A Systematic Review of Route Optimization for Ambulance Routing Problem

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Abstract. Ambulance Routing Problem (ARP) is the part of Emergency Medical Services (EMS), which provide timely medical help for those who are in need. In Medical emergency situation, the key concern is, to provide early treatment. Relocating patients quickly to neighboring medical facilities is extremely difficult given the existing traffic situation and has to be rectified. A lack of EMS owing to urbanization and several routing considerations such as the precise location of the request, traffic problems, road width, and ambulance locations are few of the difficulties. This paper summarizes a number of recent studies on ARP in routing and the issues they raised. In this survey, Routing for Ambulance vehicles is categorized as initiating ambulance from depot to injured location (response Time) and routing from injured location to nearby medical Centre (Travel Time). And, we highlighted challenging issues and constraints related to route optimization in both above mentioned category. Also emphasized the less explored research area like Interfacility hospital transfer and importance of incorporating safety metrics during Ambulance Routing.

Keywords: Ambulance Routing Problem · Emergency Medical Services · Routing · Response Time · Safe Ambulance Routing · Route Optimization

1 Introduction

Recent years have seen EMS develop as a response to catastrophes such as rising accident rates, population growth, urbanization, and daily demands. As annual demands continue to rise, this is one of the most pressing issues that must be addressed immediately. More than 1.5 million calls were made to the National Institute of Emergency Medicine (NIEM) in 2016 [1]. Current prevailing pandemic situation facing more challenges in many industries like health care and ambulance routing. Many medical emergencies become tragedy because of delaying in medical treatment.so it is much needed to have best ambulance routing service to save many lives. Providing lifesaving medical care as quickly as possible is EMS's first priority [2]. The preemption and route optimization combined together to provide fastest travel time in ARP. Many methods like exact algorithms, heuristics, Meta heuristic, Internet of Things, Artificial Intelligence are employed in ARP problems to improve the performance. Various objective variables, like minimizing distance, cutting expenses, reducing time, situating ambulances, dynamically

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re-locating ambulances, and providing maximum coverage, are sought to optimize for an enhanced EMS service. Ambulance route optimization is particularly difficult due to the wide variety of variables that might affect it, from traffic to weather. To address these difficulties, improved route optimization is necessary. In [3], they proposed smart ambulance, which communicate with traffic light to made the travelling path congestion free. Fastest arrival time, rather than total distance travelled, will be the primary metric for optimizing routes. In order to deliver quick EMS, a dynamic routing optimization strategy based on artificial intelligence is preferable than static strategies [4].

The article is organized as follows:

- Section II presents related works of ARP
- Section III gives overview of ARP and its category
- Section IV discussed about challenges and gaps in existing works
- Section V presents conclusion

2 Related Work

EMS plays a vital role in managing and providing medical assistance to a person who needs a Medical Emergency. Increase in travel time and response time even lead to loss of life in medical emergency. So, Route optimization plays an Crucial role in servicing and saving Medical emergency needed person. Optimization is the methods of achieving the highest possible attaining performance under some given constraints by minimizing unsought factors and maximizing sought factors. Route Optimization suggest best route by considering desired factors with minimum overall travel time. While in ARP there are many challenges need to addressed and taken special concern of emergency medical service needed people while routing. It has many challenges like lacking of traffic information, location information, speed, etc.

So many existing methods worked on Ambulance Route Optimization challenges. Re- location of ambulances in response to traffic incidents to provide good response time on demands and maximum coverage proposed Stochastic Emergency Vehicle Redeployment Problem [5]. To increase the chance of patient survival, [6] proposed integrated platform which combines smart ambulance routing with online patient monitoring. To minimize travel delay, [7] proposed Wireless Sensor Network- Emergency Vehicle Pre-emption based on Collection Tree Protocol. For intensive care and quick response, [8] used ambulance availability information and time taken to reach accident spot. A dynamic re-location of ambulances to minimize response time was reduced for Maximum Coverage of a Location Problem [9]. In [10], author compared and summarized various Ambulance routing problem and Ambulance Location Problem as both information is needed to improve performance and the pre- emption models plays vital role in reducing the travel time of ambulance by alerting other vehicles [11].

