Optimizing Emergency Medical Services: Cost Reduction and Service Efficiency

Puchit Phasuktham*
Arunrat Sawettham**
Kanatkit Thongpool***
Panamon Chantabutr****

Abstract

This research aims to reduce costs by enhancing emergency medical services (EMS). The study analyzed data from 1,736 accident sites to develop a model that can improve EMS routing and identify overlapping service zones. This approach resulted in a 37.88% reduction in average operational costs. The accuracy and reliability of the system were validated using the Analytic Hierarchy Process (AHP). The pairwise comparisons resulted in a Consistency Ratio (CR) of 0.09323, with an eigenvalue (λmax) of 4.25172 and a consistency index (CI) of 0.08391. This validation confirms the model's effectiveness in optimizing EMS operations, which is crucial in life-saving scenarios. It also highlights the potential to streamline response times and reduce costs, providing invaluable insights for the advancement of emergency medical logistics.

Keywords: Decision-making; Emergency Medical Services; Analysis Hierarchy Process; Cost of Performance

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* MBA. candidate, Ubon Ratchathani Business School, Ubon Ratchathani University.
** Lecturer, Master of Business Administration Program, Ubon Ratchathani Business School, Ubon Ratchathani University (Corresponding Author).
*** Lecturer, International Business Management Program, Ubon Ratchathani Business School, Ubon Ratchathani University.
**** Lecturer, Master of Business Administration Program, Ubon Ratchathani Business School, Ubon Ratchathani University.

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Introduction

World Health Organization data indicates that, without adequate accident prevention measures, approximately 1.25 million people are involved in road accidents annually (World Health Organization, 2021). In Thailand, the government has realized the importance of preventing emergency accidents by encouraging and supporting medical units and prioritizing their preparedness. This can be observed in several government policies to improve the quality of public health services. According to national statistics, Thailand has an average of 530,000 accidents annually (ThaiRsc, 2020). In Thailand, emergency medical service (EMS) systems have been developed using international standards from the United States. Performance indicators are response times to emergency patients (Road Safety Thailand, 2018). Therefore, it is necessary to spend as little time as possible to reduce the risk of injury to patients; a standard emergency response time of four minutes was set in place, which requires medical preparedness and personnel capable of caring for emergency patients. For example, in cardiac arrest patients, the chance of patient survival decreases by 24% for every minute delay in advanced treatment; however, in non-traumatic cardiac arrest patients, the probability of patient survival could be increased by 47% if an appropriate progressive emergency response is undertaken timely (Yoon & Albert, 2020).

EMS costs are influenced by numerous factors, including the type of service needed, location, level of care required, and the healthcare system in place. Factors influencing EMS costs include the type of ambulance service, Basic Life Support or Advanced Life Support, location (rural or urban), mileage, level of care, transportation to the hospital, insurance coverage, membership programs, government-funded services, and any additional services provided (Jittamai et al., 2019). EMS billing is inherently complex, making costs difficult to predict. It is essential to contact the EMS provider or insurance company for cost information and coverage details. The priority in any emergency is seeking EMS without hesitation to ensure health and well-being. This research utilizes traffic and transportation models, known for their ability to offer benefits such as cost savings, operational efficiency improvements, and enhanced customer satisfaction. These models are invaluable tools for businesses and organizations operating in logistics and transportation. The study uses the Vehicle Routing Problem with Time Windows (VRPTW), a transportation optimization challenge. The primary objective is to reduce vehicle pickup and delivery costs while adhering to stringent time constraints. The central challenge revolves around optimizing vehicle routing to ensure efficiency and timeliness, considering factors like capacity limitations and specific delivery time windows due to significant economic losses resulting from accidents and time constraints in emergency response. Its objective is to evaluate the operational efficiency of EMS from a cost perspective. The aim is to improve the effectiveness of EMS by creating mathematical models that can minimize costs through optimized route planning for each accident location. Additionally, the models help decide the most suitable emergency vehicles, particularly in areas with overlapping services, to ensure faster service delivery to the public. The outcome is an enhancement in the overall efficiency of emergency medical services, ensuring that all emergency patients receive quicker and more cost-effective care.

Literature Review

Regarding the impacts of accidents and EMS in Thailand, the average annual number of accidents is 529,240, with an average cost of 22,281 baht per fatality and 107,542 baht per injury. Household health expenditure in Thailand accounts for 79.82%, with government health expenditure at 20.18%, which tends to increase annually (World Health Organization, 2021). These accidents adversely affect various aspects of Thailand, including tourism, the economy, society, politics, and national security. However, the government recognizes the importance of emergency accidents by promoting medical units to prioritize preparedness for emergencies, both in normal and abnormal conditions, which can be inferred from the state's policy aimed at improving the quality of public health services (Janlawong, 2016). In 2020, the number of accidents in Ubon Ratchathani province was 27,746 with 310 fatalities and 27,436 injuries. The cost of fatalities amounted to 6,907,110 baht per year, while the cost of injuries was 2,950,522,312 baht per year. (Ubon Ratchathani Provincial Health Administration Office, 2021).

In practice, an emergency medical service (EMS) system works in an uncertain environment with stochastic demand, response times, and travel times. Several studies have undertaken an analysis of the cost-effectiveness of the deployment of EMS. To achieve this, a new objective function was utilized to minimize the expected cost of delayed emergencies and operational costs for EMS (McArthur et al., 2014). The problem was solved using the ant colony optimization algorithm, resulting in a plan for ambulance deployment in downtown Shanghai that was both optimized and cost-effective (Qiang et al., 2015). Yang et al. (2019) proposed a simulation-based optimization method for ambulance allocation. Adarang et al. (2020) address a location-routing problem (LRP) under uncertainty for providing emergency medical services (EMS) during disasters, which is formulated using a robust optimization (RO) approach. The proposed algorithm can obtain acceptable solutions for real-world cases. Another study developed a cost model for EMS that considered delayed and redeployment costs. The study found that while the Songjiang district EMS system could significantly improve responsiveness and economic efficiency, the impact of redeployment on optimization was limited (Michael et al., 2017). The key components of the optimization model are to optimize various factors, including distance, time, and resource allocation, to ensure timely and cost-effective responses to emergencies. The optimization model will be designed to be scalable and adaptable to changing demand patterns, allowing EMS providers to respond effectively to evolving emergencies and resource constraints by minimizing travel distances and optimizing resource allocation, the model will help reduce operational costs associated with emergency patient transportation.

