Both parameters are the concern of this study. Mutual assistance will be more effective if implemented with larger group sizes, shorter evacuation distances, and support with vehicles.

In suggestion, there are several efforts that can be managed by the government in handling the phenomenon of the decline in young people (supporters). The local government needs to provide intensive education for early evacuation. Young people should depart earlier and encourage many vulnerable people to leave and arrive earlier together. The local government also optimizes communication with the supporters. The authority can use a specific application of evacuation on hand phones and direct calls to young people to immediately evacuate and mutual assistance. Consequently, some young people in the group may be late but the disaster and perception risk for them is low.

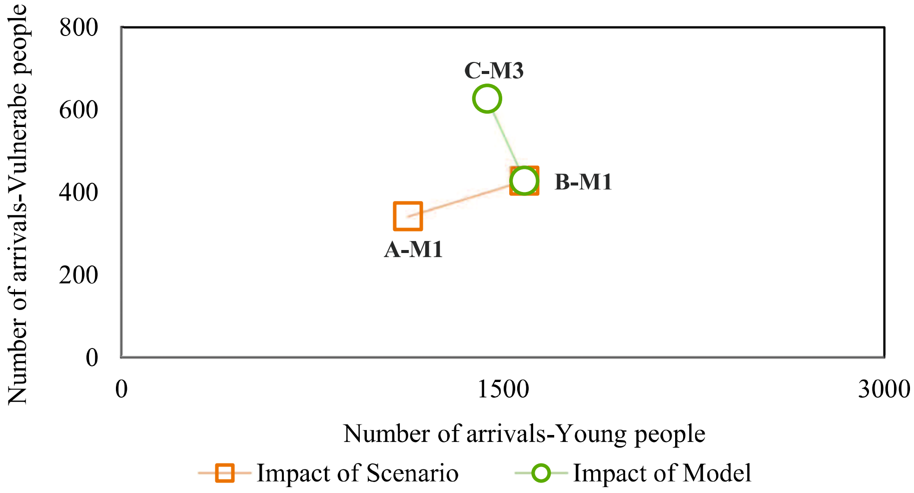

Figure 4.11 Comparison between Scenarios A (all evacuees walk) and B and C (vehicles are used). Scenarios B and C are effective for increasing the successful evacuation rates of young and vulnerable people. M2 and M3 are effective for improving the successful evacuation rates of vulnerable people.

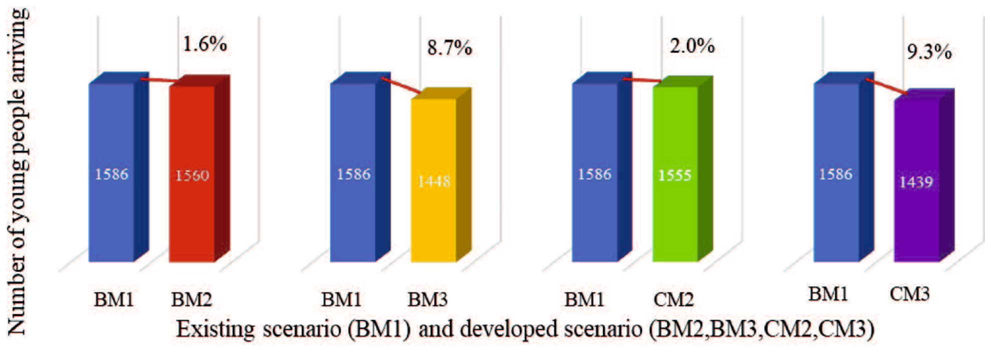

Figure 4.12 Phenomenon of the decreasing arrivals in young people

On the other hand, a comparison scenario results in Figure 4.8 can be identified that M3 is the best model according to the line chart. In Except, the Balerante village had the most successful evacuation in M2. Population distribution and distance may have a strong effect on this result. In Table 4.1, detailed information can be checked. The extremely gap distance between Balerante and other villages concluded M3 is effective for the short evacuation route, and M2 is effective for the long evacuation route. The model presented in this research has significant implications as an effective evacuation strategy for vulnerable people during a volcanic event. The density map in Section 4.4.4 also identifies the congestion propensity of the evacuation network. These data can be applied to improve rural road infrastructure and estimate the impact of traffic on major highways.

4.5.2 Effective mitigation for an aging population

Both developed and developing countries have a significant aging population (World Health Organization, 2022). According to the WHO, Indonesia will have the fifth-highest percentage of older people in the world by 2025 (Hakim, 2020). Evacuating an aging population is very challenging. The results in Section 4.4.2 confirmed that the Sleman Regency can undertake a more successful evacuation of vulnerable people than the Klaten Regency. This phenomenon occurs because the size of the vulnerable groups in Sleman is larger, and the evacuation distance is short. This assembly model has the potential to become a trend in the future.

In Table 4.3, the percentage increase in successful evacuees can be calculated and becomes a parameter of evacuation effectiveness. The total population of vulnerable people was evaluated to determine the correlation between the proportion of vulnerable people and the percentage increase in arrivals. The relationship between these two variables is shown in Figure 4.13, which illustrates that the percentage increase in arrivals will be large if the population of vulnerable people grows. This novel model provides the possibility of future effective and low-cost preparedness and mitigation plans for an aging population. However, if the number of vulnerable people exceeds the number of young people, further studies will be required. Collaboration between the assembly model and the use of vehicles may be more effective. Rahman et al. evaluated transportation alternatives for the aging population, which include owning a self-driving vehicle, using prepaid taxi services, and obtaining rides through community services. The best ratings were given to prepaid taxi services (Rahman *et al.*, 2020). However, research of this type has not yet been undertaken in a disaster emergency context.

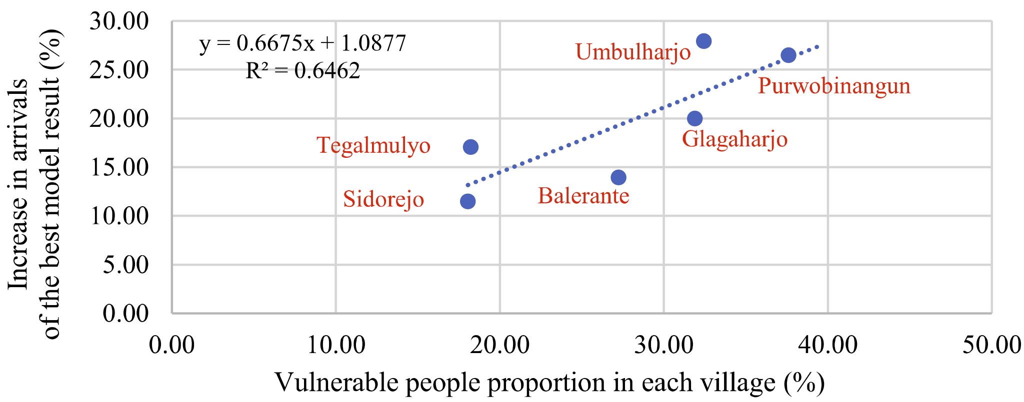

Figure 4.13 Correlation between percentage of vulnerable people and number of arrivals. Increased distribution of vulnerable people leads to more effective mutual assistance models.

4.5.3 Applicability for various natural disasters

Vulnerable people are a priority in the evacuation process; however, evacuation times may vary depending on the disaster type and local authority policies. The U.S. Administration on Aging states that there are plans in place for practically every type of disaster (Benson, 2013) and suggests that older people and their families must develop family communication by appointing a key person to coordinate it. Moreover, identifying a meeting area away from the home is crucial. In the volcano context, the local community's perception has a strong influence on the evacuation decision to stay or leave. Lechner and Rouleau showed that warning messages all had a strong impact on willingness to evacuate in the future eruption at Pacaya volcano, Guatemala. Consequently, the communication factor of evacuation needed to be improved (Lechner and Rouleau, 2019). Niroa and Nakamura confirmed that the local people in Mount Yasur in Vanuatu still believed in a traditional culture and spiritual connection, thus they are difficult to evacuate (Niroa and Nakamura, 2022). In the Mount Semeru volcano eruption in Indonesia, the fatalities found were vulnerable people such as an elderly woman together with her daughter, and a mother carrying her child. Therefore, it is crucial to construct the evacuation model to support the quick evacuation of vulnerable people by young people's assistance. Updated information and educated young people can also persuade vulnerable people who refuse to evacuate. Mutual assistance was the first study modeled for the actual situation in a volcano and proved to be effective for Mount Merapi. This model may be effective for other volcanoes as well. In fact, volcanoes have a similar problem in terms of community risk perception, weak physical conditions of vulnerable people, limited transportation capacity, limited volunteers by the government, and an increasing elderly population.

As above mentioned, the assembly group approach has previously been successful in the evacuation process during the 2011 tsunami in Japan (Alalouf-Hall, 2019). A successful evacuation of vulnerable groups was also completed during the 2018 Japan flood: There were no fatalities since all residents escaped safely in time. The local community disaster prevention organization's registration of vulnerable people in the area is comprehensive: They visited all households and used a multilayered method to monitor all families (Ohtsu *et al.*, 2021). In the context of hurricanes, Bian and Wilmot examined transit pick-up points for vulnerable individuals during storm evacuation, revealing the optimal meeting points and undertaking an efficiency analysis (Bian and Wilmot, 2018). Neighbors and group partners have a direct and strong interconnection in the landslide evacuation process in Mumbai, and the characteristics of social network partners, including their religions, castes, and languages, have a significant influence on evacuation decisions (Subhajyoti and Hirokazu, 2015). Based on previous studies, the grouping evacuation strategy, regular monitoring, and pick-up of vulnerable people by government volunteers have been partially reported in several disasters. However, the success of evacuation covering all categories of vulnerable people has not been fully achieved. Differences in characteristics between natural disasters can be evident from the early warning system, duration of the disaster, size, damage, affected area, and others. There is one significant difference between volcanic eruptions and other crises: in volcano eruptions, the disaster duration and evacuation period tend to be longer. This characteristic may be the factor that the mutual assistance model in this study has shown effectiveness and can be applied to other volcanoes. However, for the earthquakes and other disasters having characteristics of shorter duration and warning systems, further studies are needed. The mutual assistance model could potentially be applied to various types of disasters and in various countries having the similarity with Mt. Merapi characteristics. There are six characteristics approaches that affect the effectiveness of this model involving the evacuation period is uncertain and makes it easier for mutual assistance matching, early evacuation systems are applied in level 3 of the emergency status before the most dangerous level is declared, the proportion of young people is higher than vulnerable people, social culture with neighbors is good, the evacuation distance is less than 3 km, and the most private vehicles are motorcycles and limited.

4.5.4 Limitations and future research

The model has several limitations. First, the simulation time should be improved to find the average evacuation time for all populations. Second, the agent category should be expanded since the evacuation of people traveling with livestock was not investigated. Additionally, a combination of mutual assistance with a vehicle can be attempted. Third, in Scenario B, traffic collisions were not considered. Fourth, it remains necessary to determine the extent to which the evacuation distance impacts the effectiveness of this assembly model since we hold that the fatigue factor affects the speed fluctuation.

In the future, integration and cooperation with the government will be critical for the realization of the proposed model, and research and development are still required to define a low-cost and applicable model for risk reduction. Overall, the government may utilize this methodology to ensure the safety of vulnerable populations and shorten evacuation times. Group mapping data are crucial in the early stages, and community participation is necessary for this formation. A registry can aid at-risk populations with emergency planning and response: this database must be updated regularly to account for changes in information among the listed individuals (Center for Disease Control and Prevention, 2015). Additionally, rigorous educational activities should be implemented.

4.6 Summary

This chapter presents a risk reduction model for the evacuation of vulnerable people. In our simulation, when residents escaped in groups with mutual assistance model, an increase in the number of vulnerable people reaching the temporary shelters in all scenarios was confirmed. M3 ranked the highest in terms of the amount of successfully evacuated vulnerable people and CM3 is recommended for the success of vulnerable people and the total population. The proportion of vulnerable people and the evacuation distance were the essential factors that determined the effectiveness of the evacuation. Since the Balerante village had the most successful evacuation in M2, the very long distance is a concern. The phenomenon in Sleman Regency also proves that the trend of M3 is higher than in Klaten Regency due to having a large population and shortest distance. This finding also offers insights for mitigation plans for an aging population and may apply to other disasters with the same issue in the community; however, the mutual assistance model must be re-evaluated when the number of vulnerable people exceeds that of young people. Overall, this technique can be selected as a low-risk and rapid evacuation alternative, while cooperation between the local government and community associations is essential for implementing a mutual assistance strategy.

References

Abdurachman, E. K., Bourdier, J. L. and Voight, B. (2000) 'Nuées ardentes of 22 November 1994 at Merapi volcano, Java, Indonesia', *Journal of Volcanology and Geothermal Research*, 100(1–4), pp. 345–361. doi: 10.1016/S0377-0273(00)00144-X.

Abdurrachman, E. . (1998) *Geologic des Produits de I' Activite Historique et Contribution a I'Evaluation des Risques au Merapi (Java), Indonesia. Doctoral Thesis,* *Universite d'Orleans, France*.

Alalouf-Hall, D. (2019) '"The Kamaishi miracle": Lessons learned from the 2011 tsunami in Japan', *Alternatives Humanitaires/Humanitarian Alternatives*, (March), pp. 1–6. Available at: http://alternatives-humanitaires.org/en/2019/03/25/kamaishi-miracle-lessons-learned-2011-tsunami-japan/.

Avdeeva, M., Uzun, O. and Borodkina, Y. (2020) 'Simulation of the evacuation process at various economic facilities using the Anylogic software product', in *E3S Web of Conferences*. doi: 10.1051/e3sconf/202017511031.

Balerante Village Authority (2020) *Data Analisis PRB Desa Balerante 2020*. Klaten Regency, Indonesia.

Benson, W. F. (2013) 'Disaster Planning Tips for Older Adults and their Families', *CDC Healthy Aging Program, Atlanta*.

Bian, R. and Wilmot, C. G. (2018) 'An analysis on transit pick-up points for vulnerable people during hurricane evacuation: A case study of New Orleans', *International Journal of Disaster Risk Reduction*, 31, pp. 1143–1151. doi: 10.1016/j.ijdrr.2017.07.005.

Burger, A. *et al.* (2019) 'Computational social science of disasters: Opportunities and challenges', *Future Internet*, 11(5), pp. 1–31. doi: 10.3390/fi11050103.

Center for Disease Control and Prevention (2015) *Planning for an Emergency: Strategies for Identifying and Engaging At-Risk Groups*, *Center for Disease Control and Prevention*. Available at: http://www.cdc.gov/nceh/hsb/disaster/default.htm.

Center for Volcanology and Geological Hazard Mitigation (2020) *Peningkatan Status Aktivitas Gunung Merapi dari Level II ke Level III*. Yogyakarta, Indonesia. Available at: https://vsi.esdm.go.id/index.php/kegiatan-pvmbg/download-center/doc_download/5673-peningkatan-status-aktivitas-g-merapi-tanggal-5-november-2020.

Chasanah, F. and Sakakibara, H. (2021) 'Assessment of social vulnerability in the evacuation process from mount Merapi: focusing on people's behavior and mutual assistance', *IDRiM Journal*, 10(2020), pp. 46–65. doi: 10.5595/001c.21409.

Gaudru, H. (2004) 'Overview of potential impact of eruptions on volcanic islands: Global approaches for volcanic risk mitigation', *European Volcanological Society*, (December 1995). Available at: https://www.preventionweb.net/publication/overview-potential-impact-eruptions-volcanic-islands.

Geological Disaster Technology Research and Development Center (2021) *Laporan Aktivitas Gunung Merapi Tanggal 2-8 Juli 2021*. Yogyakarta, Indonesia. Available at: https://merapi.bgl.esdm.go.id/pub/page.php?idx=565.

Gilbert, N. (2008) *Agent-Based Models*. London: SAGE Publications.

Glagaharjo Village Authority (2019) *Dokumen Rencana Kontijensi Bencana Erupsi Merapi Desa Glagaharjo 2019*. Sleman Regency, Indonesia.

Guha-Sapir, D., Hoyois, P. and Below, R. (2016) *Annual Disaster Statistical Review 2015: The numbers and trends Centre for Research on the Epidemiology of Disasters*

(CRED), Centre for Research on the Epidemiology of Disasters (CRED) Institute of Health and Society (IRSS) Université catholique de Louvain – Brussels, Belgium. Available at: https://reliefweb.int/report/world/annual-disaster-statistical-review-2015-numbers-and-trends.

Hakim, L. N. (2020) 'The urgency of the elderly welfare law revision', *Aspirasi: Jurnal Masalah-masalah Sosial*, 11(1), pp. 43–55. doi: 10.46807/aspirasi.v11i1.1589.

Hardiansyah *et al.* (2018) 'Effect of merapi disaster evacuation on road network performance in Yogyakarta Special Region', *International Journal of Science and Applied Technology*, 3(1). Available at: https://ijsat.unri.ac.id/index.php/IJSAT/article/view/54/pdf.

Hawe, G. I. *et al.* (2012) 'Agent-Based Simulation for Large-Scale Emergency Response: A Survey of Usage and Implementation', *ACM Computing Surveys (CSUR)*, 45(June), pp. 1–51. doi: http://doi.acm.org/10.1145/2379776.2379784.

Jumadi *et al.* (2018) 'Modelling individual evacuation decisions during natural disasters: A case study of volcanic crisis in Merapi, Indonesia', *Geosciences (Switzerland)*, 8(6), pp. 1–30. doi: 10.3390/geosciences8060196.

Jumadi, J. *et al.* (2020) 'Estimating spatio-temporal risks from volcanic eruptions using an agent-based model', *Jasss*, 23(2). doi: 10.18564/jasss.4241.

Jumadi, J., Carver, S. J. and Quincey, D. J. (2019) 'An agent-based evaluation of varying evacuation scenarios in Merapi : Simultaneous and staged', *Geosciences*, 9, pp. 1–19. doi: 10.3390/geosciences9070317.

Karaaslan, E. *et al.* (2018) 'Modeling the effect of electric vehicle adoption on pedestrian traffic safety: An agent-based approach', *Transportation Research Part C: Emerging Technologies*, 93(February), pp. 198–210. doi: 10.1016/j.trc.2018.05.026.

Klaten Regional Disaster Management Agency (2018) *Rencana Kontingensi Menghadapi Ancaman Erupsi Gunung Merapi di Kabupaten Klaten*. Klaten Regency, Indonesia.

Lechner, H. N. and Rouleau, M. D. (2019) 'Should we stay or should we go now? Factors affecting evacuation decisions at Pacaya volcano, Guatemala', *International Journal of Disaster Risk Reduction*, 40(April), p. 101160. doi: 10.1016/j.ijdrr.2019.101160.

Liu, L. and Chen, H. (2021) 'Microscopic simulation-based pedestrian distribution service network in urban rail station', *Transportation Research Interdisciplinary Perspectives*, 9(January), p. 100313. doi: 10.1016/j.trip.2021.100313.

Liu, Q. *et al.* (2022) 'Modeling the dynamics of pedestrian evacuation in a complex environment', *Physica A: Statistical Mechanics and its Applications*, 585, p. 126426. doi: 10.1016/j.physa.2021.126426.

Ma, Y., Liu, X. and Huo, F. (2022) 'Analysis of Cooperation Behaviors and Crowd Dynamics during Pedestrian Evacuation with Group Existence', *Sustainability*, 14. doi: https://doi.org/10.3390/su14095278.

Maharani, Y. N., Lee, S. and Ki, S. J. (2016) 'Social vulnerability at a local level around the Merapi volcano', *International Journal of Disaster Risk Reduction*, 20(October), pp. 63–77. doi: 10.1016/j.ijdrr.2016.10.012.

Mei, E. T. W. *et al.* (2013) 'Lessons learned from the 2010 evacuations at Merapi volcano', *Journal of Volcanology and Geothermal Research*, 261, pp. 348–365. doi: 10.1016/j.jvolgeores.2013.03.010.

Ministry of Public Works and Housing (2020) *Pedoman Desain Geometrik Jalan 2020, Direktorat Jenderal Bina Marga (DJBM)*. Jakarta, Indonesia.

Ministry of Transportation (2015) *Peraturan Menteri Perhubungan Republik Indonesia Nomor PM 111 Tahun 2015, Tentang Tata Cara Penetapan Batas Kecepatan*. Republic of Indonesia.

