CHAPTER 1

INTRODUCTION

The resources necessary to provide goods or services to an individual are often referred to as the supply chain. Therefore, collecting assets, managing inventories, and delivering products and services to providers and clients are all part of healthcare supply chain management.

1.1 BACKGROUND

Several hospitals and medical practices have made cutting healthcare costs their top priority, especially as suppliers begin to link claims compensation amounts to cost and quality effectiveness. While many firms have started to look at healthcare supply chain management, others have been looking at the billing and services side of the revenue cycle.

The resources needed to provide goods or services to a customer are often referred to as the supply chain. Consequently, collecting resources, managing supplies, and delivering goods and services to providers and clients are all part of healthcare supply chain management. Physical items and data about medical goods and services typically pass through various stakeholders, including producers, insurers, hospitals, providers, group purchasing groups, and various regulatory bodies, to be completed [Mosadeghrad 2014]. The oversight of supply chains is frequently a challenging, and disjointed process in the healthcare industry.

Yet, hospitals and medical practices can generate significant cost-cutting opportunities across their whole organisation by encouraging productivity in the healthcare supply chain. Despite ongoing attempts to increase access and quality, healthcare in India is

characterised by rising prices and a rise in the prevalence of chronic diseases. Also, minority groups bear a disproportionate share of the burden of particular diseases and impairments, contributing to the health inequities in our society. The current health care system will struggle to provide sufficiently equitable health services if alternative models aren't investigated and implemented to fulfil the population's health demands [Kruk 2018].

Developing nations commonly struggle with the conflict between a growing population and severe budgetary restrictions for healthcare expenses. The availability of affordable healthcare facilities is crucial in such a circumstance. One of the most important variables affecting how often people used healthcare services was distance, especially in rural areas of developing countries like India. As a result, in these areas, having healthcare centres close to people's homes is essential for adequate medical care [Singh and Badaya 2014].

Many governments and institutions propose adding Mobile Medical Units (MMUs) to hospitals and fixed dispensaries as a potential means of providing primary healthcare at a reasonable cost within a developing country's severely constrained financial constraints. Expanding public access to health services is one of the most important goals of such mobile facilities. The expenses for employees and equipment would rise significantly if more geographically fixed healthcare units were constructed to have the same accessibility effect, which is frequently unaffordable [Neumann and Weinstein 1991]. On the other hand, these mobile medical units can go to certain locations at specific times and provide care for people nearby. Of course, mobile units can't provide all the services a hospital provides. These can therefore be viewed as an addition to other medical services, addressing the most urgent requirements or services from specific specialised medical fields like dental care, the knowledge of eye specialists, or CT scanners. The medical equipment in a developing nation will typically not be up to extremely high

standards, but essential medical services can still be provided with high standards [Moyimane et al. 2017].

1.2 MOBILE MEDICAL UNITS (MMUs)

To deliver primary care in rural areas, mobile medical units (MMUs) are specialised vans outfitted with medical equipment. An approach to healthcare delivery, Mobile Medical Units (MMUs), can potentially reduce health disparities among vulnerable groups and people with chronic illnesses. Moreover, some research has found that MMUs have a significant impact when giving emergency care, conducting preventative health screenings, and starting chronic illness management. MMUs may provide specialised, high-impact, and economic health care that dynamically adapts to the community's changing needs by stepping directly into areas and developing sustainable community resources [Khanna and Narula 2017].

Millions of individuals now have access to healthcare because of the introduction of mobile medical units (MMUs), launched in response to the requirements of underserved communities. MMUs are specialised vehicles equipped with medical supplies that are portable and capable of offering the majority of the medical services that a traditional stationary office could. MHU is a specialized vehicle fully equipped with medical supplies, equipment, and trained personnel. It is designed to bring healthcare, currently unavailable, closer to people's homes and places of employment. They play a special role in connecting with vulnerable groups, such as patients with complex diseases who could have trouble navigating the healthcare system and the uninsured and homeless who may live in distant, rural areas without access to care. So far, MMUs' application is not limited to emergencies. They assist the underprivileged urban, suburban, or peri-urban population and the remote, rural areas by offering preventative, diagnostic, curative, comforting, and educational interventions. MMUs use accessible and patient-centered methods to treat

both acute and chronic diseases. They also assist patients in finding more conventional services [Mobile_Medical_Units.pdf (nhm.gov.in)].