One approach to cost reduction is the Vehicle Routing Problem with Time Windows (VRPTW), a logistics problem that optimizes the routes and schedules for vehicles delivering goods to customers within specified time windows. Several papers have proposed algorithms and heuristics to solve this problem. Villalba and Rotta (2022) developed a novel algorithm based on clustering techniques and heuristics that generated reasonable solutions for large customer instances. Dorian et al. (2021) presented a VRPTW approach that combined an extensive neighborhood search with exact components to solve various variants, achieving competitive results. VRPTW reduces the cost of moving goods between several destinations (Gautam et al., 2023) while accommodating constraints like set time windows for specific locations and vehicle capacity and a standard optimization problem faced within the logistics industry (Leonidas et al., 2023). VRPTW is a form of transportation problem to reduce the cost of pickup and delivery time required for vehicles to reach their destination within a specific time frame; for example, the routing of vehicles leaving the starting point, such as warehouses and distribution centers, to provide services to consumers. Each vehicle has a specific capacity, and consumers must be serviced only once per year. Each consumer has a time frame within which the vehicle is delivered to the destination, and the objectives are to route the vehicle under time constraints to reduce costs and reduce per-annum travel routes under time constraints (Srivastava et al., 2021). The transportation route within the time frame becomes problematic, especially when there are time constraints as customers are geographically dispersed while the vehicles to serve them may also have capacity constraints. Therefore, solving the transportation route within the given time frame is considered an NP-hard problem, indicating its difficulty (Zhang et al., 2020).

The Analysis Hierarchy Process (AHP) is based on multi-criterion decision-making. It has many applications, and the selection of factors that impact the decision-making process for emergency transport routes (i.e., the ideal distance from the hospital to the accident site) is one usage case. Most previous research uses analytics to prioritize and consider five aspects: reliability, assurance, responsiveness, empathy, and tangibleness, to determine emergency transport routes (Laksono et al., 2017). AHP is a decision-making method with three key steps. First, it involves structuring the decision problem hierarchically, breaking it down into objectives, criteria, and alternatives. Second, experts assess the relative importance of these elements through pairwise comparisons, assigning numerical values to express preferences. Third, a consistency check is performed to ensure reliability, and the method produces precise weights for criteria. AHP is valued for its simplicity, transparency, and applicability across diverse fields, providing a systematic approach to decision-making (Chaopanitcharoen & Opasanon, 2019). Its popularity is also attributed to its adaptability across various fields, including business, engineering, healthcare, and environmental management.

The Analytical Hierarchy Process (AHP) and the Vehicle Routing Problem (VRP) serve unique decision-making and logistics optimization purposes. AHP is a well-defined method that helps break down complex decisions into manageable parts. It uses mathematical and psychological principles to dissect a decision into a hierarchy of simpler issues, each assessed independently. Moslem et al. (2023) review of the Analytic Hierarchy Process (AHP) in solving transportation problems, as reflected in the 58 papers published between 2003 and 2019, shows a broad spectrum of applications. AHP has been effectively utilized in several key areas of transportation, including route selection, infrastructure development, prioritization of transportation projects, and optimizing transportation operations. Conversely, VRP is concerned with the optimization of vehicle routes to reduce expenses like travel distance and fuel usage while meeting specific requirements such as delivery times and vehicle load limits. While AHP supports strategic decision-making by sorting and prioritizing different elements, VRP enhances logistical operational efficiency. Although they operate in distinct spheres, both methods significantly enhance their respective areas by enabling well-informed decision-making and streamlining logistic operations. The combination of AHP for initial decision-making tasks, like choosing locations or services, with VRP for refining delivery or service routes offers a holistic strategy to address intricate logistic problems effectively. AHP helps in evaluating multiple criteria, such as cost, distance, time, and safety, to choose the most effective transportation routes.

The existing research predominantly concentrates on a model designed to optimize key operational parameters such as distance, time, and resource allocation for emergency patient transportation. However, despite the advancements and application of current methodologies, there is a discernible and significant research gap in effectively reducing costs specifically associated with overlapping areas in emergency services. This lacuna persists because previous models have not fully addressed the geographic and logistical complexities that contribute to inefficiencies and increased costs.

This research proposes a novel approach utilizing a mixed-method strategy validated through the Analytic Hierarchy Process (AHP). The model is innovative in its comprehensive cost assessment which includes vehicle operation and precise identification of the district where the emergency occurred. Crucially, it also addresses the optimization of resource deployment, determining which district's emergency vehicles are dispatched, a factor critical when resources are limited. By aiming to minimize travel time, reduce the distance covered, and lower associated costs, the model seeks to identify the most efficient routes that ensure arrival at the accident site within a stipulated 30-minute window.

This research finding, the gap in the model overlapping area, gives weights to each factor. This study intends to explore is the integration of spatial and logistical data to enhance decision-making processes, which will not only optimize emergency transportation efficiency but also ensure cost-effectiveness and the maintenance of high-quality patient care. The overarching goal is to provide a robust framework for emergency logistics that can dynamically adapt to varying emergency scenarios and resource availabilities, thereby mitigating the challenges posed by overlapping service areas.

Conceptual framework

This research endeavors to advance the understanding of emergency medical services (EMS) by establishing a comprehensive conceptual framework for assessing cost efficiency. Through the integration of logistics modeling, cost estimation, and service quality evaluation, the study aims to offer valuable insights and pragmatic solutions for improving the effectiveness and sustainability of EMS operations. Therefore, the conceptual framework Figure 1, provides a structured approach to evaluate the cost efficiency of EMS, with a focus on emergency medical service vehicles by analyzing factors related to travel, costs, and service quality followed by Qiang et al. (2015) through the use of the following factors: 1) accident locations to identify the geographical distribution and frequency of accidents necessitating EMS within the province, 2) types of EMS vehicles, which classify and analyze the vehicles employed for EMS, including ambulances and specialized vehicles, 3) travel duration, which determines the average time taken by EMS vehicles to reach accident sites from their origin points, 4) total distance traveled, which measures the aggregate distance covered by EMS vehicles over specified periods, 5) total travel expenses, which calculate the expenses incurred during EMS operations, including fuel, maintenance, and personnel costs, 6) emergency medical management, which evaluates the efficacy of emergency medical protocols and procedures in responding to incidents, and 7) route of emergency ambulance service 1669, which analyzes the route and coverage area of the emergency ambulance service 1669 within the province.