National Disaster Management Agency (2014) *Rencana Nasional Penanggulangan Bencana 2015-2019*. Jakarta: Republic of Indonesia. Available at: https://www.bnpb.go.id//uploads/renas/1/BUKU RENAS PB.pdf.

Niroa, J. J. and Nakamura, N. (2022) 'Volcanic disaster risk reduction in indigenous communities on Tanna Island, Vanuatu', *International Journal of Disaster Risk Reduction*, 74(March), p. 102937. doi: 10.1016/j.ijdrr.2022.102937.

Nugraha, A. L. *et al.* (2019) 'Analysis of risk assessment of Mount Merapi eruption in settlement area of Sleman Regency', *IOP Conference Series: Earth and Environmental Science*, 313(1). doi: 10.1088/1755-1315/313/1/012003.

Ohtsu, N. *et al.* (2021) 'Evacuation of vulnerable people during a Natech: A case study of a flood and factory explosion in Japan', *International Journal of Disaster Resilience in the Built Environment*. doi: 10.1108/IJDRBE-04-2021-0043.

Ostad-Ali-Askari, K. (2022) 'Management of risks substances and sustainable development', *Applied Water Science*, 12(4), pp. 1–23. doi: 10.1007/s13201-021-01562-7.

Palinkas, L. A. *et al.* (2015) 'Purposeful sampling for qualitative data collection and analysis in mixed method implementation research', *HHS Public Access*, 42(5), pp. 533–544. doi: 10.1007/s10488-013-0528-y.

Purnomo, S. and Sunartono (2011) 'Peraturan Bupati Sleman Nomor 20 Tahun 2011 Tentang Kawasan Rawan Bencana Gunungapi Merapi', pp. 1–13. Available at: https://peraturan.bpk.go.id/Home/Details/37567.

Purwobinangun Village Authority (2019) *Dokumen Rencana Kontijensi Bencana Erupsi Merapi Desa Purwobinangun 2019*. Sleman Regency, Indonesia.

Rahman, M. M. *et al.* (2020) 'Evaluation of transportation alternatives for aging population in the era of self-driving vehicles', *IATSS Research*, 44(1), pp. 30–35. doi: 10.1016/j.iatssr.2019.05.004.

Roess, R. P., Prassas, E. S. and McShane, W. (2011) *Traffic Engineering, Fourth Edition, Pearson Higher Education*. USA.

Sayudi, DS, Nurnaning A, Juliani Dj, Muzani, M. (2010) 'Peta Kawasan Rawan Bencana

Gunung Api Merapi Jawa Tengah dan Daerah Istimewa Yogyakarta 2010 (Merapi Hazard Map, Central Java and Yogyakarta Special Region Provinces).' Kementerian Energi dan Sumber daya Mineral, Badan Geologi, Pusat Vulkanologi dan Mitigasi Bencana Geologi, Bandung. Available at: https://merapi.bgl.esdm.go.id/pub/page.php?idx=358.

Sidorejo Village Authority (2019) *Data KK dan Aset Keluarga Desa Sidorejo 2019*. Klaten Regency, Indonesia.

Sleman Regional Disaster Management Agency (2019) *Rencana Kontijensi Erupsi Gunungapi Merapi*. Sleman Regency, Indonesia.

Subhajyoti, S. and Hirokazu, T. (2015) 'Where do individuals seek opinions for evacuation? A case study from landslide-prone slum communities in Mumbai', *Journal of Natural Disaster Science*, 36(1), pp. 13–24. doi: 10.2328/jnds.36.13.

Surono *et al.* (2012) 'The 2010 explosive eruption of Java's Merapi volcano-A "100-year" event', *Journal of Volcanology and Geothermal Research*, 241–242(May 2018), pp. 121–135. doi: 10.1016/j.jvolgeores.2012.06.018.

Taylor, S. J. (2014) *Agent-Based Modeling and Simulation*. Palgrave Macmillan. doi: 10.1057/9781137453648.

Tegalmulyo Village Authority (2019) *Dokumen Rencana Kontijensi Bencana Erupsi Merapi Desa Tegalmulyo 2019*. Klaten Regency, Indonesia.

Tegalmulyo Village Authority (2020) *Hasil Assessment Desa Tegalmulyo 2020*. Klaten, Indonesia.

Tongco, M. D. C. (2007) 'Purposive sampling as a tool for informant selection', *Ethnobotany Research and Applications*, 5, pp. 147–158. doi: 10.17348/era.5.0.147-158.

Transportation Research Board (2000) *Highway Capacity Manual*, *National Research Council, Washington, DC*. Washington DC.

Transportation Research Board (2010) *HCM 2010-Highway Capacity Manual, Volume 1: Concepts*. Washington, DC.

Troitzsch, K. G. (2004) 'Validating simulation models.', in *Proceeding's 18th European Simulation Multiconference Graham Horton (c) SCS Europe*.

Umbulharjo Village Authority (2019) *Dokumen Rencana Kontinjensi Bencana Erupsi Merapi Desa Umbulharjo 2019*. Sleman Regency, Indonesia.

Wiley, J. and S. (2016) *Traffic Engineering Handbook, 7th Edition*, *Institute of Transportation Engineers*. Canada.

World Health Organization (2022) *Active Ageing: A Policy Framework.* Madrid, Spain.

Zuo, J. *et al.* (2021) 'Simulation and optimization of pedestrian evacuation in high-density urban areas for effectiveness improvement', *Environmental Impact Assessment Review*, 87(92), p. 106521. doi: 10.1016/j.eiar.2020.106521.

CHAPTER V
CONCLUSIONS AND FUTURE WORKS

5.1 Conclusions

Below are the conclusions gathered from this study:

1. The local communities in the four regencies have similar characteristics. Young people represent most of the population. The elderly and children have a large number among other vulnerable people. The social culture of supporting each other here is good. Vehicle ownership is still limited, and the most used are motorcycles. Community perception and government evacuation issues and rules are almost the same for all regions.
2. The mean walking speed of young and vulnerable persons differs significantly in all affected regencies. Mutual assistance groups have a median pace.
3. Mutual assistance is more effective in evacuation risk reduction compared to the existing scenario of the government's contingency plans. The social and age structure factor has a stronger risk impact than the perception factor. The subjective social vulnerability index was high in each regency due to the focus on the evacuation problem of vulnerable people. The objective index was low because the elderly people proportion is not big yet.
4. Scenarios using a vehicle (B and C) are effective for increasing the successful evacuation rates of young and vulnerable people. Assembly models (M2 and M3) are effective in improving the successful evacuation rates of vulnerable people. Mutual assistance by walking led to changes in the proportions where the vulnerable people rise and young people down. However, the total population success between the existing model and the mutual assistance model is almost the same. CM3 ranked highest for the arrival of vulnerable communities and total population.

5.2 Future works

Suggestions for future research topics concerning the advanced evacuation model are listed as follows:

1. Development of models covering human and livestock evacuation.
2. A comprehensive assessment of the social vulnerability index considering several factors such as education, politics, income, health, and others.

3. Development of assembly model and mutual assistance using a private vehicle.
4. Evaluation of traffic collision potential, changes in the young and vulnerable population, and effective evacuation distances.
5. Integration and cooperation with the government and local community for the realization of the proposed mutual assistance model.

The following are issues that can be considered for the implementation of a mutual assistance evacuation model:

1. The local government must conduct a population census regularly including vehicle ownership and demographic map.
2. The local government registers all residents involving young people and vulnerable people to form partners for mutual assistance action. Volunteers or supporters are family members and neighbors.
3. The local government establishes the methodological approach of mutual assistance tactic considering the group and households mapping data, supporters' capability as key persons, and effective communication system. The great potential is the local government or village office sends direct messages or calls to supporters to start evacuating vulnerable persons after emergency state 3 is announced. This early evacuation process will take place before the most dangerous status level 4 is declared.
4. The local government and the disaster risk reduction forum with local community members held workshops to develop the technical procedure considering various scenarios on weekdays, weekends, nights, and the daytime. Mutual assistance in Model 3 is recommended.
5. The local government held training, simulations, and educational activities every year.
6. The local government updates the mutual assistance database and map every year.

APPENDIX

A. RESULT OF SCENARIO B AND SCENARIO C

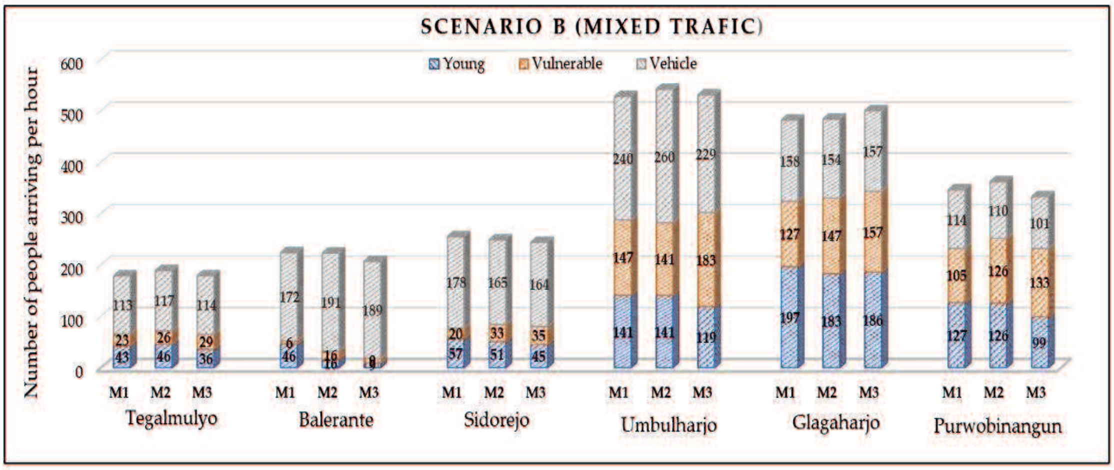

Figure A1. Simulation result in Scenario B (Mixed Traffic)

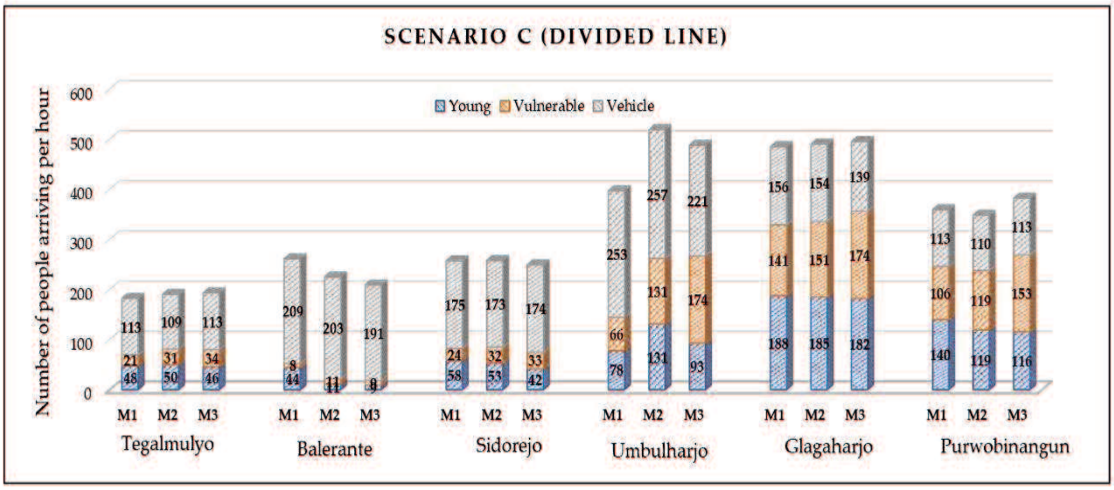

Figure A2. Simulation result in Scenario C (Divided Line).

B. RESULT OF MODELING SIMULATION

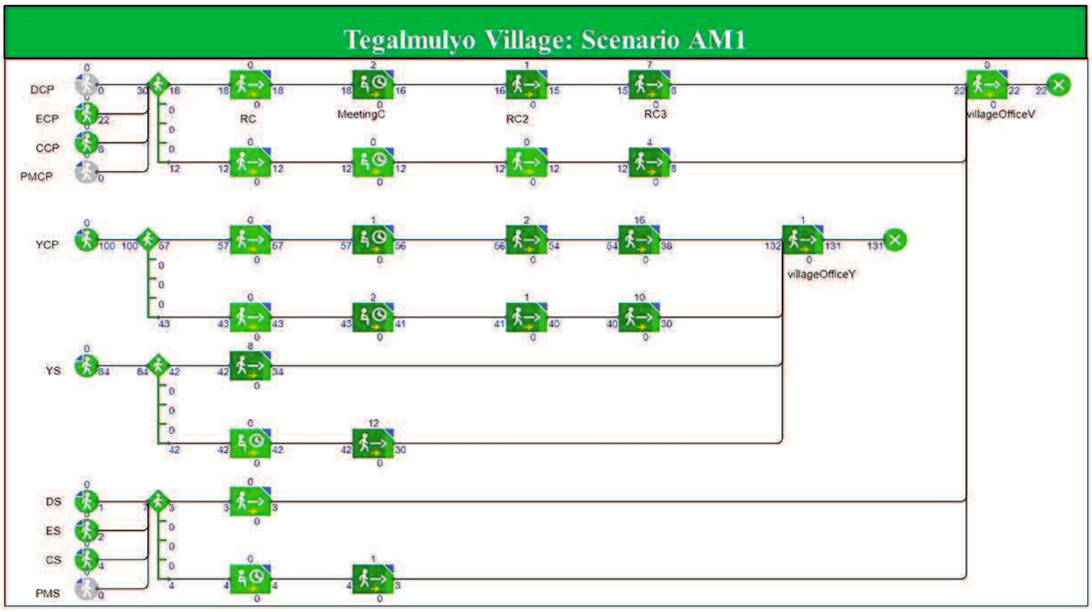

Figure B1. Simulation result in Tegalmulyo Village (AM1)

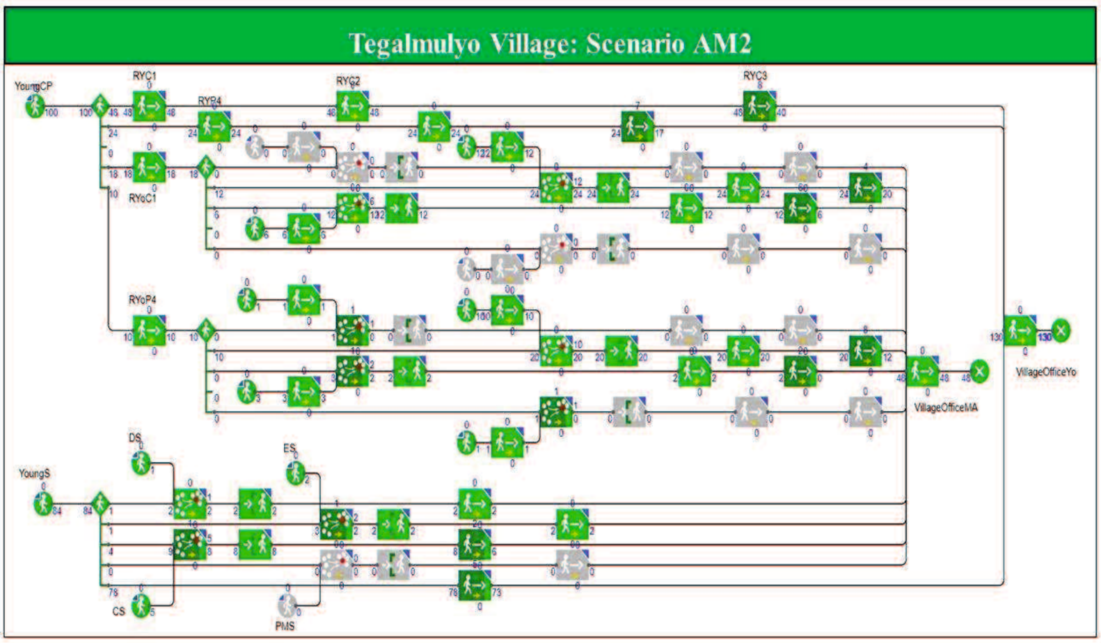

Figure B2. Simulation result in Tegalmulyo Village (AM2)

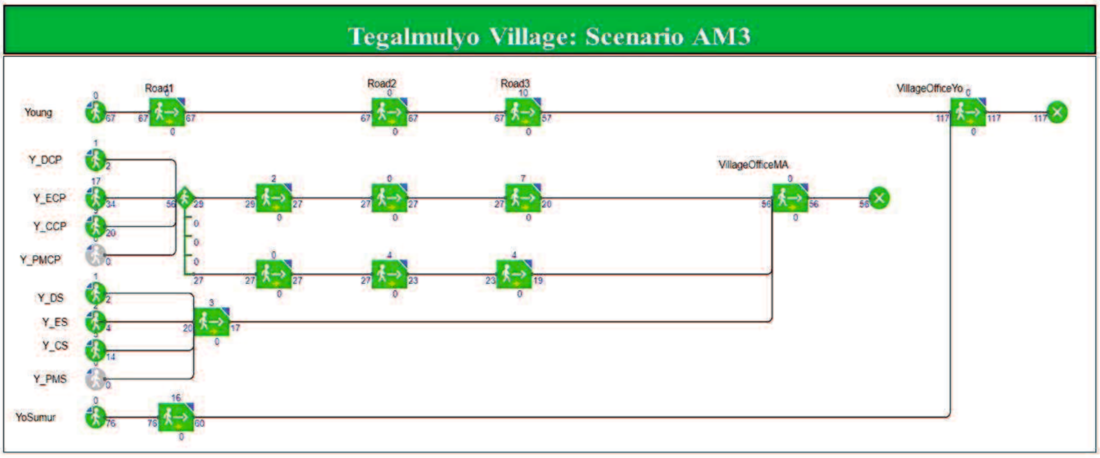

Figure B3. Simulation result in Tegalmulyo Village (AM3)

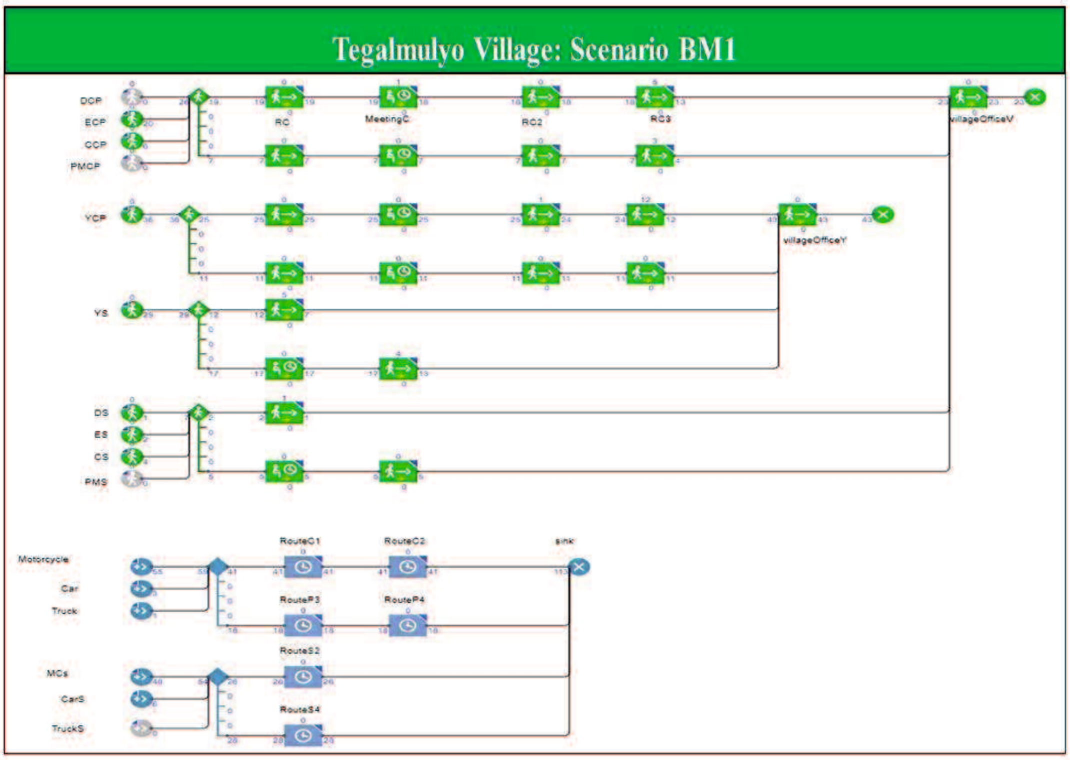

Figure B4. Simulation result in Tegalmulyo Village (BM1)

