REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE
الجمهورية الجزائرية الديمقراطية الشعبية

MINISTERE DE L'ENSEIGNEMENT SUPERIEUR
ET DE LA RECHERCHE SCIENTIFIQUE

ECOLE SUPERIEURE EN SCIENCES APPLIQUEES
--TLEMCEN--

وزارة التعليم العالي والبحث العلمي

المدرسة العليا في العلوم التطبيقية
-تلمسان-

Mémoire de fin d'étude

Présenté pour l'obtention du diplôme d'Ingénieur d'état

Filière : Génie Industriel
Spécialité : Management Industriel et Management

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Thème

Un outil d'aide à la décision pour la gestion du transport des patients hémodialysés de la wilaya de TLEMCEN

Soutenu publiquement, le 2 / 11 / 2020 , devant le jury composé de :

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Année universitaire : 2019 /2020

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

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Dedication:

I dedicate my dissertation work to my family: my loving mother ***HADJA****, my supporting father* ***MOHAMMED****, my encouraging two little sisters* ***OUM ELKHEIR*** *and* ***OUMAIMA****, my very dear old brother* ***MOHAMMED ELAMINE****. A special feeling of gratitude to my family, theirs love is what keeps me motivated.*

I dedicate this work to my friends: ***HAYET, IMY, KENZA, MANEL, NABILA, ROMEISSA, SABRINA*** *and* ***SIMINA*** *who have supported me throughout the process. I will always appreciate all they have done and all the unforgettable memories.*

I also dedicate this work to all my teachers who have taught me one day, without them, I would have never achieved and been what I am today.

OUM KELTOUM

Acknowledgements

Primarily, I thank Allah for giving me the knowledge, ability, the strength and the opportunity to undertake this thesis work and to persevere and complete it satisfactorily. Without his blessings and guidance, this achievement would not have been possible.

I also would like to express sincere appreciation to ***Dr. Fouad MALIKI*** *for his valuable supervision, precious time and endless support throughout this study.*

I am grateful to my second supervisor ***M. Mehdi SOUIR*** *for his guidance. I would like to acknowledge him for providing me the opportunity to work on this project.*

I would like to thank the members of the jury for their precious time and for judging this work.

I am forever in debt to my classmates and my ESSAT friends for their constant motivation, association, guidance and help.

Finally, I would like to express my gratitude to my family for believing in me, for all their encouragement, endless love and support.

Oum Keltoum BENABDELKRIM

OCTOBER 2020

Abbreviations

CKD: Chronical Kidney Disease.
RRT: Renal Replacement Therapy.
ESRD: End Stage Renal Disease.
HD: Hemodialysis.
CPD: Continuous Peritoneal Dialysis.
CNAS: National Social Insurance Fund for Salaried Workers. (Caisse Nationale des Assurances Sociales des Travailleurs Salariés).
CASNOS: The National Social Security Fund for Non-Employees. (La Caisse nationale de sécurité sociale des non-salariés).
NEMT: Non-Emergency Medical Transportation.
IFT: Inter-Facility Transfer.
VRP: Vehicle Routing Problem.
TSP: Travelling Salesman Problem.
CVRP: Capacitated Vehicle Routing Problem.
VRPMT: Vehicle routing problem with Multiple Trips.
OVRP: Open Vehicle Routing Problem.
IRP: Inventory Routing Problem.
VRPP: Vehicle Routing Problem with Profits.
TOP: Team Orienteering Problem.
CTOP: Capacitated Team Orienteering Problem.
TOPTW: Team Orienteering Problem with Time Windows.
VRPTW: Vehicle Routing Problem with Time Windows.
PDP: Pick-up and Delivery Problem.
PDPTW: Pick-up and Delivery Problem with Time Windows.
LIFO: Last-In-First-Out.
DARP: Dial-a-Ride Problem.
TS: Tabu Search.

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General introduction:

The increase of the number of persons having end stage renal disease (ESRD) is very alarming. When a person's kidneys are no longer functioning, he will be treatment dependent. Unless he receives a new kidney. Dialysis is the most common treatment modality for ESRD where it involves a process that filters the patient's blood once his kidneys no longer can. Hemodialysis is a dialysis treatment performed predominately in medical facilities. Many dialysis patients treated at dialysis facilities require six trips each week, three trips to dialysis centers and three trips from the dialysis centers.

Patients without private transportation rely on the public sector mode such as non-emergency medical transportation (NEMT), since the vast majority of individuals undergoing dialysis are elderly or with other compromising medical conditions, the patients are weak and often ill, especially for the return trip from the center. This only means that theirs transportation is an important component of health-care systems.

Transportation to dialysis facilities has become a significant concern for the public transportation agencies as increasing number of individuals with ESRD turn to these agencies for their six treatment trips each week. This comes to more than 300 trips each year. The growing demand for dialysis trips is taxing the operations and funding of public transportation providers.

We consider the hemodialysis patients' transportation problem as the problem of determining an optimal routing for a fleet of vehicles used to cover the regular trips requested. This problem is usually modeled as a dial-a-ride problem with time windows (DARPTW), one of the major academic problems in logistics. DARPTW has been studied in literature in recent years and is still one of the most attractive problems because of all the challenges it exposes and its various applications. It is also a generalization of the Pickup and Delivery Problem with Time Windows (PDPTW), which calls for the determination of a min-cost set of routes for vehicles with given capacity, satisfying a set of n transportation requests, each requiring pickup at a given origin and delivery at a given destination, within given time windows.
Each transport request; also called trip, is characterized by an origin location, where the patient must be picked up, and a destination location, where the patient must be delivered.

The transportation problem for hemodialysis patients comes with challenges such as the scheduling problems, extra care and support for the patients and the increased cost of the trips. This thesis focuses on reducing the total cost of transportation.

For an overview of this thesis, the plan in the first chapter is to introduce the problem, to define hemodialysis and the importance of the reliability and the quality of transportation for patients undergoing this treatment.
The second chapter presents the types of Vehicles Routing Problems and the solution approaches in order to solve VRPs.

Chapter three defines what kind of routing problem is the problem studied in this thesis, which is a Dial a Ride Problem with Time Windows (DARPTW), we also model the problem mathematically and solve it using LINGO optimizer. The last chapter focuses on the application of tabu search, a widely used metaheuristic in literature for this kind of routing problem, where the aim is to reduce the total cost of the total trips.

Chapter one

Generalities and Basic Concepts

Chapter one: Generalities and Basic Concepts

1.1 Introduction:

All kind of chronic diseases affect the life of the person having them and with CKD or Chronical Kidney Disease an individual's daily life and routine changes completely as he must receive a renal replacement therapy (RRT) such as dialysis treatment.

End stage renal disease (ESRD) has become a very common disease nowadays as the number of patients is increasing. As a result, an increase in the number of dialysis treatment is noticed.

23,527 dialysis patients, including 22,667 hemodialysis patients, have been identified by the end of 2018 in Algeria, revealed professor Tahar Rayan (PR, Tahar Rayan, head of the nephrology department at Parnet University Hospital.).

In Algeria, almost all (97%) of patients with the chronic end-stage renal failure are treated by hemodialysis (HD).

Usually, patients that need in-center HD require a trip to and from the dialysis centers. On average, they attend the treatment center three time a week, which is 6 trips every week, all year long. With such frequency, one can only assume the importance of transportation for an HD patient. The quality of those trips has a large impact upon the patient’s health status. Therefore, reliability, safety and an optimized time and cost are necessary.

1.2 Dialysis:

1.2.1 Definition of dialysis:

The main function of a human’s kidneys is to clean his blood by removing extra fluids in the form of urine. They also make substances that keep the healthiness of one’s body. That is the case of a healthy kidney, but sometimes this critical organ can fail and stop working due to variable causes.

According to the article “Hemodialysis” [1] published on the National Kidney Foundation website[2]; a person needs dialysis if his kidneys no longer remove enough wastes and fluid from the blood to keep him healthy. This usually happens when the person have only 10 to 15 percent of his kidney function left. Symptoms such as nausea, vomiting, swelling and fatigue can be experienced. However, even if a person does not have these symptoms yet, he can still have a high level of wastes in his blood that may be toxic to the body.

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[1] Hemodialysis. National Kidney Foundation. https://www.kidney.org/atoz/content/hemodialysis.

[2] https://www.kidney.org/

Dialysis is the most common RTT. This treatment is usually needed at a stage where the kidney function has failed, the elimination of waste products from the body has become insufficient and the level of toxic products increases in the blood[3] .

1.2.2 Types of dialysis:

In fact, there are two main types of dialysis, hemodialysis and peritoneal dialysis:

- Peritoneal dialysis uses a fluid (dialysate) that is placed into the patient's abdominal cavity to remove waste products and fluid from the body. This type of dialysis is done at home and the blood is cleaned inside the body.
- Hemodialysis can be done either at the dialysis facility or at home in three to five hours treatment session and must be done 3 to 4 times a week. Hemodialysis uses a machine and a filter to remove waste products and water from the blood and then the blood return to the body.

1.2.3 How does hemodialysis work?

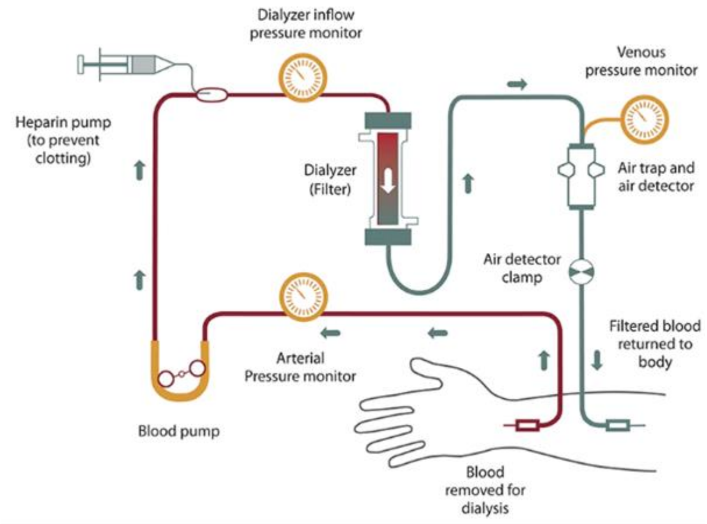

Figure 1-1: blood's Journey in the machine

Source: *Hemodialysis*. (2018, January). Niddk.Nih- National Institute of Diabetes and Digestive and Kidney Diseases.

Hemodialysis treatment is performed using a special filter called a "dialyzer" or the "artificial kidney". In the dialyzer, the blood is cleaned and then returned to the body. Blood travels through plastic tubes to the dialyzer.

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[3] *What Is Hemodialysis?* (n.d.). DaVita.https://www.davita.com/treatment-services/dialysis/in-center-hemodialysis/what-is-hemodialysis

Before starting the dialysis treatment, a small surgery is done in the arm or the foot for the patient. The purpose is to create access for the hemodialysis machine and at the beginning of each treatment; two needles are placed in the access. These needles allow the blood to travel to the dialyzer.

The role of the dialysis machine is to pump the blood through the dialysis system and to control the treatment time, fluid removal, pressure, and temperature[4] .

Only a small amount of blood leaves the body at a time but it never actually goes through the dialysis machine. It stays only in filter where it mixes with the dialysate, or the dialysis solution (contains water and chemicals). When the blood enters at one end of the filter, it is forced into many thin, hollow fibers.

The dialysate is responsible for pulling toxins from the blood. Then they go down the drain. Filtered blood remains in the fibers and returns to the body[5] .

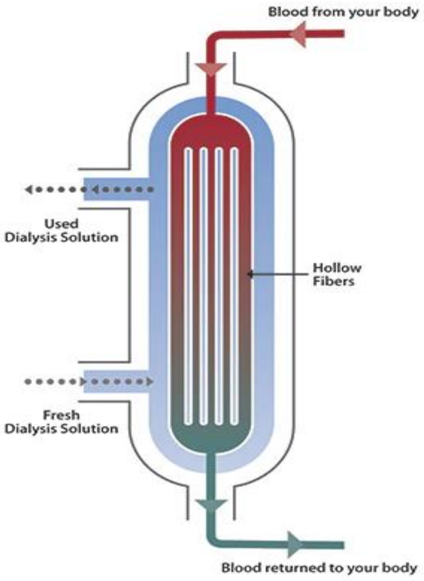

Figure 1-3: Blood in the filter

Source: *Hemodialysis*. (2018, January). Niddk.Nih- National Institute of Diabetes and Digestive and Kidney Diseases.

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[4] *Hemodialysis*. (2018, January). Niddk.Nih- National Institute of Diabetes and Digestive and Kidney Diseases. https://www.niddk.nih.gov/health-information/kidney-disease/kidney-failure/hemodialysis

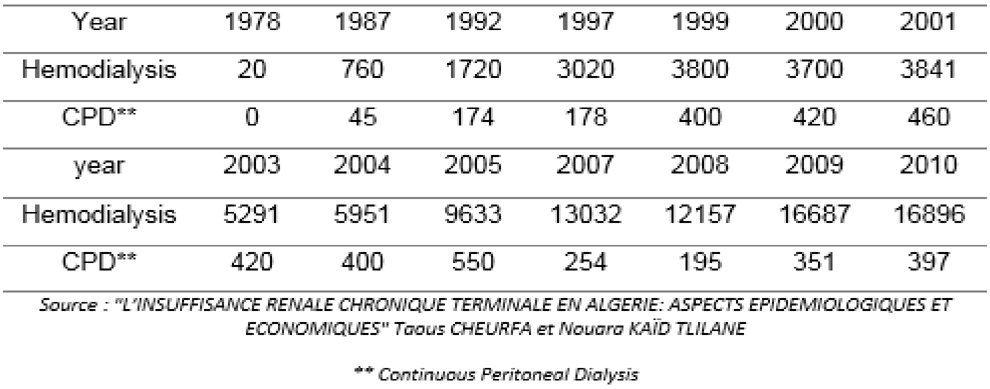
[5] *What Is Hemodialysis?* (n.d.). DaVita.https://www.davita.com/treatment-services/dialysis/in-center-hemodialysis/what-is-hemodialysis

1.3 Hemodialysis in Algeria:

1.3.1 Number of ESRD patients in Algeria:

Due to the increase in population, the ageing and the increase in metabolic pathologies that damage the kidneys, in particular diabetes and hypertension. The prevalence of chronic kidney failure is steadily increasing in Algeria. Resulting in more than 3500 new cases registered each year with an incidence rate of 100 new cases per million of population per year. (Graba, 2010) [6]

23,527 dialysis patients, including 22,667 hemodialysis patients, have been identified



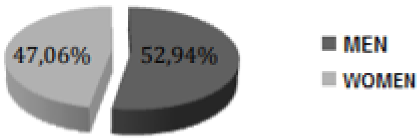
Year	1978	1987	1992	1997	1999	2000	2001
Hemodialysis	20	760	1720	3020	3800	3700	3841
CPD**	0	45	174	178	400	420	460
year	2003	2004	2005	2007	2008	2009	2010
Hemodialysis	5291	5951	9633	13032	12157	16687	16896
CPD**	420	400	550	254	195	351	397

Source : "L'INSUFFISANCE RENALE CHRONIQUE TERMINALE EN ALGERIE: ASPECTS EPIDEMIOLOGIQUES ET ECONOMIQUES" Taous CHEURFA et Nouara KAÏD TLILANE

*** Continuous Peritoneal Dialysis*

Table 1-1: Evolution of the number of ESRD patients treated by extra-renal purification therapy in Algeria from 1978 to 2010

and nearly 380 public and private dialysis centers in Algeria at the end of 2018, revealed the Professor of Nephrology, Tahar Rayan[7] in the 1st National Register dedicated to dialysis patients,.