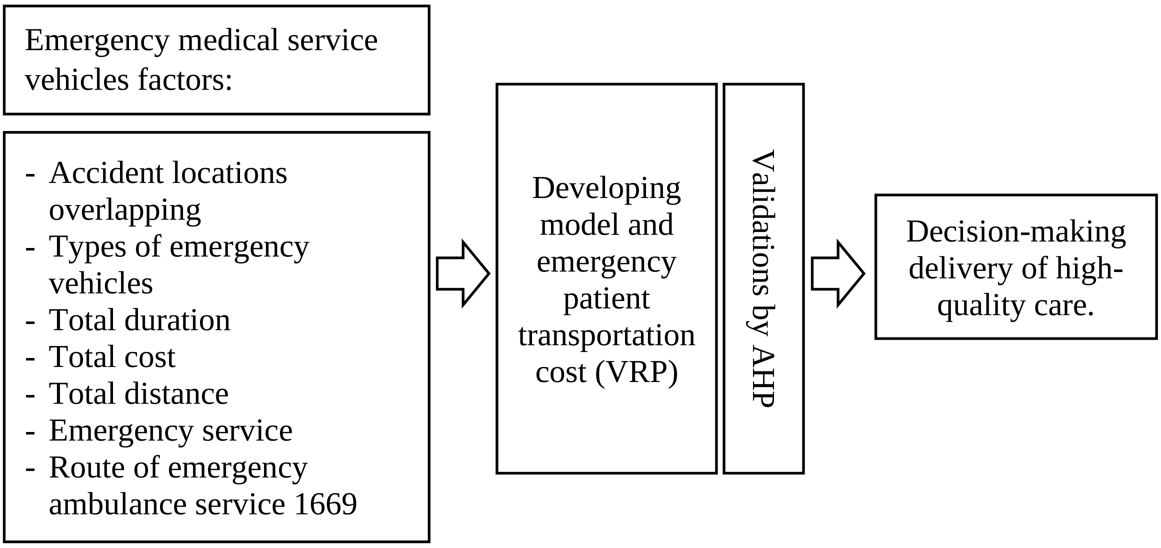

Figure 1: Conceptual Framework

The model will be designed to optimize VRP's various factors including distance, time, and allocation of resources. Additionally, the costs associated with emergency patient transportation will be estimated comprehensively and validated by AHP. This estimation will encompass expenses related to vehicle operations. The overarching objective is to provide insights that can inform decision-making processes, particularly those aimed at optimizing emergency patient transportation while simultaneously ensuring cost-effectiveness and the delivery of high-quality care.

Research Methodology

This research examines the routes emergency hospital vehicles follow, intending to create travel models that efficiently reduce costs related to transporting emergency patients and optimize the vehicles' routes. Furthermore, the study evaluates the effectiveness of the developed model.

Sample and data collection

Key informants in this research are personnel and chief officers in emergency medical services with experience working in 25 district hospitals.

Selection of the primary contributor group

This research used purposive sampling methods based on a group of registered nurses with a minimum of 1 year of working experience who served in the emergency medical department in all 25 district hospitals in Ubon Ratchathani province.

Data collection

This research used semi-structured, in-depth interviews using open-ended questions as data collection tools. It allowed key informants to answer freely without pre-defining the answers. To provide an opportunity for informants to respond to various issues of interest to the researcher, the format of the interview can be divided into the following three sections:

Section 1: Authorization was sought to gather data from the Public Health Office of Ubon Ratchathani Province. Research-related information such as research title, researcher, etc.

Section 2: Primary data were collected from key informants via in-depth interviews.

Information about the interviewer and the general condition of the interview, including the name and surname of the interviewer, the date, time, and place of the interview. Comprehensive data compilation, such as the geographic coordinates of the incident in latitude and longitude, travel time to the incident site in minutes, total cost in baht, and the total distance from the hospital to the incident site and return in kilometers, was achieved by note-taking and audio recording of statements from these primary informants.

Section 3: Collect data on emergency medical services from 25 district hospitals in Ubon Ratchathani province, from 2018 to 2022. This data includes the volume of emergency patient needs, the number of emergency hospital vehicles, the speed of emergency patient transport, accident locations, travel times, total travel expenses, the distance covered in the entire journey, and the routes of emergency ambulances called via the 1669 hotline.

After collection, data derived from the interviews were systematically analyzed. Individuals, who were interviewed, were those who have previously utilized emergency hospital transportation services to identify factors related to the model. The structured interviews encompassed five key aspects: management of emergency ambulance services, transportation costs, logistics routes, and decision-making processes influenced by the correlation between travel distances and patient symptoms. The aim of the interview was to summarize the factors that affect the efficiency of the model.

Data analytics

The optimization problem for routing emergency hospital vehicles is delineated by equations and inequalities that account for many parameters, decision variables, an objective function aimed at cost minimization, and constraints designed to guarantee the fulfilment of specific requirements. These equations and inequalities are presented with a comprehensive set of notations, parameters, decision variables, objective functions, and constraints, thus facilitating the development of a mathematical model for the routing of emergency hospital vehicles.

Objective functions:

$$Min\ Z = \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{k} Cijk \quad (1)$$

$$å_{k=1}^{K} X_{ijk} = 1 \text{ for i, i}^{1}1 \quad (2)$$

$$\sum_{i=1}^{N} d_i X_{ik} \leq Q_k \text{ for i } \neq 1\ \forall k \in k \quad (3)$$

Constraints:

$$Y_{ijk} \geq X_{ijk}, \quad \forall i, j, k$$

$$80 \leq V_{ijk} \geq 0, \quad \forall i, j, k$$

$$C_{ijk} \geq 0, \quad \forall i, j, k$$

$$d_i \geq 0, \quad \forall i \in Patients$$

$$b_i \geq 0, \quad \forall i, j$$

$$30 \leq T_{ijk} \geq 0, \quad \forall i, j, k$$

 Creative Business and Sustainability Journal (CBSJ)
Vol.46 No.1 January – June 2024, pp.66-85

Parameter:

i	set of the number of patients.
j	set of the number of hospitals.
k	set of the hospital sends emergency vehicles.
V_{ijk}	set of speed for transporting emergency patients.
Q_k	set of emergency patients can be transported.
C_{ijk}	set of costs for emergency patients who can be transported.
d_i	set of needs to receive emergency patient services.
b_{ij}	set of total distance in service.
T_{ijk}	set of the total duration of service.

Decision variables:

$X_{ijk} \in \{0,1\}$ if X_{ijk}=1 patient i to be transported to hospital j by transport vehicle type *k*; otherwise, it is equal to 0.

$Y_{ijk} \in \{0,1\}$ =1 transport type *k* transport emergency patient *I;* otherwise, it is equal to 0.

Assumption and Constraints:

Patient Assignment Constraint

$$\sum_{j\in \text{Hospitals}} \sum_{k\in \text{Transport Vehicles}} X_{ijk} = 1, \quad \forall i \in Patients$$

Hospital Service Constraint

$$\sum_{j\in \text{Patients}} \sum_{k\in \text{Transport Vehicles}} X_{ijk} = 1, \quad \forall i \in Hospitals$$

Binary Decision Variables Constraints

$$X_{ijk} \in \{0,1\}, \quad \forall i, j\ , k$$
$$Y_{ijk} \in \{0,1\}, \quad \forall i, j\ , k$$

Ensure Y_{ijk} is activated if $X_{ijk} = 1$

$$Y_{ijk} \geq X_{ijk}, \quad \forall i, j\ , k$$

Patient Transportation Speed Constraint

$$V_{ijk} \geq 0, \quad \forall i, j\ , k$$

Emergency Patients Capacity Constraint

$$\sum_{j\in Patients} X_{ijk} \leq Q_k, \quad \forall k \in \text{Transport Vehicles}$$

Cost Constraint

$$C_{ijk} \geq 0, \quad \forall i, j\ , k$$

Emergency Service Need Constraint

$$d_i \geq 0, \quad \forall i \in Patients$$

Total Distance in Service Constraint

$$b_i \geq 0, \quad \forall i, j$$

Total Duration of Service Constraint

$$T_{ijk} \geq 0, \quad \forall i, j, k$$

1) The emergency patient volume:

The number of emergency patients equals the number of villages in the overlapping service area that can be allocated to emergency hospital vehicles from other areas. Emergency patients can be picked up from areas outside their area of responsibility.