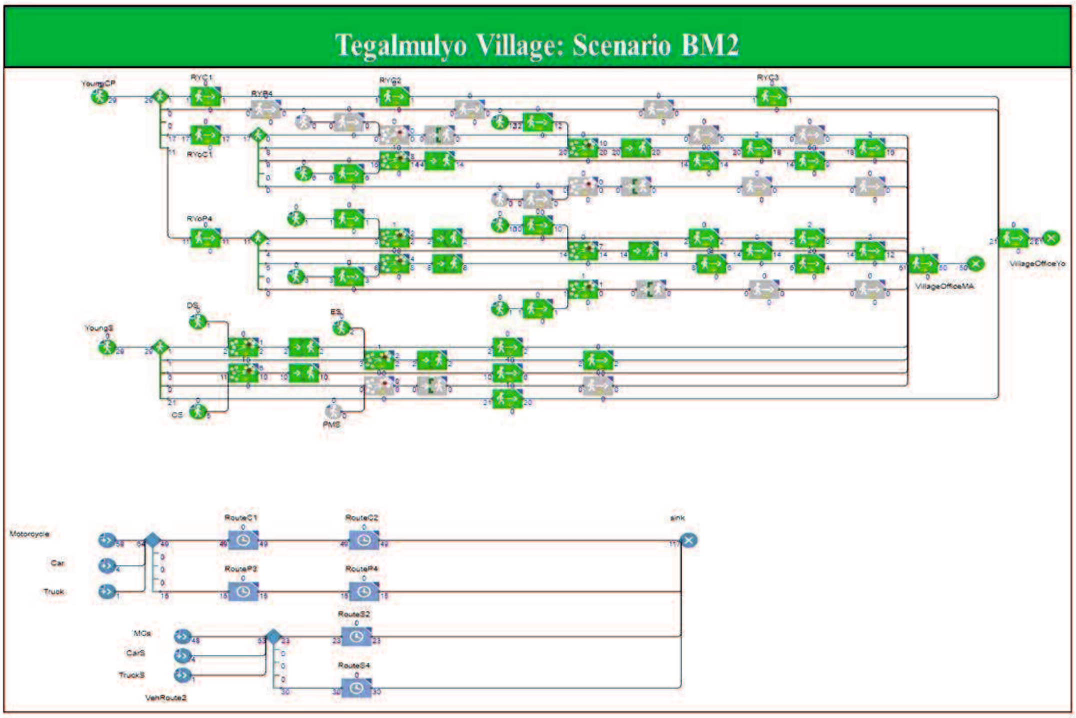

Figure B5. Simulation result in Tegalmulyo Village (BM2)

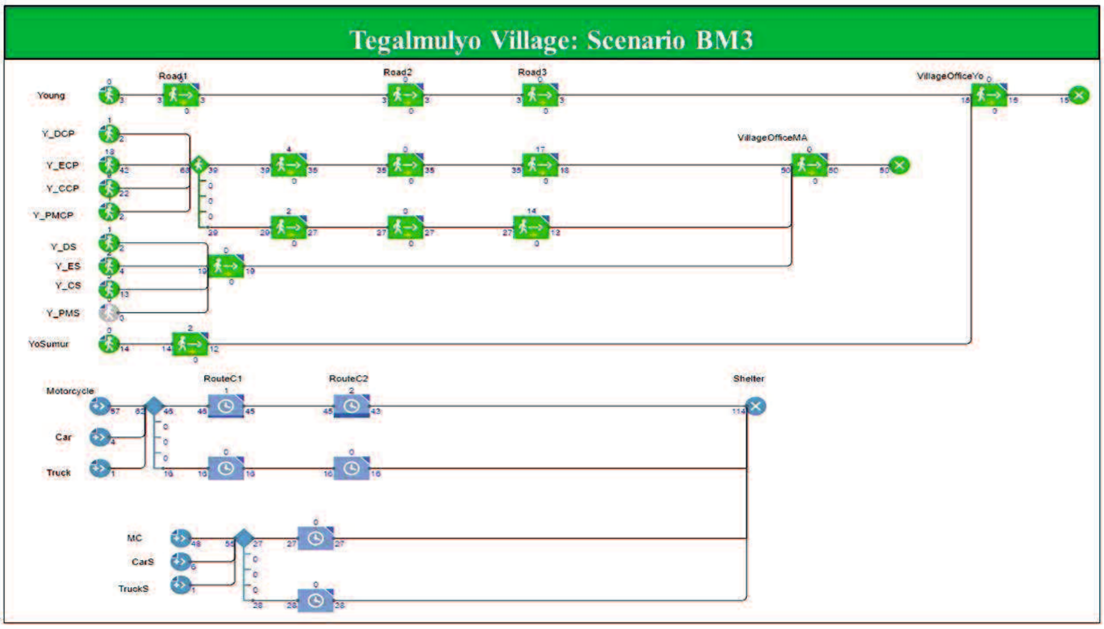

Figure B6. Simulation result in Tegalmulyo Village (BM3)

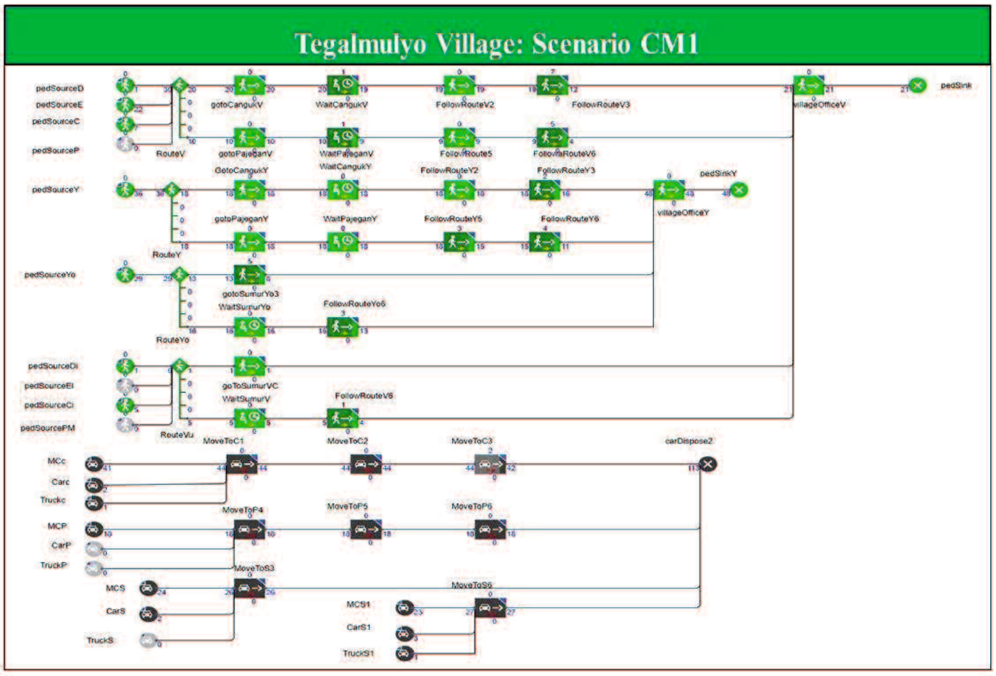

Figure B7. Simulation result in Tegalmulyo Village (CM1)

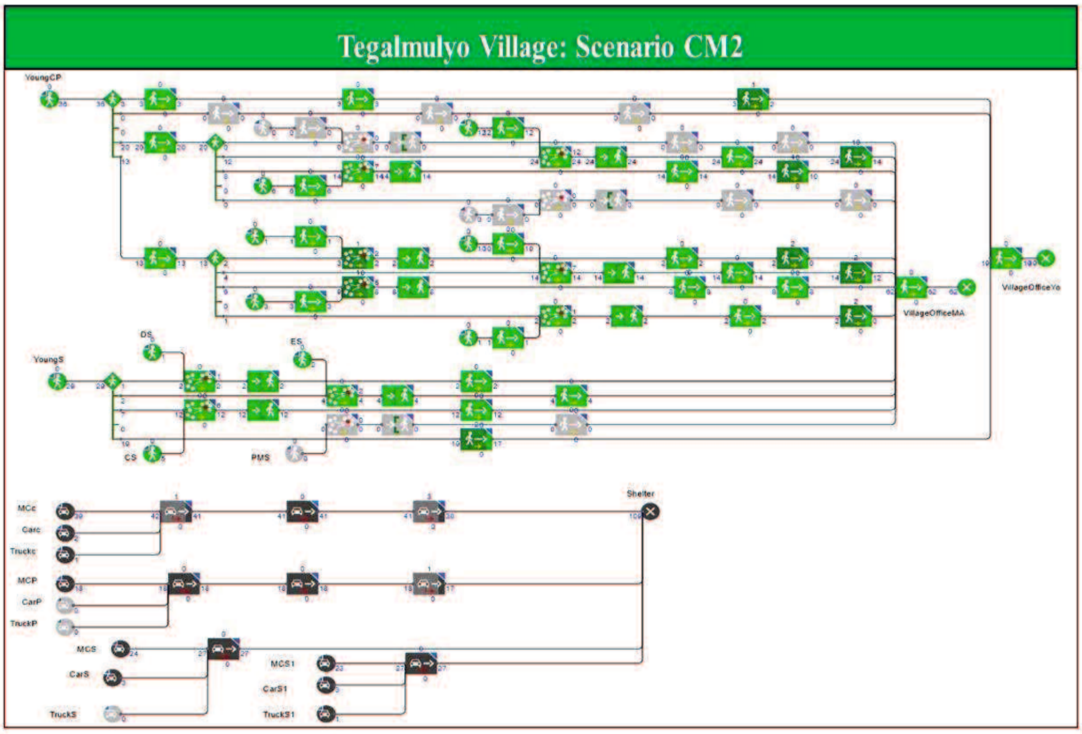

Figure B8. Simulation result in Tegalmulyo Village (CM2)

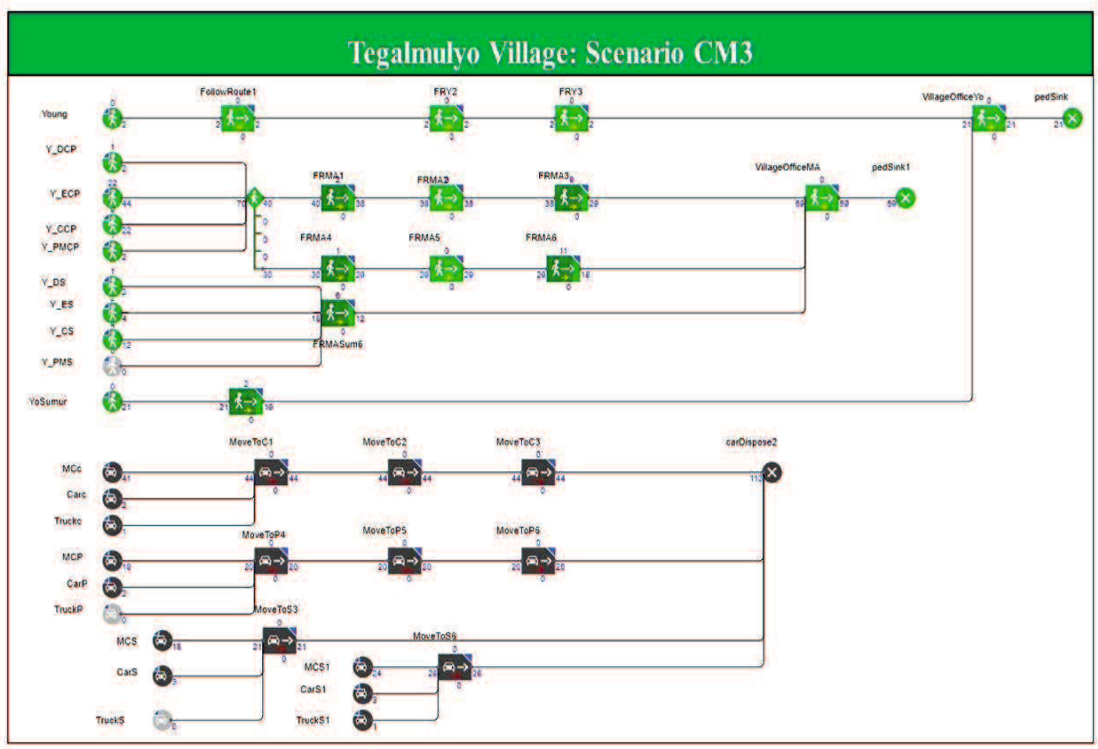

Figure B9. Simulation result in Tegalmulyo Village (CM3)

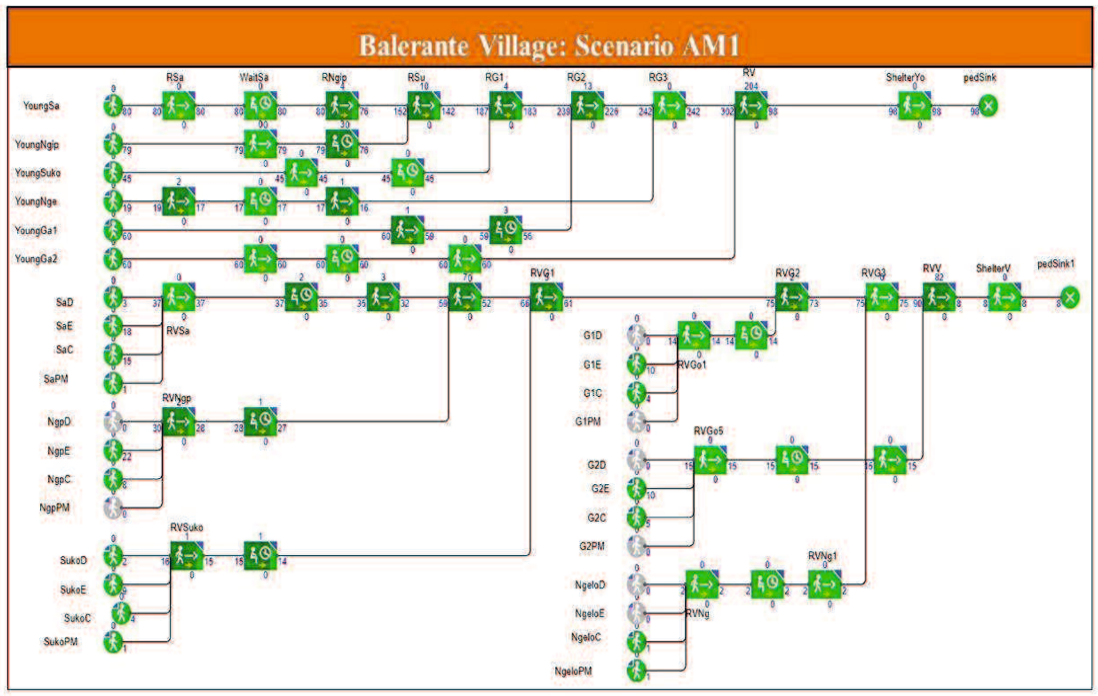

Figure B10. Simulation result in Balerante Village (AM1)

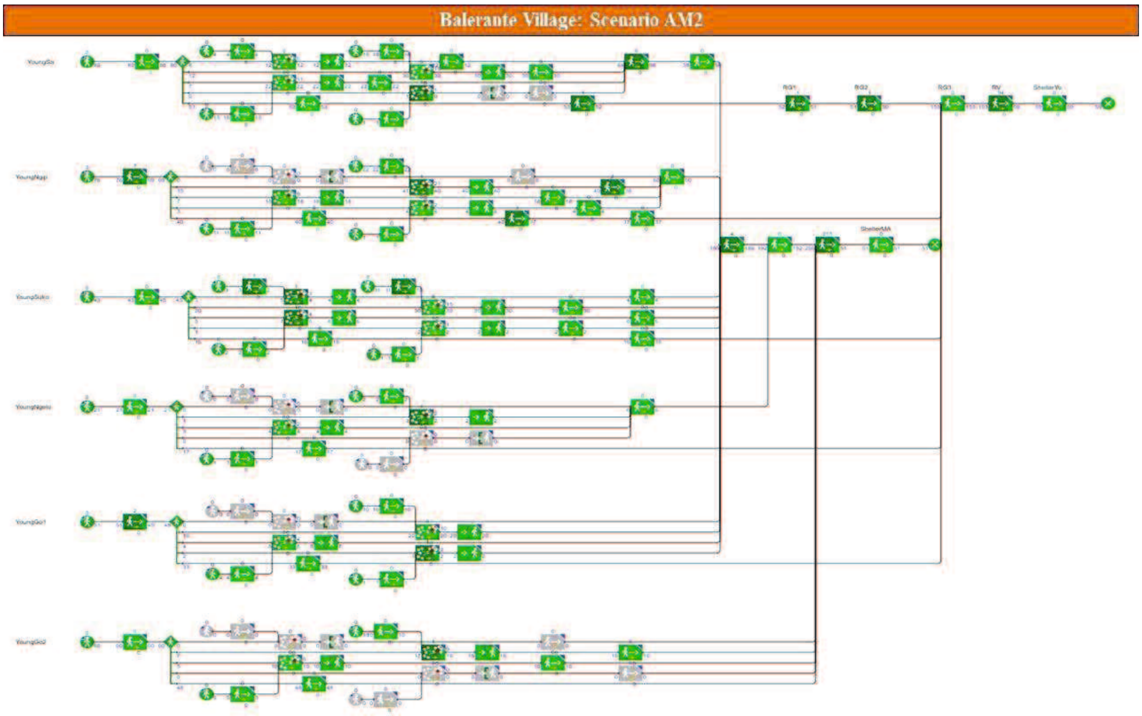

Figure B11. Simulation result in Balerante Village (AM2)

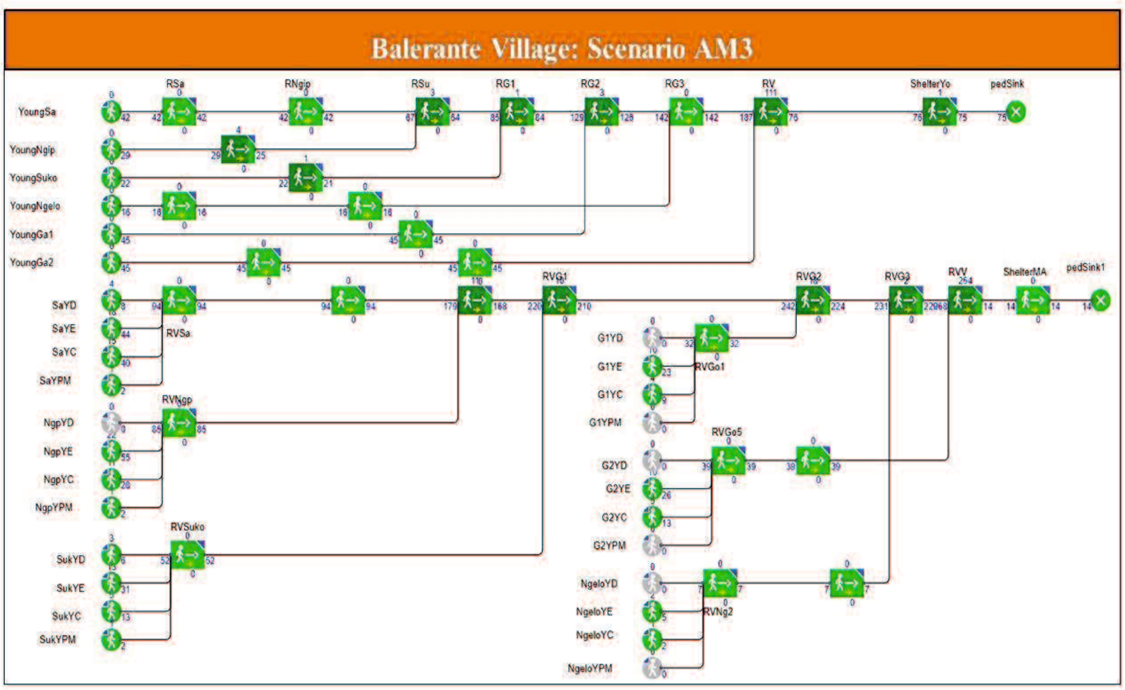

Figure B12. Simulation result in Balerante Village (AM3)