1.2.1 STRUCTURE AND OPERATION OF MOBILE MEDICAL UNIT

As mentioned earlier, the Mobile Medical Units (MMUs) operate to provide varied health services for populations living in rural, vulnerable, and un-served areas as a major initiative under the NRHM. They also reach the people having no infrastructure with the advent of NUHM. It functions intending to deliver healthcare services to these populations' doorsteps. As per a report by nhm.gov.in, 1691 MMUs are operating across 25 out of 36 States and UTs in India. The details of the same are given in the table 1.1 as below.

Table 1.1 Details of Mobile Medicals Units (Operational) under National Health Mission (NHM)

[Mobile_Medical_Units.pdf (nhm.gov.in)]

Sr. No	State/UTs	Mobile Medical Units (MMUs)
1	Bihar	0
2	Chhattisgarh	30
3	Himachal Pradesh	12
4	Jammu & Kashmir	10
5	Jharkhand	92
6	Madhya Pradesh	150
7	Orissa	9
8	Rajasthan	214
9	Uttar Pradesh	170
10	Uttarakhand	17
11	Arunachal Pradesh	16
12	Assam	130

13	Manipur	9
14	Meghalaya	4
15	Mizoram	9
16	Nagaland	11
17	Sikkim	0
18	Tripura	0
19	Andhra Pradesh	67
20	Goa	0
21	Gujarat	74
22	Haryana	12
23	Karnataka	70
24	Kerala	28
25	Maharashtra	50
26	Punjab	33
27	Tamil Nadu	415
28	Telangana	0
29	West Bengal	49
30	A&N Island	0
31	Chandigarh	0
32	D&N Haveli/Daman & Diu	3
33	Delhi	2
34	Ladakh	1
35	Lakshadweep	0
36	Puducherry	4
	Total	1691

Source: NHM-MIS reports as of Dec 2020.[

https://nhm.gov.in/index1.php?lang=1&level=2&sublinkid=1221&lid=188

(Accessed on April 27, 2022)]

These MMUs' are meeting the recommended package of services in 12 thematic areas to meet the technical and service quality standards for a primary health centre: maternal, neonatal, and infant health; child and adolescent health; reproductive health and contraceptive services; management of chronic infectious diseases; primary OPD care (simple acute illnesses); management of common non-communicable diseases; and management of common non-communicable diseases. MMUs offer these services without charge, as well as facilitating referrals. [https://nhm.gov.in/index1.php?lang=1&level=2&sublinkid=1221&lid=188 (Accessed on April 27, 2022)]

According to the guidelines given by the national health ministry, the composition of MMU must be as follow shown in Table 1.2:

Table 1.2 Composition of Mobile Medical Unit

Position	Number
Medical Officer (MBBS only, preferably women)	1
GNM	1
Lab Technician	1
Pharmacist cum Administrative Assistant	1
One Driver cum Support Staff	1

Source (NHM 2021) [Post PA. Mobile Health Care for Homeless People: Using vehicles to extend care. National Health Care for the Homeless Council. 2007; https://www.nhchc.org/wp-content/uploads/2012/02/mobilehealth.pdf. (Accessed 26 Mar 2022)]

As the rural areas face a lot of differences in accessing healthcare and social factors of health, many illnesses disproportionately afflict particular populations. These discrepancies are critical to address to improve general health and reduce healthcare costs.

Even in well- developed States, many regions of the country, primarily tribal and hilly areas, lack infrastructure, thereby limiting healthcare services. Various attempts have been attempted throughout the years to address this issue, with varying results.

WHO believes that MMUs may serve as an interesting resource in times of crisis brought by severe security concerns, inadequate communications, and ongoing emigrations. In other circumstances, MMUs may be the only available option because the existing support systems are unreliable, and the peripheral healthcare system is badly compromised.

But the problem does not end here. It becomes very complex to plan the travel of these MMUs satisfying the demand of each village, different criteria, cost-friendly, accessibility, etc. Also, covering the distance is highly dependent on concrete situations. To plan the tour of these MMUs with maximum distance coverage at effective cost requires an optimization algorithm with maximum distance as the objective function. Vehicle Route Optimization (VRP) can prove a boon to this challenge.