2) Emergency patient transport restrictions:

Each emergency patient can only use one route as per the equation, $\text{å}_{k=1}^{K} X_{ijk} = 1, i, i^{1}\ One,$ and each transport vehicle can only accept one patient per vehicle as per the equation, $\sum_{i=1}^{N} 1\, d_i X_{ik} \leq Q_k, i \neq 1\ \forall k \in k$. The speed of transporting patients by emergency hospital vehicles is 80 kilometers per hour, and the starting point and destination must be the exact location.

3) Time constraints:

Emergency vehicles can pick up the patient immediately when they travel to the accident scene. The total service duration is not more than 30 minutes. $(T_{ijk} \leq 30)$

Data analysis and development of routing models

Step 1: Determine the overlapping area by using the QGIS geographic information program to find the radius of 20 kilometers of all district hospital services in Ubon Ratchathani province and then to determine the shortest route from the hospital to the accident site and from the location of the accident to the hospital. The data is based on 1,736 accident sites in the area. The location of the incident was set using its longitude and latitude coordinates, travel time to the incident site in minutes, total cost in baht, and total distance from the hospital to the incident site and back to the hospital in kilometers.

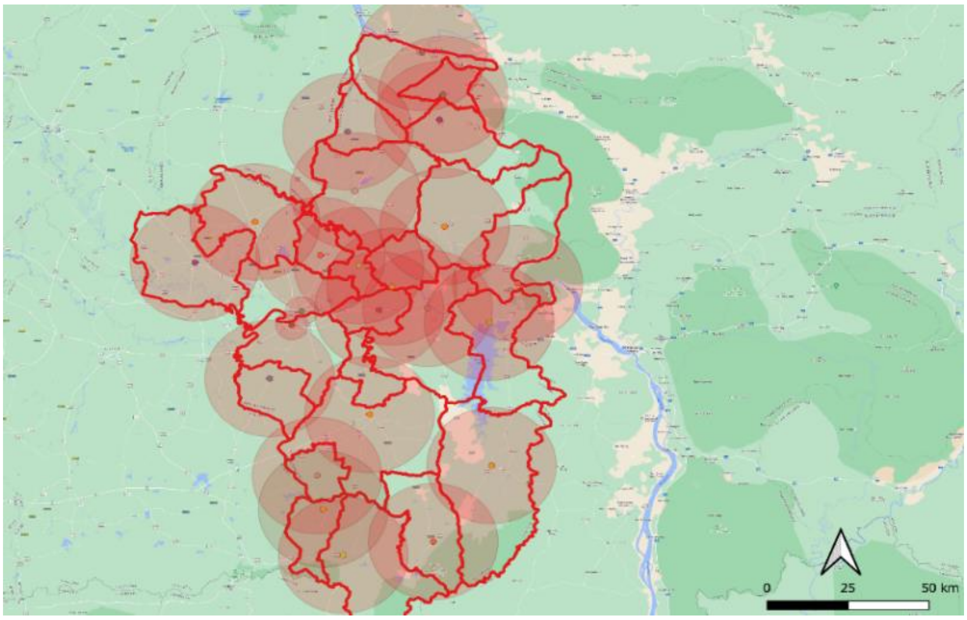

Figure 2: The Radius of The District Hospital in Ubon Ratchathani

The overlapping service areas of emergency hospitals in each district were identified. As illustrated in Figure 2, concurrent incidents might confuse the central facility, causing delays in reporting and decision-making regarding deploying emergency hospital vehicles to specific areas.

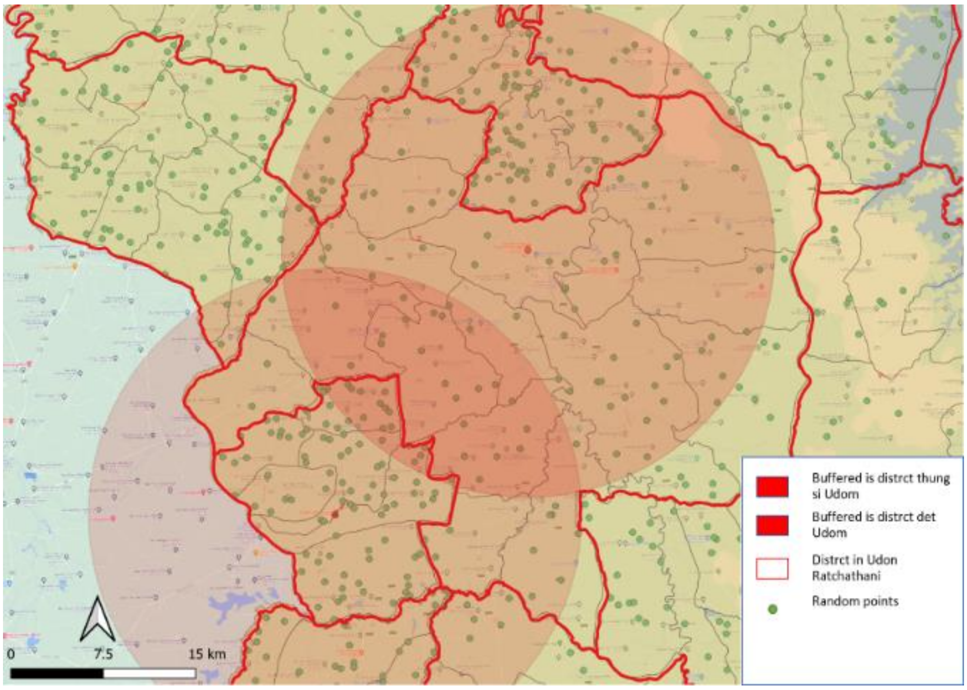

Figure 3: Overlapping Thung Si Udom and Det Udom District Hospital Service Areas

The villages are in areas where services overlap, as illustrated in Figure 3. It is impossible to tell which district's emergency hospital vehicles should be sent from in case of simultaneous emergencies. The following equation represents the lowest duration, the shortest path, and the lowest cost:

$$Min\ Z = \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{k} Cijk$$

Step 2: Apply the coordinates and attach the overlapping service area villages 1,736 accident sites in the area to find the answer in the VRP Spreadsheet Solver program; enter the number of emergency hospital vehicles in each area to determine which district's emergency vehicle was to be sent to the scene. Under these conditions, the number of emergency hospital vehicles is limited.