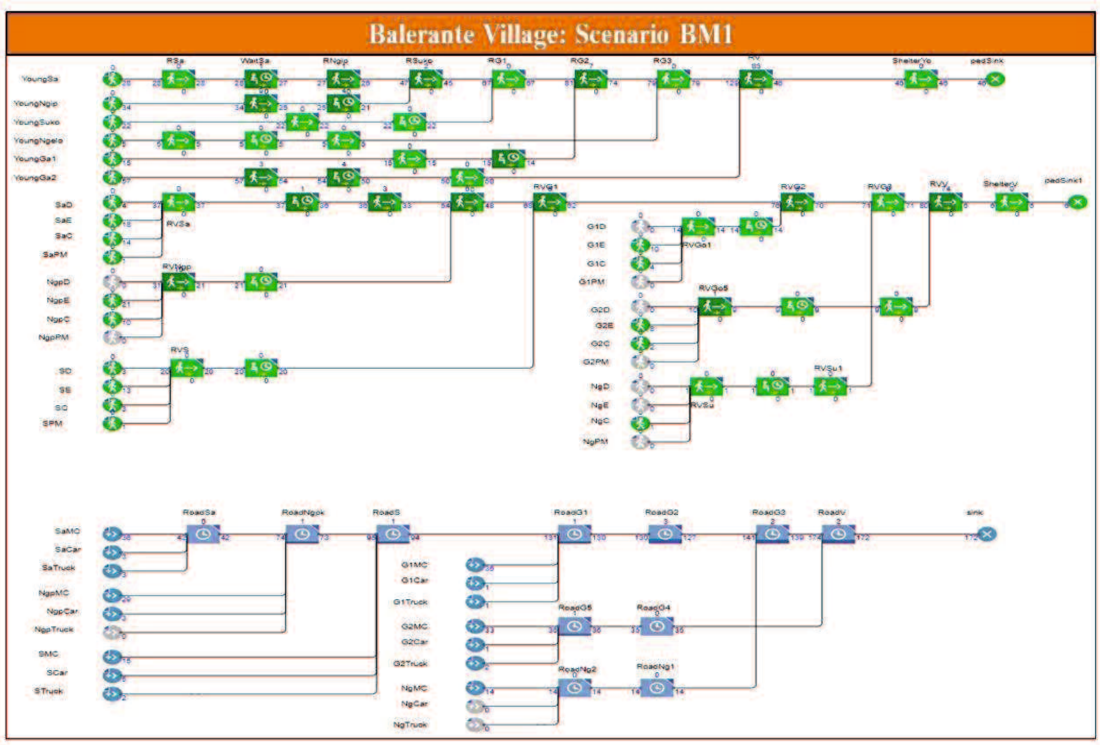

Figure B13. Simulation result in Balerante Village (BM1)

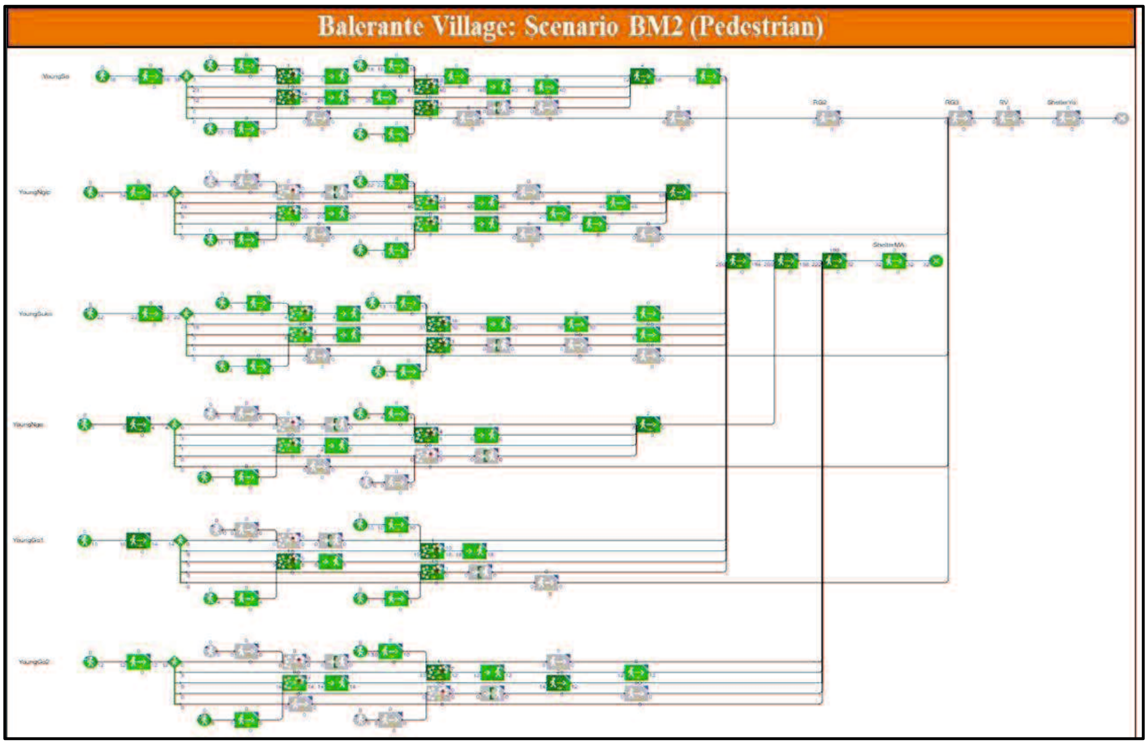

Figure B14. Simulation result in Balerante Village (BM2) pedestrian

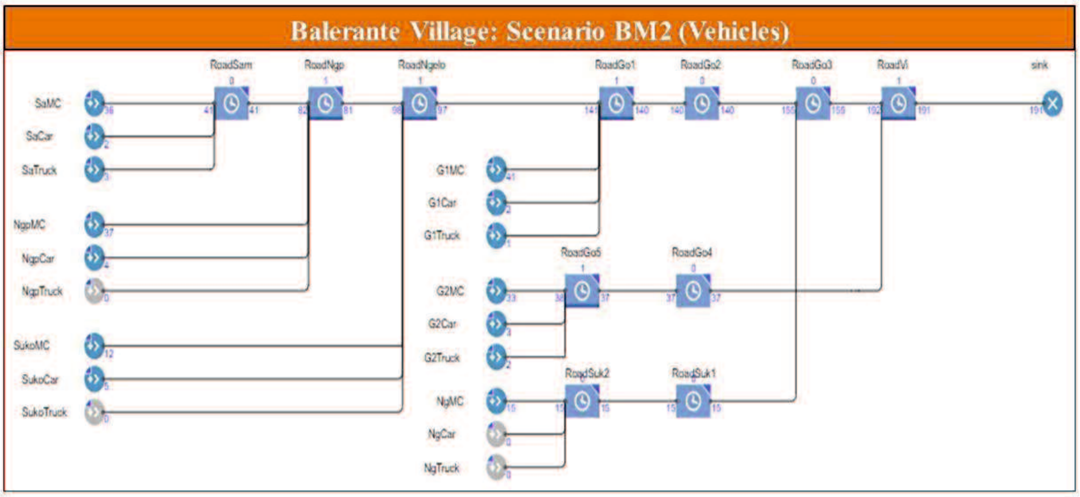

Figure B15. Simulation result in Balerante Village (BM2) vehicles

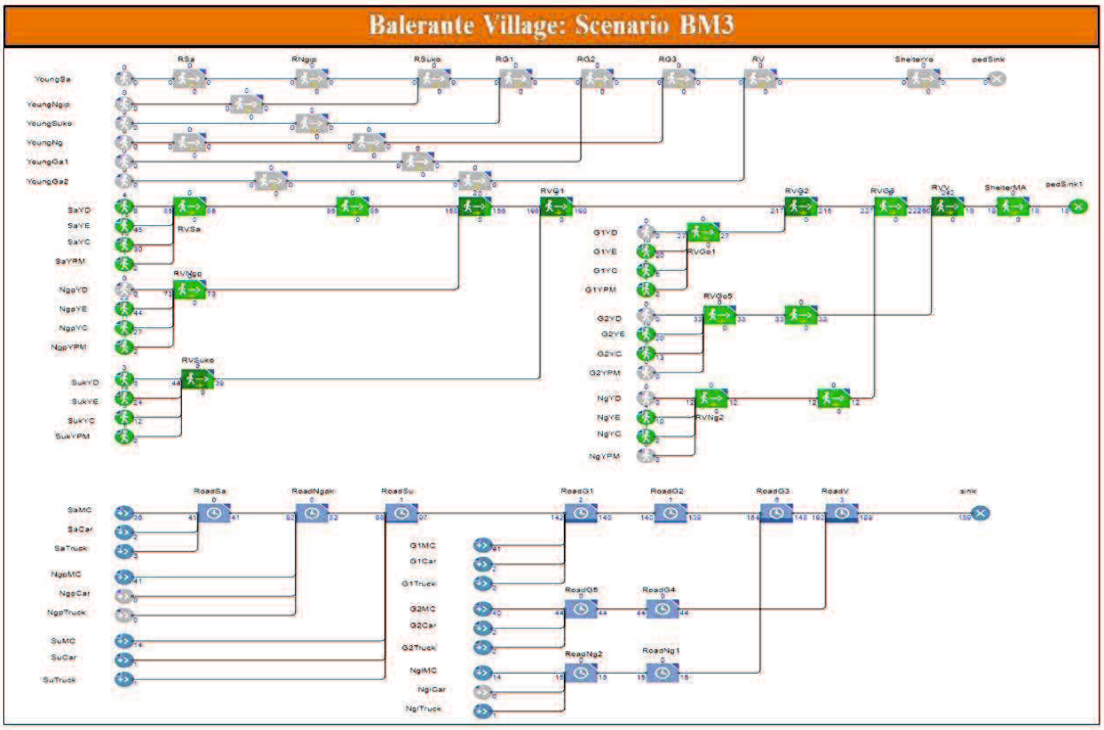

Figure B16. Simulation result in Balerante Village (BM3)

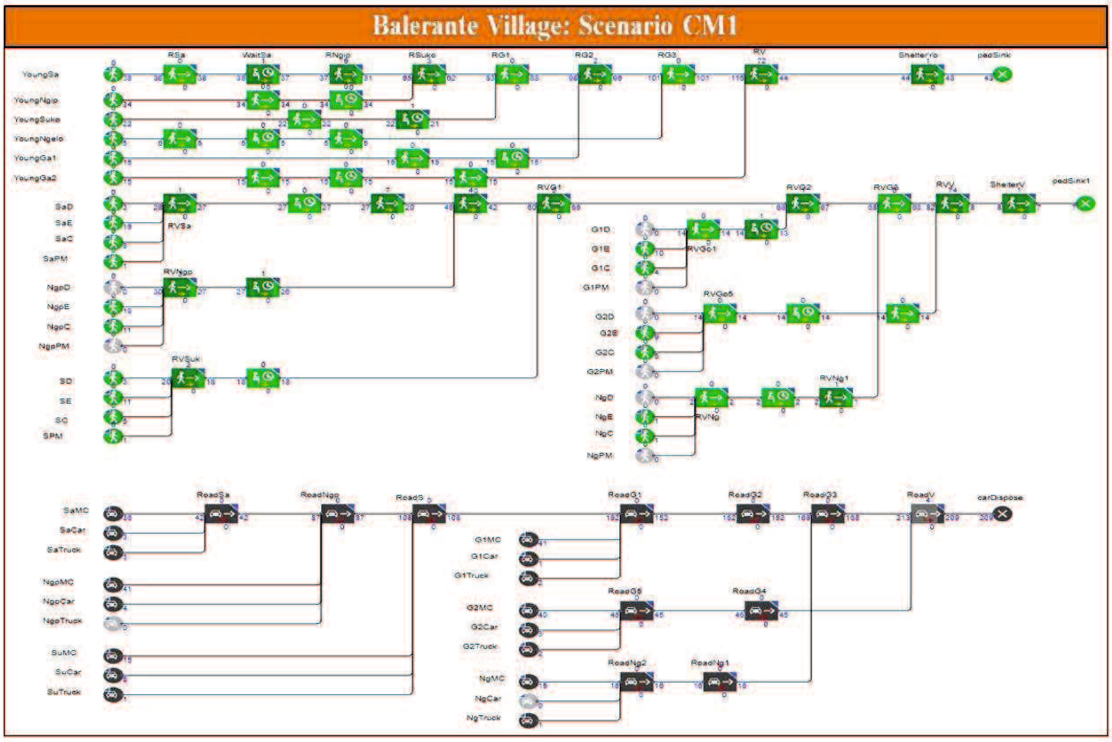

Figure B17. Simulation result in Balerante Village (CM1)

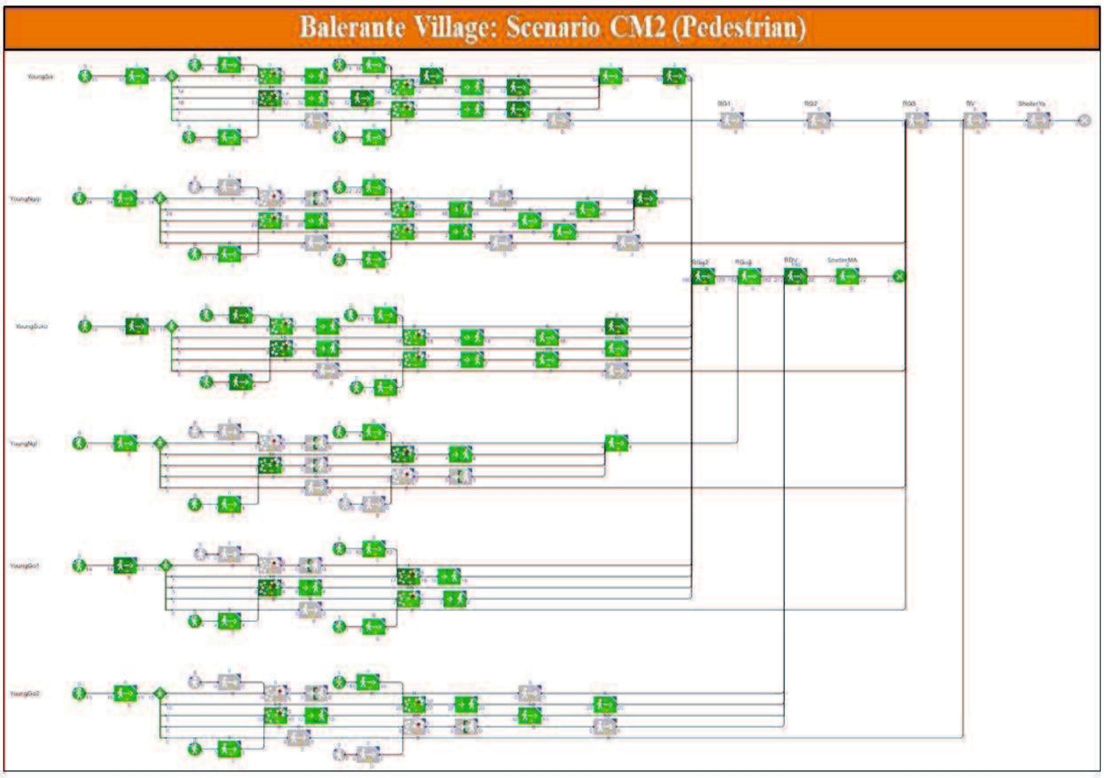

Figure B18. Simulation result in Balerante Village (CM2) pedestrian

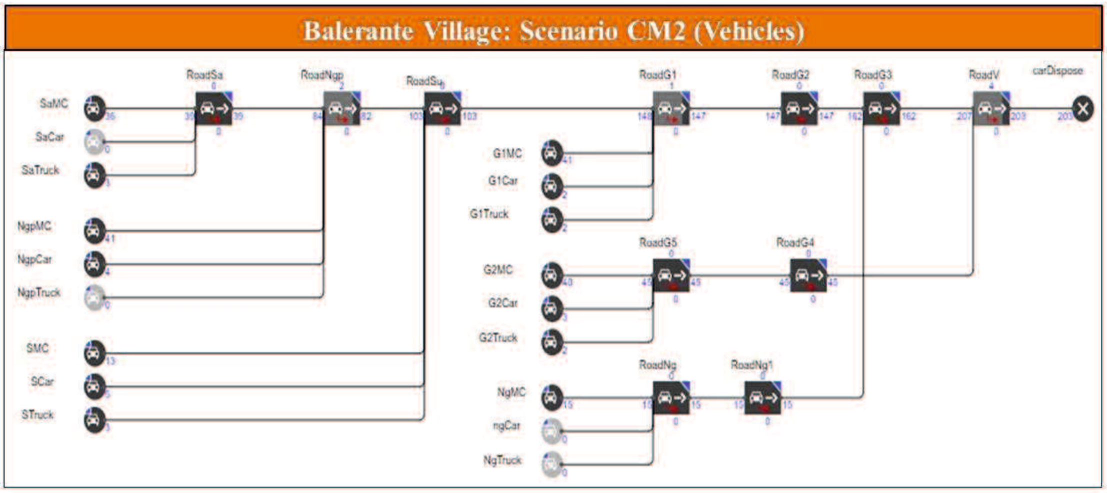

Figure B19. Simulation result in Balerante Village (CM2) vehicles

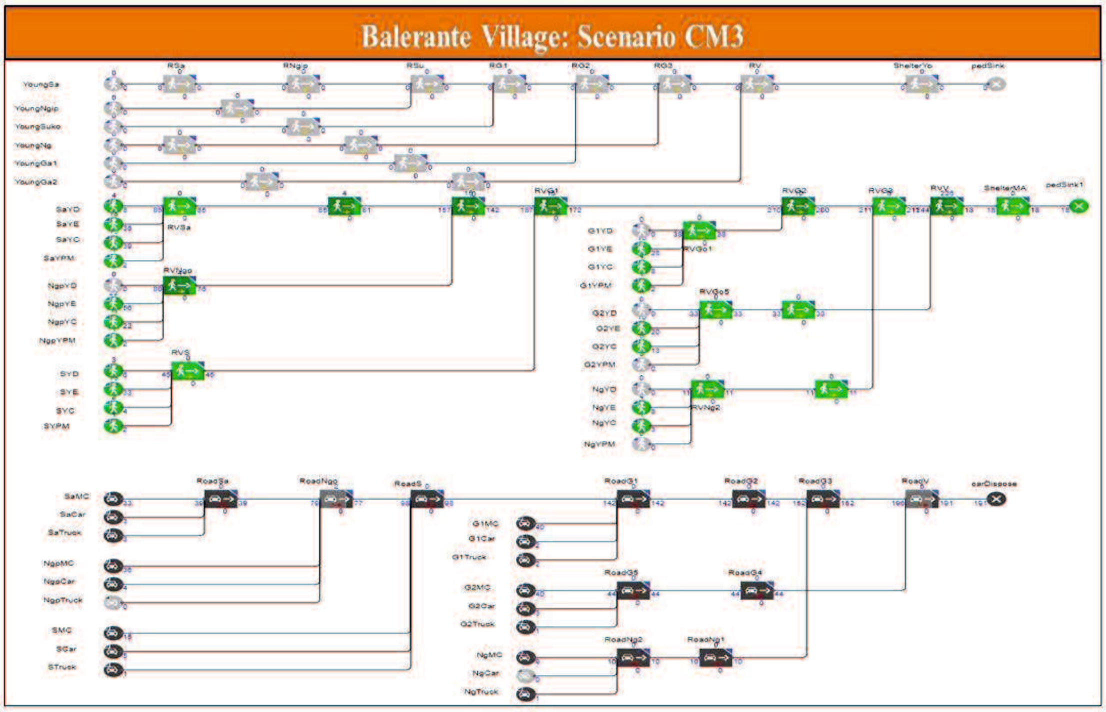

Figure B20. Simulation result in Balerante Village (CM3)