1.3 VEHICLE ROUTING OPTMIZATION

In the area of optimization, there are two ways to help optimize the rote of vehicles, viz., traveling salesman problem (TSP) and vehicle routing problem (VRP). Because VRP can create multiple routes that travel through every client location, it varies from TSP. VRP provides services to multiple routes, whereas TSP provides services to single route, as explained in figure 1.1.

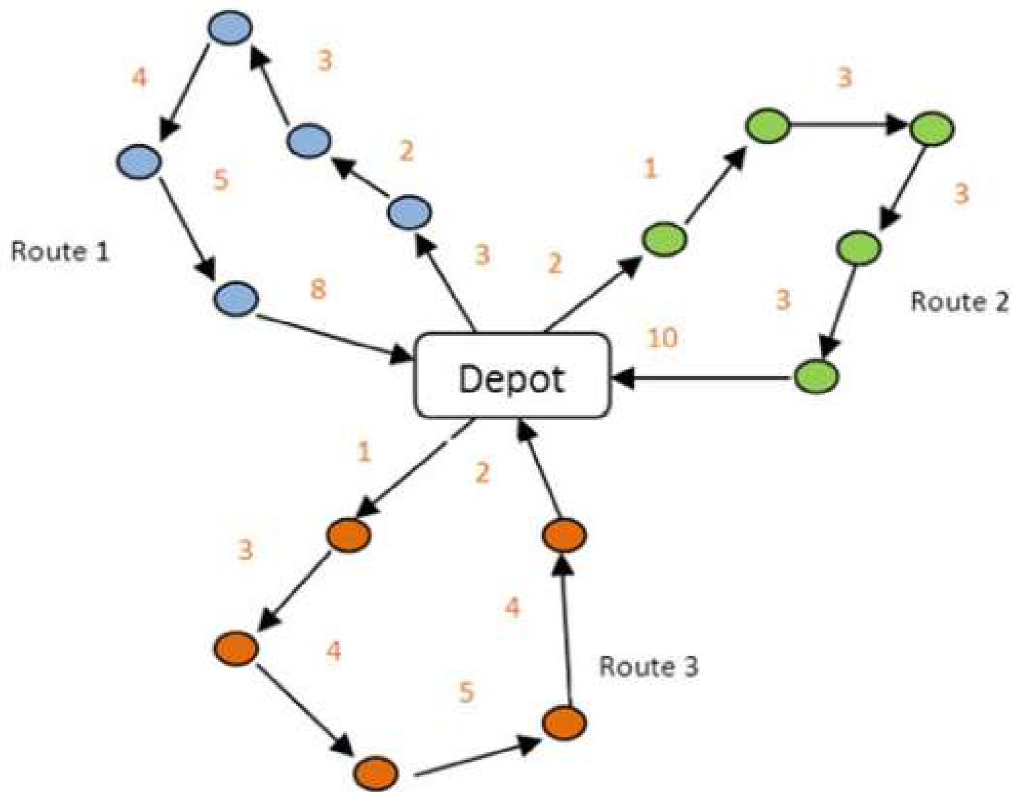

Figure 1.1 VRP with multi-depot [Dixit 2018]

The term "vehicle routing problem" (VRP) refers to a group of issues where a group of vehicles located at one or more depots must be structured into a set of routes to provide service to customers spread out widely. The VRP's primary objective is to develop the least expensive route to service all customers.

In particular, the solution of a VRP requires the determination of an array of routes, each accomplished by a single or multiple vehicle(s) that begins and finishes right at the depot, such that all the consumer needs are satisfied, subject to some operational constraints and the overall transportation cost is minimised. The operational restrictions may include vehicle density, planning, time frame, customer precedence relationships, etc. The well-known integer programming issue VRP belongs to the class of NP-hard problems, which means that the algorithmic effort required to solve the problem grows exponentially in

proportion to the size of the problem. Since they can be found quickly and are precise enough for a reason, estimated solutions to these problems are frequently preferred [Yu, H. (2014)].