Step 3: Validation by AHP and the consistency ratio (CR). After obtaining the weight of the importance of each factor, the consistency of the factors is checked by pairwise comparison by having the interviewers give the weights to each factor. The selection of emergency hospital routing patterns begins with the study and compilation of primary data and the collection of factors that affect the emergency hospital routing model. This includes a speed factor for transporting emergency patients from the scene to the hospital, distance from the accident site to the hospital, time to assist patients at the scene, and the cost of transporting emergency patients. These factors are considered and analyzed using the AHP method to decide the most efficient transport route.

The criteria of the targets to be studied must be defined in a hierarchical form with a sub-criterion at the lower level, followed by the principle of pairwise comparison. The comparison values are numbered 1 to 9, according to Table 1 below.

Table 1: Definition of pair-by-Pair Comparison

Priority	Healing	Explanation
1	Equal importance	Both criteria affect the objectives equally.
3	More important than moderate.	Let the opinion of one criterion be more important than the other, which is moderate.
5	Much more important.	Let the opinion of one criterion be much more important than the other.
7	More important than most.	Let the opinion of one criterion be more important than the other.
9	More important than the maximum.	Let the opinion of one criterion be more important than the other at the highest level.
2,4,6,8	In the middle	It is between the levels described above.

Then, confirm the model to determine if a factor is reasonable; $CR \leq 0.10$ indicates that the factors are consistent. If the CR value is ≥ 0.10, this indicates that the factor does not have a consistent value.

Research Findings

In this case study, the methodology for identifying overlapping areas involved utilizing the QGIS geographic information program. EMS computed a radius of 20 kilometers around all district hospital services in Ubon Ratchathani province. Subsequently, using the geographic information system, the study determined the shortest routes from the hospitals to the accident sites and vice versa. The dataset for this extensive analysis was drawn from information related to 1,736 accident sites within the specified region.

Figure 4: Finding Out Where to Send The Ambulance

Moreover, the study revealed that in certain regions, the arrival time of emergency hospital vehicles could extend up to 107 minutes, encompassing distances of 100 kilometers or more. This extended time frame was often attributed to the necessity of borrowing vehicles from adjacent districts, as illustrated in Figure 4. It is possible to recognize the district in which the emergency took place and which district's emergency hospital vehicles should be sent to the scene under conditions where there is a limited number of emergency hospital vehicles, with the number of emergency vehicles shown in Figure 5. The minimal amount of time should be spent getting to the accident site, along with the shortest distance covered and the lowest cost used. The result is to identify the most straightforward route that ensures an arrival time at the accident site within 30 minutes (Figure 6).

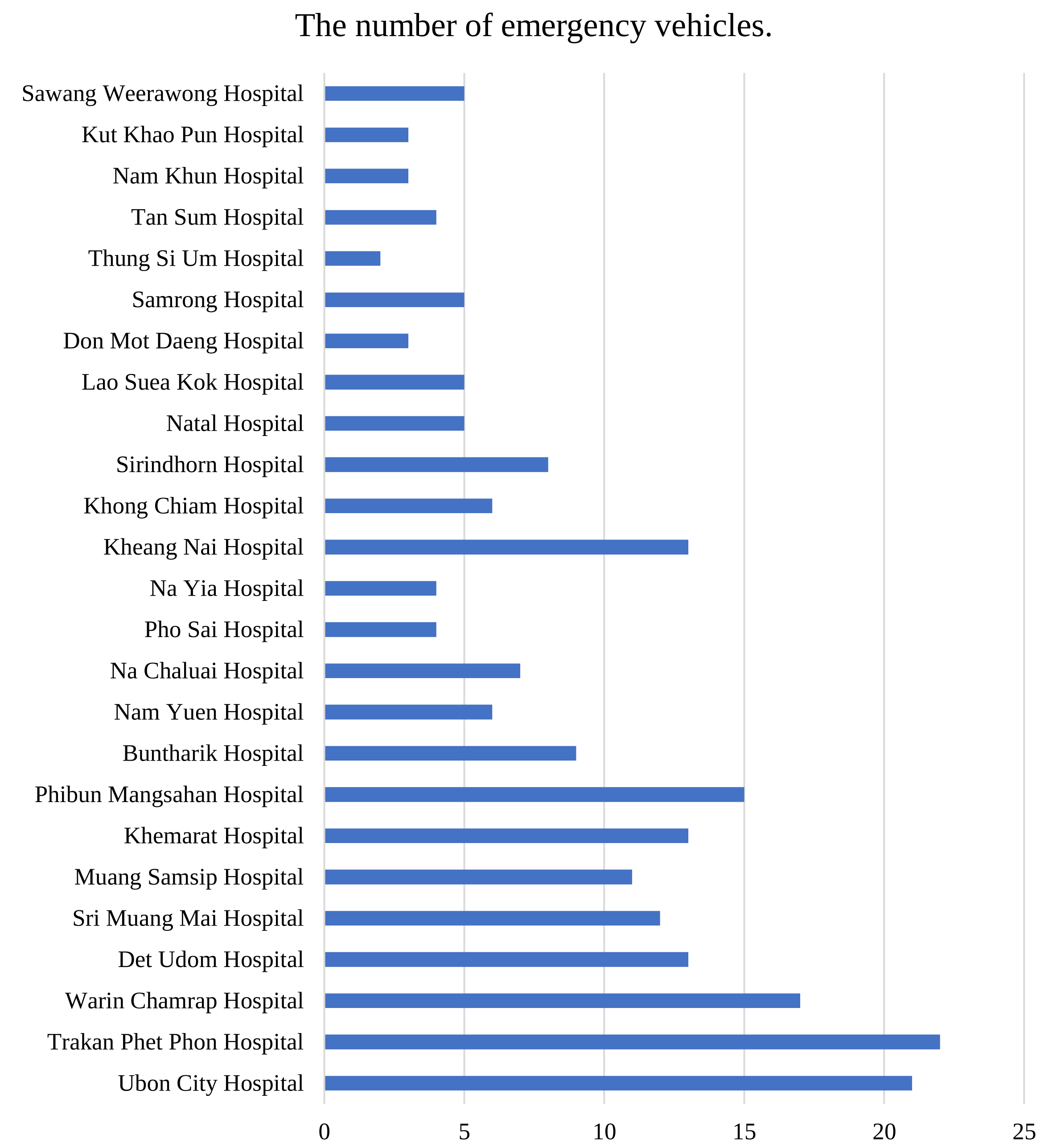

Figure 5: Number of Emergency Hospital Vehicles in Each of The 25 District Hospitals

Creative Business and Sustainability Journal (CBSJ)
Vol.46 No.1 January – June 2024, pp.66-85