Source: "L'INSUFFISANCE RENALE CHRONIQUE TERMINALE EN ALGERIE: ASPECTS EPIDEMIOLOGIQUES ET ECONOMIQUES" Taous CHEURFA et Nouara KAÏD TLILANE

Figure 1-5: Distribution of dialysis patients by gender in algeria-2011

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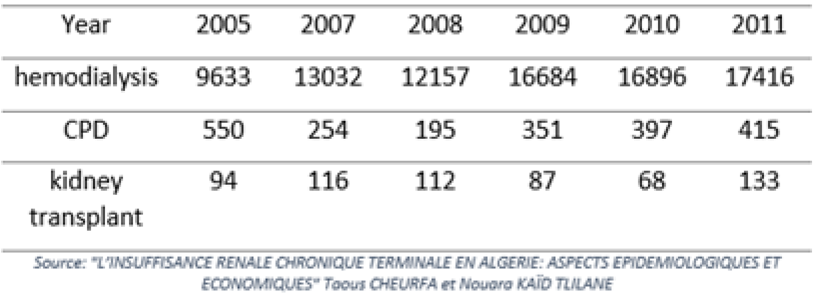
[6] Graba A, (2010). « La greffe d'organes, de tissus et cellules : Etats des lieux et perspectives ». Journée parlementaire sur la santé, Conseil de la Nation, Palais Zirout Youcef-Alger.

[7] PR, Tahar Rayane, head of the nephrology department at Parnet University Hospital.

In Algeria, almost all (97%) of patients with chronic end-stage renal failure are treated by hemodialysis.

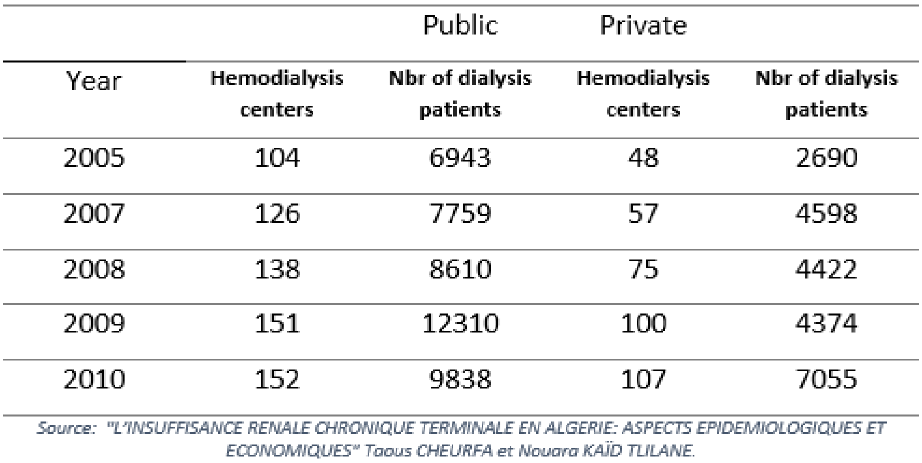


Year	2005	2007	2008	2009	2010	2011
hemodialysis	9633	13032	12157	16684	16896	17416
CPD	550	254	195	351	397	415
kidney transplant	94	116	112	87	68	133

Source: "L'INSUFFISANCE RENALE CHRONIQUE TERMINALE EN ALGERIE: ASPECTS EPIDEMIOLOGIQUES ET ECONOMIQUES" Taous CHEURFA et Nouara KAÏD TLILANE

Table1-2: patient distribution by ESRD treatment modality in algeria

1.3.2 Number of dialysis clinics in Algeria:



	Public		Private	
Year	**Hemodialysis centers**	**Nbr of dialysis patients**	**Hemodialysis centers**	**Nbr of dialysis patients**
2005	104	6943	48	2690
2007	126	7759	57	4598
2008	138	8610	75	4422
2009	151	12310	100	4374
2010	152	9838	107	7055

Source: "L'INSUFFISANCE RENALE CHRONIQUE TERMINALE EN ALGERIE: ASPECTS EPIDEMIOLOGIQUES ET ECONOMIQUES" Taous CHEURFA et Nouara KAÏD TLILANE.

Table 1-3: Evolution in the number of hemodialysis patients by sector

The increase in the number of dialysis patients require an increase in the number of facilities and centers especially for hemodialysis patients since they follow an in-center treatment 3 times a week. The table below shows the change in the number of hemodialysis patients by sector (public or private) but also gives an idea of the number of centers until 2010.

In 2018, Algeria counted 380 public and private dialysis centers, with an objective of 400 centers in the near future to improve the care of people with renal failure. (Tahar 2019)[8]

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[8] PR, Tahar Rayane, head of the nephrology department at Parnet University Hospital.

1.3.3 Cost of hemodialysis in Algeria:

The government mostly covers the healthcare budget in Algeria. Dialysis is free in public hospitals and the transportation to and from dialysis centers is covered by insurance, which is mainly supported by the government also (About 50% of patients are taken care of in private establishments by agreements with the social security funds such as CNAS and CASNOS). The cost of managing these patients has increased with the growth in the rate of this disease, which affect the national health budget to meet the medical needs of the patients.

Treatment of renal failure costs 10,000 DA/day per patient and "the State mobilizes a total cost of nearly 130 million DA per day" said PR. Rayan[9].

According to him, the cost of hemodialysis alone would reach "20 billion dinars per year".

Cost	Cost of one session	Cost of one hemodialysis per month	Cost of one hemodialysis per year
Amount in DZA	9.682,63	116.191,56	1.510.490,28

Table 1-3 Average annual hospital cost of dialysis care[10]

1.3.4 Tlemcen:

Tlemcen is an Algerian state. It has 949,132 inhabitants on a surface area of 10,182 km². The population density of the Wilaya of Tlemcen is therefore 93.2 inhabitants per km².

Source: Google Image

Figure 1-6: Tlemcen's location according to the map of Algeria

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[9] PR, Tahar Rayane, head of the nephrology department at Parnet University Hospital.

[10] Taous CHEURFA and Nouara KAÏD TLILANE "L'INSUFFISANCE RENALE CHRONIQUE TERMINALE EN ALGERIE: ASPECTS EPIDEMIOLOGIQUES ET ECONOMIQUES".

1.3.5 Number of ESRD patients in Tlemcen:

Even though the exact number of patients in Tlemcen is not determined but This Wilaya has counted +600 patients undergoing hemodialysis that are covered by (CNAS TLEMCEN). More are covered by CASNOS and some uses the in-hospital free service. The patients are dispersed all over the 53 provinces of Tlemcen.

1.3.6 Number of dialysis clinics in Tlemcen:

There are eight clinics and dialysis centers, which are:

- Renadial 2 (Kiffan)
- Mansourah hemodialysis center (Kiffan)
- TABET (Birouina)
- Renadial 1 Boulevard Larbi Ben M'Hidi ،Tlemcen
- Ettakwa Medical (Sabra)
- Medical Center Ibn Sina (Maghnia)
- Clinic Hamel (Ghazzaouat)
- Chrif BenMoussa (Imama)

- The dialysis centers in hospitals such as CHU Tlemcen.

In the map below, we can see the eight centers (red houses).

Figure 1-7: Tlemcen Map showing all 8 hemodialysis centers working with CNAS

Created by Google MyMaps

1.3.7 Number of health care transit agencies in Tlemcen:

According to a worker in CNAS Tlemcen, they contracted with eight enterprises of health care transportation. Therefore, in Tlemcen the transportation of hemodialysis patients is covered by at least eight enterprises. The exact number is not available.

1.4 Non-emergency transportation for hemodialysis patients:

1.4.1 Difficulties experienced in hemodialysis:

People who depend on kidney dialysis may experience :

- Daily muscle cramps
- Itchy skin often worsens before or after a treatment.
- Low blood pressure, especially in people with diabetes
- Sleep problems due to itchiness, short breathing known as apnea or due to restless legs.
- Fluid overload.
- Infections at the access area for dialysis.
- Mood fluctuations and depression.

Experiencing such difficulties makes it hard for hemodialysis patients to travel to the dialysis facility. Therefore, before starting the dialysis, the patient often finds himself before a heavy question "How am I supposed to get to my dialysis facility 3 times a week?"

The choice of the way of transportation is an issue that can affect his quality of life, both physically and mentally.

1.4.2 Travelling to the dialysis center options:

Among the chronically ill, travelling to medical centers can be burdensome in the perspective of both time and cost. Especially for patients with ESRD who receive hemodialysis.

In order to get to their treatment, some patients choose to drive themselves, ride a bike or even walk to clinics. Some others ride a taxi, a bus, a relative or a friend drops them. Lastly, the patients who choose to depend on contracted medical transportation services. In USA, ¼ of dialysis patients arrive in privately owned cars. The remaining ¾ of patients arrive in passenger vans, wheelchair cars, taxis or buses .

A recent evaluation of factors associated with missed dialysis appointments (Chan, Thadhani, & Maddux) found that patients who drive to dialysis for more than 17 minutes or who travel via a transportation van to a clinic were at increased risk of missing their hemodialysis treatment. Even more, patients with private transportation to the clinic had significantly better outcomes and attendance when compared to patients who relied on public transportation.

Either way chosen, the patients still experience many troubles. Such as:

- Inability to afford the cost of transportation or the financial burden.
- Feeling guilty or sorry about consistently burdening their relatives.
- Unavailability of sustainable transportation and being late to the appointment.

This case study will mainly focus on the non-emergency or private patients' transportation and not the other options. This type is more manageable so the optimization process can be oriented.

1.4.3 NEMT for Hemodialysis patients:

1.4.3.1 Definition of transportation:

Dictionary definition: transportation is means of conveyance or travel from one place to another. It is the act of transporting or being transported.

1.4.3.2 The past of medical transportation:

As defined previously, transportation is the action of moving people, goods and animals from one location to another using different means, medical transportation has also a history of its own.

Through time, the man experienced things that threatened his wellbeing and his survival, there was war, different diseases and epidemics and many other threats. Moreover, with the development of medicine and the application of primary surgeries, people found themselves in need to move to the doctor or for the doctor himself to move to them, the patients.

Patients were dragged or carried even before the invention of wheel. Romans were the first to use chariots to move the wounded soldiers in war to operate on them in battlefield surgery, Greeks used to practice that also, it saved countless lives at that time.

"Ambulance systems were first established in 1400s for the transportation of war casualties. These ambulances assumed many forms, from horse-pulled stretchers to wagons developed specifically for patient transport."

An intense interest in the development of medical transportation began in the 18th century. In 1767, exactly in Amsterdam, a group of wealthy men known as the Society for the Recovery of Drowned Persons suggested that persons who needed resuscitation should be taken to receiving houses (hospitals) where trained individuals could resuscitate them.

To get to the medical transportation service people are able to use today, this field of transportation followed many milestones. Whether it was by a vehicle, aircraft or a helicopter, there have been multiple important dates to stop at. Here is some of them:

The first hospital-based ambulance service in the United States at Cincinnati Hospital, 1865.

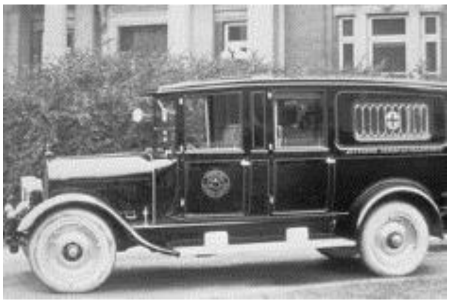

Figure 1-8: the first hospital-based ambulance service in the United States at Cincinnati Hospital 1865

The first electric ambulance at the Michael Reese hospital in Chicago in 1899.

During World War I, buses converted into mobile surgical units for treatments of the wounded. During the same time, USA converted old JN-4 aircrafts into air ambulances and French successfully used planes to evacuate patients.

1928, the first fixed-wings civilian air ambulance service in the world in the Australian outback.

The first civilian air ambulance service in Africa was established in Morocco, 1934.

In 1966, Mobile coronary care unit was started in Belfast. Two years later, similar units were used in Great Britain, United States and in Australia, the care units were staffed with both nurses and physicians.

…etc.

The history of ambulances focuses on their use as rapid transportation of the sick and injured for emergencies. However, with time, ambulances started to do different trips other than only responding to immediate calls for help. Many started to give inter-facility transfer (IFT) meaning to move patients to and from hospitals, and some of them started to provide specialty care themselves. Now, ambulances even have teams of caregivers that include emergency medical technicians, doctors, nurses, respiratory therapists…

1.4.3.3 Non Emergency Medical Transportation:

Moving away from responding only to emergencies, medical transportation services today add non-emergency cases and scheduled medical appointments into their list of service. The difference between the two types is urgency and regulations. We all know that the main purpose for an ambulance is to respond to emergency calls and to rush to persons in need in a short period of time, when the most unexpected things happen to them.

However, for some patients, it is not always an unexpected visit to the emergency room, but rather a regular appointment, which they cannot skip or be late to.

Providing medical service is a right to everyone, but some fragile segment of our population is very dependent on the medical service and transportation is a necessity for them to get the treatment they need, yet it is still a challenge for most of them.