This papers exclusively surveyed the recent articles related to Route Optimization for Ambulance from (2015 -2022) taken from publication databases like IEEE, Science Direct, Research gate and ACM. And we summarized methods and models used for optimization which is given in Table 1.

3 Route Optimization for Ambulance

Presently, EMS over ambulances is emergent due to amplified disasters and many health issues. There is a requirement to attain and uphold ambulance services. The main dictum is to save lives and afford medical assistance as profligate as possible. The improved routing of ambulances can accomplish reckless services. In this paper we categories ARP into two division as showed in Fig 1.

The Ambulance starts from its location to the location of a person in need as fast as possible by navigation of the road (response time – Type 1) and services take person from a remote location to the nearest hospital with the help of ambulances (Travel time-Type 2) are two different routing of ambulance service. Both routing will affect the overall travel time of the ARP. In second routing is more crucial than first one, as patient boarded in ambulance should be taken to hospital not only with fastest arrival time but also should consider safety concern and health condition of the patient.

The best ambulance routing can achieve fast EMS services based on time and distance metrics. Time metrics will always achieve an optimal best solution. Many challenges lack ambulance time where traffic congestion is the vital one. A good EMS will respond in minimum time upon a request to reach injured location and takes back to a person's hospital in minimum time, i.e., minimum Total travel Time (TT), with minimum Waiting Time (WT). The complete comparison study of recent works in ARP are presented in Table 1.