The vehicle routing problem's objective is to find the optimum routes of single or multiple vehicles using many optimization algorithms. The traditional way of finding the optimum routes is using optimization algorithms such as ant colony optimization, genetic algorithm, particle swarm optimization algorithms, etc. good results. However, introducing a machine learning algorithm for solving vehicle routing problems has given encouraging results compared to these benchmarking algorithms. One such machine learning algorithm is Reinforcement Learning.

1.4 REINFORCEMENT LEARNING

One subfield of machine learning is reinforcement learning. It involves acting in a way that will maximise benefit in a specific situation. A number of programmes and computers utilises it to decide what action to take in a particular situation. In reinforcement learning, there is no ideal response, however the reinforcement agent selects what to do to complete the job. This differs from supervised learning, where the model is pre-programmed with the solution, and the training data contains the solution key. Without a training dataset, it is required to learn from its experience.

The discipline of reinforcement learning (RL) focuses on decision-making. It entails being aware of how to react in a circumstance to profit the most. Data for RL is gathered from machine learning systems that employ a trial-and-error process. Input for either supervised or unsupervised machine learning does not include data [Singh et al. 2022].

Algorithms used in reinforcement learning determine the next course of action based on results. The algorithm provides feedback after each step that aids in determining whether

the decision it made was good, bad, or indifferent. It is a useful method for automated systems that must make numerous tiny judgments without human supervision [Farazi et al. 2021].

A self-teaching, autonomous system called reinforcement learning fundamentally learns through trial and error. It acts to maximize rewards, or, to put it another way, it learns by doing to get the best results. When decisions need to be adjusted dynamically to a stochastic environment, reinforcement learning (RL) offers prospective ways to optimise policies that take actions based on the environment's current condition in a sequential decision-making process. Precise RL methods may not scale well to the task's dimensionality. To ensure that the subset of solutions we study is congruent with the complexity of the issues, we need specialized approximate models that are developed. Thus, this subgroup seems more inclined to be close to ideal solutions [Habib and Filchenkov 2022].

Fortunately, Deep Neural Networks' (DNNs') ability to generalize and their capacity to learn intricate non-linear functions have created new opportunities for Deep RL, especially in its implementation to combinatorial problems. The main difficulties are efficiently adjusting for the problem constraints and constructing relevant vector representations of data using a graph structure. Although this is the case, all prior research in this field has reframed the VRP as a single-vehicle problem [Alzubaidi, 2021].

1.5 MOTIVATION AND NEED FOR STUDY

One of the critical factors in determining the health and welfare of a country is the accessibility of healthcare facilities, such as multispecialty hospitals or medical clinics. The number of these facilities and their geographic distribution affect how widely accessible health services are. Yet, access to healthcare facilities is challenging for older people or those living in remote locations. Making lengthy journeys to the nearest hospital

for routine check-ups or simple medical attention may be pretty stressful for this group. The most effective method to address this widely recognised issue is the provision of mobile or home healthcare services, in which medical experts visit patients rather than expecting them to travel to medical facilities. As our population ages and the number of people 65 and older continuously rises over the next 50 years, there will be an increasing need for home nursing services [Alzubaidi 2021].

Recent occurrences suggest that home healthcare might be increasingly important during pandemics. The immune system of older persons is impaired, and they are more likely to have co-morbid conditions (such as respiratory, cardiovascular, etc.). Compared to hospitalisation, receiving healthcare at home should expose patients to infectious diseases far less frequently. Previous COVID-19 outbreaks have demonstrated the importance of giving these patients the necessary assistance while they are safely at home to prevent their public exposure in healthcare institutions. These services also assist in freeing up hospital beds and other resources during the pandemic for patients who require breathing ventilators or who are in severe condition and require specialised medical equipment [Monaghesh and Hajizadeh 2020].

In addition to the standard home healthcare services, mobile healthcare professionals and nurses visited patients in high-risk and vulnerable groups at homes for COVID-19 testing and immunization. For those who are susceptible and can't get to a testing center, testing using mobile units has been made available from the start of the epidemic. To support the old peoples, expand coverage to medical care in remote locations, and reduce hospital room and resource constraints during pandemics and otherwise, home healthcare services are crucial. To deliver effective home healthcare services, it is imperative to support healthcare decision-makers [Filip et al. 2022].