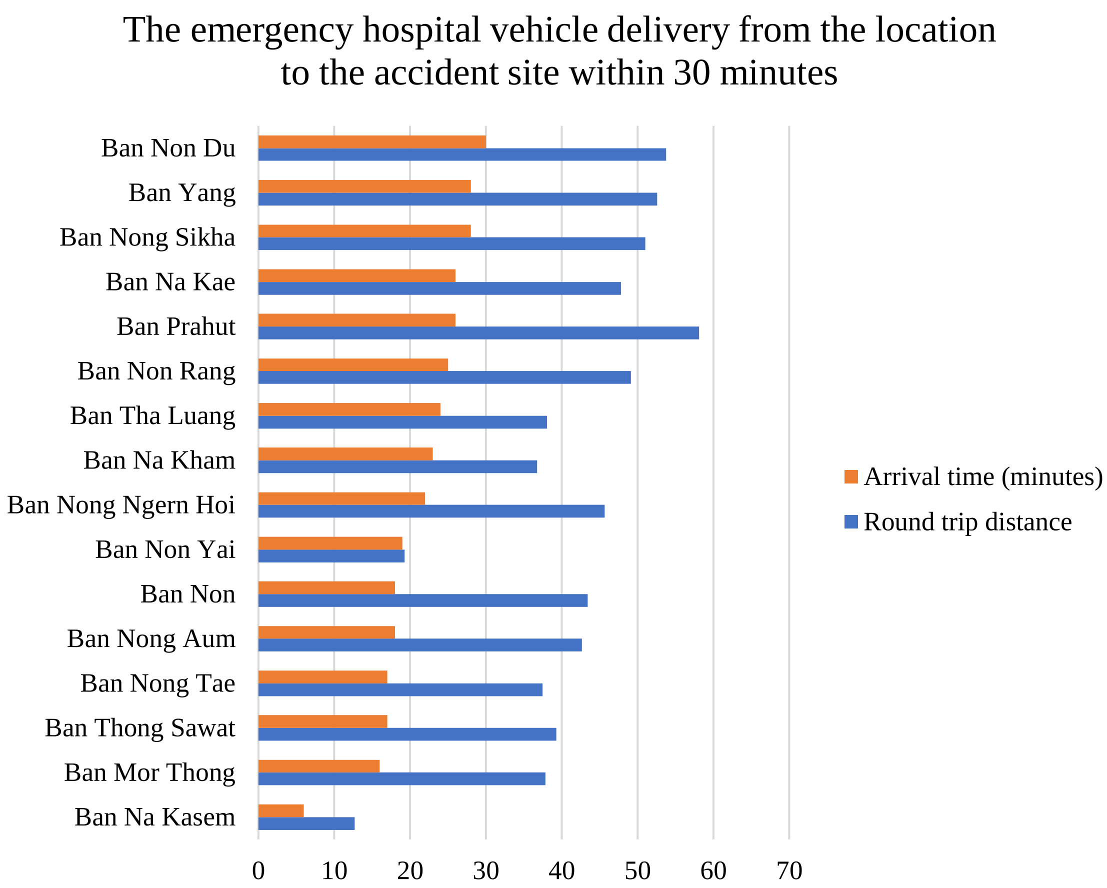

Figure 6: The Emergency Hospital Vehicle's Arrival at The Accident Site Within 30 Minutes

Figure 7 below provides a visual representation of the costs associated with overlapping service areas after the model has been developed in situations where incidents coincide. Additionally, the figure depicts the cumulative duration for all areas, the combined distance across the entire region, and the overall cost incurred.

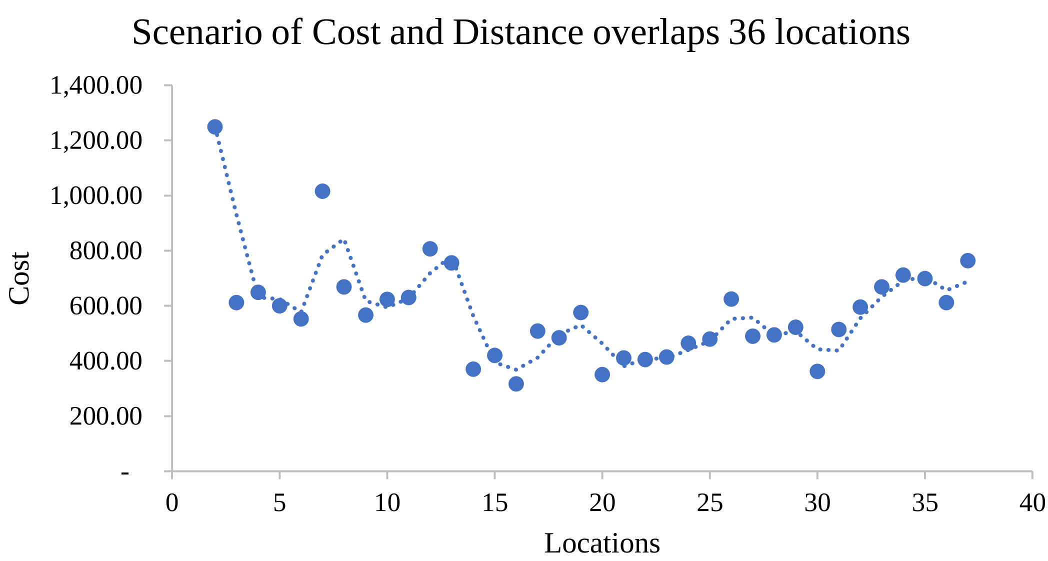

Figure 7: The Cost-of-service Areas Overlap After Model Development

Creative Business and Sustainability Journal (CBSJ)
Vol.46 No.1 January – June 2024, pp.66-85

Utilizing the VRP Spreadsheet Solver program to minimize costs, it was evident that expenses decreased in a total of 31 out of 36 areas. An illustration of overlapping service areas, such as those between Thung Si Udom District Hospital and Det Udom District Hospital, is elucidated by Equation (1):

$$MinZ = \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{k} Cijk \quad (1)$$

In this specific case, the equation is further detailed as

$$Min\ Z = 2{,}690b_{ijk} + 32{,}098C_{ijk}$$

The trial results indicate a notable reduction of 37.88% in emergency patient transport costs across all overlapping service areas in Ubon Ratchathani Province, utilizing data derived from relevant research as detailed in Figure 8.

