MULTI-DEPOT DISPATCH FOR ROUTING HEURISTICS USING LOCATION-ALLOCATION INSTANCES ON FORMULATING FLOOD PRONE DEMOGRAPHY IN SARAWAK

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SULTAN IDRIS EDUCATION UNIVERSITY

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Before writing this, I spent a year doing self-reflection, searching for the words that could convey my honest opinion. My innermost feelings will be understood by everyone who has traveled this path. Intense peer pressure asphyxia from virtually everyone else, unspoken demotivation that oozes out of your soul with every breath, and an inability to adjust into a new person that you aren't yet while stuck living in yesteryear. The daily cycle of never-ending emotional division, waking up to experience each new day like it was yesterday, and harboring remorse and misconceptions whenever the topic of "higher education" is discussed. This trip alone has taught me that people's deceptive intuitions, even if they have pedantic intentions, should not be easily trusted; because what may seem as motivation at first is simply an individual's avarice for achieving their ideal level of success by using us as a stepping stone toward it. While they smile and comfort us in dark times, those who receive favors that they didn't earn from us become resentful the moment they need to rectitude it. Those who appear to have noble intentions but thoroughly rear-end shiv instead. I gave benefits to those who treated me with contempt. I was able to grow as a person throughout this period of postgraduate study alone, exploring aspects of myself that I never would have known at 10. When I was young, I never thought at any point in life in the future that I could type with my eyes closed or explore coding jargon that commoners would scratch heads for. The void feeling within these 5 years, not including my few years of Master's degree, made me learn how to perceive people in a different light. Rather than merely helping me become a scholar in a field that most individuals will never even heard of, this journey is intended to be more of a continuous source of nourishment that emphasizes the nurturing parts in my next chapters of life. This life journey showed me to be aware of people's intentions because sometimes our misguiding intuitions may be accurate in the end. The lessons we gained about distinguishing what sets them apart from us are what empower us to embrace and relate to them more fully, whether it's about refraining from becoming like them ourselves or projecting their attributes onto ourselves as a growth catalyst in steering our attempts at bettering ourselves. Looking at you, *undelivered promises*. Pledges are given easily in the heat of the moment, but promises should not be reneged as if they never occur. Thanks to my supervisor who's with me through thick & thin, Dr Wang Shir Li. As a final note, thank you to Yayasan Sarawak for the brief extended lifeline of scholarship in the middle of my studies when I had already given it all up. Those slight years of receiving gratification at the semester's beginning for accomplishing something that not many can do gave me the intrepid nudge to persevere until the end, even if with or without its privileges and consequences. And love you so much, Mom.

ABSTRACT

Disaster relief logistics is vital for effective disaster preparedness and response, involving strategic depots and distribution networks. Intelligent decision-making optimizes routing and customer targeting, while heuristics predict expenses for round-trip deployments. Recent efforts aim to develop temporary logistics solutions to meet demand and enhance coverage. Presently, distribution networks designed to address the lack of a strategic autonomous intelligent relief distribution network also prioritizes specific proposals that involve tradeoff in prioritizing demographic priorities while optimizing resource allocation for tasks. This research employs computational intelligence to improve a scheduling model for distributing commodities in flood-prone, low-lying divisions of the Sarawak region. To attain minimal resource use and optimal route coverage, the Multi-Depot Vehicle Routing Problem, tailored for this scenario, integrates advanced routing optimization techniques with demographic clustering. The research framework integrates sophisticated data clustering and computational intelligence methods, featuring a variant of the genetic algorithm with repopulation crossovers, alongside several important iterated local search techniques (Clarke-Wright savings algorithm, route relocation, Greedy, and Tabu search) to enhance flood relief routing schedules. The study shows how to enhance flood relief distribution by improving local search heuristics and shortest path estimations. Furthermore, the study augments coverage areas, reduces costs, and increases operational efficiency. The routing heuristic method, combined with autonomous computational intelligence techniques, had positive results for costs and overall routes. The method identifies customer-depot links intelligently whilst adhering to the conditions of an established set of parameters. Ultimately, the study displayed the viability of developing disaster-tailored solutions for flood mitigation selections to deliver relief supplies during phases of crisis response. The study can be considered a proof-of-concept for establishing efficiently a scheduling system coupled with flood mitigation for the Sarawak region, which depends on the related solution heuristics (MDVRP instance) of preceding research.

PENGHANTARAN MULTI-DEPOH UNTUK PENJADUALAN HEURISTIK HALUAN BERDASARKAN PERUNTUKAN LOKASI DALAM MEMBENTUK DEMOGRAFI RENCANA BANJIR DI SARAWAK

ABSTRAK

Penjadualan logistik bencana merupakan elemen penting dalam usaha pengurusan bencana alam bagi mangsa yang memerlukan prosedur persediaan semasa dan perlaksanaan maklum balas bantuan bencana kepada kawasan terjejas. Hal ini termasuk aspek peruntukan lokasi bagi agihan bekalan bantuan bencana, sebagai contoh usaha mengenal pasti kawasan strategik tumpuan agihan bekalan kecemasan dan penentuan corak pembahagian bantuan bencana yang berdaya efisien dan proaktif. Aplikasi kepintaran komputasi telah diintegrasi oleh beberapa kajian berkaitan logistik bencana dalam usaha penyelarasan pengoptimaan penjadualan bantuan bencana bagi kawasan berkait di samping ciri-ciri kepintaran buatan dalam mengelaskan kluster kumpulan pengguna tumpuan utama dalam usaha memaksimumkan edaran bekalan bantuan kepada kawasan bertumpu. Penyelarasan corak agihan bantuan bencana berdasarkan aplikasi heuristik yang mengambil kira jarak terdekat bertujuan menjana dan mengagak strategi penyelesaian masalah dari segi kos berbangkit pada kadar minimum di samping mengelakkan pembaziran sumber dalam sesuatu penempatan pergi-balik bantuan bencana. Penyelidikan ini bertujuan mengintegrasi kecerdasan komputeran untuk membangunkan model penjadualan bagi strategi pengedaran komoditi untuk kawasan risiko banjir di Sarawak berdasarkan heuristik MDVRP untuk mengenal pasti dan menyelesaikan permasalahan objektif urusan pengendalian pengangkutan agihan bantuan bencana dalam usaha mencapai kadar peruntukan agihan sumber minima di samping menggalakkan liputan laluan maksimum. Antara heuristik pencarian yang dilaksanakan dalam ciri pengoptimuman termasuk penjarakan laluan terpendek dan gabungan heuristik carian dalaman yang ditumpukan terhadap usaha menjana strategi penyelesaian terbaik bagi aspek kawasan liputan maksimum dan meminimakan kos tanggungan akhir. Heuristik penjadualan agihan yang dicadangkan menunjukkan prestasi yang lebih baik berbanding algoritma genetik asas, berdasarkan ujian simulasi antara pendekatan pengklusteran pengguna dan heuristik jarak terpendek. Keputusan ini menekankan kepentingan strategi pengasingan laluan yang berkesan dalam memastikan agihan barangan bantuan segera ke kawasan keutamaan dilakukan dengan lebih cekap. Penyelidikan ini membuktikan manfaat aplikasi MDVRP dengan aplikasi dunia sebenar seperti perancangan agihan bantuan bencana

dalam usaha membangunkan sistem kepintaran perancangan bantuan bencana merangkumi keseluruhan negeri Sarawak.