Only 26% of hospitals in India have beds, and only 33% of healthcare staff work there, despite roughly 69% of the country's population residing in rural areas. The Indian rural public health system is still ineffective because of the uneven distribution of healthcare resources. These inefficiencies are caused mainly by a shortage of healthcare facilities, a persistent lack of human resources, and frequent medicine stockouts, especially in rural health care systems. In 2017, there were insufficient government healthcare institutions, physicians, nurses, and pharmacists offering primary healthcare services by 24%, 21%, 17.3%, and 14.5%, respectively. People frequently have to drive more than 6 kilometres to attend primary healthcare facilities, and the average absenteeism rate among available personnel is as high as 40% [Akhtar and Ramkumar 2023].

People are more likely to seek medical treatment from the unorganised, informal, and expensive private healthcare sector in rural areas due to steep terrain, irregular transportation services, illiteracy, and financial restraints. Data indicates that just 11.5% of rural families (apart from those who gave birth) accessed primary-level outpatient treatment in healthcare organizations, and that the average medical expense of rural households is rising.

The Government of India launched the Mobile Medical Unit (MMU) facility as a component of its flagship health initiative, the "National Health Mission," to make primary care accessible and available in rural areas. MMUs are designed to offer primary health care close to people's homes to the residents residing in distant and underserved locations [Roy et al. 2023].

1.6 OBJECTIVE AND SCOPE

The increasing demand for quality healthcare inspired us to think about applications where healthcare practitioners could periodically travel to remote rural areas (villages) without a nearby medical institution. Mobile medical units, a government initiative, is a

boon to these rural areas to meet the increasing demand of better health services in rural areas. Also, these MMUs have proved to be financially friendly and more convenient in terms of efforts taken by people in rural areas to travel long distances to the hospitals that are not adequately equipped.

In a standard MMC, healthcare providers use various modes of transportation within set time slots to move from one or many depots to provide health services to single or more patients. As the need for MMC grows, there is an increasing need for adequate planning and scheduling of MMC. Planning takes place at several levels, including operational, tactical, and strategic, and allocating specialists to a patient in need. They also match the right medical practitioner to the correct location based on the demanded services. The significance of travel planning stems from the reality that as and when demand grows, vehicle sizes for doctors and MMUs grow together. From a time and financial standpoint, this has significant implications for MMUs, as improving profitability and service levels can be accomplished by reducing travel expenses and satisfying consumer demands promptly and competently. In addition, as the expansion of operational operations may result in detrimental violations to the environment and employees, MMUs have social and environmental duties that need to be considered when developing vehicle routes [Büsing et al. 2021].

Moreover, research objectives must be linked with demands, challenges, and trends in the real world to create a real Mobile Medical Unit Vehicle Routing problem (MMUVRP) model. MMUVRP researchers need to address trends, including the move towards a technology-based lifestyle, which uses technology to facilitate practically all tasks' execution (and the process of issue solving). This original study aims to develop and solve a smart-sustainable MMUVRP with time and demand optimization that can be applied in real-world scenarios. Currently, we are aware that variables suggested in our

model are usually taken into account alone, and the in other cases, they are not taken into account (in the study of MMUVRP and to summarize the accountability of demand and time). A valuable contribution to the literature of MMUVRP would, thus, be:

Objective 1: To maximize patient demand in all villages that can be covered from location centers by all available specialists and mobile medical units.

Objective 2: to create a realistic and holistic model that considers to fulfil the maximum demand within the given time constraints that make it appropriate for the rural areas of developing countries.

Also, with the above objective, an effort is made:

Objective 3: to develop a model to prepare transparency in providing drugs to the patients from the MMUs inventory to facilitate the patients and make it easy for the organization/government to trace and verify the process.

1.7 RESEARCH SIGNIFICANCE

According to what has already been mentioned, a model that addresses MMUVRP with demand satisfaction at each node issues is expected to be used in rural areas as an improvement over the models considered in the mentioned literature. Routing of vehicles and their planning processes get more cumbersome and complex because logistical services are one of the world's most significant and expanding sectors. The model's primary contribution is to consider various VRP variants and limitations to create a real-world scenario to ensure a continuous flow of events. A key component of ongoing attempts to improve and optimise routes of MMUs in rural areas is to incorporate vehicle routing problems with healthcare management that use various forms of new technology. Last but not least, the study of demand satisfaction will reduce the likelihood of errors, improving the patient experience and increasing the profitability of MMUs.