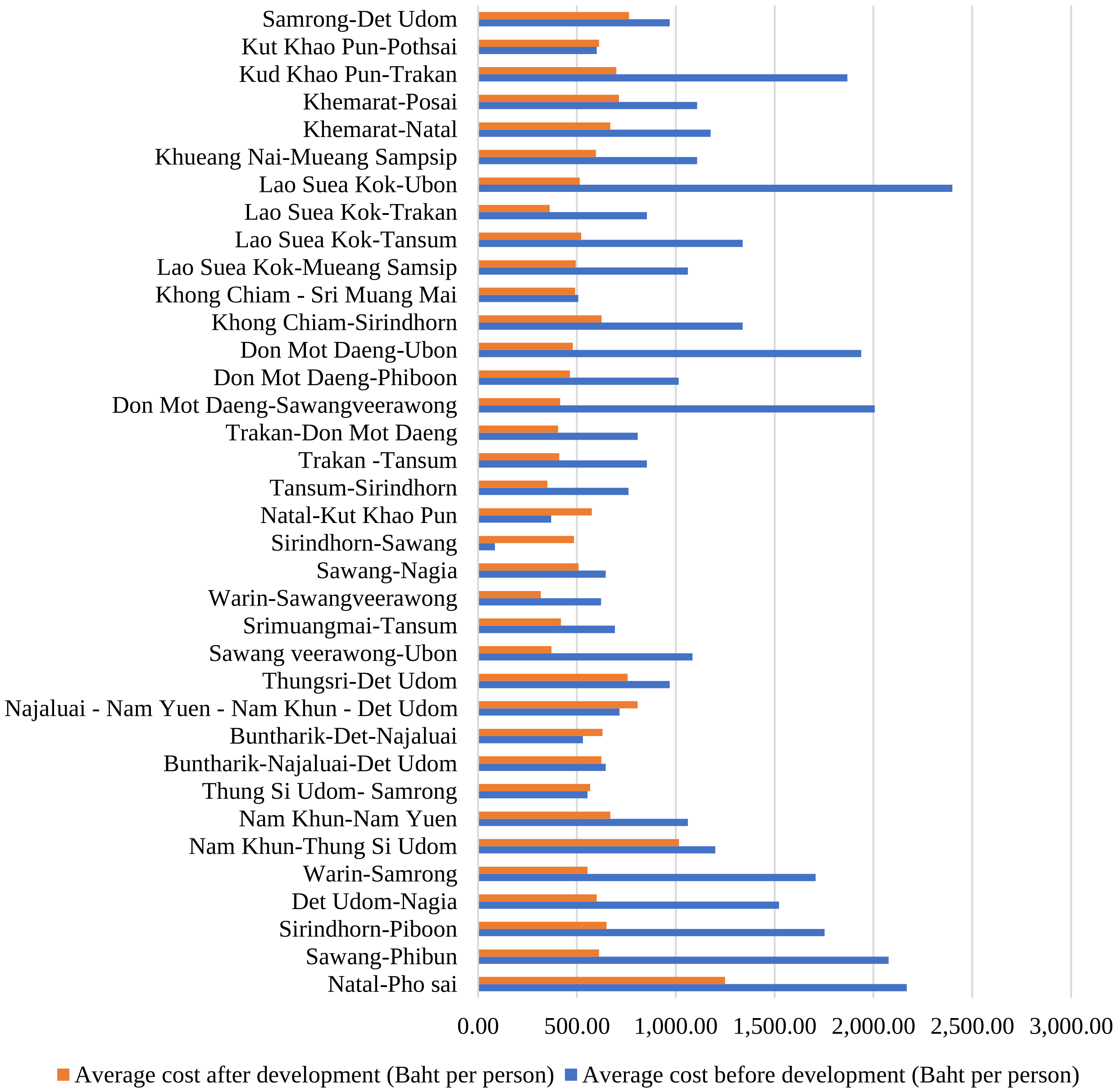

Figure 8: Comparison of The Average Cost Per Person in Overlapping Service Areas Before and After Development

Performance model testing with AHP

All factors considered for the AHP include the speed at which emergency patients are transported from the scene to the hospital, the distance from the accident site to the hospital, the time to assist patients at the scene to the hospital, and the cost of transporting emergency patients. This is used to consider the emergency hospital delivery model, as shown in Figure 9.

The study's findings presented the percentage influence each factor has on the decision-making process for selecting an emergency hospital delivery model. The percentages in Table 2 represent the weight or influence of each factor. For instance, the "Distance from Hospital to Accident Site" factor has the highest influence at 54%, indicating its significant impact on the decision-making process for the emergency hospital delivery model. This comparative analysis allows for a clear understanding of how these factors contribute to changes in the average cost per person in overlapping service areas before and after the development of the model.

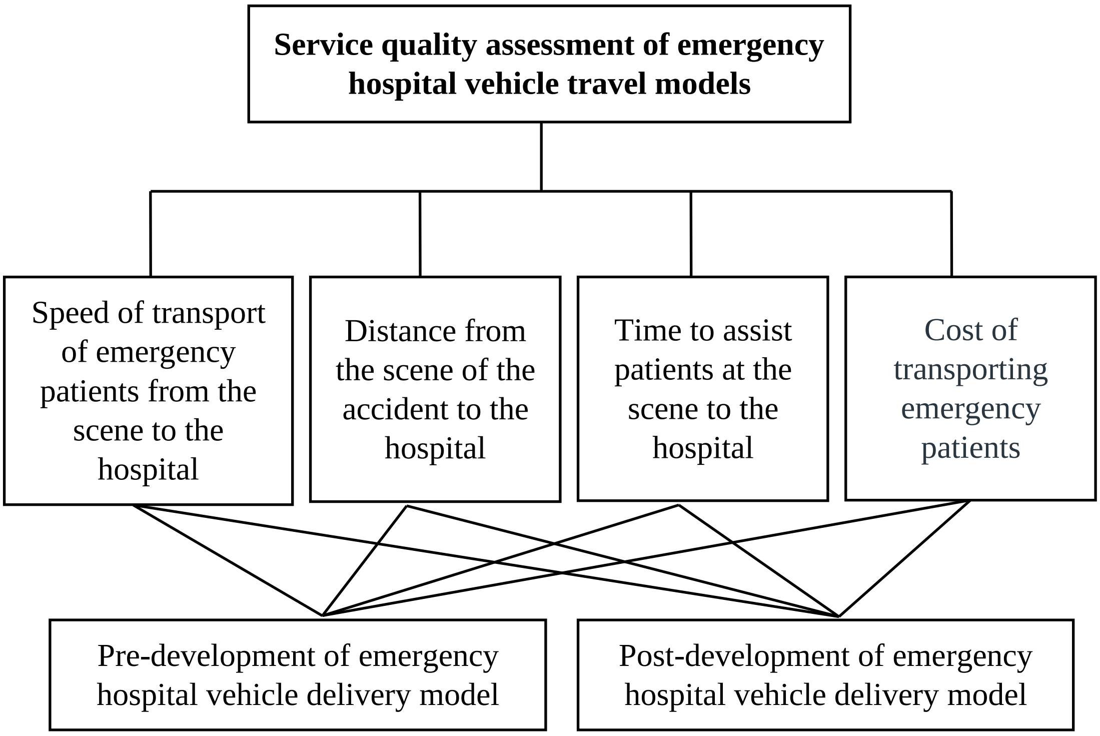

Figure 9: Consideration of Emergency Hospital Delivery Model

The consistency ratio (CR)

After obtaining the weight of importance for each factor, the consistency of the factors was checked by pairwise comparison by having the interviewers give the weights to each factor, as shown in Table 3.