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LIST OF ABBREVIATION

A*	A-Star Algorithm
ABC	Artificial Bee Colony
ACS	Advanced Cuckoo Search
ACO	Ant Colony Optimization
BFS	Breadth-First Search
CVRP	Capacitated Vehicle Routing Problem
CW	Clarke-Wright Algorithm
EA	Evolutionary Algorithm
GA	Genetic Algorithm
HADC	Humanitarian Aid Distribution Centres
HL	Humanitarian Logistic
LSH	Local Search Hybrid
MDVRP	Multi-Depot Vehicle Routing Problem
MOP	Multi-Objective Problems
PSO	Particle Swarm Optimization
SOS	Symbiotic Organisms Search
TSP	Travelling Salesman Problem
VRP	Vehicle Routing Problem

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VRP-TW	Vehicle Routing Problem with Time Windows

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Disaster logistics have been subjected to operational study to aid those in need as efficiently and effectively as possible. Emergency relief methods have been integrated with automated systems that identify the preventative steps to be performed in the event of a disaster (Gharib et al., 2018; Sun et al., 2022). This component entails thorough preparation of humanitarian supplies among the most vulnerable populations as well as choosing an optimal place as a structured distribution point. The primary reasons for each catastrophe relief logistic schedule are to reduce total relief expenditures, enhance commodities distribution satisfaction, and effectively intersect devastated areas (Bruni et al., 2018; Morsidi et al., 2023a). Due to the unpredictable nature of catastrophes, research into enhancing real-time response is vital to cater to the effects of disasters.

Several traits of disaster relief infrastructures that are constantly emphasized or monitored to improve resource allotment include the availability of infrastructure logistics, population demography, resource availability, and transportation routes. These parameters are pivotal to better understanding the implications and situation of the customary distribution of disaster relief. There is a lacking in terms of credible techniques for devising an optimal strategy to plan the distribution of prioritized location-allocation issues such as seen for emergency resources in functioning under the most optimized effort, even though past studies have contributed to the improvisation of location-allocation purposes for disaster relief logistic scheduling by implementing emergency resource scheduling solutions (C.-M. Chen et al., 2023; Gharib et al., 2018; Y. Zhang et al., 2022).

The most important concepts upheld by disaster relief logistics management are responsiveness and efficiency (Guo et al., 2018; Maheshwari et al., 2023), which both interpolate versatility to respond to unanticipated scenarios over short periods as well as maximizing expenditures in which demand is constant and linear, respectively. Logistics is a critical component of disaster preparation, and the sort of infrastructure that must be deployed is entirely dictated by the amount of risk, the impacted environment, plus simulations for carrying out necessary tasks in certain scenarios (Tavana et al., 2018a; Vahdani et al., 2018; Y. Zhou et al., 2017). The dissemination distribution networks that constitute the crucial ingredient in disaster logistics require meticulous design and execution under tight time constraints to enhance efficiency. The often-demolished nature after the post-disaster period also reflects severe deficiencies in resources (commodities, transportation), and lack of partaking infrastructure, apart from reduced manpower.

Regarding resolving the ongoing problems encountered in disaster logistics, accentuated towards optimizing operations research techniques for emergency relief distribution management, vehicle routing problems are gauged as a routing criterion to address prominent issues encountered. Significant disaster response challenge contexts that have been significantly addressed to date in recent years involve lowering deployment interruptions and ensuring distribution coverage integrity, disaster severity/prioritization, and distribution effort quality (Alam & Faruq, 2019; Morsidi, 2022; Sun et al., 2022). Optimization techniques have been adopted by the complexity of optimization queries within disaster logistics to handle computationally complex tasks resembling real-world issues involving nonlinearity and inconsistency. Computational intelligence is frequently employed in disaster relief operations, such as developing strategy phases for supply distribution amongst dispatch facilities, facility tracking difficulties, evacuation transportation issues, and system grid strategic allocation (Alam & Faruq, 2019; Kunnapapdeelert & Thawnern, 2021; Morsidi, 2023a; Morsidi & Panessai, 2023; Ouhader & El kyal, 2017a). The most straightforward way to create a viable disaster recovery strategy is to establish a model that promotes decision-making in an essential area. Computational intelligence variants, which are frequently used to address numerous objective improvements in vehicle routing issues, are regarded as an intriguing option for supporting location-allocation strategies.

1.2 Problem Statement

For the decision-making features bound to scheduling logistics in the wake of a disaster aftermath, the dissipation of accommodating relief supplies to the affected victims is crucial because of their vulnerabilities at stake (Suryawanshi & Dutta, 2022; Y. Zhang et al., 2022). Among the logistics, sub-problem management issues during a critical situation are the appropriate mechanism that could be identified for dealing with classifying prioritized demands and allocating strategic distribution centers for the preparedness and response phase (Morsidi, 2022; Revanna & Al-Nakash, 2023). The success of a robust disaster relief logistic scheduling is greatly influenced by the distribution capacity and choice of total traversed areas, as the quantity and location of distribution centers become the negative factor of response time and operation cost representing the entire supply chain network (Ali Torabi et al., 2018; Saeidian et al., 2018; Sun et al., 2022). For crisis management to function optimally and provide an appropriate response to damaged areas, several factors of uncertainty and credibility are considered, such as operational costs, time, supplies, and labor (Saeidian et al., 2018; Sularno et al., 2021; Tavana et al., 2018a).

i. What are the main issues arising for multi-depot dispatch and routing heuristics techniques particularly involving disaster relief logistic scheduling?

The primary difficulty in multi-depot dispatch and routing heuristics is managing vehicles and routes among multiple depots while complying with restrictions such as vehicle capacity, delivery time frames, and customer requirements (Nura et al., 2022). Allocating customers to depots requires managing workloads to avoid both excess and insufficient utilization. Following assignments, enhancing vehicle routes turns into a computationally demanding task, particularly for reducing travel expenses. Issues occur with depot collaboration, like transferring goods or sharing vehicles. Real-life elements, such as traffic and weather, add additional unpredictability. Since the problem instance is NP-hard, heuristic approaches, while typically faster, comes with trade-offs, and adapting these solutions for larger systems complicates matters further (D. G. N. D. Jayarathna et al., 2021; Morsidi et al., 2023b). Conventional methods of optimizing vehicle schedules, including trial-and-error, deductive reasoning, and practical expertise, are ineffective and cannot ensure optimal outcomes. Making decisions for disaster mitigation preplanning implies high uncertainty due to influencing factors, primarily resource and coverage boundaries (Sun et al., 2022). For example, supply-demand forecasting is typically based on educated assumptions. Furthermore, a lack of trustworthy information regarding deteriorating roads and damaged infrastructure could render estimating the duration it will require to get from one place to the next challenging. Because transportation resources are scarce, the problem becomes more complicated. However, if certain good computational intelligence algorithms enhance the solutions, the deviation from the true optimal solutions caused by ambiguities can be prevented.

ii. *What are the gaps observable for multi-depot dispatch and routing heuristics techniques particularly involving disaster relief logistic scheduling?*

The shortcoming in multi-depot dispatch and routing heuristics arises from their failure to simultaneously attain optimality, scalability, and adaptability to real-world complexities (C.-M. Chen et al., 2023; D. G. N. D. Jayarathna et al., 2021; Nura et al., 2022). These methods prioritize fast solutions rather than the best outcomes, restricting their efficiency in cost-sensitive situations. They are unable to efficiently handle shifting conditions such as traffic interruptions and do not have inter-depot cooperation systems in place (Szmelter-Jarosz et al., 2021). Scalability challenges emerge with larger problem sizes, leading to longer computation times and diminished solution quality. Additionally, these heuristics frequently lack integration with advanced technologies. To tackle this issue, hybrid methods are required that utilize sophisticated algorithms, real-time flexibility, and multi-objective optimization. Vehicle scheduling is a multi-objective restricted optimization problem. Using multi-objective optimization techniques such as vehicle problem-solving and metaheuristic optimization (Revanna & Al-Nakash, 2023; Vahdani et al., 2018) may ease the design of disaster relief logistics scheduling. The logistic distribution ought to be swift and objective to reduce casualties while still assisting those affected. Additional objectives are developed inside the planning systems to deal with specific difficulties, such as constraining transportation costs and evaluating demand fulfillment in terms of resources as well as distribution time. A collection of viable solutions that lower any of the goals might not exert an identical influence on the other objectives. Disaster relief planning often focuses on goals like improving transportation services and supporting community well-being (Gharib et al., 2018; Vahdani et al., 2018). However, there's a clear gap in evaluating effective vehicle scheduling systems for logistics. Better inventory management and streamlined operations could significantly enhance the efficiency of aid delivery. Techniques of computational intelligence, such as evolutionary computation, can enhance decision-making and boost overall efficiency. Simulating distribution patterns in the preparation stage can shorten the time required for logistics modifications, allowing for rapid adjustments to vehicle schedules rather than beginning anew. This method improves the effectiveness of distribution and agility in times of crises.