Using machine learning technology in MMUVRP model is a novel idea whose contributions are also stated previously and support the importance of this study. Additionally, the innovation strategy of satisfying customer demand and within a given distance is implemented for the very first time in vehicle routing by considering the deviation between expected services and perceived service, which previously was not considered by authors in vehicle routing problems, also discussed in the literature review chapter, that justifies the importance of this study. The study also considers the time period within which the demand is maximised.

1.8 ACHIEVING GOALS USING SOLUTION METHODOLOGY

The following is the strategy used to carry out this study: First, a thorough analysis of the MMUVRP literature was conducted to comprehend earlier contributions, identify research gaps, and ultimately define the research challenge. The problem was then transformed into mathematical equations and associated restrictions using a mathematical model, which was then known as a Mixed Integer Nonlinear Programming for Mobile Medical Units (MINLPMMUs) model. After that, the sequence of events was introduced speculatively and a few relevant previous investigations were organized.

The mathematical model was solved using the GUROBI program, preparing it for validation and solution generation. Using precise methods to tackle the optimization problem is nearly difficult because it is well known that VRP is regarded as an NP-hard problem because solving realistic scenarios is coupled, with many parameters, variables, and restrictions complexities. The model was solved in Python because the GUROBI optimizer can handle relatively little data.

In order to provide answers for the suggested problem, approximate approaches, such as the Ant-Colony algorithm, were applied for the optimization problem. Now,

computational findings are produced to offer answers and determine whether they are reasonable and relevant.

Finally, reinforcement learning, a machine learning method, is used to explain the correctness of the past optimized routes and predict the optimized routes in the future in Vehicle Routing Problem.

This study aims to develop a prediction model using historical data gathered from a real-world issue. So, the aim of this thesis is summarized in three different objectives:

1. This study aims to develop a prediction model using historical data gathered from a real-world issue.
    a. To predict the routes of MMU from a single depot to multiple depots
    b. To estimate the different routes that can be covered in the given time period.
    c. Integrated model for the routing and scheduling for the decision-making.
2. Second, to cover the maximum demand within a given time-period and maximise resource utilisation for a real-world vehicle routing problem, this thesis aims to integrate a machine learning-based prediction model into the routing and scheduling optimization framework. The thesis focuses on:
    a. To create a system that includes forecasts from historical data into the vehicle routing model to facilitate real-time decision-making
    b. Formulate a non-linear integer programming mathematical model to participate in the decision-making process for the routing and scheduling process.
    c. To make training data available to the algorithm for learning and then calculate the predicted route's accuracy via machine learning algorithms.

The characteristics presented by the algorithm in real-world applications are:

i. The depot and center locations

ii. Distance traveled by MMU

iii. Estimating time taken

iv. Number of MMUs

v. Decision-making in real-world case applications

vi. Routes of MMUs

3. To maintain transparency while providing required drugs to the patients, a model is developed to monitor and keep track of drug delivery continuously.

1.9 THESIS ORGANIZATION

The rest of the thesis is organized as follows: chapter 2 represents literature review the healthcare supply chain, work carried out in Mobile Medical Unit, and contributions made by VRP and its different variants in finding optimal routes. Few more literature reviews on maintaining transparency in the delivery of drugs, medicines, etc. Also, a detailed description of different machine learning algorithms used to solve VRP problems in healthcare is presented, followed by research gaps.

The mathematical model that was created is detailed in chapter three. The MINLPM MUS model, which comprises indices, definitions, parameters, decision variables, a nd constraints, is given and thoroughly explained. The methodology for the research is covered in Chapter 4. The outcomes for the intended objective functions are presented in chapter five, where they are analysed and explained. In chapter six, a flowchart is drawn, representing the transparency in the delivery of the drugs to the patients. In particular, various parameter values are used to ensure that each value produces valid and trustworthy results. The seventh chapter offers conclusions, ideas for more research, and future activities.