A = Speed of emergency patient delivery from the scene to the hospital
B = Distance from the hospital to the accident site
C = Time to assist patients at the scene
D = Emergency patient transportation costs

Table 2: Comparison of The Average Cost per Person in Overlapping Service Areas Before and After Development.

Factor	Speed of Transporting Patients to the Hospital	Distance from the Hospital to the Accident Site	Time to Assist the Patient on Accident Site	Cost of Transporting Patients
After	26 %	54%	13%	5%

Table 3: Dual Comparison Table Values

Factor	A	B	C	D
A	1.000	0.333	4.000	5.000
B	3.000	1.000	5.000	7.000
C	0.250	0.200	1.000	4.000
D	0.200	0.143	0.250	1.000
	4.450	1.676	10.250	17.000

To determine if a factor is reasonable, CR ≤ 0.10 indicates that the factors are consistent. If the CR value is ≥ 0.10, this indicates that the factor does not have a consistency value. The CR value is calculated as follows:

$$CR = \left[\frac{CI}{RI}\right]$$

where CI is the Consistency Index, it can be calculated from:

$$CI = \left[\frac{\lambda_{max} - n}{n - 1}\right]$$

where n is squared size, and λ_{max} is the maximum (Eigen Value) of a particular coefficient.

$$CI = \left[\frac{\lambda_{max} - n}{n - 1}\right]$$

Table 4: Normalize Matrix.

	Normalize Matrix						
Factors	A	B	C	D			
A	0.225	0.199	0.390	0.294	1.108	0.276	6.90%
B	0.674	0.597	0.488	0.412	2.170	0.542	13.60%
C	0.056	0.119	0.098	0.235	0.508	0.127	3.20%
D	0.045	0.085	0.024	0.059	0.213	0.053	1.30%
	1.000	1.000	1.000	1.000			

Take the result divided by the priority weight value, and then find the average of the result:

$$\lambda_{max} = 4.25172$$

$$CI = \left[\frac{4.25172 - 4}{4 - 1}\right]$$

$$CI = 0.08391$$

RI is the (Random Consistency Index)

Table 5: Consistency Values From Sampling

The Number of Factors Compared.	**1**	**2**	**3**	**4**
RI	0.00	0.00	0.58	0.90

Therefore, the rational consistency ratio compared to the RI values from Table 5 are four factors:

$$CR = \left[\frac{CI}{RI}\right]$$

$$= \frac{0.08391}{0.9}$$

$$= 0.09323$$

According to the study, CR=0.09323 is a comparable pair of reasons. The pairs are consistent in their reasoning.

The performance of the model was tested using the Analytic Hierarchy Process (AHP) by determining the weight of each factor in deciding which type of emergency hospital transport to use. It was found that the most important factor was the distance from the hospital to the incident, accounting for 54%, the speed of transporting emergency patients from the incident to the hospital at 28%, the time taken to assist patients at the scene at 13%, and the cost of transporting emergency patients at 5%.

The Consistency Ratio (CR) was calculated using pairwise comparison methods, where interviewees were asked to weigh the importance and calculate the eigenvalue (λmax = 4.25172) and the consistency index (CI = 0.08391) to find the consistency ratio, which was found to be (CR = 0.09323). The pairwise comparison had a consistency ratio within an acceptable range.

In conclusion, the Analytic Hierarchy Process (AHP) emphasizes the importance of distance, speed of transportation, time to assist patients, and transportation costs for emergency patients from origin to destination. The results of the comparisons thus justify the importance of these factors, which are suitable for developing future emergency transport services to create strategies or policies to support this development.

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Discussion

The developed model demonstrates practical applications for improving the efficiency and cost-effectiveness of emergency patient transport. Using GIS tools for spatial analysis and VRP Solver for optimization contributes to better resource allocation and route planning. The substantial cost reduction of 37.88% in emergency patient transport costs across 36 overlapping service areas highlights the potential impact of the developed model. The AHP assessment involving service users provides valuable insights into the factors influencing the ambulance travel model, with distance emerging as the most critical factor

Theoretical Contributions

The theoretical contributions of this research significantly advance the field of emergency medical services by demonstrating how systematic optimization of ambulance travel can markedly improve response times, reduce costs, and enhance patient outcomes. The model developed through this research reveals effective cost-reduction strategies, suggesting that EMS operations can be more cost-effective without sacrificing service quality. It also facilitates optimized resource allocation, allowing managers to strategically deploy vehicles, personnel, and equipment to maximize efficiency and reduce expenses. Additionally, the research serves as a guide for strategic planning in emergency response, addressing critical factors such as vehicle routing, time constraints, and overlapping service areas to improve service effectiveness during emergencies. The integration of cost, confidence, and time considerations enhances decision-making capabilities, leading to more informed and efficient management practices. Furthermore, establishing performance metrics and evaluation criteria helps assess the operational efficiency of EMS and pinpoint areas for ongoing improvement. The findings also support investment in specific technologies and training that boost operational efficiency and cost savings, influence policy development, and aid in creating public awareness campaigns and educational initiatives. Overall, this research equips EMS managers with the insights needed to enhance decision-making, optimize resource allocation, and increase the overall efficiency of emergency medical services.

Managerial Implications

The critical steps for effective route planning into accident areas for emergency responders prioritize understanding the incident's nature, seamless communication, access to real-time information, and safety. Technology, local expertise, and continuous training are highlighted as crucial elements for ensuring a swift and efficient response to emergencies, ultimately saving lives and minimizing the impact of such situations. The National Institute for Emergency Medicine has also outlined six critical procedures for responding to emergency patients. These include identifying emergency illnesses, prompt incident reporting, coordinated response, on-scene medical care, safe patient transport during transit, and the smooth delivery of patients to appropriate medical facilities.

Conclusion

The research focuses on optimizing emergency hospital vehicle travel by developing a Vehicle Routing Problem (VRP) model. The overarching goal is to minimize the total cost of transporting emergency patients. The study incorporates various decision variables and constraints, encompassing factors such as patient transportation speed, capacity, cost, service needs, distance, and duration of service.

The research has two main stages: using QGIS to determine service radii and the VRP Spreadsheet Solver for optimal route planning within overlapping service areas. The model achieves a substantial 37.88% reduction in emergency patient transport costs across 36 overlapping areas. An Analytic Hierarchy Process (AHP) assesses factors influencing the emergency ambulance travel model. Service users prioritize the distance from the accident site to the hospital as the most critical factor.

Limitations and Directions of Future Research

Future research could explore real-time dynamic routing, integration of emerging technologies, multi-objective optimization, sensitivity analysis, collaboration with stakeholders, human factors and behavioural analysis, expansion to different geographical contexts, cost-benefit analysis, and simulation studies. Addressing these areas would contribute to a more comprehensive understanding of ambulance travel optimization, paving the way for practical and effective implementations in emergency medical services.

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