iii. *What is the problem of using location-allocation instances technique in disaster relief commodity distribution?*

The aim of location-allocation methods in disaster relief is to address the urgent and evolving nature of emergencies; however, they often face challenges like rapidly shifting demands, disrupted transportation networks, and limited access to real-time data (D. G. N. D. Jayarathna et al., 2022; Morsidi & Budiman, 2023; Sun et al., 2022). Traditional techniques may be slow, needing extended computation times that lead to significant decisions being postponed. They also overlook resource limitations and the complex dynamics of supply chains. Balancing efficiency, like cutting costs or delivery times, with equitable resource distribution poses additional difficulties, especially in major disasters that impact several centers and supplies (Morsidi, 2022; Tavana et al., 2018b). Moreover, these approaches lack effective coordination mechanisms among stakeholders, highlighting the need for more flexible, prompt, and collaborative strategies tailored to the complexities of disaster response. Although there have been advancements in computational intelligence for disaster emergency operations, there are still few effective strategies available for enhancing logistic scheduling in disaster relief. The majority of current models, encompassing metaheuristic, stochastic, and deterministic methods, mainly concentrate on singular optimization objectives, like resource and cost effectiveness (Maheshwari et al., 2023; Marković et al., 2020; Olcaytu & Kuyzu, 2018). They often focus on fixed problem elements, overlooking the necessity for flexibility in single-objective tasks. Moreover, the uncertainty of data makes heuristic approaches less appealing for multi-objective situations, even though they are quick. The successful use of heuristics necessitates prior knowledge to guide predictive approaches, whereas existing methods may result in high computational and operational expenses. Consequently, improved representation of uncertain variables in scheduling is vital for enhancing distribution tactics in regions susceptible to disasters.

The following study intends to integrate the distinct characteristics of computational intelligence methods into the creation of a multi-objective disaster relief scheduling design which is intended to complement the existing approach and strategies in improving the current emergency response preparedness phase. The principal objectives of the research study include examining coverage distance values alongside cost optimality and ultimately providing an optimization heuristic that has the potential to optimize distribution node categorization and associations among traversal points for a routing network. The proposed framework has the goal of assisting critical decision-making for routing heuristics within disaster relief route deployment classification, in addition to exploring the practicality of computational intelligence in streamlining multi-objective problems associated with establishing the best relief distribution routing strategy, as well as investigating the constructive contribution of evolution methods in resolving prominent routing issues about distance allocation and routing optimization.

1.3 Research Objective

Despite the scientific community's recent dedication to developing adept operation research classification techniques to address the stages of preparedness and response within operational management, a rather below-average research effort on computational intelligence applications for supplementing decision-making processes was innovated towards resolving specific relief routing issues (Gharib et al., 2018; Morsidi et al., 2023a; Sun et al., 2022). These solution phases and techniques are interpolated based on the nature of the niche problems, which are usually concerned with route distance and resource allocation. Prior work on emergency relief route scheduling planning stages emphasized the relationship between two critical variables in deciding the performance evaluation for response efforts, namely routing capacity (travel time, distribution supply demands, travel distance) and infrastructure compatibility (distribution centers, supply chain, transportation capacities). Affected areas are prioritized based on the degree of severity of disaster aftermaths, with efforts to maximize cost allocation strongly related to route complexity (Luo et al., 2021; Sun et al., 2022).

Regardless of the scientific community's current commitment to the creation of effective operation research categorization methods for addressing the stages of readiness and reaction phases throughout the context of operational management, a generally inconsistent investigation of computational intelligence instances for enhancing decision-making processes has been implemented regarding handling certain relief routing issues. These solution phases and methodologies are mathematically interpolated depending on the particulars of the niche problems, which typically have to do with path mileage and resource allocation. The following highlights several distinctive main study objectives that would be emphasized as a baseline metric to further the analysis in theoretical framework representation and implementation of the proposed routing solution strategy.

i. *To develop design strategy for optimization of disaster relief logistic scheduling with uncertain variables representing the preparedness phase of disaster mitigation routing strategy based on computational intelligence frameworks,*

ii. *To identify relative scheduling mechanisms that could be improvised in stochastic optimization for modelling parameters in logistic networks, and*

iii. *To develop location-allocation based models with optimization heuristics for route complexity approximation as a better representation of disaster relief's preparedness and responsiveness stages.*

1.4 Research Questions

With the hindsight of the increasing number of unpredictable disasters, heavy casualties are constantly being reported apart from victims who are left unattended when emergency supplies are not distributed on time or strategically. These crises entail minimum response time for rescue efforts to be smoothly deployed. Not only does the issue of planning appropriately organized rescue efforts need to be enforced, but diligent supply chain logistics management is also seen as critical to reducing the impact of such catastrophes. As indicated by prior works, operational research models are identified to be proactive in successfully augmenting varied types of disaster logistics. Coordination between affected disaster areas is made possible via logistics transporting commodities between regional warehouses and affected squatters.

Disaster relief logistic scheduling is one way to increase the number of rescue operations, however this aspect still needs to get more adept at functioning with minimal amounts of human intervention. Through location routing, vehicle routing, and multi-objective optimization, disaster relief logistic scheduling modules that include multi-objective optimization, location routing, and vehicle routing are tested in this research investigation in a bid to enhance decision-making skills under time and resource restrictions. The key objective of the research is to address prevalent issues in current logistics management by covering an extensive spectrum of foundational issues. The following are included in the research conjecture:

i. *What are the most appropriate design strategies for modelling an acceptable routing complexity within the planning phase for a relief distribution system that is proficient for cost optimization?*

In order to accomplish cost optimization, it is necessary to balance a number of elements while determining the most suitable modeling parameters for producing an acceptable routing complexity during the planning phase of a relief distribution system (Chowlur Revanna & B.Al-Nakash, 2022; Kocaoglu et al., 2020; Morsidi, 2022; Y. Wang et al., 2021). Precise demand forecasting, well-planned distribution center placement, and careful modeling of variables like vehicle capacity, fleet size, trip duration, and distance are all necessary to maximize routing complexity in a relief distribution system (Giovanni et al., 2018; Kunnapapdeelert & Thawnern, 2021; Maheshwari et al., 2023; Morsidi, 2022). Road conditions, adherence to the law, and adaptability to last-minute adjustments are among the routing constraints, while labor, fuel, and maintenance are top cost factors. While exact procedures are effective for simpler issues, heuristic solutions are better suited for more complicated ones. Efficiency is improved through integrating real-time data and advanced analytics, taking environmental effects into account, and balancing cost and service levels. To minimize the maximal routing optimization strategy, this research study aims to establish the relevance of routing modeling in a premediate environment as a scaffold to a solution strategy that can be implemented in the real world. This includes determining the passable customer-depot interlink relationship, quantifying the extent to which compromises can be made in relation to modeling conjectures reflective of ideal parameter settings supported by autonomous decision-making in order to improve the deployment strategy for the preparedness and response phase of relief scheduling purposes (Morsidi, 2023c; Revanna & Al-Nakash, 2023).

ii. What are among the best improvisation techniques that could be invoked for the current automated solution strategy for annotating an effective routing deployment infrastructure to further optimize the disaster relief logistic distribution?