Disabled patients, seniors, bariatric patients, people recovering from surgery and in need of wheelchair transportation, people receiving dialysis and many other types of patients, experience a daily struggle with how to get to their destinations. Therefore, in order not to burden a relative by asking for a ride each time or not to burden the driver by asking his help to get in and out of the taxi or the bus, NEMT or Non-Emergency Medical Transportation is required.

> *"NEMT can be defined as a transportation service provided to individuals who are not in an emergency but need more assistance than a taxi service is able to provide. Service providers will be specially equipped to transport riders in wheelchairs, stretchers or with other special needs."*[11]

This kind of transportation has many points that should be optimized, just like the other types. Flexibility and dependability is necessary, patients shall not wait too long for the ride and they must not have problems with the professionalism of drivers and dispatch. Coordination between the transportation agency and the dialysis center is required. If not, these transportation problems result in shortened treatment, with negative impacts on patients' health.

NEMT is not only about picking up the patient from a location and giving him a ride to another one; it is more about the quality of service itself. What the patient needs more than the ride is the trust that he is cared for, and that his appointment is not delayed because of transportation. The patient needs easy access, flexibility and reliability of service, a trained medical escort to assist him on the way to and from appointments and procedures. The ride must be safe, comfortable and on time. That is the importance of NEMT.

One of the problems of non-emergency transportation that we will focus on later in this thesis is the 'Cost'.

1.5 Conclusion:

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[11] Dow K. What is Non-Emergency Medical Transport and How Can it Benefit You?. Ecolane.com. https://www.ecolane.com/blog/what-is-non-emergency-medical-transport-and-how-can-it-benefit-you.

The Algerian government covers the transportation fare for almost all the individuals. Treatment of renal failure costs 10,000 DA/day per patient, said prof. Rayan. According to him, the cost of hemodialysis alone would reach "20 billion dinars per year". In conclusion, transportation cost represents a big part of the total healthcare budget.

Minimizing these costs require many studies, however in this thesis, we only focus on reducing the cost of the trips where the aim of this study is to optimize the total distance travelled and minimize the cost of rides for a group of individuals. Patients' transportation is a routing problem and in order to optimize such a problem, we need first to study it and understand how the problem works. Then, design it in a way that allow us to optimize it.

"Optimization: the action of making the best or most effective use of a situation or resource"

Dictionary

CHAPTER TWO

Generalities on Vehicle Routing Problems

Chapter two: Generalities on Vehicle Routing Problems

1.1 Introduction:

Routing Problems have been receiving a lot of attention in recent publications in logistics because of its various practical applications and all the challenges it exposes. Vehicle routing problems and its very different types are one of the major problems in operational research. This chapter defines some of these routing problems and theirs resolving approaches. Our focus is shifted at the end of chapter to Dial a Ride Problem and how only few publications have been released on the DAP as we present a literature review.

1.2 Vehicle Routing Problem:

The vehicle routing problem (VRP)[1] calls for the determination of the optimal set of routes to be performed by a fleet of vehicles to serve a given set of customers where no vehicle can service more customers than its capacity permits. It is one of the most important, and studied, combinatorial optimization problems. The objective is to minimize the total distance traveled or the number of vehicles used, or a combination of the two.

VRPs are still one of the most attractive problems in logistics because of its various practical applications and all the challenges it exposes. Here are a few examples of routing problems:

- A package delivery company wants to assign routes for drivers to make deliveries.

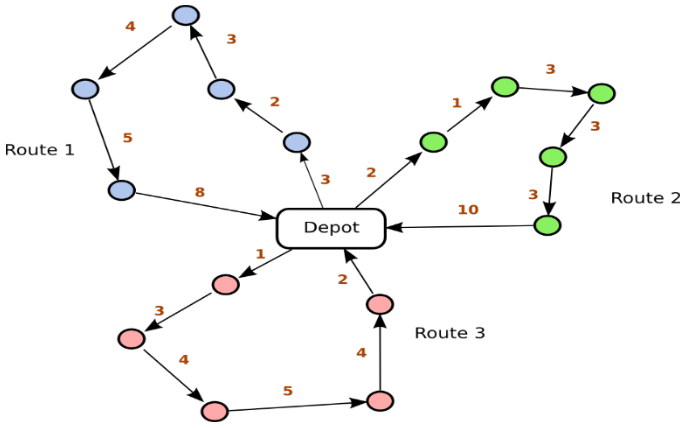

Figure 2-1: Example of a vehicle routing problem

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[1] Vehicle Routing Problem with Time Windows Brian Kallehauge-Jesper Larsen-Oli Madsen-Marius Solomon - https://link.springer.com/chapter/10.1007%2F0-387-25486-2_3

- A cable TV company wants to assign routes for technicians to make residential service calls.
- A ride-sharing company wants to assign routes for drivers to pick up and drop off passengers.

In most cases, VRPs have constraints: for example, vehicles might have capacities for the maximum weight or volume of items they can carry, or drivers might be required to visit locations during specified time windows requested by customers

1.3 Vehicle Routing Problem types:

1.3.1 Travelling salesman problem (TSP):

TSP is the most famous and the classic routing problem in which there is just one vehicle. The optimal solution is to assign just one vehicle to visit all locations, and find the shortest route for that vehicle. In other way, the goal is to find the shortest route for a salesperson who needs to visit customers at different locations and return to his initial point.

TSP can be represented by a graph, in which the nodes correspond to the locations, and the arcs denote direct travel between locations.

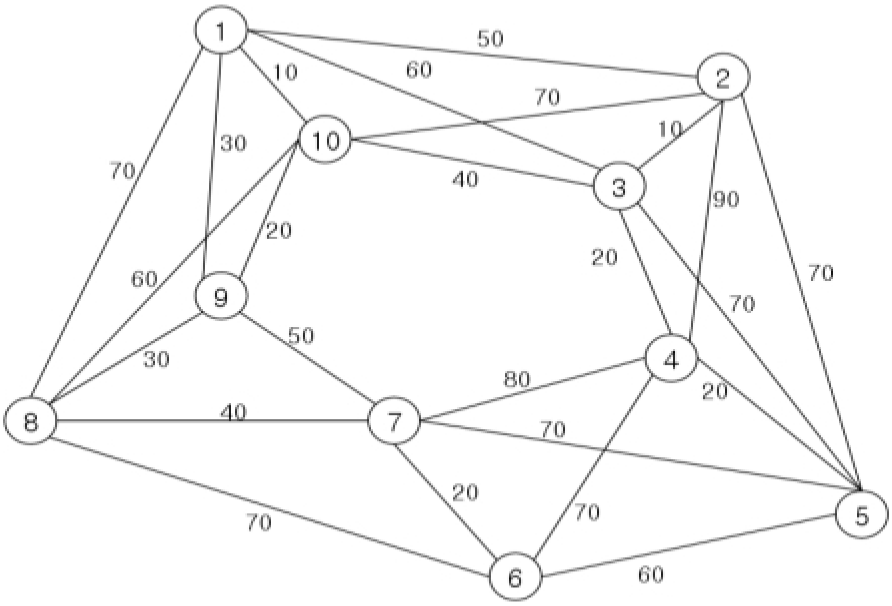

Figure 2-2 Example of a travelling salesman problem

1.3.2 Capacitated Vehicle Routing Problem (CVRP):

CVRP is a VRP in which the vehicles have a limited carrying capacity of the goods that must be delivered.

1.3.3 Vehicle Routing Problem with Multiple Trips (VRPMT):

VRPMT is a VRP in which the vehicles can do more than one route.

1.3.4 Open Vehicle Routing Problem (OVRP):

OVRP is a VRP in which vehicles are not required to return to the depot.

1.3.5 Inventory Routing Problem (IRP):

IRP is a VRP in which vehicles are responsible for satisfying the demands in each delivery point.

1.3.6 Vehicle Routing Problem with Profits (VRPP):

A maximization problem where it is not mandatory to visit all customers. The aim is to visit only the customers maximizing the sum of collected profits while respecting a vehicle time limit. Vehicles are required to start and end at the depot. Among the most known and studied VRPPs, we cite[2]:

1.3.6.1 The Team Orienteering Problem (TOP):

TOP is the most studied variant of the VRPP: In the team orienteering problem, start and ends are specified along with other locations, which have associated scores. Given a fixed amount of time for each of the M members of the team, the goal is to determine M paths from the start point to the end through a subset of locations in order to maximize the total score.

1.3.6.2 The Capacitated Team Orienteering Problem (CTOP):

The objective is to design a set of vehicle routes that maximizes the total collected profit, while respecting the vehicle capacity.

1.3.6.3 The TOP with Time Windows (TOPTW):

In the TOPTW, a set of locations is given, each with a score, a service time and a time window. The goal is to maximize the sum of the collected scores by a fixed number of routes. The routes allow visiting locations at the right time and they are limited in length.

1.3.7 VRP with time windows:

Vehicle routing problem with time windows (VRPTW)[3] is a generalization of the VRP where the service at any customer starts within a given time interval, called a time window. Important VRPTW applications include deliveries to supermarkets, bank and postal deliveries, industrial refuse collection, school bus routing, security patrol service, and urban newspaper distribution. Time windows are called soft when they can be considered non-binding for a penalty cost. They are hard when they cannot be violated, i.e., if a vehicle arrives too early at a customer, it must wait until the time window opens; and it is not allowed to arrive late.

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[2] Mukhina KD, Visheratin AA, Nasonov D (2019), Orienteering Problem with Functional Profits for multi-source dynamic path construction.

[3] Brian Kallehauge-Jesper, Larsen-Oli Madsen-Marius Solomon, Vehicle Routing Problem with Time Windows.

1.3.8 Pick-up and Delivery Problem with Time Window:

Pickup and delivery problems (PDPs) are a class of VRPs in which objects have to be transported between an origin and a destination. PAD is the problem of serving a number of transportation requests using a limited amount of vehicles. Each request involves moving a number of goods from a pickup location to a delivery location. The mission is to construct routes that visit all locations such that corresponding pickups and deliveries are placed on the same route, and such that a pickup is performed before the corresponding delivery.

The Pickup and Delivery Problem with Time Windows (PDPTW) is a generalization of the famous Vehicle Routing Problem with Time Windows (VRPTW) where it models various classic planning situations in operational transportation, logistics and in public transit.

The Pickup and Delivery Problem with Time Windows (PDPTW) can be described as follows (Savelsbergh and Sol, 1995)[4](18): A set of transportation requests with an advanced notice has to be satisfied by a given fleet of vehicles. Each transportation request is connected with its pickup location or its origin, its delivery location or its destination and the quantity of the load that has to be moved from the origin to the destination. A time window, a loading and an unloading time are specified for every pickup and delivery location. For each vehicle, a start location and an end one, a load capacity and the maximum length of its operating interval are specified. A set of routes has to be planned in order to fulfill the requests, so that each request is transported from the origin to the destination location by exactly one vehicle.

The PDPTW differs from the VRPTW by the additional precedence constraints, meaning that it is restricted that the origin has to be visited before the corresponding destination for each request.

A reasonable objective function in the model of PDPTW may use optimization criteria like the number of vehicles employed, the total schedule duration or the total of the distance traveled or a combination of these.

PDPTW is a NP-hard problem.

Applications of PDPTW differ from the neighborhood courier services to less-than-truckload transportation and long-distance haulage. Moreover, the PDPTW also goes with typical situations in public transit. For example, the Dial-a-Ride Problem with Time Windows (DARPTW) is a PDPTW in which people are transported instead of goods.

1.3.9 Vehicle Routing Problem with LIFO:

Similar to the PDPs, except an additional restriction is placed on the loading of the vehicles: at any delivery location, the item being delivered must be the item most recently picked up.

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[4] Savelsbergh, Martin & Sol, Massi. (1995).The General Pickup and Delivery Problem. Transportation Science.

This scheme reduces the loading and unloading times at delivery locations because there is no need to temporarily unload items other than the ones that should be dropped off.

1.3.10 Dial a Ride Problem with Time Window:

Since VRPTW and its version PDPTW focus on the delivery of goods, we need another version that is mainly for the transportation of people or users.

The Dial-a-Ride Problem (DARP) [5]consists of designing for a set of users theirs vehicle routes and timetables. The users specify a pickup and delivery requests between origins and destinations locations in a certain period. The aim is to plan a set of vehicle routes with the minimum cost that are capable of satisfy the requests, under a set of constraints.

This type of problem has gained an increasing importance nowadays since there are more and more people requesting such a service in order to move themselves between different places. The most common example is door-to-door transportation, like for elderly or for people that need to move from their house to hospitals or clinic centers during the day like disabled people or in our case, for hemodialysis patients.

According to the operation mode, we can differentiate two types of DARP. A static mode where the whole set of requests are known beforehand which makes it possible to plan all vehicle routes in advance, and a dynamic mode where the requests are gradually received throughout the day as users call, so that vehicle routes are designed in real-time. However, this case is much less common in hemodialysis case because normally we know the schedules before the day starts. Even when we use the dynamic mode, a static problem must be solved on a set of initial requests in order to obtain a starting solution that can be later modified as new requests are received.

1.4 Resolution Approaches:

When solving an optimization problem such the vehicle routing problems mentioned above, we can choose between different optimization methods: Exact optimization methods, which find an optimal solution, and heuristic optimization methods that do not promise to find an optimal solution.

1.4.1 Exact Algorithms:

Used if they can solve a problem with effort that grows in a polynomial way with the problem size, it also provides the optimum for any instance of the problem:

1.4.1.1 Branch and Bound:

It is a method that is generally used for solving combinatorial optimization problems. These problems are typically exponential in terms of time complexity and may require exploring all possible permutations in worst case. The algorithm is based on a tree-like method of

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[5] Cordeau, Jean-François & Laporte, Gilbert. (2007). the dial-a-ride problem (DARP): Models and algorithms. Annals OR. 153. 29-46. 10.1007/s10479-007-0170-8.

searching for an optimal solution by separations and evaluations; it solves these problems relatively quickly.

1.4.1.2 Branch and Cut:

It is a method of combinatorial optimization for solving integer linear programs (ILPs) which are linear programming (LP) problems where some or all the variables are restricted to integer values. Branch and cut involves running a branch and bound algorithm with dynamic generation of constraints and using cutting planes to tighten the linear programming relaxations. Note that if cuts are only used to tighten the initial LP relaxation, the algorithm is called cut and branch.