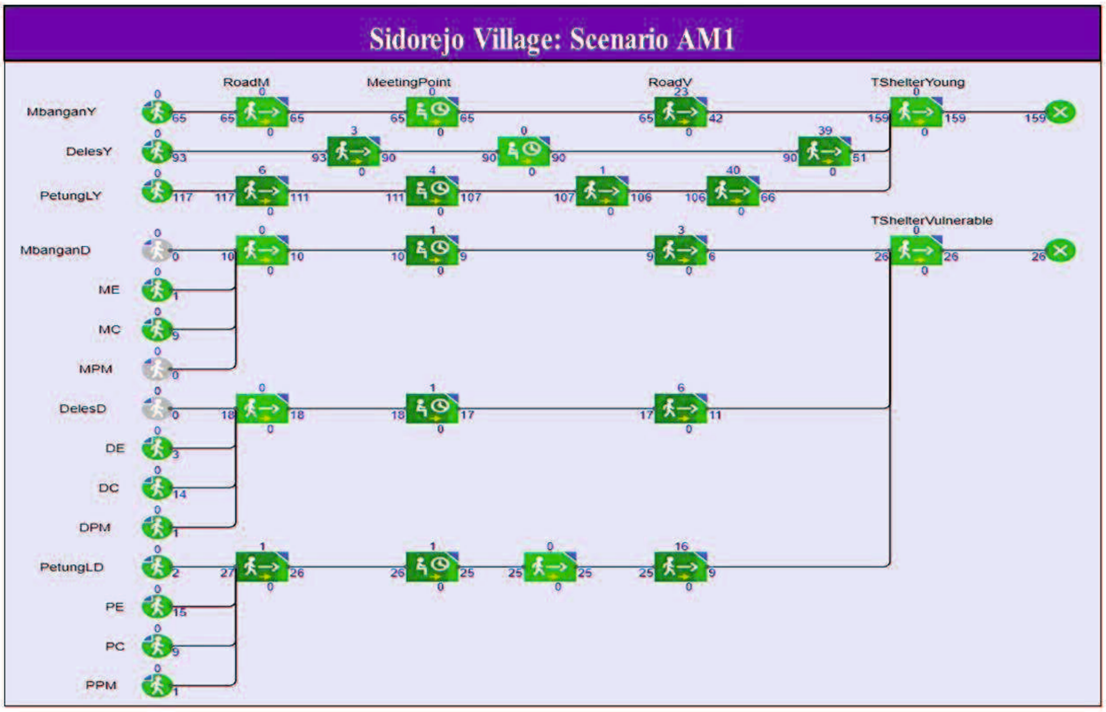

Figure B21. Simulation result in Sidorejo Village (AM1)

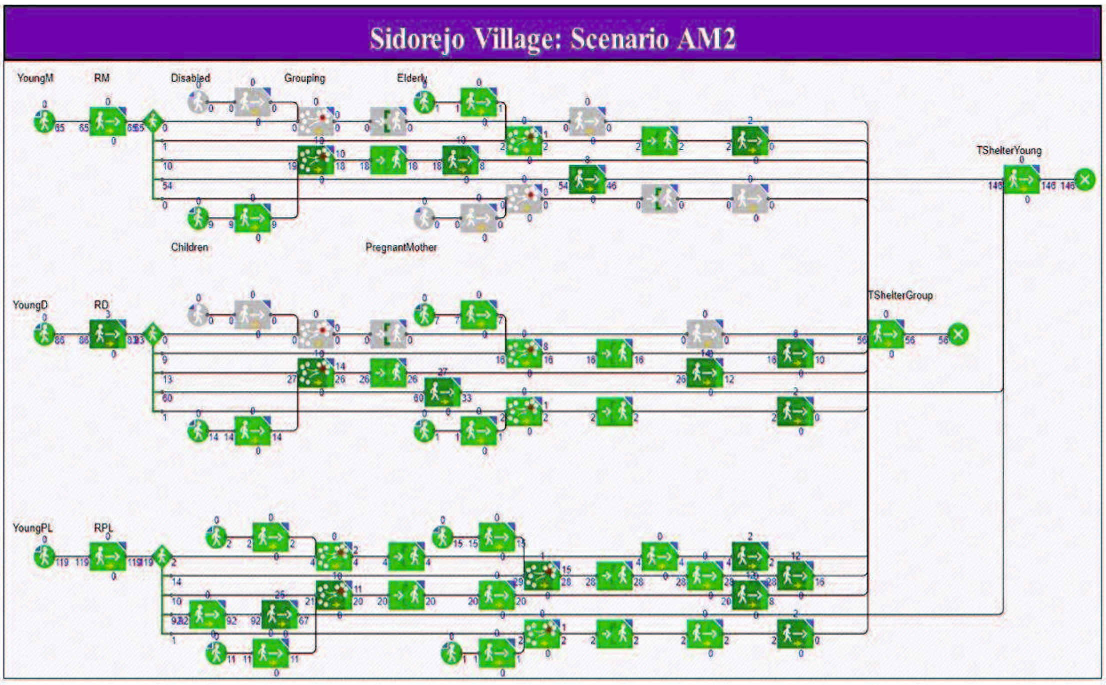

Figure B22. Simulation result in Sidorejo Village (AM2)

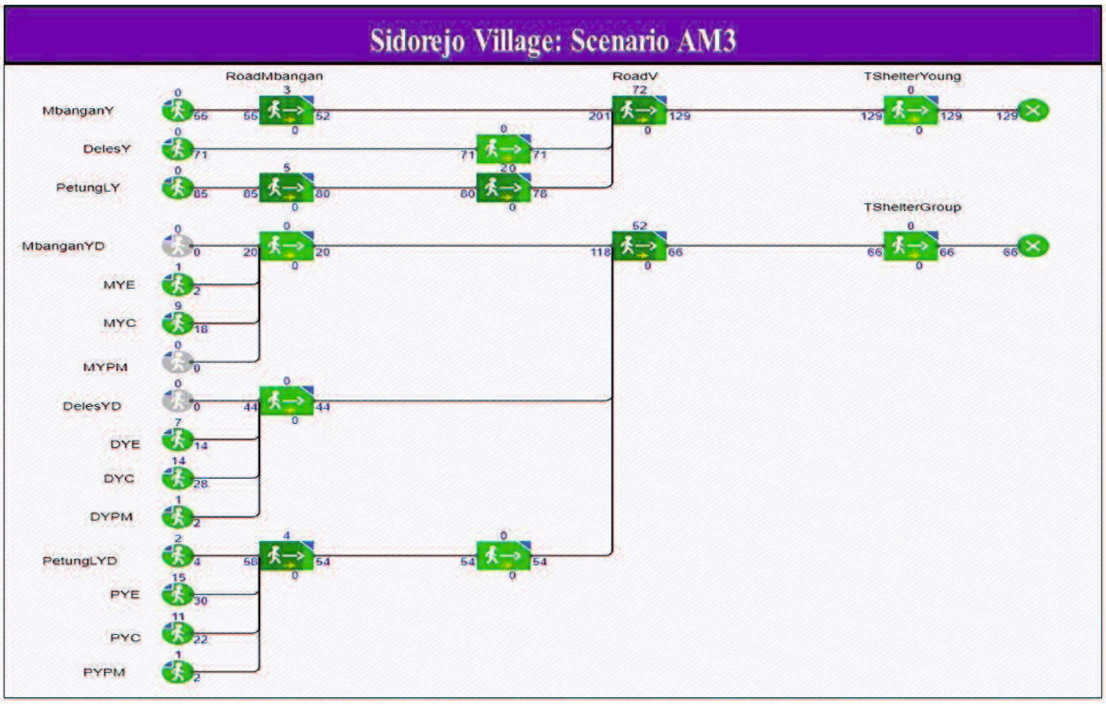

Figure B23. Simulation result in Sidorejo Village (AM3)

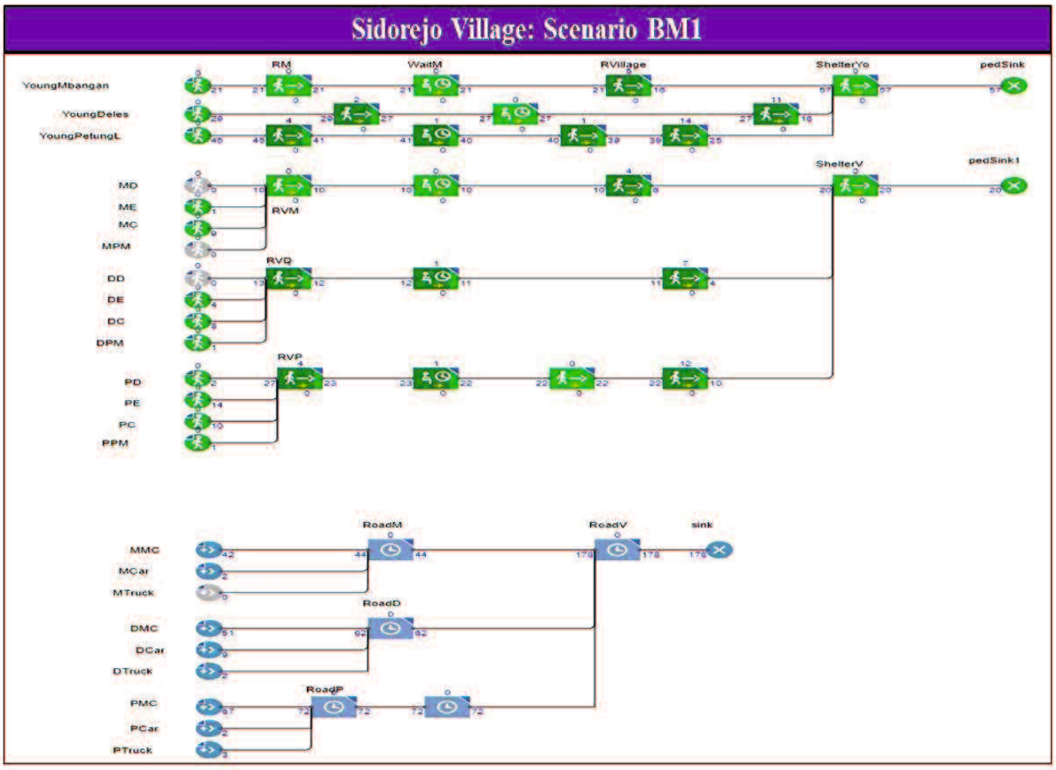

Figure B24. Simulation result in Sidorejo Village (BM1)

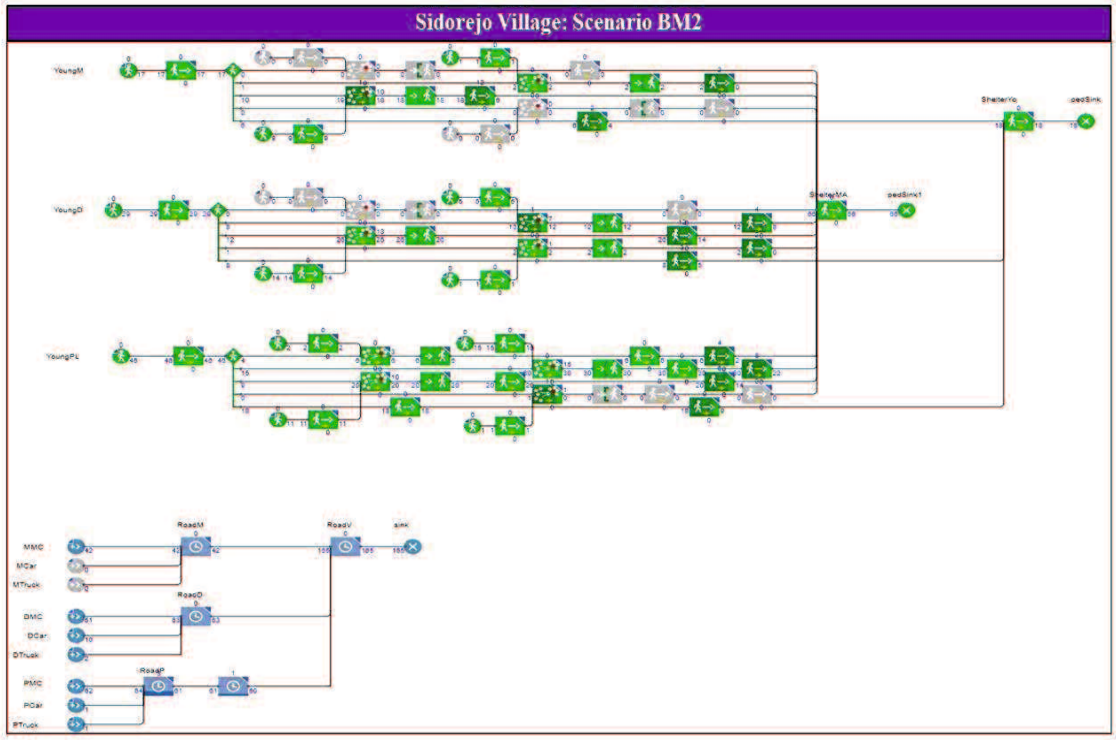

Figure B25. Simulation result in Sidorejo Village (BM2)

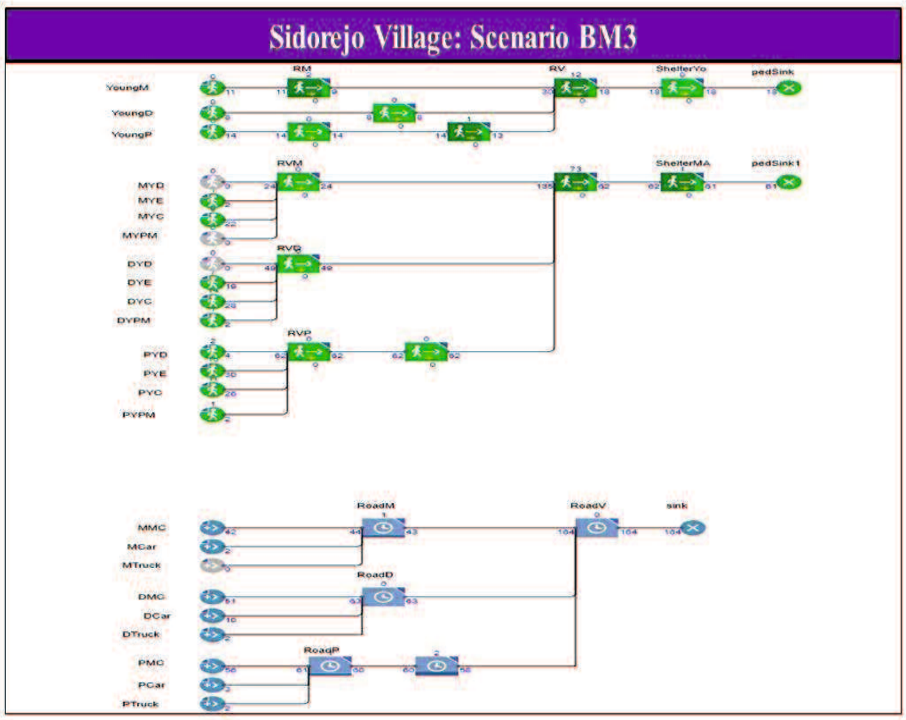

Figure B26. Simulation result in Sidorejo Village (BM3)