Adding cutting-edge methods and technology into the present automated solution plan is essential to further optimize disaster relief logistics. The integration of data from several sources, including social media and weather forecasts, can improve demand forecasting using advanced predictive analytics and machine learning. For instance, prepositioning supplies is made possible by machine learning algorithms that anticipate the places most likely to be impacted (Bruni et al., 2018; Tavana et al., 2018b). Prioritized and precise delivery routes are ensured by the use of geographic analysis and geographic information systems (GIS), which offer comprehensive maps and pinpoint important hotspots (Ahmadlou et al., 2018; Sularno et al., 2021). Reactivity is increased through real-time tracking of cargo status, road conditions, and vehicle locations using artificial intelligence integration.

The inquiry scope for this research study is to emphasize the application of optimization algorithms and heuristics in order to investigate a wider range of options and offer effective routing solutions in connection with enhancing coordination and situational awareness. Through the creation of logistics plans for various crisis situations, automated solution methods could enhance the implementation of current solutions by simulating and conducting scenario analysis, hence ensuring resilience. Real-time insights and recommendations can be obtained by combining automated decision support systems with computational intelligence approaches. This allows for dynamic route optimization and automation of planning. A more effective, responsive, and efficient disaster relief logistics system is ensured by incorporating these strategies into the current plan.

iii. *What is the output of the proposed method in optimization heuristics for route complexity approximation in terms of proficient representation of preparedness and responsiveness stages of disaster relief?*

Routing optimization strategies aim to improve cost optimality in disaster relief logistics by minimizing total logistics costs, including fuel, labor, and maintenance. Planning routing optimization according to nice purposes typically uses advanced predictive analytics and machine learning models to forecast demand accurately, allowing for better resource allocation and reduced unnecessary trips and fuel consumption. Dynamic route adjustments further optimize travel distances and times (Giovanni et al., 2018; Han & Wang, 2020; Zhao et al., 2017). By combining heuristic methods like Genetic Algorithms with other corresponding heuristic optimization strategies such as Tabu and Greedy search could assist in balancing computational efficiency with cost minimization, leading to overall operational cost reductions (Morsidi, 2023a; Nura et al., 2022). Another aspect associated with analysis on performance behavior in determining the most acceptable routing optimization under all circumstances is via maximizing resource allocation, in the form of minimizing the maximal resource allocation. Maximal route optimization focuses on minimizing travel time and distance while ensuring timely and adequate delivery of supplies (Han & Wang, 2020; Kunnapapdeelert & Thawnern, 2021; L. Zhang et al., 2022).

Intelligent decision support systems continuously analyze data and provide optimal routing recommendations, ensuring relief supplies reach affected areas quickly and effectively. The method is designed to handle varying scales of disaster scenarios, from localized incidents to large-scale catastrophes, while maintaining performance. Computational intelligence-based models can predict demand spikes and adjust logistics plans accordingly, ensuring the network remains functional despite disruptions. Predictive analytics will identify affected areas and prioritize resource allocation apart from monitoring affluent factors influencing any adaptation to the scheduling models, in turn enabling dynamic route adjustments (Han & Wang, 2020; Xu et al., 2018; Žunić et al., 2020). Automated intelligent decision support systems will continuously optimize routes, resulting in faster, more efficient deliveries, reduced operational costs, and improved service levels compared to traditional logistics methods.

1.5 Research Significance

Planning multiple facets and creating an enhanced strategy for handling practical issues in relief logistics demands assessing numerous goals at various stages of the planning process. Given that the present solutions prioritize the amount of interaction between humans and computational intelligence aspect in decision-making features, conflicting goals need to be established at the design stage of relief logistics that pertain to niche issues at hand. One of the key goals that remains constant is limiting unfulfilled requests, the consequences of cost reductions, and the shortest routes that are thought to be the most efficient in advancing the optimization of relief operation effectiveness and integrity in commodity allocation.

i. *Minimize the disaster's impact on society and maximize the welfare of the people in the disaster aftermath by developing a proper solution strategy for the distribution system in natural disasters*

A good disaster assistance distribution system is vital to improve the well-being of the community and reduce the impact of natural disasters. This element helps eliminate delays and waste, providing food, water, and medical support in an urgent, structured manner. Automated intelligent solutions help enhance stakeholder collaboration, simplify procedures, and enhance communication.

The system fosters resilience and flexibility by utilizing advanced analytics, scenario planning, and real-time monitoring, all of which enable the world to recover quickly from unexpected calamities. Environmentally sustainable processes lower ecological impact and optimizing routing increases cost-effectiveness. Thorough coverage ensures that assistance has equitable access, especially for last mile deliveries to remote areas. Using predictive analytics, data-driven decision-making plays an important role in accurate planning and continuous improvement, which is beneficial to recovery efforts and the communities affected. While there are many disaster relief scheduling systems, none provide comprehensive support to prepare local communities for unexpected disasters, for example in this research instance involving floods. It is believed that flexibility by using computationally intelligent systems will help in strengthening the local disaster preparedness and response plans.

ii. *Point out problems affecting well-known routing instances that could be resolved using computational intelligence architectures by recommending an effective framework with improved mechanisms for disaster relief commodity distribution planning*

To optimize the distribution of disaster relief supplies, it's essential to identify existing issues with routing systems and use computational intelligence frameworks for resolution. The creation of more precise and effective strategies can be achieved by organizations addressing issues like computational complexity and inefficient routing. Advanced techniques like machine learning, neural networks and evolutionary algorithms offer sophisticated approaches to complex routing problems that conventional methods might be unable to solve due to their flexibility. Establishing a strong framework that combines these computational intelligence methods guarantees a structured, scalable, and resilient approach to distribution planning. A streamlined system created to tackle essential routing issues boosts the speed of aid distribution in emergencies, while minimizing travel distances and operational expenses, thus enhancing overall effectiveness. This framework also preserves flexibility across various disaster situations and sizes. Constant progress through iterative enhancements and data-informed insights promote continuous development. Ultimately, this approach addresses not only current routing challenges but also improves disaster relief logistics by ensuring that timely and orderly assistance can reach the communities in need. Modern disaster relief scheduling models recognize the value of utilizing multi-depot location-allocation modeling to segment customers, restore ideal solution characteristics and smartly navigate flood relief routes while minimizing resource allocation costs.

iii. *Encourage the use of computational intelligence techniques to resolve multi-modal network flows where demand, supply, and routing options are uncertain.*

In order to optimize decision-making, resource allocation, and network efficiency there is a need to enable computational intelligence approaches for managing multi-modal network flows in scenarios where supply, demand, and routing options are unknown. The use of computational intelligence techniques like machine learning and evolutionary algorithms enables the creation of adaptive, real-time solutions that optimize resource allocation across transportation modes. Their ability to simulate multiple situations, reacting to real-time information, and improving network resilience can reduce disruptions while increasing productivity. Furthermore, computational intelligence approaches facilitate the integration of diverse transportation methods, resulting in efficient deployments and smooth coordination. Additionally, computational intelligence offers active supervision and real-time monitoring to ensure rapid change and reduce delays. The application of computational intelligence techniques can enable strategic planning and predictive analytics, which are used to anticipate future trends. Costs are reduced, throughput is increased, and network operations are more efficient and effective in the long run. In the context of the research study hypothesis, the proposed routing heuristic solution sought to increase cost effectiveness by exploiting several unique routing variables, such as the shortest distance between pick-up locations and connecting depots, and intelligent segmentation of customers to identify the most cost-effective customer-depot combination for deployment costs. This proposed work is considered a highly feasible proof-of-concept initiative for pinpointing appropriate population demographics to distribute relief resources while optimizing spending during the preparedness and response phases of disaster recovery, effectively mitigating effects on mortality rates and providing aid to vulnerable populations in the event of catastrophe.