1.4.2 Heuristics:

Now if the problem is NP hard, the situation is different because the exact method will need an exponential time to solve. In this case, heuristic methods are used. This type of optimization methods are problem specific since they use properties of the problem. For many instances of the problem, heuristic methods provide a result that is “good enough”.

Two types of heuristics are mainly used: construction heuristics (such as gluttonous methods), which iteratively builds a solution, and the heuristic top-down, looking for a local optimum from a given solution. The heuristic method depends on the problem to be solved, mainly in the choice of the neighborhood.

More advanced heuristics have been developed and a new family of algorithms has been developed and introduced: meta-heuristics.

1.4.3 Metaheuristics:

They were introduced at mid-80s as optimization algorithms that are able to approach and solve complex optimization problems using a set of many general heuristics. The term metaheuristic was used to define a high-level heuristic utilized to guide other heuristics for a better progress in the search space.

In mathematical optimization and computer science, a metaheuristic[6] procedure dedicated to calculate a good solution to a difficult optimization problem. Metaheuristics are a problem specific method. They make few assumptions about the optimization problem being solved, which allow them to be usable for a variety of problems. The solution found by a metaheuristic depends on the set of random variables generated because it implements a form of stochastic optimization.

Previously considered hard or impossible to solve problems are now addressed and solved since metaheuristics have been continuously developing and they can often find good

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[6] Gavrilas, Mihai. (2010). Heuristic and metaheuristic optimization techniques with application to power systems. International Conference on Mathematical Methods and Computational Techniques in Electrical Engineering - Proceedings. 13-13.

solutions with less computational time and effort than can iterative methods, algorithms, or simple heuristics.

Some famous metaheuristics include tabu search, simulated annealing, evolutionary computation techniques, memetic algorithms, artificial immune systems, particle swarm optimization, differential evolution, ant colony algorithm, bee colony optimization, harmony search.

1.5 Literature Review on DARP:

Surprisingly only few publications have been released on the PADPTW. The interest of the reader should be referred to Bodin et al 1983 and Desrochers et al. 1988 for their interesting researchers on VRPs with a special consideration of pickup and delivery problems. Moreover, Savelsbergh and Sol 1995 present a survey of the problem types and solution methods found in literature about general PDP.

In literature review, there is a distinguish between exact and approximate methods in solving PDPs. Psaraftis (1980, 1983) developed the first exact dynamic programming algorithms to solve single vehicle dial-a-ride problems (DARP). He develops a backward dynamic programming method where he imposes a maximum profit shift with respect to the order of the pickup and delivery requested times. Psaraftis then modifies his algorithm to take into account the time windows at every pickup and delivery points. The main difference between the two is the use of forward dynamic programming instead of backward. These algorithms could solve only small problem instances involving 10 or fewer customers.

Kalantari et al 1985 use a branch and bound algorithm for the PDPTW with finite and infinite vehicle capacity, his method solves up to 37 customer instances.

Sexton and Bodin (1985a, b) minimized customer inconvenience in single vehicle problems by applying Benders' decomposition procedure to a mixed binary nonlinear formulation that solves the routing and scheduling components individually. Sexton and Choi (1986) used a two-phase scheduling and routing procedure for single vehicle problems to minimize a linear combination of total vehicle operating time and total customer penalty due to missing any of the time windows. This method was only capable of solving problems with up to 18 customers.

Desrosiers et al 1986 propose a forward dynamic programming for the single vehicle dial a ride problem. The algorithm minimizes the total distance considering both the time and distance dimension when solving the shortest path problem with time window. Instances for up to 40 customers (80 vertices) can be solved.

For the approximate algorithms, literature has more focused on insertion algorithms. These algorithms try to insert customers in a partial route, while conserving its feasibility. Sexton and Bodin 1983 present an insertion method for the single vehicle PDPTW. In another paper, Sexton and Bodin 1985a, 1985b investigated the DRP in which every customer specifies his pickup or delivery time, they separate the routing and scheduling parts. Psarfatis 1983b studied a heuristic for the single vehicle problem that is based on the minimum spanning tree and then applying local interchanges, this heuristic resolves instances up to 100 nodes.

Nanry and Barnes (2000) present a reactive tabu search for simple Pickup and Delivery Problem with Time Windows (PDPTW), where each transportation request has a single origin and a single destination

Dumas et al. (1991) employed a column generation scheme with a constrained shortest path as a sub problem. Dumas et al. (1991) approach worked well for single vehicle DARPTW problems with up to 55 customers in the presence of restrictive vehicle capacity constraints. Since the problem sizes that exact methods can solve are relatively small, researchers have developed heuristic algorithms in an attempt to solve larger sized problems encountered in practice. Such heuristic algorithms do not seek global optimal solutions, but rather seek to quickly provide near-optimal solutions.

With the exception of Dumas et al. (1991), no mention is made of the development of methods to solve the multiple vehicle version of the PDPTW. Although Dumas et al. (1991) describe an extension of their approach for solving multivehicle problems was described, it was not implemented.

Van der Bruggen et al 1993 propose a two-phase method to obtain a good feasible solution with minimum route duration and when they obtain bad solutions, they combine their algorithm with simulated annealing. The algorithm is tested on 38 customers. Van der Bruggen et al. (1993) also developed an alternative algorithm based on a penalized simulated annealing algorithm that provided the power to escape local optima by accepting inferior solutions and traversing infeasible regions in the state space to second other local optima.

Healy and Roll 1995 propose a new local search extension called sacrificing, yielding significant improvements without deterioration of the running time; it solves 10 to 100 customer requests.

Duhamel et al. (1997) describe a tabu search heuristic for VRP with time windows and backhauls; it represents a special case of PDPTW in which deliveries precede pickups. Sigurd et al. (2000) extend PDPTW by considering precedence constraints among requests. Mechti et al. (2001) developed a tabu search for real-life mail collecting business, where the vehicles in the fleet are different, meaning the Fleet Size and Mix VRP with Time Windows.

Cordeau and Laporte (2003) were among the first ones to present a TS algorithm for the DARP. Besides using a simple neighborhood operator to generate the neighborhood, this heuristic has shown to be effective and efficient.

For that reason, many of the recent studies of TS on DARPs (Beaudry et al., 2010; Ho and Haugland, 2011; Guerriero et al., 2013; Paquette et al., 2013; Kirchler and Wolfler Calvo, 2013; Detti et al., 2017) are in fact inspired from Cordeau and Laporte's (2003) TS.

These studies are typically on DARPs with more complicated and real-life constraints. The authors adapted Cordeau and Laporte (2003) TS to handle the more complex DARPs. Usually, the most time-consuming task with the TS is the evaluation of the neighborhood. To speed up the evaluation, some may only consider moves within a certain threshold (Kirchler and Wolfler Calvo, 2013) while others do a random sampling (Detti et al., 2017). TS works well as a stand-alone method, but it also shows to work well when incorporating into a multi-start heuristic (Guerriero et al., 2013) or a multi-criteria framework (Paquette et al., 2013).

1.6 Conclusion:

In this chapter, we defined some types of Vehicle Routing Problems, theirs importance in operational research and theirs applications in general terms.

We were more interested in the Pick-up and Delivery Problem and its variant dial a Ride problem as it serves this thesis more, therefore a literature review on DAP and DAPTW is presented at the end of this chapter.

Chapter three

Problem Definition and Mathematical Modelling

Chapter three: Problem Definition and Mathematical Modelling

1.1 Introduction:

One of the variant of VRPs is Dial-a-Ride Problem with Time Window, which is mainly used for transporting individuals with requests. That is the case studied in our thesis, as our goal is to satisfy patients undergoing hemodialysis, theirs requests are received as trips to theirs dialysis facilities.

This chapter is dedicated for the definition of our routing problem with the consideration of proposed hypothesis. The aim of this chapter is to mathematically model our problem where the objectif function minimize the total distance travelled, while respecting some constraints. The problem is then resolved using LINGO optimizer for a case study and the optimization results are presented by the end of the chapter.

For the case of importance instances, we must use another resolution approach, which is the metaheuristics. An application of one kind of metaheuristics is presented in the next chapter.

1.2 Understanding the problem type:

The problem is composed of multiple vehicles where each one needs a planned routing; each vehicle/ambulance has a starting point and an ending point (generally, they have the same one). Meaning that this kind of transportation problem is indeed a vehicle routing problem (VRP). In Addition, the vehicles have the mission of satisfying a set of requests fixed by the patients. Every request has two nodes; an origin node and a destination node. The patients are to be picked from theirs origins in order to be transported to their destinations, so it is a Pickup and Delivery Problem, to be exact: a Dial A Ride Problem because we are transporting individuals.

This study will only be concerned with the static DARP. Therefore, the problem is modeled as a static dial a ride problem with time windows DARPTW.

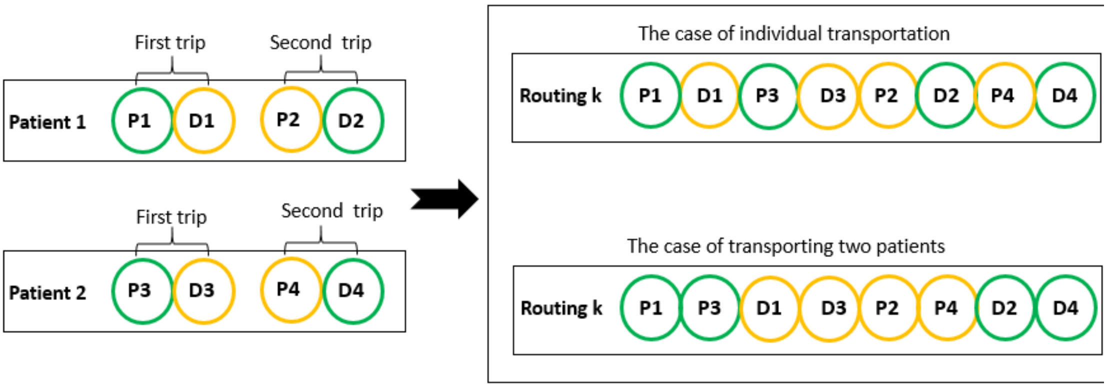

Figure 3-1 : routing of patient 1 and patient 2 in two cases

In patient transportation, especially the case of patients transported to hemodialysis:

- Patients should be picked-up from their home to be transported to centers or hospitals as late as possible (outbound request).
- Patients should be picked-up as early as possible when they are transported from the centers or hospitals to their home (inbound request).

Figure (3-1) shows an example of how each patient has two trips; one to the dialysis center (from origin to destination) and the second back home (from destination to origin)

Ideally, the patient transport service would carry one patient at a time on each route. That would not give an optimal solution since it requires many resources both human and in capital (vehicles for instance). In order to reduce the cost of transport, we should consider carpooling[1] as a solution for patients who do not require individual transportation.

From the NEMT's point of view, vehicle routing problem aims for the determination of the optimal set of routes to be performed by a fleet of ambulances to serve a given set of patients where no ambulance can service more patients than its capacity permits

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[1] Car-sharing or ride-sharing

Furthermore, for every patient in this case has a predefined schedule that must be respected. That means that this problem is also a vehicle routing problem with time windows.

1.3 The aim of the study:

With multiple patients, multiple dialysis centers and different vehicles, the transportation becomes subject to many constraints, among them the routing, the scheduling and the urgency. We have a set of routes to be performed by a fleet of non-emergency vehicles with a limited capacity to carry a given set of patients. The aim is to reduce the total distance travelled by these vehicles in order to reduce the total routing cost.

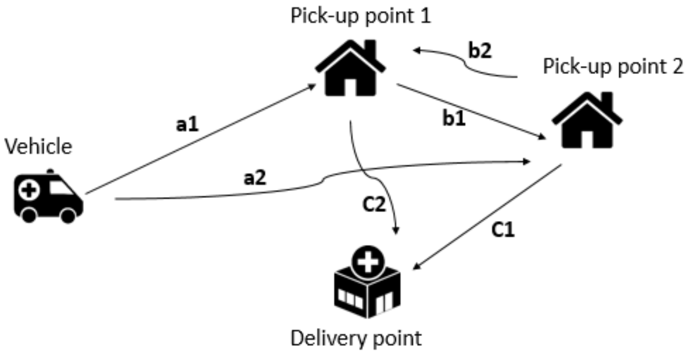


Figure 3-2: routing possibilities for two pickups before one delivery

$$a1 + b1 + C1 < a2 + b2 + C2$$

$$\text{Shortest path} = a1 + b1 + C1$$

However, this routing problem is not a simple vehicle routing problem since each patient has a schedule that cannot be violated. He should not be late nor waste time waiting by arriving so soon to the center. In other words, each patient's time window should be respected.

1.4 Model formulation:

To attain the proposed aim of this thesis, a mathematical model was developed in which a variant of the VRP, **the dial-a-ride problem** (DARP) was applied. This type of VRP is the most adequate to be applied to this particular problem because as in the route planning model, the aim is to optimize door-to-door transportation for a group of users (Patients in this case), in which they specify their pickup and delivery requests between origins and destinations.

We suppose that the n patients are picked up by m vehicles of the same type. Each vehicle can give a ride to a maximum of three patients at the same time.

Since we are working on a static model, we will model the problem for just one period.

The model formulated involves a series of, sets, parameters and decision variables that are used to define the model constraints and the objective function.

The problem is defined on a complete graph $G = (V, A)$ with:

$V = \{v_0, v_1, \dots, v_{2n}\}$ Represents the vertex set.

$A = \{(v_i, v_j): v_i, v_j \in V, i \neq \text{j}\}$ Represents the arc set.

Vertex v_0 represents a depot of the fleet of m vehicles, and the rest of the $2n$ vertices represent origins and destinations for the transportation requests.

Each pair of vertex (v_i, v_{i+n}) represents a request r for transportation from origin v_i to destination v_{i+n}. And then back to his origin.

Being i the index for vertex. The set N composed by all the vertex formed by three sub-sets: $N = P \cup D \cup \{0\}$.

Sub-set $\{0\}$ represents the vehicles' points of departure and arrival known as depots. Sub-set P represents the pick-up vertex, where $P = \{1, \dots, n\}$. Sub-set D represents the delivery vertex where $D = \{1 + n, \dots, 2n\}$.

Each vertex $v_i \in V$ is associated with :

1. Time window:

$$TW_i = [TME_i, TML_i]$$

TME: is the lower limit of time window defined for node i , it represents the earliest time at which to pick up or deliver the patient.