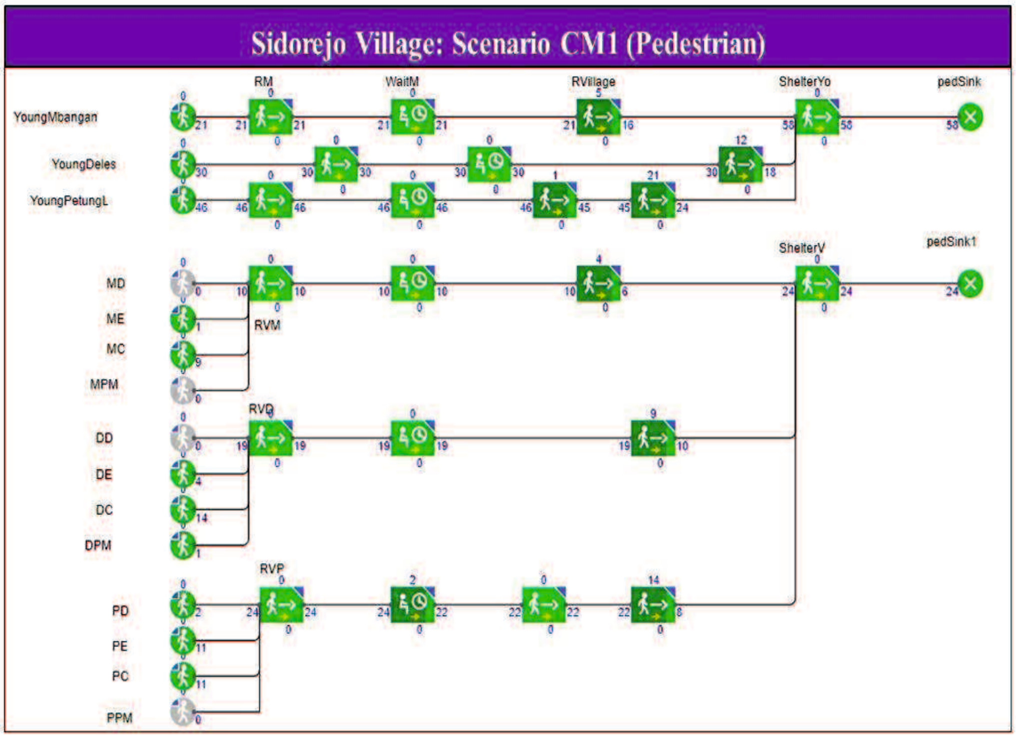

Figure B27. Simulation result in Sidorejo Village (CM1) pedestrian

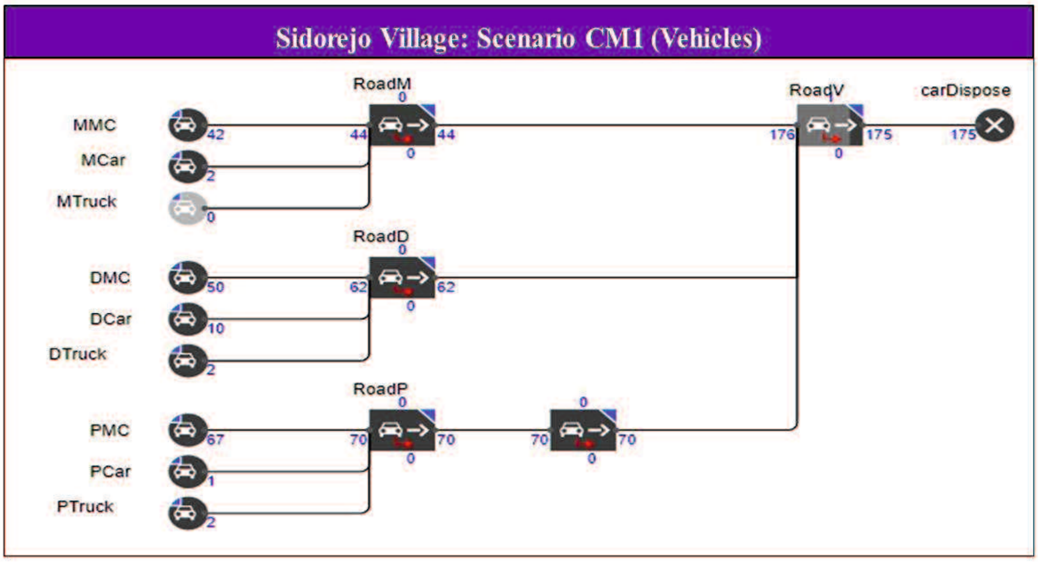

Figure B28. Simulation result in Sidorejo Village (CM1) vehicles

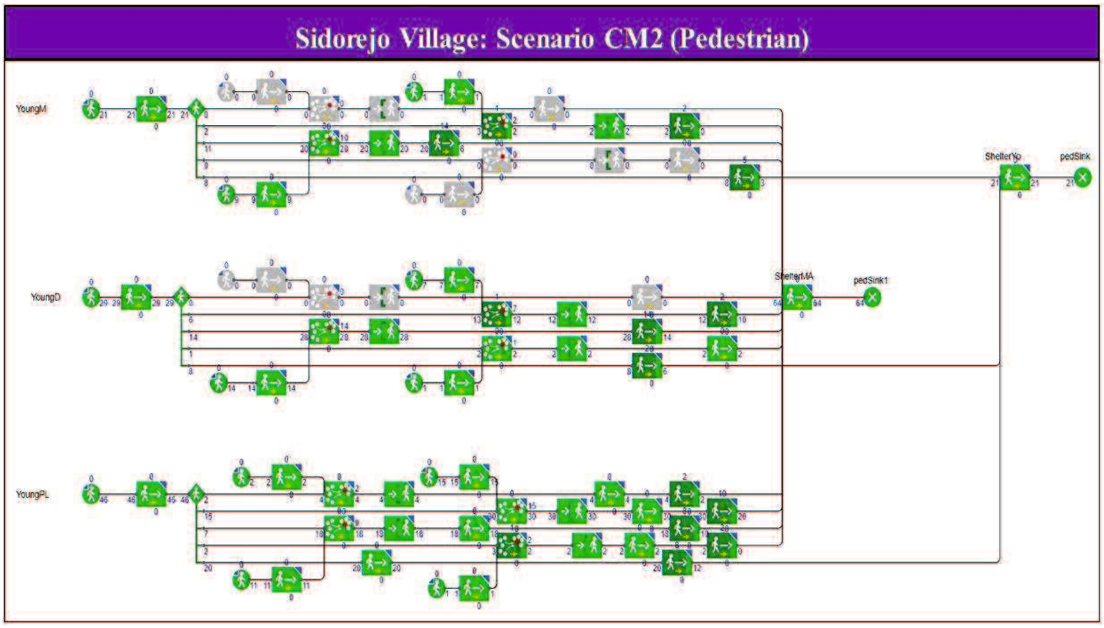

Figure B29. Simulation result in Sidorejo Village (CM2) pedestrian

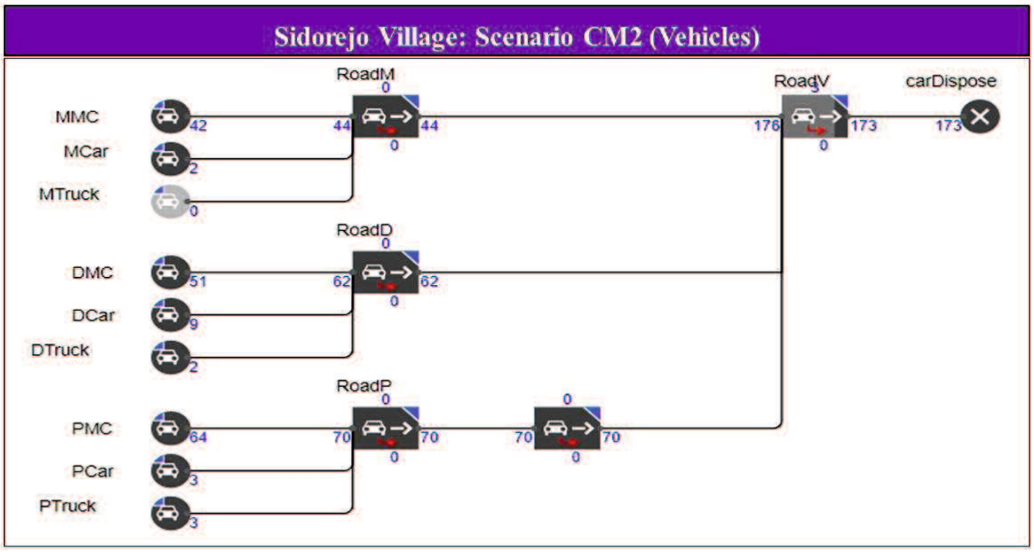

Figure B30. Simulation result in Sidorejo Village (CM2) vehicles

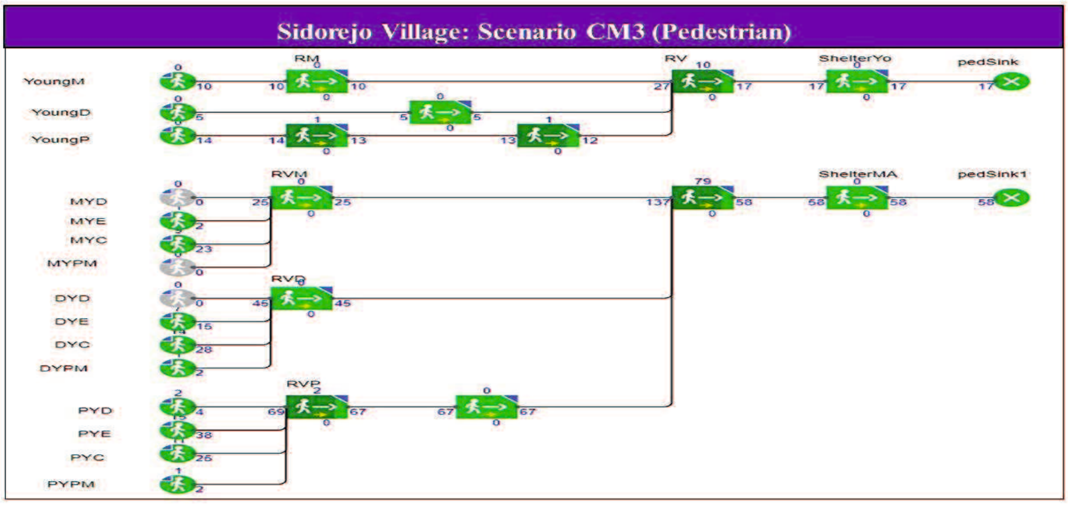

Figure B31. Simulation result in Sidorejo Village (CM3) pedestrian

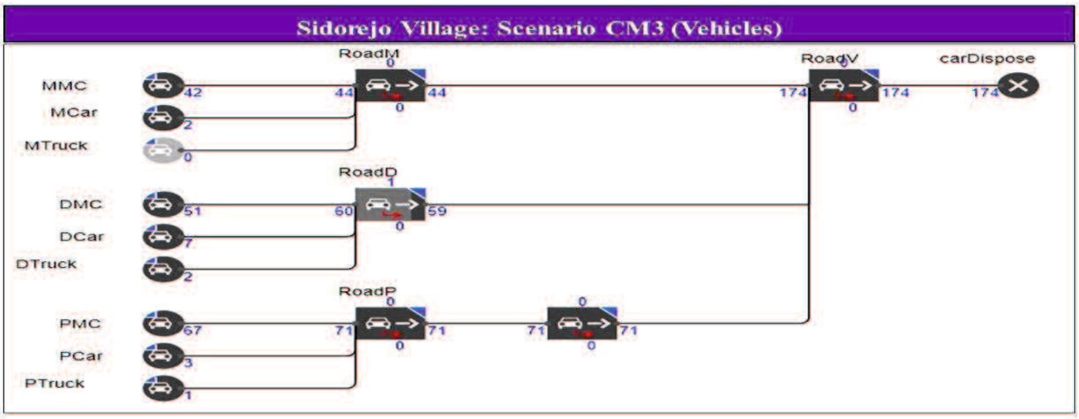

Figure B32. Simulation result in Sidorejo Village (CM3) vehicles

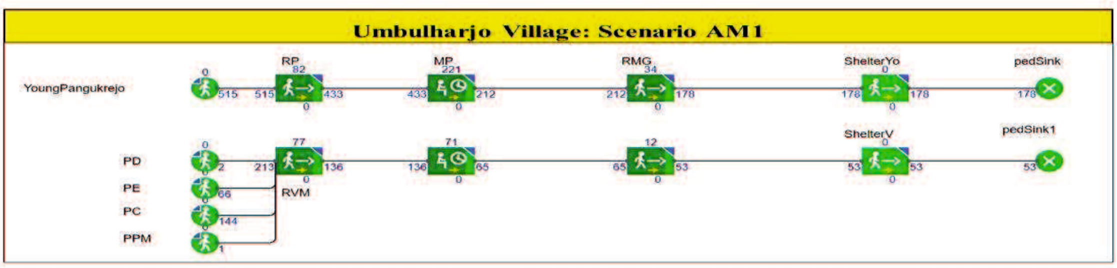

Figure B33. Simulation result in Umbulharjo Village (AM1)

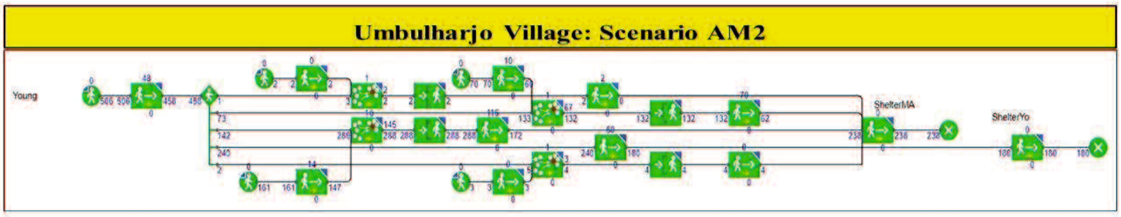

Figure B34. Simulation result in Umbulharjo Village (AM2)

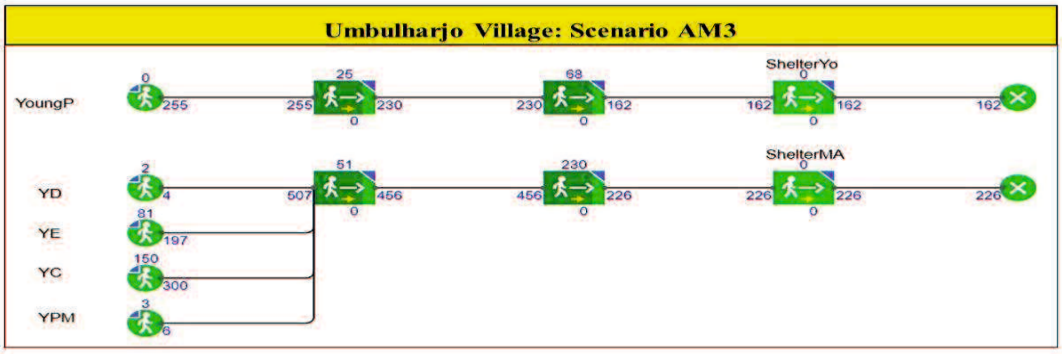

Figure B35. Simulation result in Umbulharjo Village (AM3)

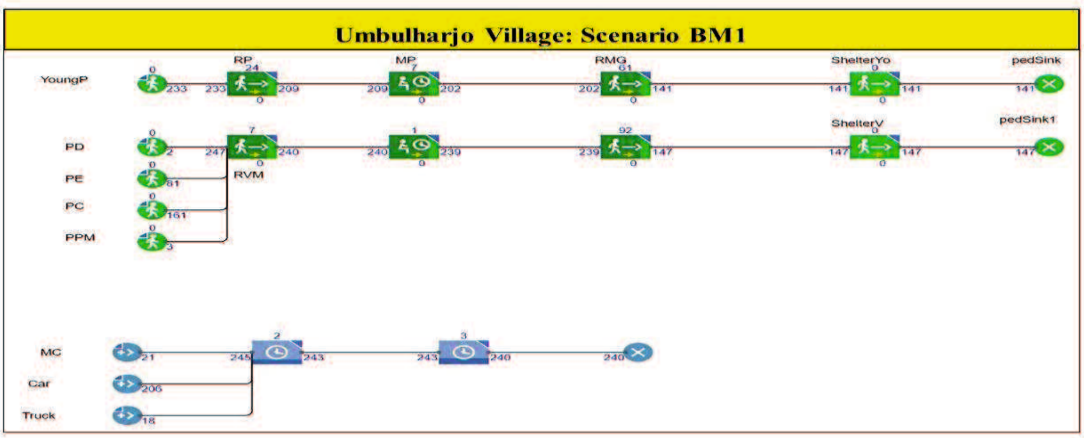

Figure B36. Simulation result in Umbulharjo Village (BM1)

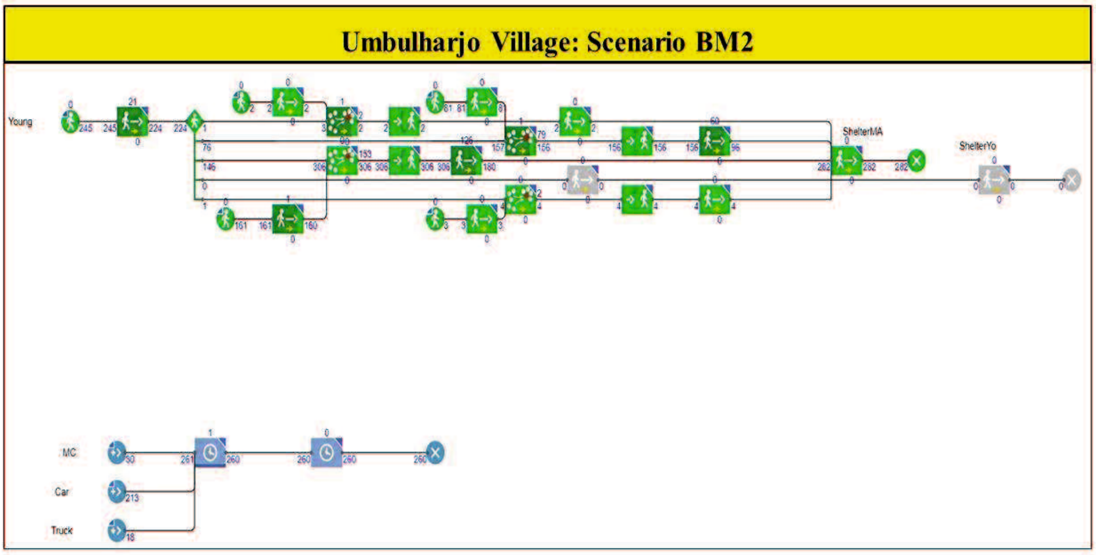

Figure B37. Simulation result in Umbulharjo Village (BM2)

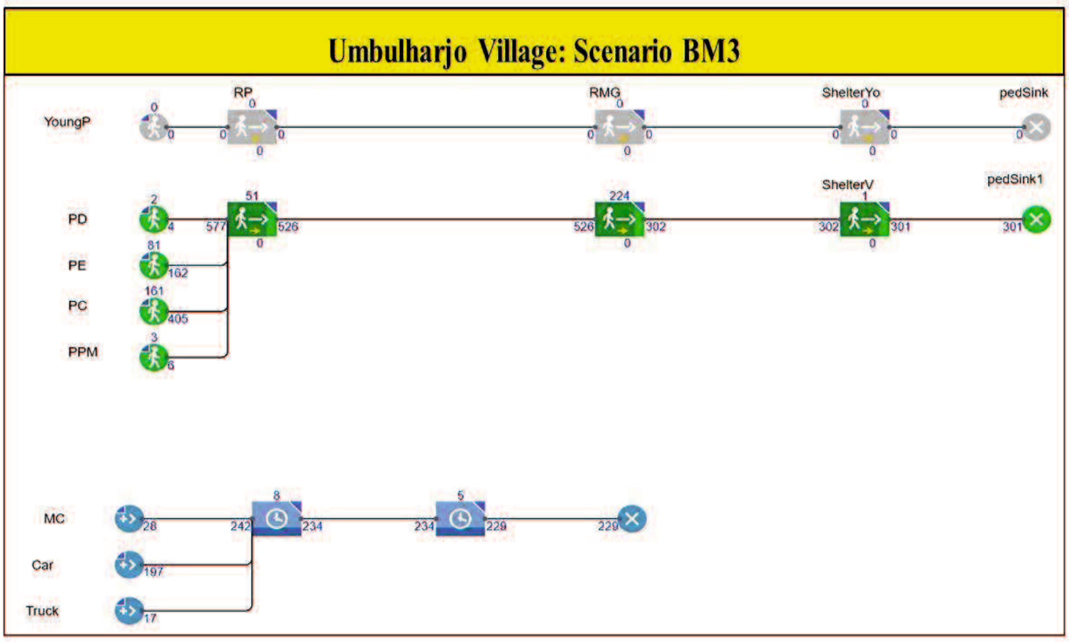

Figure B38. Simulation result in Umbulharjo Village (BM3)

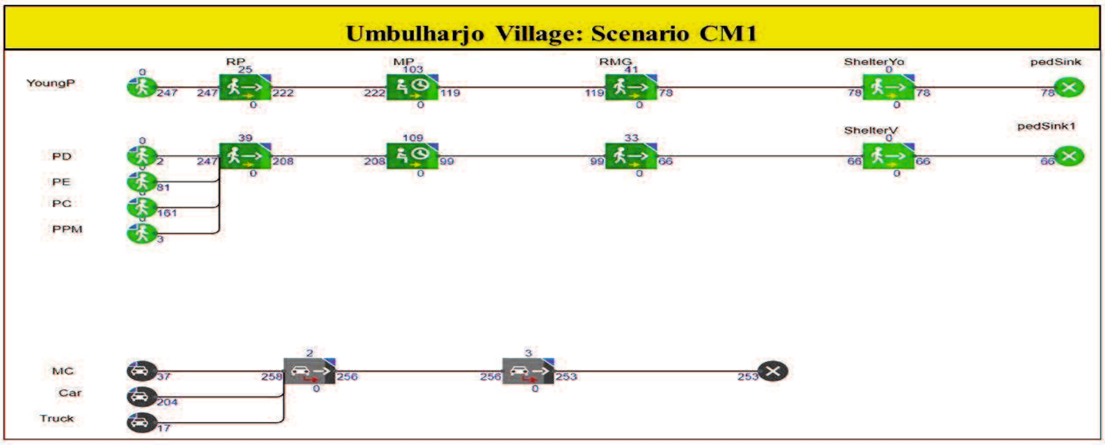

Figure B39. Simulation result in Umbulharjo Village (CM1)

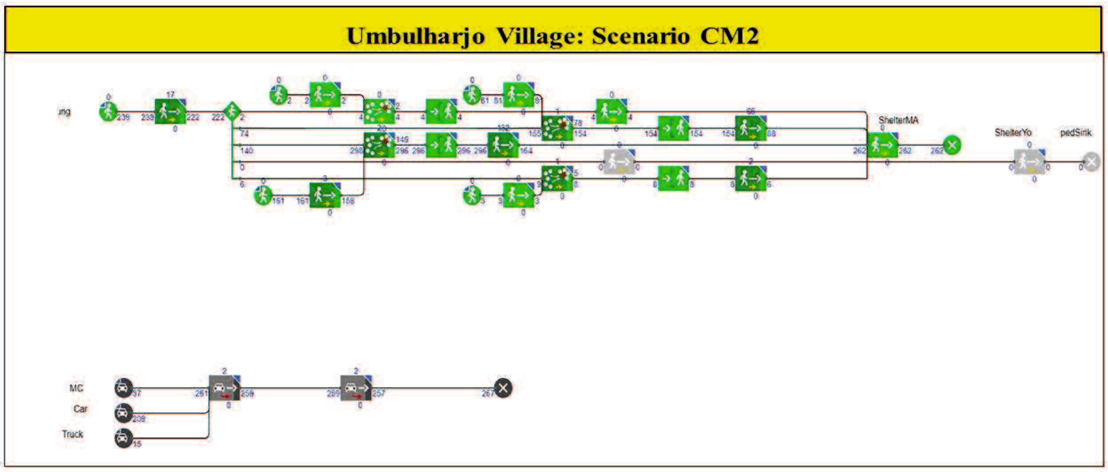

Figure B40. Simulation result in Umbulharjo Village (CM2)