1.6 Research Scope

The section that follows emphasizes the importance of providing specific strategies to address the occasionally discovered obstacles about routing probabilities, predominantly expressing structured decision-making processes subjected to developing competent disaster relief logistics strategies. Several key challenges are highlighted in relevance, while the issues become the principal objectives to be resolved for each routing capability throughout a supply chain management network flow. A small relative research cluster referenced cost-cutting priorities, location-specific interests, and computational optimization in the context of this research.

1.6.1 Cost Reduction Capabilities in Scheduling Systems

Emergency procurement in logistics involves complex optimization issues, particularly in disaster logistics. Emergency relief is crucial for cost-effective delivery of commodities and materials, as well as transmitting information between affected regions (Alam & Faruq, 2019; Gharib et al., 2018; Revanna & Al-Nakash, 2023). The current investigation focuses on procurement, transportation, and warehousing for supply chains under scheduling systems, aiming to initiate cost reduction scenarios and conduct quality rescue attempts. Research has focused on distribution and supply location cost management, aiming to maximize resource utilization and reduce supply chain network bottlenecks.

i. Computational

Routing and supply chain management challenges in humanitarian logistics are modeled upon and used through simulation models. The utilization of diverse scenarios and strategies allows stakeholders to compare different preparedness and response approaches. By anticipating logistics strategies, these models can identify bottlenecks, inefficiencies, and opportunities for improvement by predicting operational capabilities (Calabrò et al., 2020; Erdelic et al., 2019; Yeh & Tan, 2021). A built-in computational cost function is utilized to make informed decisions, particularly when managing efficiency within a given resource budget. Interactive simulation tools are utilized to optimize disaster relief scheduling by concentrating on critical factors such as optimal vehicle routing, reduced deployment costs, and comprehensive vehicle coverage (Calabrò et al., 2020; Fu et al., 2022). Simulators are utilized by logistics planners to enhance disaster relief efforts, improve strategies, anticipate potential issues, and provide timely solutions. Based on these models, disaster relief operations are designed to be both efficient and cost-friendly. The need for flexibility and adaptability is a key consideration in real-world scenarios that involve optimizing disaster relief models to minimize resource allocation, improve coverage efficiency, and reduce route complexity (Gharib et al., 2018; Morsidi, 2022; Morsidi & Panessai, 2023; Tavana et al., 2018b). Proactive logistic scheduling frameworks can enhance deployment outcomes by taking into account computational cost, rapid decision-making capabilities, and permissible operational loads.

ii. Monetary

There are cases where the expenses for purchasing and coordinating relief supplies are far more significant than what would be expected from a disaster relief operation (Ali Torabi et al., 2018; Gharib et al., 2018; Tavana et al., 2018b; Vahdani et al., 2018). The considerable charge emphasizes the importance of strategic planning and efficient procurement during distribution. Effective procurement choices and cost control are directly linked to the effectiveness of emergency response relief efforts due to their inherent complexity. Budget constraints pose a significant challenge to the establishment of dependable and efficient relief operational scheduling systems. To minimize costs and avoid costly issues, it is important to conduct a thorough evaluation of supply item retrieval and distribution methods during the early stages of planning. Financial considerations that are essential for disaster relief operations include distribution, transportation expenses, upkeep costs such as transportation and logistics costs, storage and inventory charges such as employee salaries or wages, and other related factors. When relief agencies focus on cost-saving measures and refine each aspect, they can increase operational efficiency and redirect resources to help impacted communities. The distribution network's optimization is impeded by financial constraints on both deployment and operational expenses. In disaster logistics, the financial cost is a significant aspect that must be carefully estimated and monitored, particularly when unexpected factors like the number of victims or targeted coverage areas are more numerous than anticipated (Morsidi et al., 2023a; Sun et al., 2022; Vahdani et al., 2018). Thus, a disaster relief logistics framework

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must be proposed that considers appropriate actions and adaptive strategies to maximize resources allocated for the affected population which is of the utmost importance.

iii. Commodities

To ensure efficient supplies are available and transported, disaster relief management must carefully manage logistics. Planning for logistics requires strategic positioning and advanced preparation to enable the swift delivery of critical goods through real-time demand assessments. Along with tangible goods, logistics involves essential functions such as medical attention, counseling, and temporary housing arrangements for victims. Moreover, these methods depend on the delivery of purchased goods to pre-established holdings, which function as centralized depots for stock management and replenishment, making transfer strategies more efficient (Alam & Faruq, 2019; Morsidi, 2022; Revanna & Al-Nakash, 2023). Along with providing immediate relief, this approach also supports recovery and reconstruction efforts. In addition, the utilization of multiple heuristics in routing scheduling can facilitate the placement of relief products, leading to more efficient resource allocation. This research scope intended to merge the traits of customer segregation and shortest distance traversal metric upon maximizing the proficiency of commodity distribution within a disaster relief logistic network, therefore improving survivability and mortality rate among the victim population aside from managing and predicting a better solution strategy in aggregating the best routing heuristic applicable for a distribution network undergoing duress and unpredictability. The anticipated final output is expected to be versatile and adaptive in catering to alterations in routing variables such as number of vehicles and depot placements whilst maintaining consistency in terms of generating the most feasible operational cost that could alleviate routing issues in regards with location-allocation instances based on multi-depot dispatch and route optimization in handling the preparedness and response phases for flood risk area mitigation purposes.

1.6.2 Demography of Disaster-Inflicted Areas

Disaster logistics management aims to reduce mortality rates and ensure a gradual supply allocation in the routing network. Rescue activities during disasters focus on improving unstable distribution networks and distributing relief supplies. Due to high unpredictability in disaster situations, critical decisions must be made in detail, considering the exact location of the disaster and the quantity of commodities needed. Validating model scenarios for the chain network is crucial for effective and continuous disaster relief logistic scheduling systems. This involves analyzing the chain network to ensure efficient and effective relief efforts.

i. Facility Location

In disaster relief logistics, selecting facility locations is vital for enhancing efficiency in distribution systems, guaranteeing rapid access and economic viability. When choosing facility locations, various factors need to be assessed carefully. Risk management approaches tackle essential issues, like reaching low-income regions by evaluating their closeness to impacted communities to deliver the best aid. The expansion of population coverage ensures that the placement of facilities is matched to the locations of affected individuals to provide necessary assistance (Gharib et al., 2018; Morsidi, 2022; Sun et al., 2022). Furthermore, successful distribution strategies demand the resolution of issues like subpar infrastructure and unpaved roads, which have a significant impact on logistics (Gharib et al., 2018; Nura et al., 2022). Contrasting objectives, such as extending shelters for victim population or guaranteeing that essential supplies reach affected areas, often require compromises to achieve. Such concessions will be assessed on urgency, logistics feasibility and resource availability (Dai et al., 2023; Juneja et al., 2019). The shortest distance metric imposed in the proposed study is an important tool in disaster relief logistics scheduling, as it can significantly speed up the delivery of essential supplies like food, water, and medicine to affected communities. The shortening of travel time could result in faster relief efforts to reach those who require it more quickly, thereby decreasing delays and potentially saving lives (Morsidi, 2022; Ochelska-Mierzejewska et al., 2021; Zhan et al., 2022). This technique can assist in optimizing resource usage by reducing fuel consumption, minimizing vehicle wear-and-tear, and enabling more frequent deliveries with limited resources. Better customer segregation also motivates the outcome of better location-allocation resolutive strategy, as the strategic displacement of relief commodities can be done on relative customer-depot interlinking network thus reducing the risk of resource wastage and unfulfilled demands across a synergized participating distribution network.