TML: The upper limit of time window defined for node i, it represents the latest time at which to pick up the patient. If the vehicle arrives to the patient before the time window opens, it must wait for an extra time until the opening of the time window, the service starts right away if the vehicle arrives during the time window.

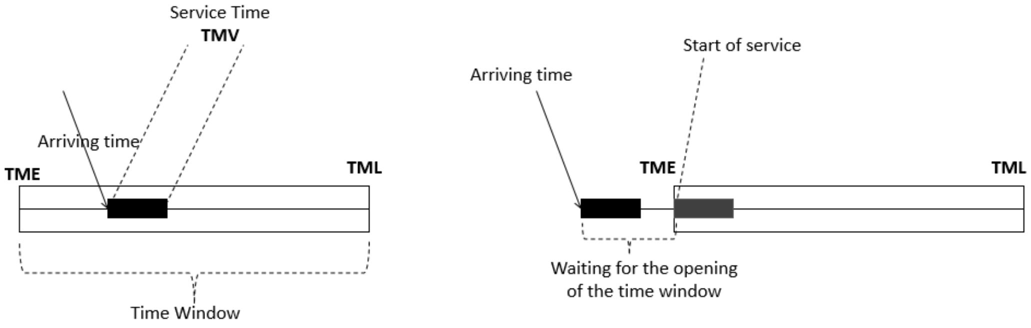


Figure 3-3 Time window, arriving time, service time

Figure (3-3) explains how a time window works, the vehicles must arrive within the time interval, if the vehicle arrives before that, it must wait for the opening of the time window and then starts the service. In this thesis, we suppose that all vehicles are obliged to the service to start within the time window, so waiting times before the opening of the time window are neglected.

- s_i Service time, note that $s_0 = 0$. the necessary time for a patient to get in the vehicle or to leave the vehicle, we fix $s_i = 5min$ for all the patients.
- A_{ik} The arriving time of the vehicle it is also the start of service time since no waiting before time window is allowed.

Each couple of vertex (v_i, v_j) has a:

- $C_{i,j}$ The routing cost between two nodes.
- $t_{i,j}$ The travel time between two nodes.
- d_{ij} Distance between nodes i and j.
- r_{ij} A request, $r_{ij} = 1$ when j is the destination of the origin i.

Each vehicle or ambulance as in this model is represented by k, where K is the set of available ambulances. $K = \{1, \ldots, m\}$.

Return trips:

Note that every patient must return from his destination to his origin after his treatment. This only means that patients make two requests or two trips (outward trip and return trip): (from origin to destination) and after a specific amount of time (from destination back to origin). Therefore, our mathematical model needs some modifications.

1. Each patient at node v_i now has:
    - Four time windows:

For outward trip:
$TW_i = [TME_i, TML_i]$ at the first pickup stop (origin) v_i
$TW_{i+n} = [TME_{i+n}, TML_{i+n}]$ At the first delivery stop (destination) v_{i+n}

For return trip:
$TW'_{i+n} = [TME'_{i+n}, TML'_{i+n}]$ at the second pickup stop (destination) v_{i+n}

$TW'_i = [TME'_i, TML'_i]$ At the second delivery stop (origin) v_i

2. Each vehicle has a load q_i^k that changes at every node $i \in N$ (with $q_0^k = 0$)
For outward trip

$$q_i^k = \begin{cases} 1\ if\ \ v_i \ \in \{v_1, \dots, v_n\}\ \ a\ pickup \\ -1\ if\ v_i \ \in \{v_{n+1}, \dots, v_{2n}\}\ a\ delivery \end{cases}$$

For return trip

$$q_i^k = \begin{cases} 1\ if\ v_i \in \{v_{n+1}, \dots, v_{2n}\}\ \ a\ pickup \\ -1\ if\ v_i \ \in \{v_1, \dots, v_n\}\ a\ delivery \end{cases}$$

In our mathematical model, we deleted the return trip to reduce the complexity of the model, yet and in order to receive the same results we multiplied the objectif function by two, since the vehicles are going to perform the same exact routings twice.

To resume, below we have the element sets, parameters, decision variables, the objective function and the constraints of the model.

1.4.1 Element sets

- ✓ (i, j) : Pair of nodes.
- ✓ k : Index of vehicles.

1.4.2 Sets:

- ✓ P : Set of origin vertex $P = \{1, \dots, n\}$.
- ✓ D: Set of destination vertex $D = \{n+1, \dots, 2n\}$.
- ✓ $N = P \cup D \cup \{0\}$: Set of all the nodes.
- ✓ K: Vehicle.

1.4.3 • Parameters

- ✓ n : Number of requests r (origin and destination nodes).
- ✓ m: Number of vehicles.
- ✓ $C_{i,j}^k = C_{j,i}^k$: Cost per kilometer traversed by vehicle k.
- ✓ $d_{ij} = d_{ji}$: Distance between nodes i and j.
- ✓ r_{ij}: Request of nodes i and to be transported to j.

- ✓ TME_i: Earliest allowed arrival time at node i for the first trip.
- ✓ TML_i: Latest allowed arrival time at node i for the first trip.
- ✓ s_i: Time of service at node i.
- ✓ q_i^k: indicates if a patient at node i is boarding or leaving the vehicle k.

A solution to this problem is a set of feasible routes obtained by satisfying all the requests of the patients.

The solution can be mathematically obtained by the following decision variables:

1.4.4 Decision variables:

- ✓ $X_{ijk} = \begin{cases} 1 \ if\ some\ vehicle\ k \in K\ travels\ from\ i\ to\ j \\ 0\ \ otherwise \end{cases}$
- ✓ $Y_{ik} = \begin{cases} 1\ if\ patient\ at\ node\ i\ is\ visited\ by\ vehicle\ k \\ \\ \quad 0\ \ otherwise \end{cases}$
- ✓ A_{ik} = instance of beginning of service at node i of vehicle k
- ✓ z – Variable which is only present in the objective function and which takes the value of the minimum cost of the total trip, in DZA

1.4.5 Objective Function:

Minimize:

$\min Z = 2 \sum\limits_{i \in N} \sum\limits_{j \in N} \sum\limits_{k \in K} C_{ij} * d_{ij} * X_{ijk}$	(1)
$\sum\limits_{k \in K} \sum\limits_{\substack{j \in N \\ j \neq i}} X_{ijk} = 1, \quad \forall\ i\ \in P$ $\sum\limits_{k \in K} \sum\limits_{i \in P} X_{ijk} = 1\ \forall j \in D$	(2)
$\begin{cases} \sum\limits_{j \in D} r_{i,j} \ = 1 \quad \forall i \in P \\ \sum\limits_{i \in P} r_{i,j} \geq 1 \quad \forall j \in D \end{cases}$	(3)

$\sum_{k\in K} Y_{i,k} = 1, \quad \forall i \in P$ $\sum_{k\in K} Y_{i,k} \geq 1, \quad \forall i \in D$ $\sum_{k\in K} Y_{0,k} = 3$	(4)
$\sum_{j\neq i,0} X_{i,j,k} = Y_{i,k} \qquad \forall k \in K, \forall i \in P$ $\sum_{\substack{i\neq j \\ i\in P}} X_{i,j,k} = Y_{j,k} \qquad \forall k \in K, \forall j \in P$ $\sum_{i\in P} X_{i,j,k} = Y_{j,k} \qquad \forall k \in K, \forall j \in D$	(5)
$\sum_{i\in P} X_{i,j,k} = 0 \qquad \forall j \in D$	(6)
$\sum_{j\in N} Y_{j,k} * r_{i,j} = Y_{i,k} \qquad \forall i \in P, \forall k \in K$	(7)
$\sum_{i\in P} X_{0,i,k} = Y_{0,k} \qquad \forall k \in K$	(8)
$\sum_{i\in P} X_{0,i,k} = 1 \qquad \forall k \in K$	(9)
$q_i^k = \sum_{j\in D} Y_{i,k} * r_{i,j} \quad \forall k \in K, i \in P$ $q_j^k = -Y_{j,k} \; \forall k \in K, j \in D$	(10)
$A_j^k \geq (A_i^k + s_i + t_{i,j}) X_{i,j,k} \;\; \forall i,j \in N, k \in K$	(11)
$\sum_{i\in P\cup D} q_i^k \leq 3 \quad \forall\, k \in K$	(12)
$TME_i \leq A_{ik} \leq TML_i \qquad \forall i \in N\,, \forall k \in K$	(13)
$X_{i,j}^k, Y_{i,k} \in \{0,1\} \quad k,i,j \in N$ $A_{ik} \in R$	(14)

Equation (2) ensures that arc (i, j) is traversed once from i to j.

Equation (3) ensures that a pickup node has one request, but a delivery node can receive multiple requests.

Equation (4) is for making sure that every origin point is visited exactly once and a destination point is visited more than once, and the depot is visited exactly three times with the three vehicles.

Equations (5) establish a relationship between the two decision variables X and$Y$, they ensure that if arc (i, j) is traversed, then node i and node j are visited.

Since we assumed there is no return trips so equation (6) guarantees that the routes are ending at a delivery node.

Equation (7) specifies that for a request to be satisfied, the same vehicle must visit both the pickup and the delivery node.

Equation (8) ensures that there is an arc between the depot and some pick-up nodes if these pickup nodes are visited after departing from depot.

Equation (9) establishes that every vehicle visits only one pick-up node from depot.

Equation (10) indicated that if a patient is boarding the vehicle then the load increases by one and if he is leaving the vehicle, the load decreases by one. Equation (12) guarantees the consistency in the vehicle's load and that the capacity of three patients is not violated.

Equation (11) establishes that the start service in a certain request depends on the sum of the start service in the previous request and the service time in that node plus the travelling time between the two nodes.

Obligation of arriving within the time window $[TME, TML]$ is established in equation (13)

The last constraint (14) defines the domain and the nature of the variables and parameters used in this problem.

1.5 Solving the model:

In order to solve our mathematical model, we have chosen LINGO as our optimization modeling software.

1.5.1 LINGO:

Lingo is an optimization modeling software for linear, nonlinear, and integer programming. It is a comprehensive tool designed to make building and solving all kind of optimization models faster, easier and more efficient. LINGO provides a completely integrated package that includes a powerful language for expressing optimization models, a full featured environment for building and editing problems, and a set of fast built-in solvers.

Figure 3-4 LINGO's logo

1.5.2 Input data in LINGO:

- Number of patients: 10 patients.
- Number of hemodialysis centers: 3 centers.
- Number of used vehicles: 3 vehicles.

Origins/destinations	D1	D2	D3
P1	0	1	0
P2	0	1	0
P3	0	0	1
P4	0	0	1
P5	1	0	0
P6	0	1	0
P7	0	0	1
P8	1	0	0
P9	1	0	0
P10	1	0	0

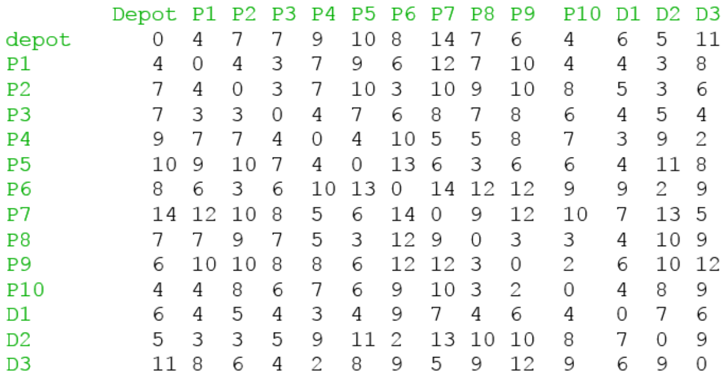
Table 3-1: Request table

- Schedules:

Patients/time windows	TME	TML
P1	8:05	8:30
P2	8:00	8:20
P3	8:00	8:20
P4	8:30	8:50
P5	9:00	9:25
P6	9.05	9:25
P7	9:30	10:00
P8	9:30	9:50
P9	10:05	10:30
P10	10:30	10:55

Table 3-2: Time Windows data

- Service time is 5 minutes (0.08h).
- Distance matrix between all the nodes: all the distances are in kilometers.

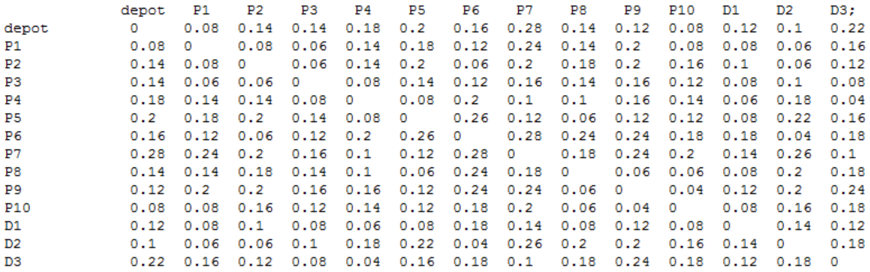


```
        Depot P1 P2 P3 P4 P5 P6 P7 P8 P9  P10 D1 D2 D3
depot      0  4  7  7  9  10 8  14 7  6   4   6  5  11
P1         4  0  4  3  7  9  6  12 7  10  4   4  3  8
P2         7  4  0  3  7  10 3  10 9  10  8   5  3  6
P3         7  3  3  0  4  7  6  8  7  8   6   4  5  4
P4         9  7  7  4  0  4  10 5  5  8   7   3  9  2
P5         10 9  10 7  4  0  13 6  3  6   6   4  11 8
P6         8  6  3  6  10 13 0  14 12 12  9   9  2  9
P7         14 12 10 8  5  6  14 0  9  12  10  7  13 5
P8         7  7  9  7  5  3  12 9  0  3   3   4  10 9
P9         6  10 10 8  8  6  12 12 3  0   2   6  10 12
P10        4  4  8  6  7  6  9  10 3  2   0   4  8  9
D1         6  4  5  4  3  4  9  7  4  6   4   0  7  6
D2         5  3  3  5  9  11 2  13 10 10  8   7  0  9
D3         11 8  6  4  2  8  9  5  9  12  9   6  9  0
```

Figure 3-5: Distance Matrix

- Time matrix: in order to estimate the time matrix, we had to fix the speed of our vehicle and then calculate the time between two nodes based on the distance matrix above. 50km per hour is the speed chosen for this model.