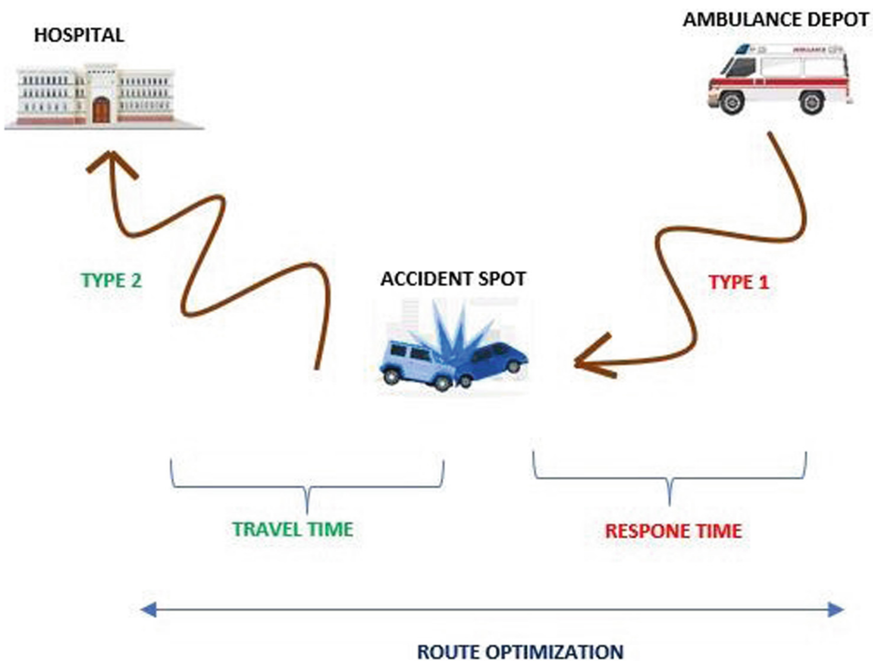

Fig. 1. Ambulance route optimization

Table 1. Summarization of surveyed Papers

Ref No.	Objective	Method	Data Set	Merits	Limitations	Type
[12]	Total Travel Time	Markov decision Process Model	LTA (Land Transport Authority) in Singapore	Usage of Traffic congestion estimation	Integration of the stochastic Shortest path problem into the dynamic vehicle routing problem is a future challenge	Type 2
[13]	Minimize response Time	GSM	Simulation dataset	Categorizati on of patients	Should be implemented on the real-time data	Type 1
[14]	Overall Travel Time	Petal Algorithm, Particle Swarm Optmization (PSO)	Testbed from Augerat et al. (1995), Rochart and Taillard (1995) and Golden etal. (1998)	Reduced response time	Traffic information and congestion not considered	Type 2
[15]	Minimize the travel delay Reroute the other vehicles from accident area.	SAINT + Delay-constrained shortest path (Dijkstra's)	Philadelph ia traffic managem ent centre	Communica tion of vehicles using VANET and 4G LTE to TCC Rerouting other vehicles	Need to do for more accuracy in traffic management	Both
[16]	Minimize total travel cost	Genetic Algorithm (GA)	public hospital in the city of Jendouba, Tunisia	Categorization of patients	Not considering many constraints and working with small problem instance	Type 2
[17]	Optimize path selection based on traffic, speed, availability, position and Minimize total travel time	Ant Colony optimization, GPS	No implementation	Based on patient health condition, best matching hospital is given priority	They have not justified by any implementation and simulation	Both
[18]	Minimize the total response time	ε-constraint bi objective method	Tehran city	Categorization of patients as red and green based on severity	By meta heuristic can get more minimum response time furtherly	Type 2

(continued)

Table 1. (*continued*)

Ref No.	Objective	Method	Data Set	Merits	Limitations	Type
[19]	Minimize expected response time, To estimate and eliminate ALDP busy fraction	busy fraction, Simulator DES, BRM, PSSM, QTSSM, EQTSSM	Montreal city and suburb of Laval,' Quebec, Canada pseudo-real data	Reduced the response time delay gap of the ambulance.	They considered the response of the ambulance, but location information is missing; real-time implementation required	Both
[20]	Minimize time, cost and effort. To find nearest ambulance and best route.	Dijkstra's, Geographic Information Systems (GIS)	Not mentioned	Classifying AHP and usage of GIS Using AI	Focused only on the ALP and Distance. But not focused on traffic congestion.	Type 1
[21]	Minimize the total travel time, waiting time and congestion time.	PATcom, SUMO OMNet + + Veins IOT	Simulation	Vehicle2Vehic le and Vehicle2Infrastruture communication	Real-time implementation and many constraints should be considered	Type 2
[22]	Minimize the time Find nearest hospital	Google API, List of hospitals database	Istanbul hospital database (150 hospitals)	Considering the hospital list database to know the nearest one	Lack of information and should consider traffic congestion.	Both
[23]	Minimize response time Minimize travel time and total cycle time	Advanced A* with Dispersion index IOT-RFID	KR Puram Traffic Junction Bangalore	Usage of RFID for communication and work with parallel strategies and traffic data	The accuracy of RFID may not be the same always. Real-time implementation is required.	Both
[24]	Minimize the response time and Waiting time	EVP VANET SUMO OMNET + VEINS	Auckland city's arterial road network	Response time reduced	Not Worked with Large data and real- world required	Both
[25]	Minimize the time travel, Traffic control efficiency	Internet of vehicle, SUMO	Simulation	Worked with the traffic history data and live data, Traffic clear-out and fastest driving path.	Real-time implementatio n is required.	Type 2

(*continued*)

Table 1. (*continued*)

Ref No.	Objective	Method	Data Set	Merits	Limitations	Type
[26]	Minimize time of information reach. Detect accident.	GPS, Vibration Sensor	No dataset used	Send a message with GPS to the hospital by detection with a sensor	Focus on reducing response time and real-time work.	Both
[27]	Minimize the distance, supply emergency based on the available accident data.	Bat Algorithm-CNN ResNet Simulation using MATLAB	No data used to support this study	Accuracy in information delivery using VANET	Real-time implementation is not done. Communication may not be possible at all times.	Both
[28]	Minimize the travel time	Dynamic Dijkstra's, Reinforcement Learning Emergency vehicle light SUMO	Synthetic & Manhattan Hell's	Historic and real time traffic flow data is considered	There is a gap between synthetic to real	Type 2
[29]	Minimize response time Minimize the latest service completion time (SCT)	NSGA-II, Multi objective PSO	Lorestan province hospital locations	Categorizati on of patients in post-disaster gives better allocation of the ambulance.	Uncertainty in travel time, service duration, and demands or regroup. A combination of both methods may give better results.	Type 2
[30]	Interfacilit y hospital transfer (IHT)	Case study	Taiwan City	Categorised patients as advanced life support and basic Life support	The patient care during IFT in Taiwan is inadequate currently and should warrant attention.	Both
[31]	Interfacilit y hospital transfer (IHT)	Survey	1990–2021	Summaries advancement in IHT	Methods, constraint have to compared	Not applicab le