ii. Location Model

With their advanced methods for anticipating journey times, commodity delivery schedules, risk assessments, and unmet emergency relief demands, location and allocation models play a critical role in coordinating disaster relief activities. With the use of these models, disaster response teams may more precisely and quickly plan by estimating the time it will take for supplies to get to affected areas (Sularno et al., 2021; Zhan et al., 2022). These models assist in visualizing distribution center locations, which are crucial for planning the logistics of relief delivery, by simulating different scenarios. They aid in the discovery of the best distribution strategies adapted to the unique circumstances of disaster-prone places. Examples of these strategies include figuring out the best routes or ways to allocate resources in lieu of the limitations imposed by

dangerous or destroyed infrastructure (Sularno et al., 2021; Zhan et al., 2022). The limitations and difficulties in conducting rescue routing operations, such as road blockages, traffic congestion, or geographic barriers, are also outlined by location and allocation models. These models are essential for creating practical and efficient response plans. They give supply chains for disaster relief a formal framework to follow, making sure that every part of the logistics network is well-managed and organized (D. G. N. D. Jayarathna et al., 2022; Ouhader & El kyal, 2017a; Sun et al., 2022). These models also assess different methods for dealing with problems that emerge following natural disasters, like distributing medical supplies most effectively, giving priority to high-risk areas, or controlling resource flow under different degrees of supply and demand constraints. Location and allocation models boost the overall efficacy and efficiency of disaster relief operations by merging these different factors, which eventually leads to a more responsive and coordinated relief effort that can better satisfy the requirements of affected communities (Morsidi, 2022; Sularno et al., 2021; Sun et al., 2022). Focusing on the quickest paths guarantees that vital resources such as food, water, and medicine arrive at impacted communities promptly, reducing delays and possibly preserving lives. Shorter pathways lead to decreased fuel use and less wear on transport vehicles, aiding in resource conservation and lowering operational expenses. By minimizing the travel duration for each journey, aid organizations can conduct more frequent deliveries, guaranteeing a regular and reliable provision of assistance to those requiring emergency assistance.

iii. Distance between the Distribution Depots

Depending on the size and arrangement of buildings and distribution hubs, disaster relief chains can be considered as having significant impact on response times and operating costs (Gharib et al., 2018; Y. Zhou et al., 2017). Effective transport networks are essential for maximizing relief operations, with consideration given to location and allocation assignments (Morsidi & Budiman, 2023; Sun et al., 2022). Additionally, effective coordination across geographical areas is critical. This entails establishing the geographical position of vital management facilities, providing emergency commodities to affected areas, locating distribution depots, and outsourcing conveyance on relief provisions and medical supplies. Rapid response and coordination require facilities that are strategically placed near areas of high need. Effective emergency supplies to affected areas require careful planning. Having distribution centers in place is crucial to reaching victims and having resources available when needed (Gharib et al., 2018; Pimentel & Alvelos, 2018; Vahdani et al., 2018). The balance between cost-effectiveness and prompt delivery is often compromised by outsourcing conveyance, such as relief supplies and medical equipment. Another important factor is uncertainty in distributing relief supplies among affected areas. The risk assessments encompass response times, supply chain delays and demand fluctuations. By incorporating variables like total costs, response times, and demand levels from customers involved, the model allows for a more flexible and responsive relief approach (Calabrò et al., 2020; Yeh & Tan, 2021). Considering all logistical aspects, this comprehensive approach enhances the overall effectiveness and efficiency of disaster relief operations while also improving the ability of affected populations to respond to any challenges that may be encountered. In urgent situations, logistical resources like vehicles, drivers, and fuel are often limited. Using the shortest distance metric helps to enhance the use of these resources, ensuring effective utilization (Alam & Faruq, 2019; Morsidi, 2022). By focusing on the most direct paths, logistics coordinators can quickly find and aid remote or hard-to-reach locations, ensuring equitable delivery of assistance. By incorporating real-time information and technology, the shortest distance measurement can be constantly updated to adapt to changing conditions, such as obstructions or newly identified regions needing focus. This characteristic is especially advantageous in scenarios involving location-allocation, where there is a focus on maximizing the minimization of resource distribution to attain cost efficiency.

1.6.3 Resource Optimization

The logistical scheduling is significantly impacted by the intricate distribution and routing of resources. Effectively allocating resources and managing logistical challenges is necessary for disaster relief. By utilizing optimization algorithms, it is possible to overcome routing challenges and provide computationally realistic approximations for real-world variables like location, quantity, and purpose of strategic distribution centers (Calabrò et al., 2020; Tavana et al., 2018b; Yeh & Tan, 2021). Multi-objective mathematical models for location-allocation problems are still being developed, with the aim of reducing turnaround time, optimizing transport capacity, and decreasing deployment time while also improving distances between facilities and affected areas. Taking on these problems in all its complexity requires the integration of various objective functions. In addition, a stochastic programming model has been suggested to factor in changes in demand and disruptions while accounting for distribution planning and resource availability. Stochastic factors in the model contribute to the improvement of disaster response and resource management for affected populations, thereby strengthening the resilience and adaptability of distribution methods. This method enhances the responsiveness and durable nature of disaster relief operations. A more effective approach to segmenting customers in customer-depot interactions can result in resource optimization within logistics networks (Christopher et al., 2021; Elatar et al., 2023; Y. Wang et al., 2021). Optimizing operations and waste reduction are the goals of logistics planners who classify customers based on factors such as location, demand size, and service requirements. The aim is to maximize the usage of vehicles and reduce transportation expenses and fuel consumption over longer distances while taking shorter routes. Overstock management and deficiencies are reduced by enabling depots to stock products tailored to customer requirements. In addition, redundancies are reduced by segregating depots as it prevents multiple depots from sharing service areas, ensuring that each depot operates efficiently. Moreover, this method enhances flexibility by allowing for resource reallocation in emergencies or on high demand during peak periods. Sustainability is promoted by customer segregation, which also reduces operational expenses, improves turnaround times, and enhances vehicle reliability. Ultimately, this raises customer satisfaction levels by providing faster, more reliable deliveries and setting up a flexible and efficient logistics system.

1.7 Operational Definition

The following section elaborates on the common terminologies that will be encountered during the entire course of research.

1.7.1 Disaster Relief Logistics Scheduling

Logistics scheduling could be defined as the systematic and strategic process of organizing and planning the distribution of supplies in accordance with demand levels and commodity availability (Calabrò et al., 2020; Yeh & Tan, 2021). This process involves a detailed assessment of various factors to ensure that resources are allocated efficiently and effectively. In the context of business and supply chain management, logistics planning is similarly critical in disaster management, where the stakes are high, and the need for a coordinated response is paramount. The goals of logistics planning for disaster relief are multifaceted and crucial for effective emergency response. One key objective is to minimize unfulfilled demands, ensuring that all affected individuals receive the essential supplies and services they require. This involves accurate forecasting and dynamic adjustment to rapidly changing conditions on the ground. Another goal is to reduce costs associated with the logistics process, including transportation, warehousing, and resource management, while still maintaining a high level of service. Promoting fairness in commodity distribution is also essential, as it ensures that aid is distributed equitably among all affected populations, preventing any group from being overlooked or underserved. Additionally, minimizing casualties is a critical objective, achieved by ensuring that essential supplies such as medical aid and food reach those in need without delay. Lastly, logistics planning aims to foster growth by building resilient and adaptive

supply chains that can not only respond effectively to immediate needs but also support long-term recovery and development efforts. This holistic approach to logistics scheduling enhances the overall effectiveness of disaster relief operations, ensuring a well-organized response that addresses both immediate and long-term needs of affected communities.