$$Time\ matrix(hours) = \frac{distance\ matrix * 1hour}{50km\ per\ hour}$$

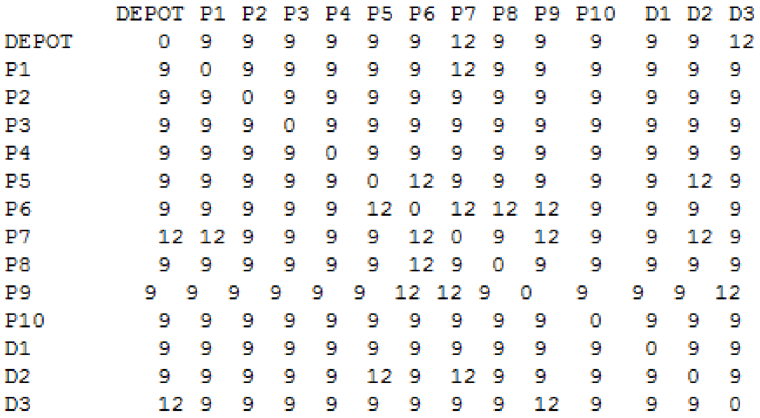


	depot	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	D1	D2	D3;
depot	0	0.08	0.14	0.14	0.18	0.2	0.16	0.28	0.14	0.12	0.08	0.12	0.1	0.22
P1	0.08	0	0.08	0.06	0.14	0.18	0.12	0.24	0.14	0.2	0.08	0.08	0.06	0.16
P2	0.14	0.08	0	0.06	0.14	0.2	0.06	0.2	0.18	0.2	0.16	0.1	0.06	0.12
P3	0.14	0.06	0.06	0	0.08	0.14	0.12	0.16	0.14	0.16	0.12	0.08	0.1	0.08
P4	0.18	0.14	0.14	0.08	0	0.08	0.2	0.1	0.1	0.16	0.14	0.06	0.18	0.04
P5	0.2	0.18	0.2	0.14	0.08	0	0.26	0.12	0.06	0.12	0.12	0.08	0.22	0.16
P6	0.16	0.12	0.06	0.12	0.2	0.26	0	0.28	0.24	0.24	0.18	0.18	0.04	0.18
P7	0.28	0.24	0.2	0.16	0.1	0.12	0.28	0	0.18	0.24	0.2	0.14	0.26	0.1
P8	0.14	0.14	0.18	0.14	0.1	0.06	0.24	0.18	0	0.06	0.06	0.08	0.2	0.18
P9	0.12	0.2	0.2	0.16	0.16	0.12	0.24	0.24	0.06	0	0.04	0.12	0.2	0.24
P10	0.08	0.08	0.16	0.12	0.14	0.12	0.18	0.2	0.06	0.04	0	0.08	0.16	0.18
D1	0.12	0.08	0.1	0.08	0.06	0.08	0.18	0.14	0.08	0.12	0.08	0	0.14	0.12
D2	0.1	0.06	0.06	0.1	0.18	0.22	0.04	0.26	0.2	0.2	0.16	0.14	0	0.18
D3	0.22	0.16	0.12	0.08	0.04	0.16	0.18	0.1	0.18	0.24	0.18	0.12	0.18	0

Figure 3-6: calculated time matrix

- Cost matrix: in order to estimate the cost matrix, we had to fix a cost for each distance travelled by the vehicles. (These costs are not the ones fixed by the Algerian government; they are just an example to test our mathematical model).

$$cost = \begin{cases} 9\ da\ if\ distance \leq 10km \\ 12\ da\ if\ 10km < distance \leq 20km \\ 14\ da\ if\ distance > 20km \end{cases}$$



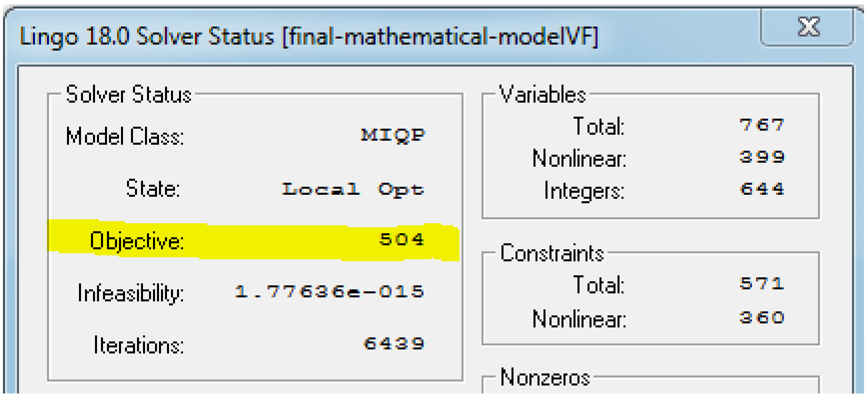
	DEPOT	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	D1	D2	D3
DEPOT	0	9	9	9	9	9	9	12	9	9	9	9	9	12
P1	9	0	9	9	9	9	9	12	9	9	9	9	9	9
P2	9	9	0	9	9	9	9	9	9	9	9	9	9	9
P3	9	9	9	0	9	9	9	9	9	9	9	9	9	9
P4	9	9	9	9	0	9	9	9	9	9	9	9	9	9
P5	9	9	9	9	9	0	12	9	9	9	9	9	12	9
P6	9	9	9	9	9	12	0	12	12	12	9	9	9	9
P7	12	12	9	9	9	9	12	0	9	12	9	9	12	9
P8	9	9	9	9	9	9	12	9	0	9	9	9	9	9
P9	9	9	9	9	9	9	12	12	9	0	9	9	9	12
P10	9	9	9	9	9	9	9	9	9	9	0	9	9	9
D1	9	9	9	9	9	9	9	9	9	9	9	0	9	9
D2	9	9	9	9	9	12	9	12	9	9	9	9	0	9
D3	12	9	9	9	9	9	9	9	9	12	9	9	9	0

Figure 3-7: the resulted cost matrix

1.5.3 LINGO execution:

After inserting all the input data and the model into LINGO, we solve it by clicking on "solve" icon. Two-command windows will appear. One with the final objective function value, and another with all the details on the decision variables used in the model.

1.5.4 Objectif function:


Lingo 18.0 Solver Status [final-mathematical-modelVF]

Solver Status
Model Class: MIQP
State: Local Opt
Objective: 504
Infeasibility: 1.77636e-015
Iterations: 6439

Variables
Total: 767
Nonlinear: 399
Integers: 644

Constraints
Total: 571
Nonlinear: 360

Nonzeros

Figure 3-8: Objective function

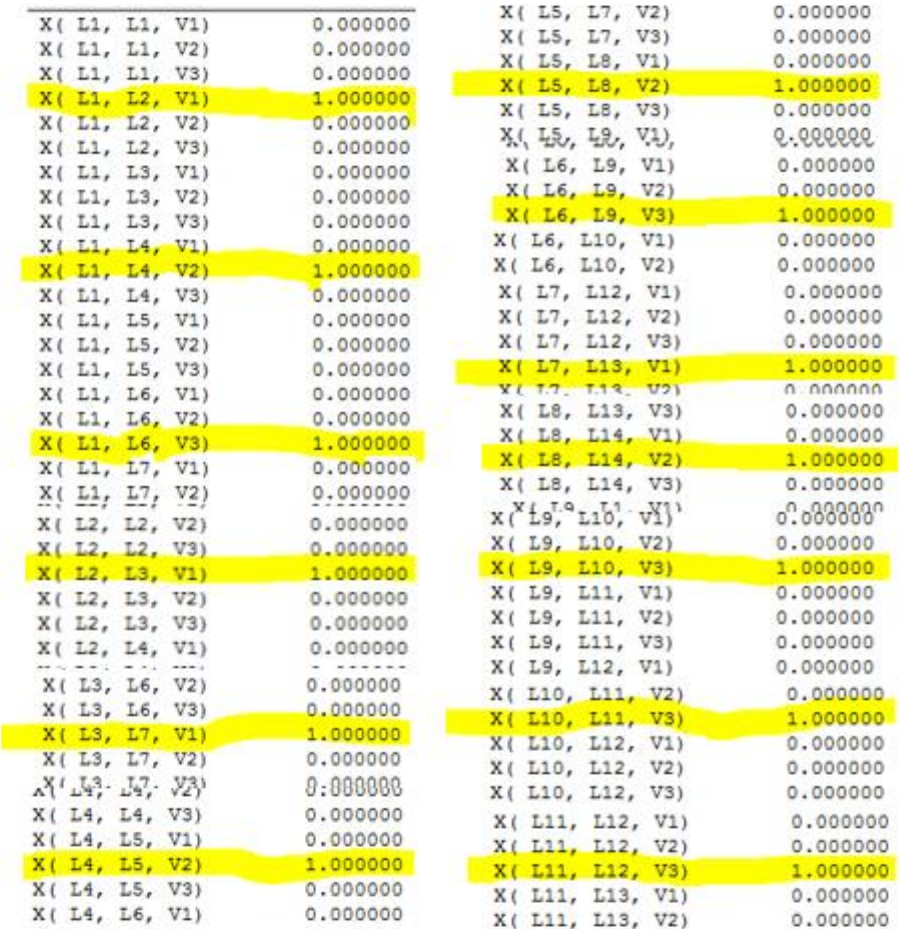
The model gave the 504 as an objective function value. This value is the minimum total cost of transportation for the data presented previously.

1.5.5 Decision Variables:

The information provided by variable $X\ (i,j,k)$ indicates which vehicle travels between the nodes chosen. It also gives an idea about the order of visited nodes.

The second variable is $Y(i,k)$ which allows us to insure that the same vehicle visits the origin node of a patient and his destination node.

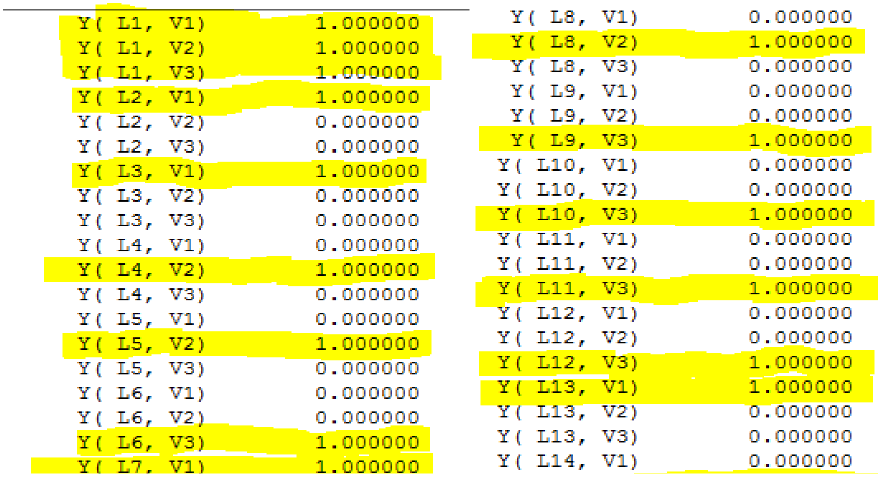
The last variable $A(i,k)$ shows the beginning of service of vehicle at the nodes:



```
X( L1, L1, V1)        0.000000
X( L1, L1, V2)        0.000000
X( L1, L1, V3)        0.000000
X( L1, L2, V1)        1.000000
X( L1, L2, V2)        0.000000
X( L1, L2, V3)        0.000000
X( L1, L3, V1)        0.000000
X( L1, L3, V2)        0.000000
X( L1, L3, V3)        0.000000
X( L1, L4, V1)        0.000000
X( L1, L4, V2)        1.000000
X( L1, L4, V3)        0.000000
X( L1, L5, V1)        0.000000
X( L1, L5, V2)        0.000000
X( L1, L5, V3)        0.000000
X( L1, L6, V1)        0.000000
X( L1, L6, V2)        0.000000
X( L1, L6, V3)        1.000000
X( L1, L7, V1)        0.000000
X( L1, L7, V2)        0.000000
X( L2, L2, V2)        0.000000
X( L2, L2, V3)        0.000000
X( L2, L3, V1)        1.000000
X( L2, L3, V2)        0.000000
X( L2, L3, V3)        0.000000
X( L2, L4, V1)        0.000000
X( L3, L6, V2)        0.000000
X( L3, L6, V3)        0.000000
X( L3, L7, V1)        1.000000
X( L3, L7, V2)        0.000000
X( L3, L7, V3)
X( L4, L4, V2)        0.000000
X( L4, L4, V3)        0.000000
X( L4, L5, V1)        0.000000
X( L4, L5, V2)        1.000000
X( L4, L5, V3)        0.000000
X( L4, L6, V1)        0.000000
```

```
X( L5, L7, V2)        0.000000
X( L5, L7, V3)        0.000000
X( L5, L8, V1)        0.000000
X( L5, L8, V2)        1.000000
X( L5, L8, V3)        0.000000
X( L5, L9, V1)        0.000000
X( L6, L9, V1)        0.000000
X( L6, L9, V2)        0.000000
X( L6, L9, V3)        1.000000
X( L6, L10, V1)       0.000000
X( L6, L10, V2)       0.000000
X( L7, L12, V1)       0.000000
X( L7, L12, V2)       0.000000
X( L7, L12, V3)       0.000000
X( L7, L13, V1)       1.000000
X( L7, L13, V2)       0.000000
X( L8, L13, V3)       0.000000
X( L8, L14, V1)       0.000000
X( L8, L14, V2)       1.000000
X( L8, L14, V3)       0.000000
X( L9, L10, V1)       0.000000
X( L9, L10, V2)       0.000000
X( L9, L10, V3)       1.000000
X( L9, L11, V1)       0.000000
X( L9, L11, V2)       0.000000
X( L9, L11, V3)       0.000000
X( L9, L12, V1)       0.000000
X( L10, L11, V2)      0.000000
X( L10, L11, V3)      1.000000
X( L10, L12, V1)      0.000000
X( L10, L12, V2)      0.000000
X( L10, L12, V3)      0.000000
X( L11, L12, V1)      0.000000
X( L11, L12, V2)      0.000000
X( L11, L12, V3)      1.000000
X( L11, L13, V1)      0.000000
X( L11, L13, V2)      0.000000
```

Figure 3-9: Results obtained by variable X



```
Y( L1, V1)        1.000000
Y( L1, V2)        1.000000
Y( L1, V3)        1.000000
Y( L2, V1)        1.000000
Y( L2, V2)        0.000000
Y( L2, V3)        0.000000
Y( L3, V1)        1.000000
Y( L3, V2)        0.000000
Y( L3, V3)        0.000000
Y( L4, V1)        0.000000
Y( L4, V2)        1.000000
Y( L4, V3)        0.000000
Y( L5, V1)        0.000000
Y( L5, V2)        1.000000
Y( L5, V3)        0.000000
Y( L6, V1)        0.000000
Y( L6, V2)        0.000000
Y( L6, V3)        1.000000
Y( L7, V1)        1.000000
```

```
Y( L8, V1)        0.000000
Y( L8, V2)        1.000000
Y( L8, V3)        0.000000
Y( L9, V1)        0.000000
Y( L9, V2)        0.000000
Y( L9, V3)        1.000000
Y( L10, V1)       0.000000
Y( L10, V2)       0.000000
Y( L10, V3)       1.000000
Y( L11, V1)       0.000000
Y( L11, V2)       0.000000
Y( L11, V3)       1.000000
Y( L12, V1)       0.000000
Y( L12, V2)       0.000000
Y( L12, V3)       1.000000
Y( L13, V1)       1.000000
Y( L13, V2)       0.000000
Y( L13, V3)       0.000000
Y( L14, V1)       0.000000
```

Figure 3-10: Results obtained by variable Y

Nodes	Arriving time =beginning of service
Depot	8:00
2	8:05
3	8:15
4	8:09
5	8:30
6	9:00
7	9:05
8	10:00
9	9:50
10	10:30
11	10:55

Table 3-3: results obtained by A

Figure (3-8) resume the obtained routing for the three vehicles, based on the results of the decision variables.