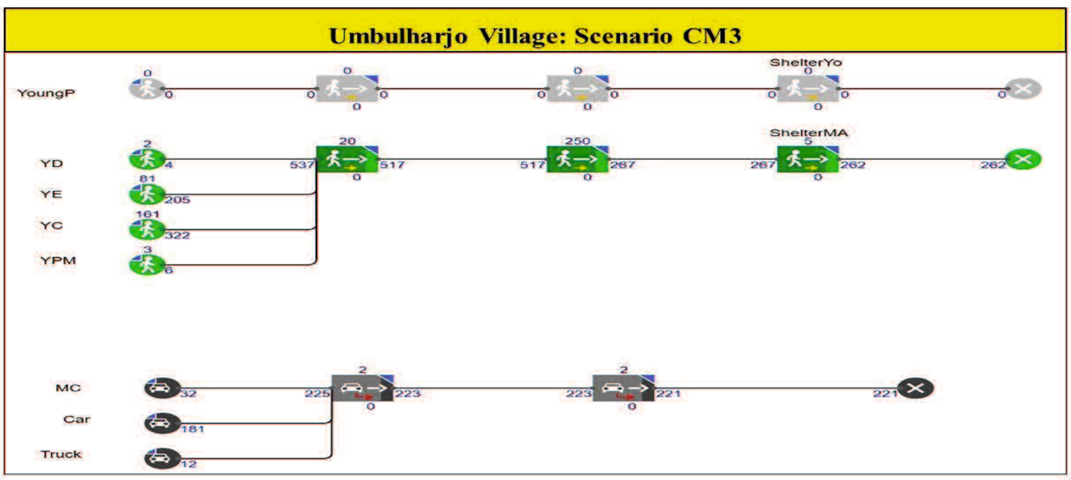

Figure B41. Simulation result in Umbulharjo Village (CM3)

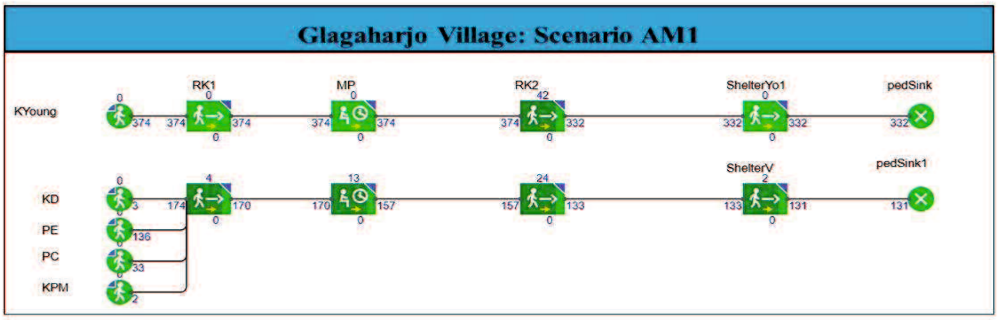

Figure B42. Simulation result in Glagaharjo Village (AM1)

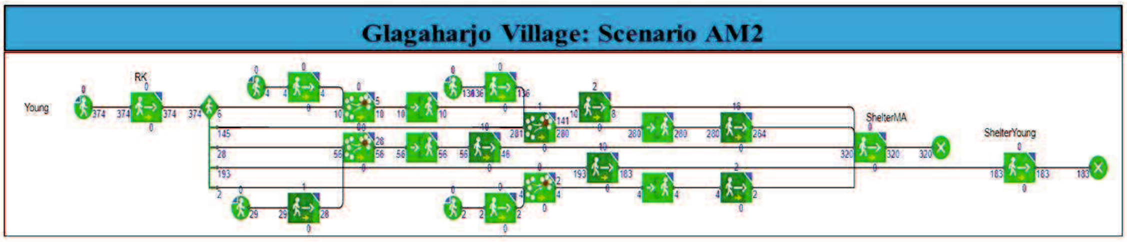

Figure B43. Simulation result in Glagaharjo Village (AM2)

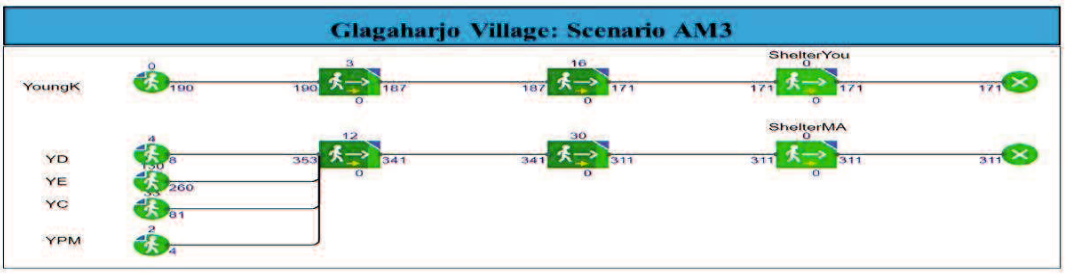

Figure B44. Simulation result in Glagaharjo Village (AM3)

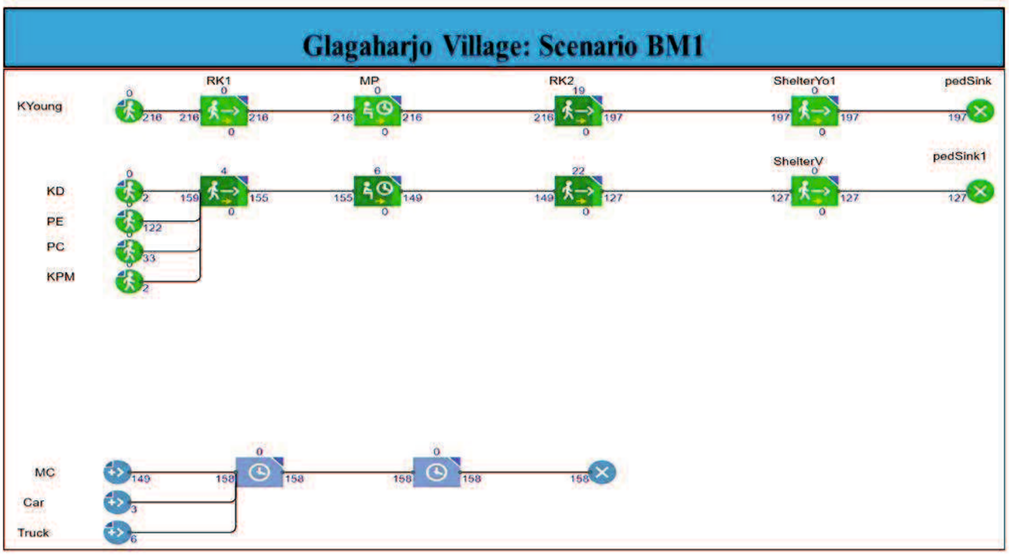

Figure B45. Simulation result in Glagaharjo Village (BM1)

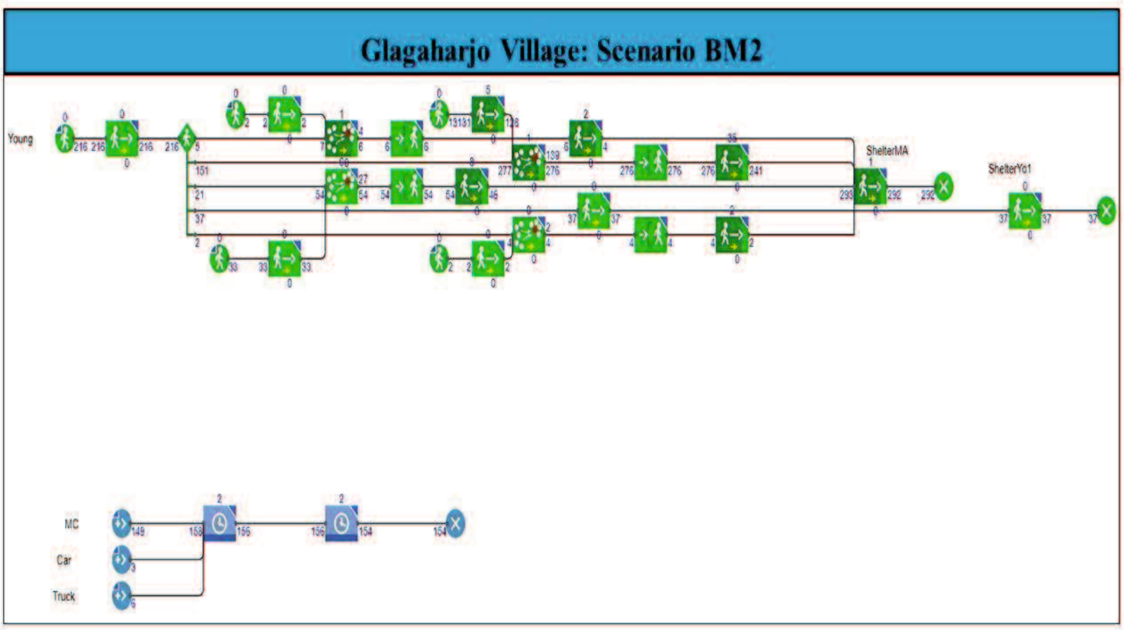

Figure B46. Simulation result in Glagaharjo Village (BM2)

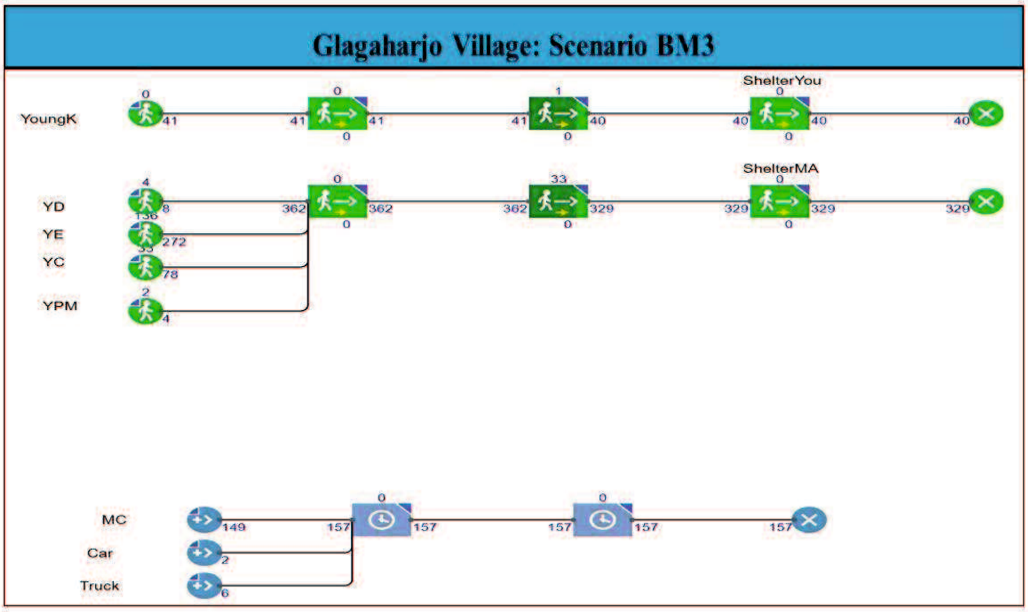

Figure B47. Simulation result in Glagaharjo Village (BM3)

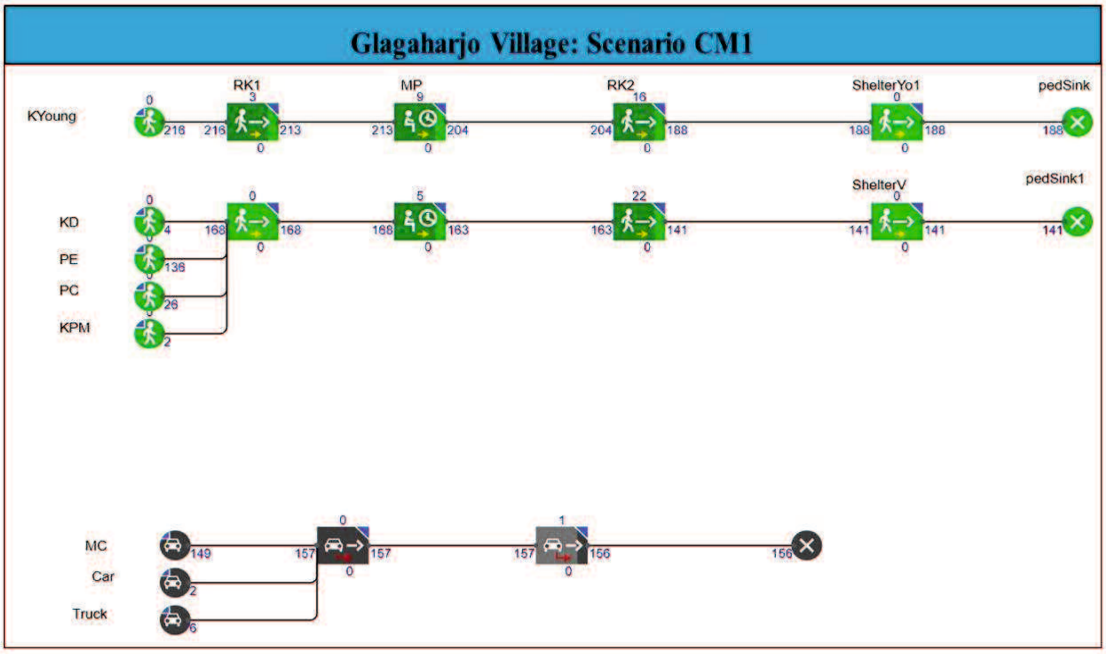

Figure B48. Simulation result in Glagaharjo Village (CM1)

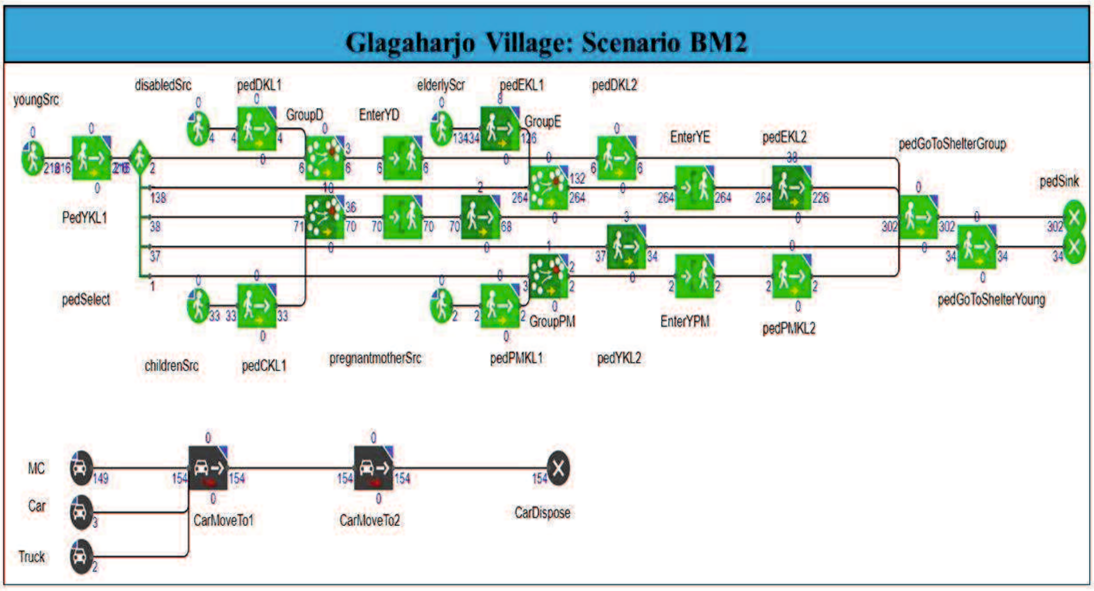

Figure B49. Simulation result in Glagaharjo Village (CM2)

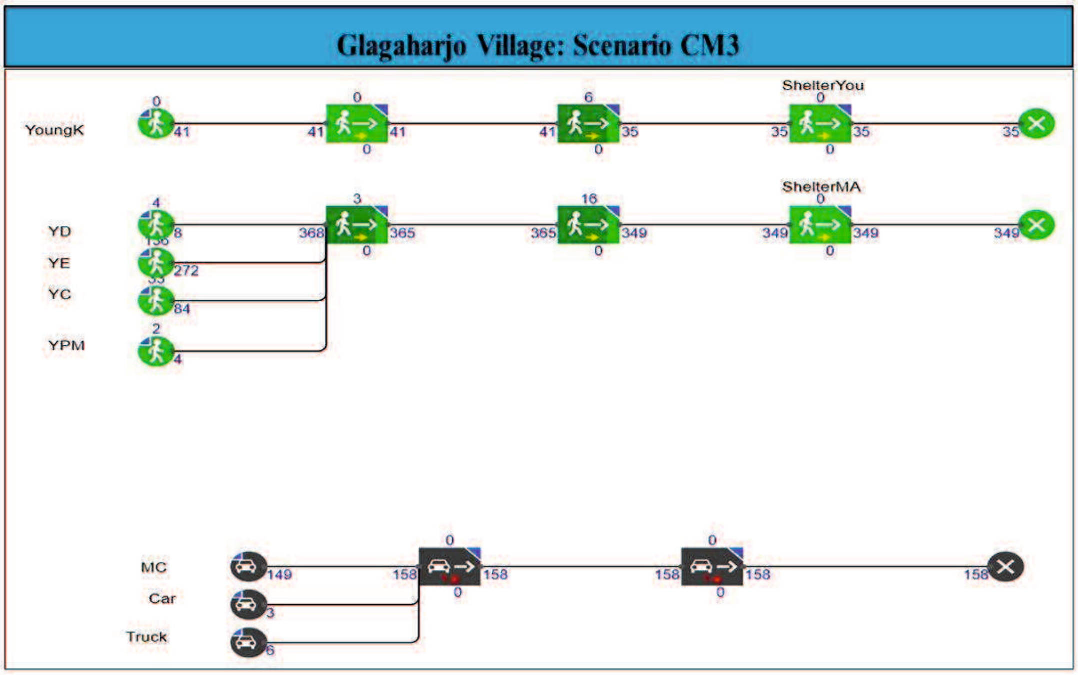

Figure B50. Simulation result in Glagaharjo Village (CM3)

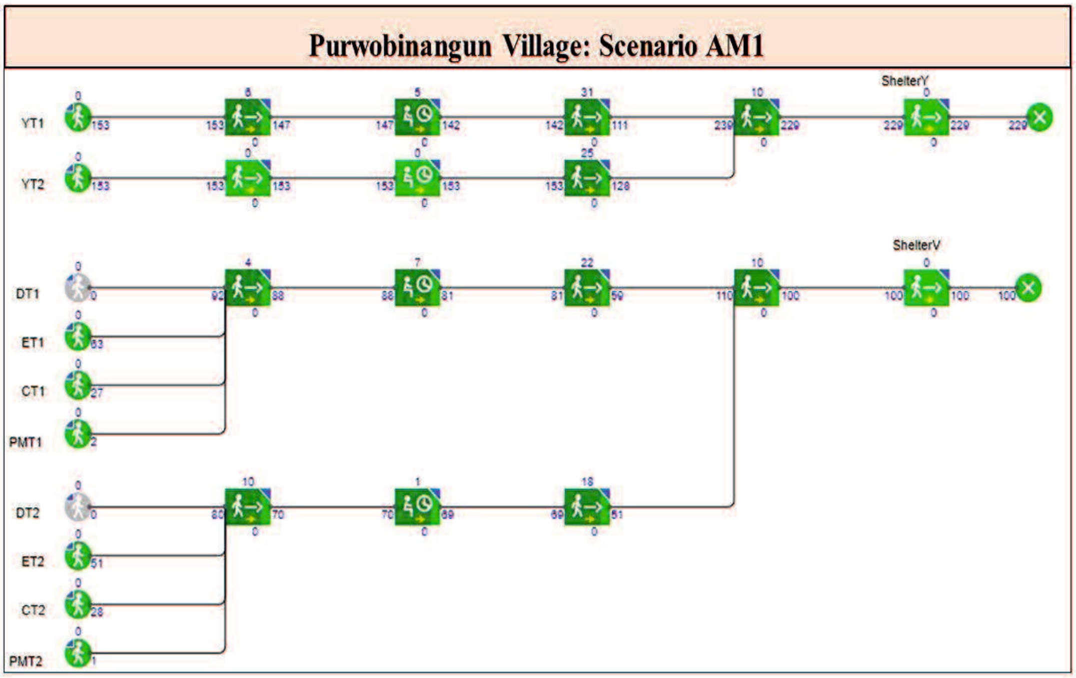

Figure B51. Simulation result in Purwobinangun Village (AM1)