1.7.2 Location-Allocation

Location-Allocation is a specialized category within vehicle routing problems, focusing on optimizing the placement and utilization of distribution facilities within a supply chain management context (Morsidi & Budiman, 2023; Saeidian et al., 2018; Sun et al., 2022). This problem-solving approach integrates two distinct but complementary aspects: location and allocation. Location refers to the process of determining the optimal number and positioning of facilities, such as warehouses or distribution centers, within a given geographic area (Qin et al., 2021). The goal is to strategically place these facilities to maximize efficiency and minimize costs associated with transportation and storage. On the other hand, allocation involves determining how to best distribute demand across these facilities (Nura et al., 2022). This means evaluating the demand rate for each distribution center and ensuring that each facility can handle its share of the workload while meeting the needs of its designated area. The challenge lies in balancing these two aspects to achieve an optimal configuration. The integration of location and allocation strategies aims to select the most ideal distribution centers while maintaining the integrity of commodity distribution across manageable depot clusters. This involves not only choosing the right number and placement of facilities but also ensuring that each facility is appropriately sized and equipped to handle the expected demand. By effectively solving location-allocation problems, organizations can enhance their supply chain efficiency, reduce operational costs, and improve service levels. This approach is particularly valuable in complex supply chain scenarios where both facility placement and demand distribution are critical to achieving optimal performance and meeting customer needs effectively.

1.7.3 Commodity

In the context of disaster relief, the term "commodity" encompasses a broad range of essential supplies crucial for effective preparedness and mitigation efforts. These commodities include, but are not limited to, food and water, which are fundamental for meeting the immediate nutritional and hydration needs of disaster victims (Gharib et al., 2018; Vahdani et al., 2018). Equipment such as tents, generators, and tools is vital for setting up temporary shelters, restoring essential services, and conducting rescue operations. Medicines and medical supplies are indispensable for treating injuries and managing health crises that arise in the aftermath of a disaster. Additionally, professional services, including medical care, psychological support, and technical assistance, play a critical role in addressing the diverse needs of affected populations. Financial aid provides the necessary funding for purchasing supplies, supporting relief operations, and facilitating recovery efforts. Basic needs such as clothing, sanitation supplies, and household items also form an integral part of the relief effort, ensuring that individuals and families can maintain a semblance of normalcy and hygiene during crises. Effective emergency management hinges on the availability and strategic deployment of these commodity resources. Inventory management is essential to ensure that sufficient supplies are on hand and that they can be quickly mobilized to areas in need. The workforce, including volunteers and professional responders, must be adequately trained and equipped to handle the demands of disaster response. Sustainable reserves of critical supplies are necessary to maintain a steady flow of aid and to address prolonged or recurring needs. These commodities not only provide immediate relief to disaster victims but also contribute to longer-term solutions by supporting recovery and rebuilding efforts. By ensuring that essential supplies and resources are available and effectively managed, disaster relief operations can better sustain affected communities, promote resilience, and facilitate the transition from immediate response to long-term recovery and development.

1.7.4 Computational Cost

Computational cost refers to the complexity and resource consumption associated with executing an algorithm to solve a given problem (Djigal et al., 2021; Haidri et al., 2019). This concept encompasses the amount of computational power, memory, and time required to perform fundamental operations within a specified timeframe to produce a solution. In practical terms, computational costs are often measured by the number of basic operations, such as arithmetic calculations, data comparisons, or memory accesses, that an algorithm requires. As algorithms become more complex or as the problem size increases, the number of operations typically rises, leading to longer processing times and higher computational expenses. Longer turnarounds, characterized by extended processing times, result in increased computational costs, which can significantly impact system performance and efficiency. This can be particularly detrimental in time-sensitive applications where prompt responses are crucial. Conversely, algorithms designed for quicker turnarounds enhance decision-making efficiency by reducing the time required to derive solutions, thereby meeting user-centric demands more effectively. Faster computational processes not only improve responsiveness but also contribute to more agile and effective problem-solving, particularly in dynamic environments where timely decisions are critical. Computational costs bear similarities to financial costs, as both involve evaluating the trade-offs between resources invested and the benefits gained. Just as financial costs represent the expenditure required to achieve certain outcomes, computational costs reflect the resources expended to explore and implement potential solutions to problems. Balancing computational costs with performance requirements is essential for optimizing algorithmic efficiency and effectiveness, ensuring that solutions are not only accurate but also practical and feasible within resource constraints. By carefully managing computational costs, organizations can achieve a more efficient use of resources, enhance system performance, and better address complex problems in various domains.

1.7.5 Planning Model

Planning modeling is a crucial methodology employed to simulate functional decomposition in disaster relief logistic scheduling, allowing for a structured approach to managing complex logistics operations (Han & Wang, 2020; Shen et al., 2018; Tan & Yeh, 2021). This technique involves the application of various models to replicate and analyze the impact of multiple components within the disaster relief framework. Specifically, this includes simulating inventory quantities to ensure that the right amounts of essential supplies are available and allocated effectively. This feature helps in managing stock levels and avoiding shortages or surpluses that could hinder relief efforts. Additionally, planning modeling considers the demography of damaged areas, providing insights into the scale and distribution of affected populations. This information is vital for tailoring relief efforts to meet the specific needs of different communities, ensuring that aid reaches all those in need. The simulation of distribution centers is also a key component, as it helps in determining the optimal locations for these facilities to enhance accessibility and efficiency in delivering supplies. Moreover, the modeling of supply chains allows for the evaluation of various logistical pathways, identifying potential bottlenecks and optimizing routes to ensure timely and cost-effective delivery (Calabrò et al., 2020; Yeh & Tan, 2021). By integrating these elements, modeling aims to predict and assess the behavior of the entire relief system, facilitating the development of strategies that effectively balance response effectiveness with cost management. The goal is to minimize total costs while maximizing coverage and efficiency in deploying relief resources. This approach not only improves the coordination and execution of disaster relief operations but also enhances the overall resilience and responsiveness of the logistics network, leading to more effective support for affected communities and better outcomes in the aftermath of disasters.

1.7.6 Evolutionary Algorithm (EA)

Evolutionary algorithms (EA) are a class of population-based metaheuristics that draw inspiration from the principles of biological evolution, such as reproduction, mutation, recombination, and natural selection (Faris et al., 2018; Hussain et al., 2018; Saeedi et al., 2020). These algorithms are designed to tackle complex global numerical optimization problems that exhibit characteristics such as multi-modality, non-continuity, and noise in the solution space. The core idea behind EAs is to mimic the process of natural evolution to iteratively improve candidate solutions through a series of evolutionary operations, leading to the discovery of highly efficient solutions. EA is broadly categorized into three main classes within the field of natural computing: metaheuristic, deterministic, and stochastic algorithms. Metaheuristic EAs are generally characterized by their heuristic nature and ability to explore large, complex solution spaces without relying on specific problem structures (Ochelska-Mierzejewska et al., 2021). Deterministic EAs follow fixed procedures and rules, providing predictable and repeatable outcomes based on their initial conditions (Singh et al., 2020; Zouache & Ben Abdelaziz, 2018). Stochastic EAs incorporate randomness and probabilistic elements into their search processes, enhancing their ability to explore diverse regions of the solution space and avoid local optima (Ali Torabi et al., 2018; Maheshwari et al., 2023; S. L. Wang et al., 2018).