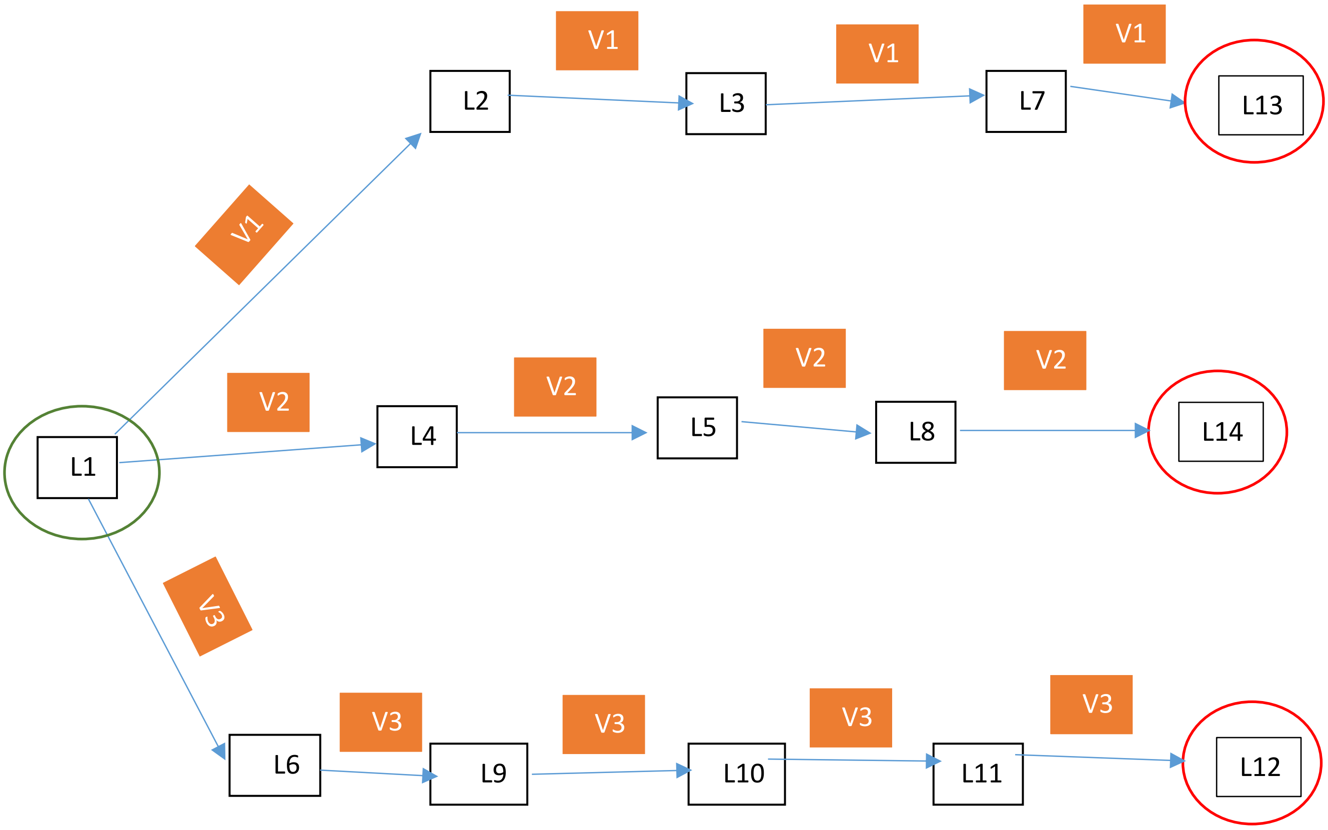


Figure 3-11: Final routing results

1.5.6 Results interpretation:

The results obtained by LINGO optimizer give a logical order of visits. The vehicles respect the requests of patients while performing theirs routes. The choice of the next stop is based on the shortest path between nodes since the objective function minimize the total cost and distance travelled. The time windows constraints are also respected for every node. However, in the problem description we ignored the waiting time before the opening of time windows, so the vehicles spend a lot of time waiting for a time window to open in order to perform a pick-up. Sometimes they even perform the pickups at the end of the time window, which is not the optimal case since we are transporting individuals.

1.6 Conclusion:

In this chapter, a detailed description of our studied problem was given. We modelled the problem mathematically and the resolved it using LINGO Optimizer. The goal was to minimize the total distance travelled by the vehicles, so we tested the model for a small case study. The results given by Lingo are presented at the second part of the chapter. The interpretation of the results shows that the model optimize the total distance travelled by the vehicles resulting in minimizing the total cost of transportation. However, in the problem description we assumed that the waiting time is not taken into consideration so we ignored it. Therefore, the time windows constraints are respected but the waiting time of a vehicle before the opening of a time window. This amount of waiting time might be accepted if the transportation case was for products and goods, but since we are studying a model that is designed for individuals; this can be a problem in real-life.

Chapter four

Tabu Search Application

Chapter four: Tabu Search Application

1.1 Introduction:

In the previous chapter, LINGO optimizer was used to solve the problem we are studying for small instances. For important instances, metaheuristics must be applied in order to optimize the problem. Note that, metaheuristics does not give an optimal solution but a satisfactory one.

In literature, Tabu Search is the most used one in resolving Pickup and Delivery Problem and its variant dial a Ride Problem with Time Window. Therefore, this chapter focuses on defining tabu search and its parameters and then applying it for resolving our problem.

1.2 Tabu Search (TS):

Because of the high complexity level of the VRPTW and its wide applicability to real-life situations, solution techniques capable of producing high-quality solutions in limited time, i.e., heuristics are of prime importance. Over the last few years, many authors have proposed new heuristic approaches, mostly metaheuristics, for addressing the VRPTW. So far, tabu searches have showed the best performance in solving the problem.

1.2.1 Definition:

Tabu Search (TS) is a local search metaheuristic used for mathematical optimization, first introduced by Glover in 1986. TS is designed to escape from a local optimum by allowing flexible movements.

Contrary to classical local search methods that have the tendency to be trapped in suboptimal regions. TS enhances the mperformance of those techniques by avoiding the cycling.

TS[1] explores the solution space by moving at each iteration from a solution S to a better solution in a subset of its neighborhood $N(S)$. However, in classical descent methods, the solution S may deteriorate from one iteration to the next as the result of revisiting already visited solutions. Thus, and in order to avoid being trapped in a cycle, solutions possessing some attributes of recently explored solutions are temporarily declared tabu or forbidden.

1.2.2 Advantages of Tabu Search

- It allows even a bad solution to be accepted in order to escape from local minima.
- It makes use of tabu list to store the forbidden moves. This technique can be applied to both continuous and discrete solution spaces.

---

[1] Zhou, Kai, et al. "A Parallel Method with Hybrid Algorithms for Mixed Integer Nonlinear Programming." Computer Aided Chemical Engineering. Vol. 32. Elsevier, 2013. 271-276.

- It helps us to solve problems, which are NP-hard such as scheduling, quadratic assignment, and vehicle routing by obtaining solutions that often surpass the best solutions previously found by other algorithms.

1.2.3 Parameters used by tabu search:

The parameters used by basic TS are as follows:

1. Neighborhood structure
2. Local search process
3. Aspiration criteria
4. Form of tabu moves.
5. Adding a tabu move to list.
6. Maximum length of a tabu list.
7. Stopping condition.

1.2.4 TS Algorithm:

- Step 0: initialization

$$S_0 \text{ Initial solution}$$

$$S \leftarrow S_0, S^* \leftarrow S_0, C^* \leftarrow F(S_o), T = \emptyset$$

- Step 1: Generate a subset of solutions in neighborhood $N(S)$

$$S' \in N(S) \; such \; as \; \forall x \in N(S)$$

$$F(x) \geq F(S') \; and \; S' \notin \mathrm{T}$$

$$If \; F(S') < C^* \; so \; S^* \leftarrow S' \; and \; C^* \leftarrow F(S')$$

$$Update \; T$$

- Step 2: if the stopping condition is not satisfied, return to step 1.

1.2.5 Pseudocode of Tabu Search Algorithm:

```
Parameters:
        Length of the Tabu list $L_T$
        Number of intermediate solutions $N$
Initialization:
        Approximation $S_o$ ,
        Tabu list $T = \emptyset$,
        Optimal solution: $C^* \leftarrow F(S_o)$ ,
 WHILE {stopping criterion not met}
```

```
    Prepare the Tabu list:
            If Length $T = L_T$,
            Then delete the oldest item from the list.
    Generate $N$ new approximations in the neighborhood of $S$,
    Select the best candidate-solution $S'$, which is not tabu $T$.
    Update current approximation $S^* \leftarrow S'$ and add it in the Tabu list: Add$(T, S')$.
    Update optimal solution:
        If $F(S')$is better than $C^*$,
        Then $C^* \leftarrow F(S')$
END
```

1.2.6 TS methodology:

Tabu search[2] begin by proceeding iteratively from one point S to another until a chosen termination criterion is satisfied. Each solution S has an associated neighborhood $N(S)$, and each solution $S' \in N(S)$ is arrived at from S by an operation called a "move". The difference between TS and a simple descent method is that simple descent method only allows moves to neighbor solution that improve the current value of the objective function and only ends when we do not find improving solutions, the final S found by this method is called a local optimum. While, Tabu search allows moves that pass over the current value of the objective function and selects the moves from an adjusted neighborhood $N^*(S)$. This means that the neighborhood of S is not a static set, it is a set that can change with the history of the search i.e. TS can be described as a dynamic neighborhood method.

The memory structure is what keeps track of solutions attributes that have changed recently. The best advantage of this memory is that selected attributes that happen in solutions recently visited are marked as tabu-active. Solutions that contain tabu-active elements are those who become tabu. This prevents certain solutions from the recent past from being included in $N^*(S)$ and so from being revisited.

The TS process relies strictly on short-term strategies that may allow a solution S to be visited more than once, but to be expected that the corresponding reduced neighborhood $N^*(S)$ will be different every time however. The addition of longer-term strategies effectively removes the risk of duplicating a previous neighborhood while revisiting a solution.

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1.3 Solution structure:

A solution S is defined as a set of m routes $S = \{route_1, \ldots, route_m\}$ of m vehicles. Each route is represented as a vector used to indicate succession of nodes. Value i at position 0 indicates that i is the first node visited after the depot, i.e the first arc is $(0, i)$. Next arc in the route is from i to the value j at position i. As an example, consider requests represented as (origin, destination) pairs $(1, 4), (2, 5), (3, 6)$. $Figure$ 4.1 describes a $route = \{0, 1, 4, 2, 5, 3, 6, 0\}$.

1	4	2	5	3	6

Figure 4-1: Route representation as an array of succession

Notice that after each values of the origins (or the pickups); come the values of theirs destinations (the deliveries). Which means that the vehicle has a capacity of one seat.

- If the vehicles used in our model has the capacity of one seat, and we have n requests, then the length of route is equal to $2n$, or the vector contains $2n$ cells.

$Figure$ 4.2 Gives an example of routing for the pair of requests $\{(1,2), (2,2), (3,3), (4,3), (5,1), (6,2), (7,3), (8,1), (9,1), (10,1)\}$

V1	4	3	2	2	6	2	-	-
V2	1	2	3	3	8	1	-	-
V3	5	1	9	1	7	3	10	1

Figure 4-2: a solution presentation for three vehicles and 10 requests

$V3 = \{0, 5, 1, 9, 1, 7, 3, 10, 1, 0\}$ Shows that the vehicle satisfies four requests, while $V1 = \{0, 4, 3, 2, 2, 6, 2, 0\}$, $V2 = \{0, 1, 2, 3, 3, 8, 1, 0\}$ both satisfy only three requests.

1.4 Neighborhood generation:

The tabu search heuristic is initialized with S_0 constructed by assigning each request to a randomly selected vehicle. This solution is not necessarily feasible. At iteration It, the current solution S can be partly described by an attribute set $U_{(s)} = \{(i, V): request\ i\ is\ assigned\ to\ vehicle\ V\}$. to improve S, inter-route exchanges are performed at every iteration, and intra-route exchanges are performed whenever a new best solution is identified.

- Swap or insertion method: the algorithm attempts to move each vertex pair from one vehicle to another in a single transition. One request from route of vehicle $V1$ is swapped with a request from route of vehicle $V2$. As each request is made of two stops (i.e, origin and destination), both stops need to be swapped. Each request is removed from the original route and inserted into the other one.

Taking the example of inputs used in LINGO model in the previous chapter, consider a set of requests$\{(1,2),(2,2),(3,3),(4,3),(5,1),(6,2),(7,3),(8,1),(9,1),(10,1)\}$.