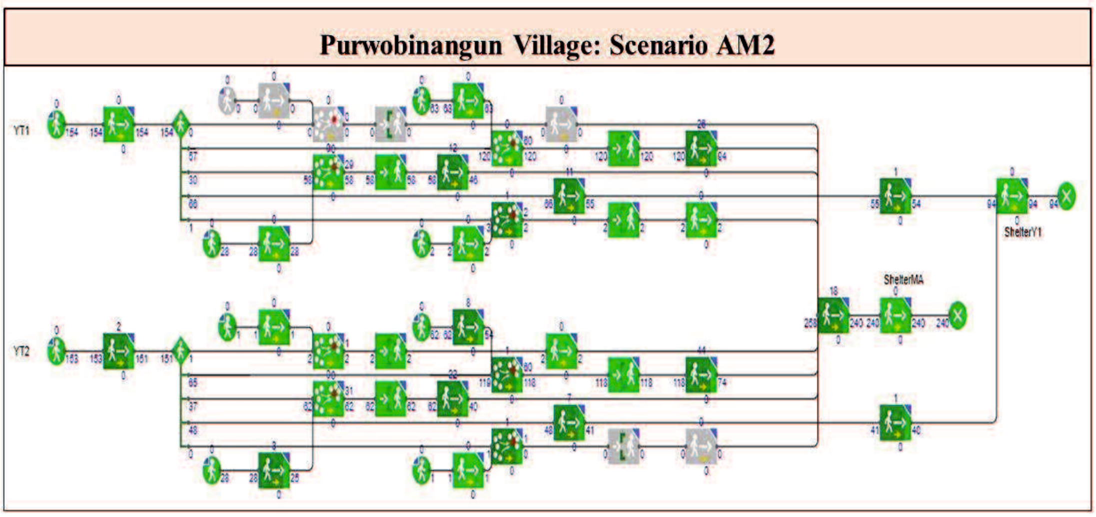

Figure B52. Simulation result in Purwobinangun Village (AM2)

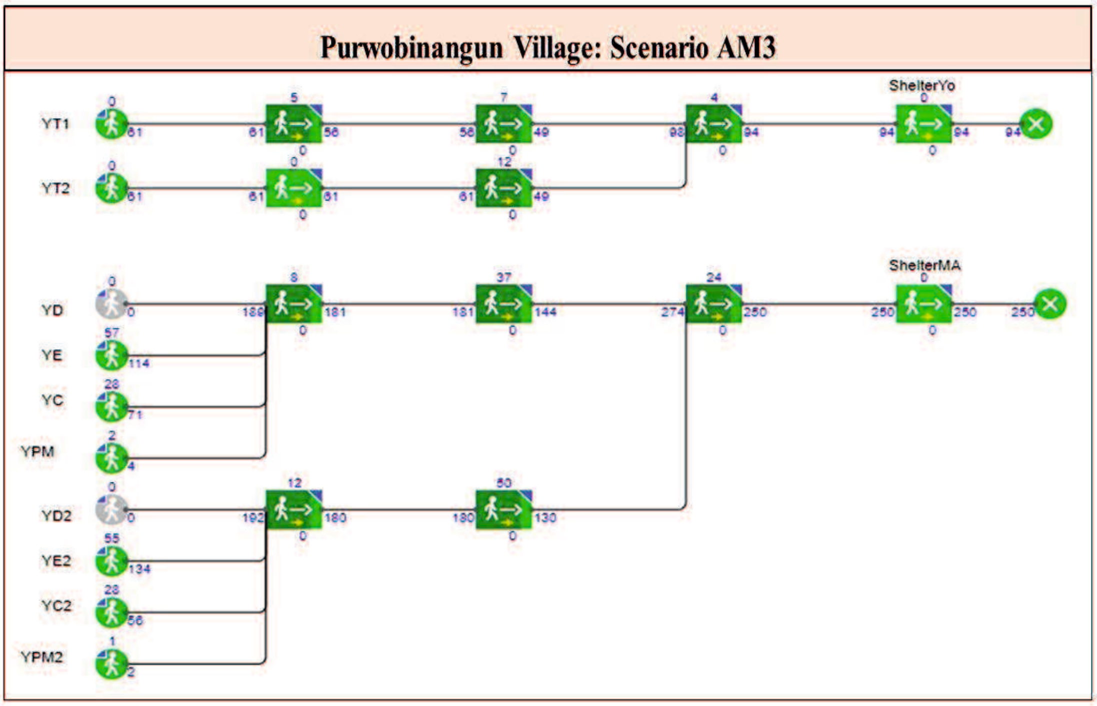

Figure B53. Simulation result in Purwobinangun Village (AM3)

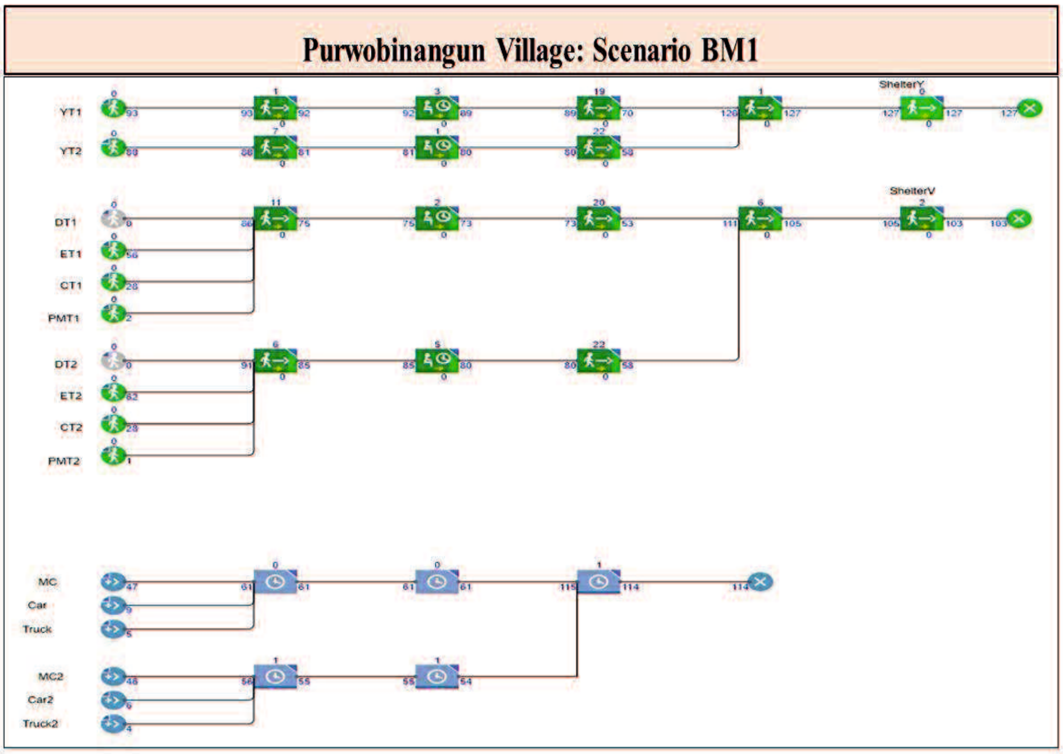

Figure B54. Simulation result in Purwobinangun Village (BM1)

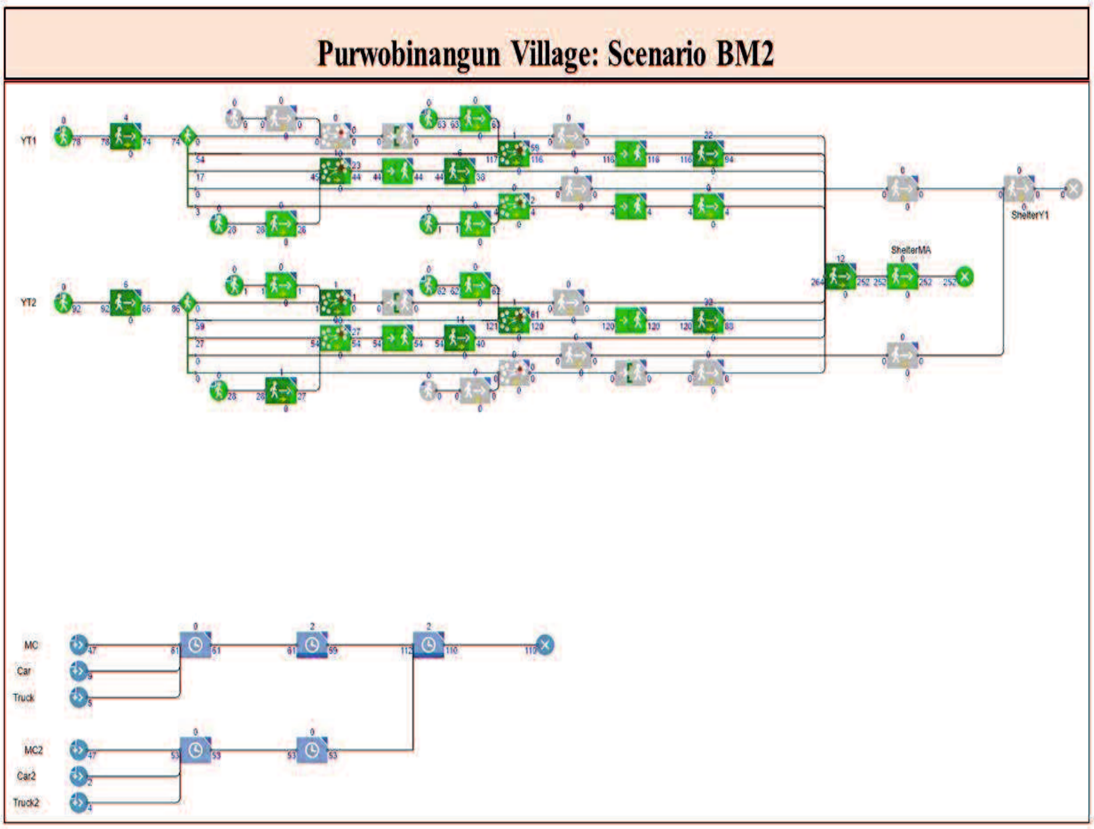

Figure B55. Simulation result in Purwobinangun Village (BM2)

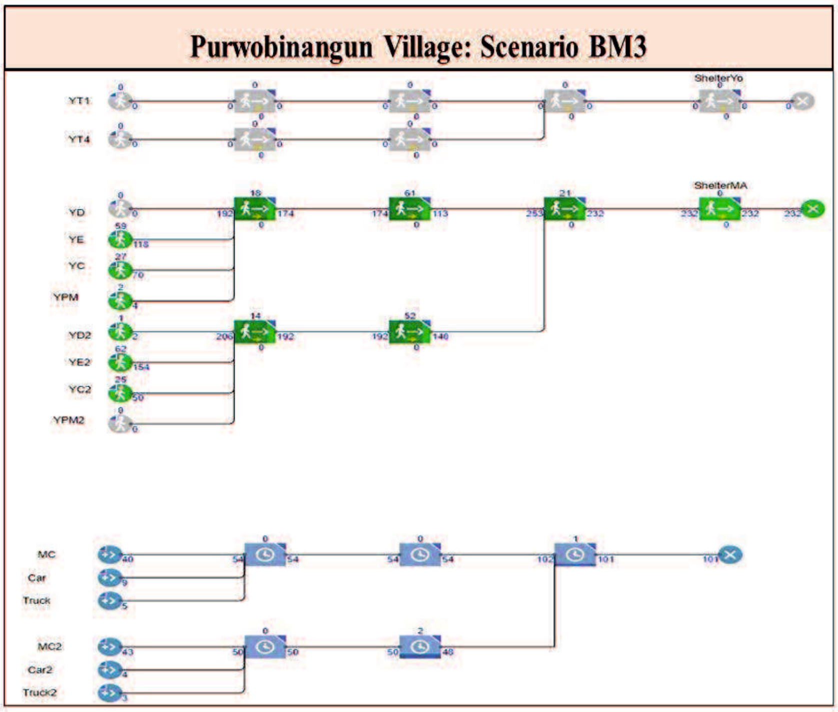

Figure B56. Simulation result in Purwobinangun Village (BM3)

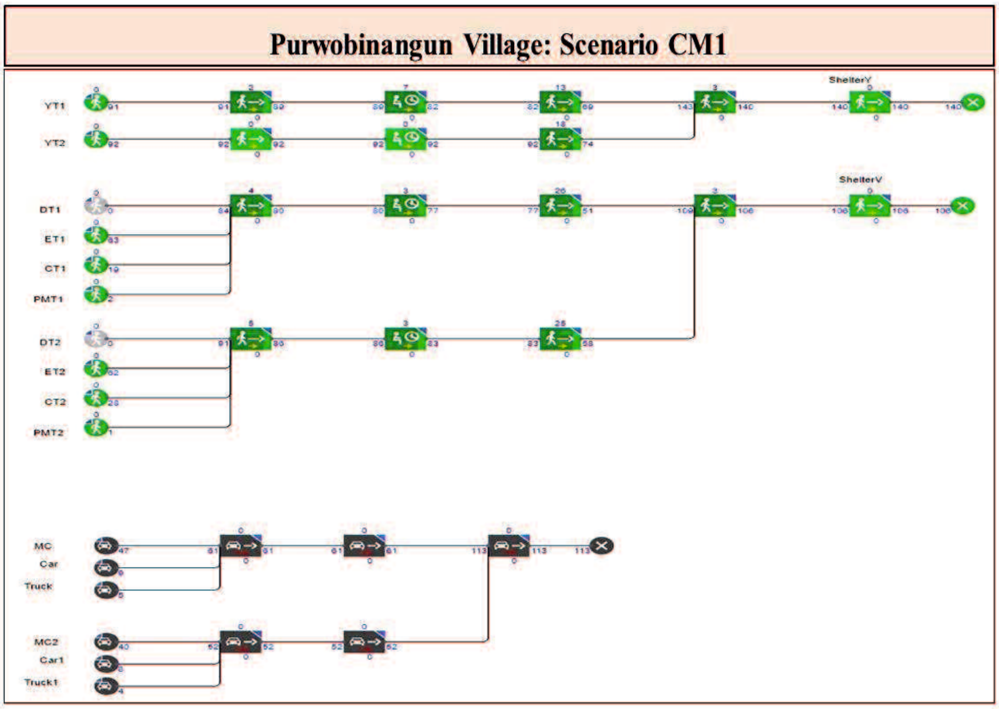

Figure B57. Simulation result in Purwobinangun Village (CM1)

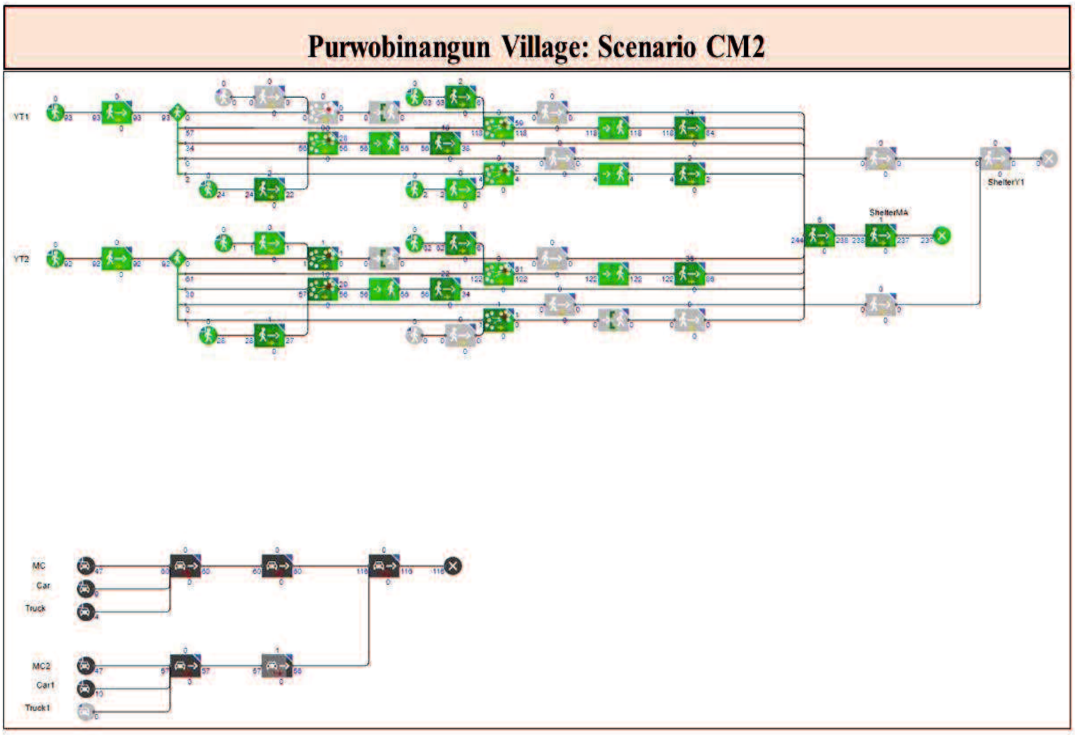

Figure B58. Simulation result in Purwobinangun Village (CM2)

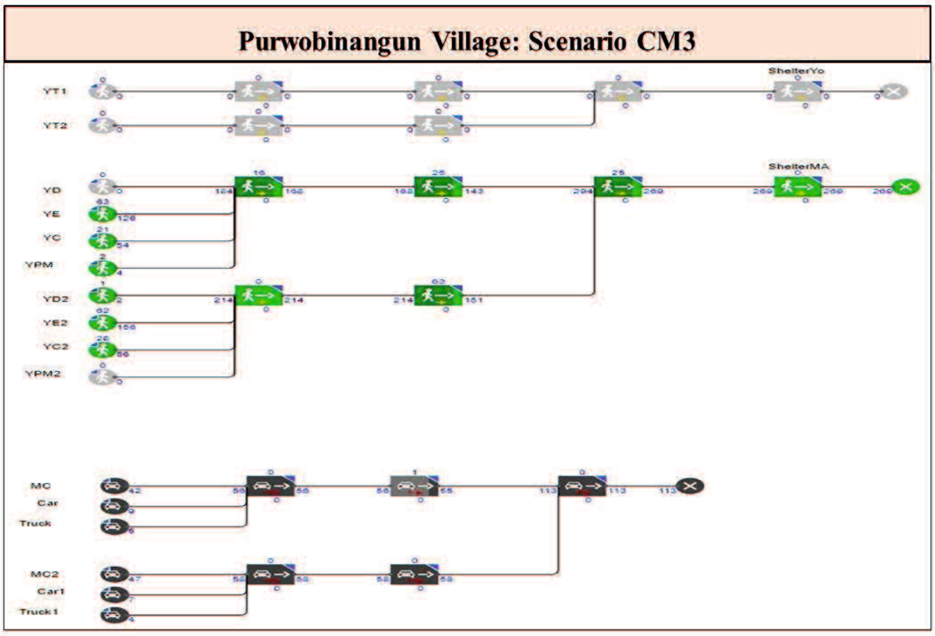

Figure B59. Simulation result in Purwobinangun Village (CM3)

C. LIST OF PUBLICATIONS

1. **Chasanah, F.;** Sakakibara, H. Assessment of Social Vulnerability in the Evacuation Process from Mount Merapi: Focusing on People's Behavior and Mutual Assistance. *Journal of Integrated Disaster Risk Management (IDRiM Journal)*. 2021, 10 (2), 15–34. https://doi.org/10.5595/001c.21409.
2. **Chasanah, F.**; Sakakibara, H. Implication of Mutual Assistance Evacuation Model to Reduce the Volcanic Risk for Vulnerable Society: Insight from Mount Merapi, Indonesia. MDPI, *Sustainability* 2022, 14 (13), 8110. https://doi.org/10.3390/su14138110.

D. LIST OF PRESENTATIONS

1. **Chasanah, F.**; Sakakibara, H. Assessment of Social Vulnerability in the Evacuation Process from Mount Merapi: Focusing on People's Behavior and Mutual Assistance. *The International Conference Special Issue on the Integrated Disaster Risk Management.* Virtual. September 23-24, 2020. (Oral presentation).
2. **Chasanah, F.**; Sakakibara, H. Construction of the Pedestrian Assembly Model for the Evacuation from Mount Merapi Eruption in Rural Area. *The 40th Annual Meeting of the Japanese Society of Natural Disasters (JSNDS).* Virtual. September 11, 2021. (Oral presentation).
3. **Chasanah, F.**; Sakakibara, H. Construction of an Agent-Based Evacuation Model for Vulnerable People: A Case Study of the Merapi Volcano in Sleman Regency, Indonesia. *Interdisciplinary Exchange Seminar Event.* Yoshida Campus, Yamaguchi University. March 22, 2022. (Poster presentation).