In scientific research and engineering practice, several evolutionary algorithms have gained prominence due to their effectiveness and versatility. For example, Particle Swarm Optimization (PSO) is inspired by the social behavior of bird flocks and fish schools, using a swarm of candidate solutions that adjust their positions based on individual and collective experiences (Saeedi et al., 2020). Genetic Algorithms (GA) emulate the process of natural selection, applying genetic operators like crossover and mutation to evolve solutions over generations (Revanna & Al-Nakash, 2023). Artificial Immune Algorithms (AIA) draw on the principles of the immune system to identify and eliminate suboptimal solutions while preserving promising candidates (P. Wang et al., 2020). Memetic Algorithms (MA) combine evolutionary techniques with local search heuristics, blending global exploration with fine-tuned local optimization to achieve enhanced performance (El Krari et al., 2020). Each of these evolutionary algorithms offers unique strengths and is suited to different types of optimization challenges. By leveraging their adaptive and robust nature, EAs provide powerful tools for solving complex problems across various domains, from engineering design and resource allocation to artificial intelligence and computational biology.

1.7.7 Cost Optimization

Cost optimization is the process of systematically reducing costs while maintaining or improving operational efficiency, quality, and performance (Chowlur Revanna & B.Al-Nakash, 2022; Dahmani, 2023; Morsidi & Budiman, 2023). It is especially important in routing and scheduling where cost considerations are taken into account to take into accounts fuel consumption, labor costs, delivery times, while also keeping resources constrained away from cost principle, for instance Dijkstra's and A* graph traversal algorithms is applied to route minimization in the distribution network for minimizing operational cost as much as possible (Alam & Faruq, 2019; Morsidi, 2023b; Rachmawati & Gustin, 2020). Cost-effective routes are determined by optimizing toll fees, fuel economy, and traffic conditions. Schedules are optimized for public transportation systems by adjusting service frequency during both peak and non-peak periods, which helps to reduce operational costs while meeting passenger demand.

Energy-conserving and time-sensitive delivery methods are utilized in cold chain logistics to manage perishable goods, thereby reducing transportation and refrigeration costs (Fu et al., 2022; Phuc & Nguyen Le Phuong Thao, 2021; Taal et al., 2019). The use of computational intelligence and other optimization techniques can lead to significant cost reductions and operational improvements for organizations across multiple domains.

1.7.8 Scheduling Mechanism

Scheduling mechanisms are routing schematics designed to efficiently achieve operational goals by implementing an organized method or algorithm for allocating resources, tasks, or activities across a timeline (Ahmad et al., 2021; Morsidi, 2023c; X. Zhou et al., 2019). Although this may not prioritize distance or fuel efficiency, the contemporary scheduling mechanism strategy known as FCFS (first-come, first-served) scheduling maintains a fair distribution of delivery requests based on their order of arrival (Morsidi et al., 2023a; Sahu et al., 2023; X. Zhou et al., 2019). Frequently, priority-based scheduling mechanisms such as emergency services use priority-driven scheduling, allocating assets according to the severity of the situation to give first priority to crucial tasks. For instance, by using scheduling in e-commerce, customers can choose their preferred delivery times, and routing algorithms ensure that vehicles follow these decisions, while reducing travel time and costs (Gdowska et al., 2018; Revanna & Al-Nakash, 2023; Serafini et al., 2018). The use of dynamic scheduling systems in public transportation reduces the need for unnecessary trips and improves service quality by utilizing real-time information, such as traffic status or passenger preferences, to adjust bus or train timetables. Another instance of scheduling mechanism, batch scheduling enables the merging of multiple orders with similar destinations to the same vehicles into a single delivery route, which results in reduced number of trips (D. G. N. D. Jayarathna et al., 2021).

1.7.9 Scheduling Model

The term scheduling model refers to a mathematical or computational system that defines the standards, limitations, and targets for organizing and allocating tasks, resources, or activities across different timescales (Calabrò et al., 2020; Nabiel Al-Khanak et al., 2021; Yeh & Tan, 2021). The management of vehicles, routes, and time slots through scheduling models is necessary for achieving objectives such as cost reductions, timely deliveries or effective resource utilization. By assigning delivery paths to a group of vehicles, the routing model seeks to minimize travel distances or expenses while accommodating certain constraints such as vehicle length and customer time slots (Fu et al., 2022; Pinto et al., 2020; Wahyuningsih & Satyananda, 2020). Time-window restricted models are frequently used in e–commerce to improve routing efficiency, while also providing time deliveries within scheduled slots (Luo et al., 2021; Phuc & Nguyen Le Phuong Thao, 2021; Wahyuningsih & Satyananda, 2020). Another instance of scheduling model application is via ride-sharing services often use dynamic scheduling models that depend on current information, such as traffic conditions and demand, to continuously adjust schedules and minimize delays (Qin et al., 2021). Sustainable logistics methods incorporate multi-objective optimization models that consider intricate trade-offs called sustainable logistics practices, such as cost savings and delivery timelines. Job-shop scheduling models in industries like manufacturing and distribution allow for the assignment of resources to a specific set of tasks, leading to efficient operations (Huang et al., 2022). By utilizing collaborative scheduling models, many companies can share their routes and vehicles, which results in cost savings and resource utilization.

1.7.10 Design Strategy

A design strategy within the context of development of routing models involves systematic steps to create better algorithms that determine routes or schedules considering multiple limits along with the motivation of accomplish certain goals (Boumpa et al., 2022; Kunnapapdeelert & Thawnern, 2021; H. Li et al., 2021; Pop et al., 2024). The design strategy improves how well operations work by looking at costs, time or resource allocation next to changes in conditions. The main approach uses optimization where experts model problems through Linear Programming (LP) or Integer Programming (IP) to find the best solution qualities to resolve real-world problems (Nucamendi-Guillén et al., 2021; Yu et al., 2022). Large-scale problem instances need different techniques for further analysis due to the factor of dimensional complexity. Heuristic or metaheuristic techniques like Genetic Algorithms (GA), Simulated Annealing (SA), as well as Ant Colony Optimization (ACO) help discovering good solutions in a more rapid manner (Calabrò et al., 2020; DOUMI et al., 2021; H. Li et al., 2021). A graph-based design shows routes as visual networks that use shortest path calculations to make costs or travel time better (Morsidi, 2023b). Mixed methods combine exact computational approximation with swift heuristic solutions to achieve better results (Kocaoglu et al., 2020; Qin et al., 2021; Yu et al., 2022). Any design strategies focus on real problems that need both speed and accuracy to solve transportation challenges.

1.8 Thesis Organization

The following lists down the organization of the entire thesis structure: Chapter 2 examines an effective disaster logistics framework that addresses vehicle routing issues considering time limitations and fluctuations in demand by examining optimization tactics, underscores the influence of routing choices on expenses, and wraps up with observations on efficient resource utilization, paving the way for a novel heuristic model. Chapter 3 analyzes populations at risk of flooding and transportation challenges that need to be resolved by proposing an optimization approach for emergency support. The chapter highlights computational intelligence applications in routing heuristics, the strategic allocation of locations for cost efficiency, and introduces a multi-objective programming model for the MDVRP to enhance reliability and lower expenses. Chapter 4 outlines a logistics plan for flood relief that employs multi-depot dispatch and computational intelligence to enhance routing and significantly lower expenses, highlighting the importance of constrained modeling to boost operational efficiency in disaster readiness using novel optimization algorithms to refine optimal route allocation under flood management scenarios. Chapter 5 concludes the discussion on the proposed theoretical framework of complex multi-dispatch scenarios, emphasizing cost compatibility and resource reduction in flood assistance preparedness. The chapter delves into the relevance of determining the best MDVRP routing approaches, boosting efficiency and cost-effectiveness in Sarawak’s supply chains.