The requests are grouped in one binary matrix:

Origins/destinations	D1	D2	D3
P1	0	1	0
P2	0	1	0
P3	0	0	1
P4	0	0	1
P5	1	0	0
P6	0	1	0
P7	0	0	1
P8	1	0	0
P9	1	0	0
P10	1	0	0

The coding of the solutions requires three vectors (three vehicles) with a length that equals to 20 (we have 10 requests; the extreme case is when one vehicle satisfies all the requests). To simplify the solution representations, we assume that all the vehicles satisfy the requests, so the length is reduced.

$$V1 = \{0,4,3,2,2,6,2,0\}, V2 = \{0,1,2,3,3,8,1,0\}$$

Swapping requests $(4,3)$ and $(8,1)$ would result in:

$$V1 = \{0,8,1,2,2,6,2,0\}, V2 = \{0,1,2,3,3,4,3,0\}.$$

When swapping between two requests the pickup cells take each other's places, and theirs delivery cells take each other's places, as shows the figure below:

V1	4	3	2	2	6	2
V2	1	2	3	3	8	1

Figure 4-3: Solution before swapping

V1	8	1	2	2	6	2
V2	1	2	3	3	4	3

Figure 4-4: New Solution after swapping

Again, the input used in LINGO in the previous chapter states that we are using three vehicles (V_1, V_2, V_3). One solution's structure is the routes of the three vehicles.

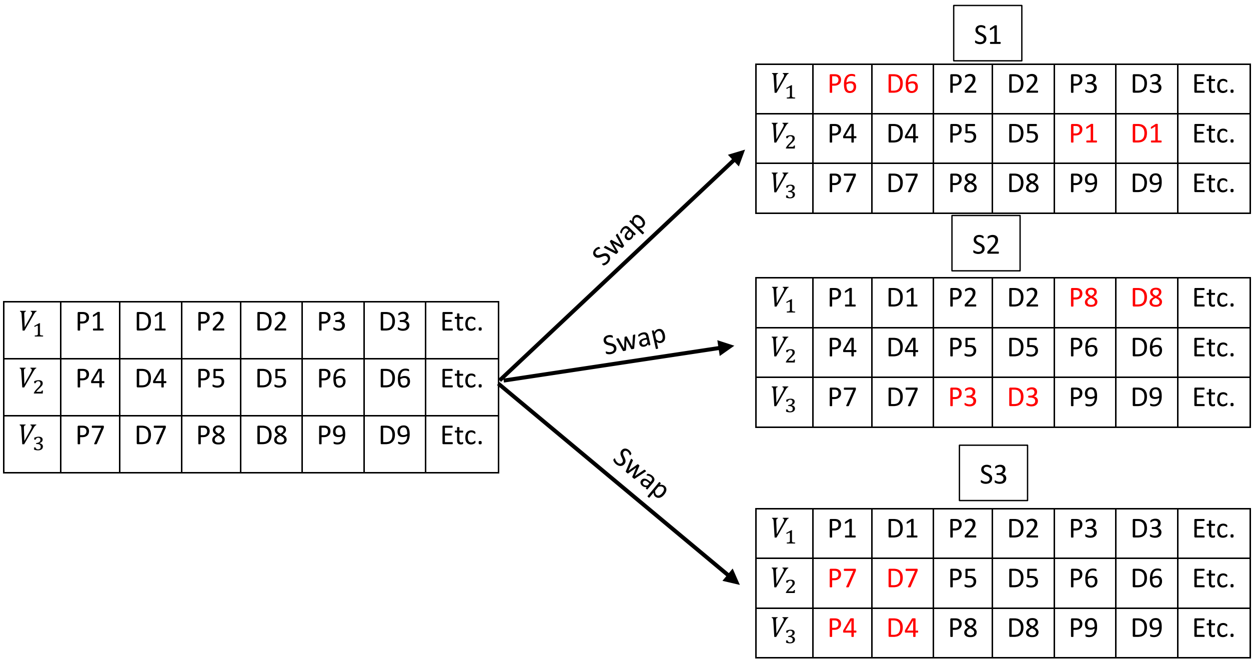
V_1	P1	D1	P2	D2	P3	D3	Etc.
V_2	P4	D4	P5	D5	P6	D6	Etc.
V_3	P7	D7	P8	D8	P9	D9	Etc.

Figure 4-5: solution Representation in the case of three vehicles

Since we swap requests between two vehicles, and we have three vehicles then we can perform three swaps: between (V_1, V_2) or between (V_1, V_3) or(V_2, V_3).

Each solution can generate three new solutions for us (if only one swap is allowed at once).

The next figure gives an example of a new neighborhood of solution we can obtain from a previous solution.



V_1	P1	D1	P2	D2	P3	D3	Etc.
V_2	P4	D4	P5	D5	P6	D6	Etc.
V_3	P7	D7	P8	D8	P9	D9	Etc.

S1

V_1	P6	D6	P2	D2	P3	D3	Etc.
V_2	P4	D4	P5	D5	P1	D1	Etc.
V_3	P7	D7	P8	D8	P9	D9	Etc.

S2

V_1	P1	D1	P2	D2	P8	D8	Etc.
V_2	P4	D4	P5	D5	P6	D6	Etc.
V_3	P7	D7	P3	D3	P9	D9	Etc.

S3

V_1	P1	D1	P2	D2	P3	D3	Etc.
V_2	P7	D7	P5	D5	P6	D6	Etc.
V_3	P4	D4	P8	D8	P9	D9	Etc.

Figure 4-6: Newly generated neighborhood representation

Generating the neighborhood of a solution is done by exhaustively swapping pairs of requests assigned to different routes. Each swap made generates a neighbor solution.

The neighborhood of a solution S is composed of all the solutions S'that can obtained from S by removing the attribute (i, V) and replacing it with attribute (i, V').

After insertion of the vertex pair, the neighborhood solutions are evaluated using the objective function. The neighbor with minimum cost is selected as the next move. Though the search process is very expensive, this type of move has the greatest potential for improvement in the objective function.

1.4.1 Neighborhood evaluation:

An important aspect of Tabu search heuristic is the procedure for neighborhood evaluation technique. The objective of neighborhood evaluation is to reduce the constraint violations and assess the feasibility of the solution. There are two objectives in neighborhood evaluation: Reduction of time-window constraint associated with requests, respecting the capacity of vehicles.

1.4.2 Determining the best candidate:

A critical step is choosing the best admissible candidate. After evaluating each of the moves of the candidates in the neighborhood in turn, admissibility is based on the tabu restrictions and aspiration criteria.

The choice can be based on the change produced in the objective function value that is the difference between the objective function values for the solutions before and after creating new candidates. Then, designate the solution obtained as the new current solution.

1.5 Tabu list:

- It has the role of lending a short-to-medium size memory to the algorithm. The List remembers and disables movements from previous iterations or searches. In short-term memory, selected attributes in solutions recently visited are labeled "tabu-active". Solutions that contain tabu-active elements are banned.

By keeping track of, what moves are made in the recent past in order to make sure that we do not go back to the same local minima we are trying to escape.

Recent moves are known to be tabu, but we can make an exception in a bad situation when the other moves are bad and this leads us to find the better solution. This is known as aspiration criteria.

- Aspiration criteria are employed that override a solution's tabu state, thereby including the otherwise-excluded solution in the allowed set (provided the solution is “good enough” according to a measure of quality or diversity). A simple and commonly used aspiration criterion is to allow solutions, which are better than the currently known best solution.
- Tenancy Period: This is the time or the number of iterations that the Tabu List disables the Tabu Moves.

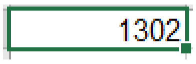
1.5.1 Completion Criteria:

The algorithm stops with the fulfillment of a specified maximum number of iterations It.

1.6 Computational results:

We will introduce the results obtained by Tabu Search coding using VBA (Visual Basic for Applications).

The objectif function obtained by Tabu search, which represents the total cost of all the trips:



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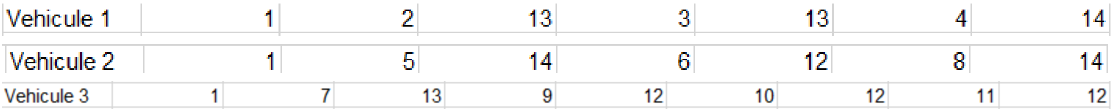
The solution obtained is a set of three vehicles satisfying ten requests:



Vehicule 1	1	2	13	3	13	4	14		
Vehicule 2	1	5	14	6	12	8	14		
Vehicule 3	1	7	13	9	12	10	12	11	12

Figure 4-7 the obtained solution by Tabu search

The last vehicle satisfies four requests, while the first two vehicles satisfy three requests.

1.6.1 Results interpretation:

In order to simplify the coding of Tabu Search, we limited the vehicles to carry only one patient at once, which means that every vehicle performs a delivery right after the pickup. The results are promising as the solution is indeed a set of three vehicles, each with a routing that respects the requests and the capacity. All the requests are satisfied but the objectif function has doubled. The reason of this big increase compared to the results obtained by LINGO is the difference in the capacity chosen. Yet, if only we did choose the same capacity for the two resolution methods, the results would have been the same.

1.7 Conclusion:

This chapter is dedicated to the application of Tabu Search for resolving our studied problem. In this chapter, we gave the detailed steps followed in order to obtain a satisfactory solution. The solution obtained gave a promising results as all the vehicles respected theirs capacity and the requests were respected. However, the objectif function has increased compared to the one found using LINGO, due to the capacity difference. LINGO gave the best results, which means that grouping patients in one vehicle is the best way to minimize the cost of transportation instead of transporting only one patient in every vehicle.

General conclusion

End-stage kidney disease is considered a public health problem where dialysis is a life-sustaining treatment modality for the patients. However, the important cost of the treatment and the transportation puts a heavy burden on communities worldwide. Logisticians and economists have always been challenged by the growing cost of the medical transport with the growth of number of patients. Ensuring the quality of service and security for them while controlling the growth of the transport cost is the optimal objective.

In order to rationalize this big budget, we must reduce the cost of the total distance travelled. This type of routing problem is introduced as a static DARP. After more than twenty years of research, it is fair to say that excellent resolution approaches exist for the static case of this type of VRP.

The DARP is an important and a very difficult routing problem encountered in several contexts and likely to gain an importance in coming years. It shares several features with pickup and delivery problems arising in courier services, but since it is concerned with the transportation of people, level of service criteria become more important. Thus, punctuality and route directness are more critical in DARP.

This thesis focuses on the transportation of patients undergoing the hemodialysis, as they request rides to theirs treatments. The rides must respect some real-life constraints such as the maximum vehicle capacity, availability of the vehicle, patient's schedule…etc.

The thesis starts by defining some general concepts like hemodialysis, Non-Emergency Medical Transportation and the importance of consistency, the high level of transit service for hemodialysis patients.

After that, we have listed some famous variants of the Vehicle Routing Problems and the methods used to resolve them. The focus at the end of second chapter was shifted towards Dial a Ride Problem with Time Window as we presented a literature review about it.

The following chapter starts with detailed description of the studied problem; we presented the mathematical model for static DARP, solved it using LINGO solver and listed the solutions obtained.

Finally, Tabu search is applied in order to give a satisfactory solution for our problem in the case of big instances.

The main goal of this thesis is to minimize transportation costs for hemodialysis patients while ensuring the quality of service. The final solution proposed in this thesis provide a complete schedule for every medical vehicle with all the stops it must perform during a period. The solution determines the routing of the vehicles.

To conclude this project, we believe that more emphasis should now be put on the dynamic version of the problem. This involves taking the full request of patients into consideration, as they need three treatments per week and how existing routes should be modified to every day to accommodate the requests.

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Abstract:

This paper presents a study on the dial a ride problem with a time window (DARPTW). It is a type of Vehicle Routing Problem that is known in the literature as a complex combinatorial optimization problem related to transportation, in which a set of users must be picked up from an origin location and they must be delivered to a destination location. The first part of the paper defines the transportation of hemodialysis patients and it gives an idea of why this kind of transportation is critical for the users. The second part models the problem mathematically where the aim or our objective function is to minimize the total cost of the transportation. The last part focuses on the application of a metaheuristic; tabu search in this case. The expected contribution of the thesis is to give a comprehensive overview of the dial a ride model for a real-life case like transportation to the dialysis center.

Keywords: transportation**,** Dial-a-ride problem**,** Metaheuristic**,** Tabu search, hemodialysis.

ملخص:

تقدم هذه المذكرة دراسة على مشكلة طلب التوصيل مع نافذة زمنية (DARPTW) . و هو نوع من أنواع مشكلة توجيه المركبات المعروفة في الأدبيات كمشكلة كومبيناتوريال الأمثل المتعلقة بالنقل ، حيث يجب اختيار مجموعة من المستخدمين و نقلهم من مواقعهم الاولية نحو مواقع وجهتهم. الجزء الأول من هذا العمل يركز على نقل مرضى غسيل الكلى ويعطي فكرة عن سبب أهمية هذا النوع من النقل لمستخدميه. الجزء الثاني يركز على تمثيل المشكلة رياضيًا بحيث يكون الهدف هو تقليل التكلفة الإجمالية للنقل. يركز الجزء الأخير على تطبيق تجريبية ؛ بحث الطابو في هذه الحالة. المساهمة المرجوة من هاته المذكرة هي تقديم نظرة عامة شاملة عن نموذج الطلب بهدف التنقل لحالة من الواقع مثل النقل إلى مركز غسيل الكلى.

كلمات مفتاحية : النقل ، التجريبيات، بحث الطابو ، تصفية الدم

Résumé:

Ce mémoire présente une étude sur le problème du "dial a ride" avec une fenêtre temporelle (DARPTW). Il s'agit d'un type de problème d'acheminement des véhicules connu dans la littérature comme un problème complexe d'optimisation combinatoire lié au transport, dans lequel un ensemble d'utilisateurs doit être pris en charge à partir d'un lieu d'origine et ils doivent être livrés à un lieu de destination. La première partie de ce travail définit le transport des patients hémodialysés et donne une idée de la raison pour laquelle ce type de transport est essentiel pour ces derniers. La deuxième partie modélise mathématiquement le problème, notre but ou notre fonction objective étant de minimiser le coût total du transport. La dernière partie se concentre sur l'application d'une métaheuristique qui est la recherche tabou dans ce cas. La contribution attendue dans ce travail est de donner une vue d'ensemble complète du modèle "dial a ride" pour un cas réel comme le transport vers le centre de dialyse.

Mots clés : transport, Dial-a-ride problem, Métaheuristique, recherche Tabou, hémodialyse.