(*continued*)

Table 1. (*continued*)

Ref No.	Objective	Method	Data Set	Merits	Limitations	Type
[32]	Minimise distance and maximise communication coverage	Eppstien k-shortest path Algorithm	Simulation	Finds trade of route between distance and communication coverage for continuous remote monitoring Patients	Only communication Coverage constraint is considered. Need to address more metrics related to safety	Type 2

4 Discussion

From the survey, ARP challenges are classified as type 1 and type 2 problems. Where type 1 deals with route optimization from ambulance location to accident path and type 2 deals with route optimization from accident spot to nearby hospital. For an efficient EMS, whole journey starting from ambulance location to accident spot and taking patient to hospital should be optimized. Only 35% of surveyed paper considered both path of routing and still those works treated both path for optimization with same constraints as shown in Fig 2. Only in few papers [22–24, 26, 27]they considered patient initial diagnosis for searching appropriate hospital with needed facility in type 2 but this medical condition was not considered for choosing appropriate route for patient.

In medical cases, some diagnosis condition needed safe route than shortest route. Safety is also major concern need to be included as cost in Type 2 route optimization in needed cases. Safety parameters like Road quality, Carbon emission level can be included. And inclusion pre-emption technique in optimization problem provides better

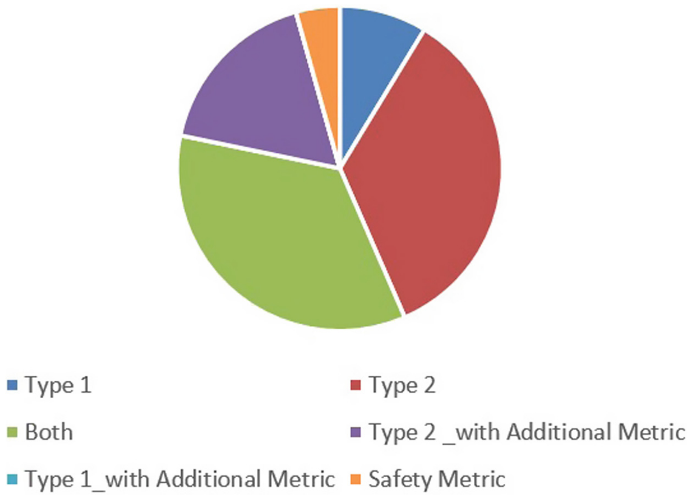

Fig. 2. Comparison of existing work based on category

result and reduction of overall travel time. It is noted from the survey that, Inter facility ambulance routing [30, 31] was least unexplored research dimension in ARP. Inter facility ambulance service is a non-emergency medical service involves carrying patient from one hospital to other specialized hospital. For that condition, it is needed to assure the competence level is enough for patient expected medical needs. Then safe Route comes into play more than fast and shortest route [32–35]. Safety factors like

- Road quality,
- Weather condition,
- Pollution,
- Accident-free zones
- Traffic Light free zone

are need to considered during route optimization for inter facility ambulance service.

5 Conclusion

This paper provides a detailed survey of ARP by focusing on several constraints and metrics. We categorized existing works based on their consideration of whole journey of ARP from ambulance request to patient transfer to hospital. The comparison table describes methods, limitation and benefits of existing works and a person in need of medical attention during a medical emergency cannot function without the help of emergency medical services (EMS). Loss of life can occur in the event of a medical emergency because of the prolonged reaction time and longer travel times. As a result, optimizing routes is critical to reaching those who are in need of medical assistance quickly. Optimization is a methodology for maximizing a desired outcome while reducing an undesirable one in order to achieve the best feasible performance within specified limitations. Optimization of travel routes recommends the fastest and most convenient path, taking into account a variety of parameters. People in need of emergency medical services are a particularly vulnerable group in ARP, and as such, great care must be given while planning routes. It faces several obstacles, such as a lack of traffic information, geo-location data, speed details, etc. Paper also suggested other important safety metrics like road quality, weather conditions, pollution need to address in routing for Inter facility ambulance services.

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