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Thème

Optimisation de la circulation des ambulances du transport des patients hémodialysés de la Wilaya de TLEMCEN

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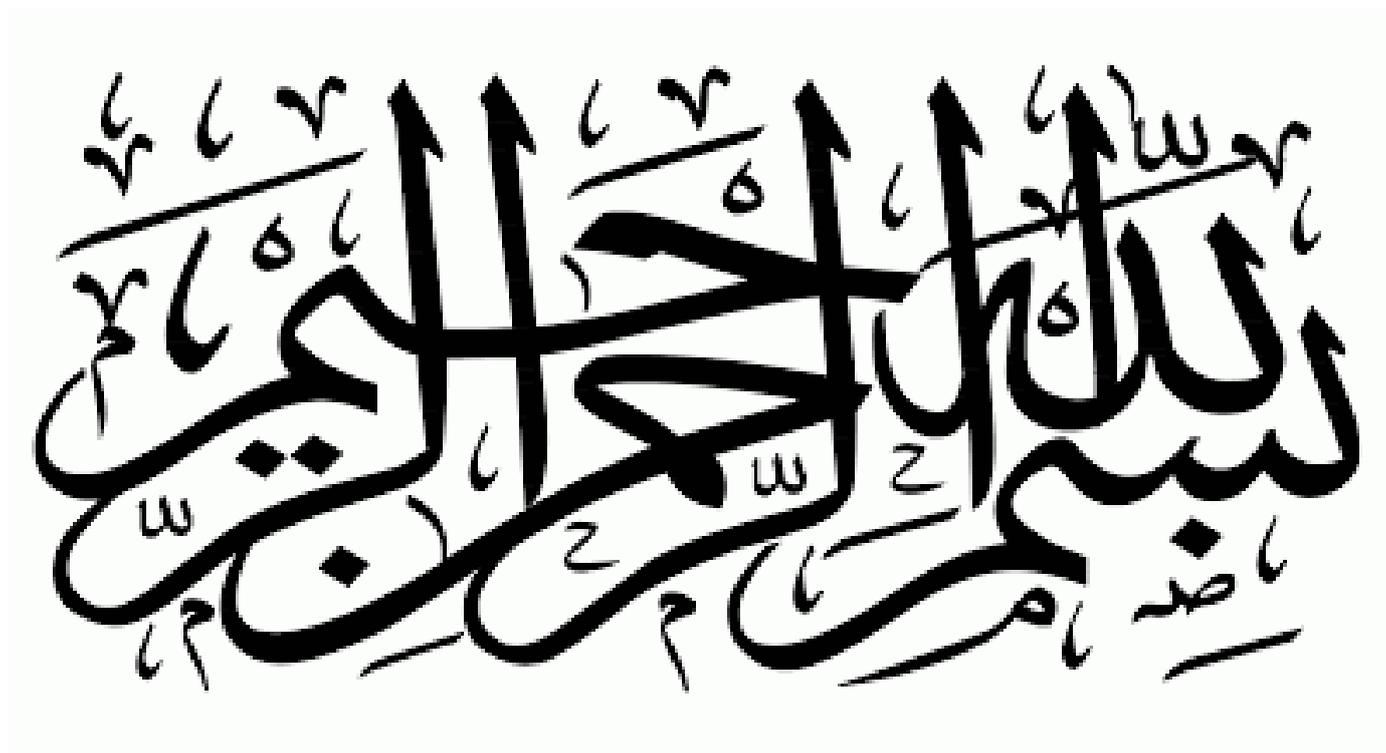
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Dedication:

*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

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.
DVRP: Dynamic Vehicle Routing Problem.
VS: Versus.
DARP: Dial-a-Ride Problem.
MTO: Many to One.
MTF: Many to Few.
MTM: Many to Many.
ILP: Integer Linear Programs.

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General introduction:

End-stage renal failure is considered a public heath problem that constitutes a heavy cost on communities worldwide. 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.

The Static Dial-a-Ride Problem (DARP) is extended to embrace the full patients' requests, as they need three treatments per week. If we consider the full requests, existing routes should be modified every day to satisfy the schedule, which leaves us with a new dynamic system, despite the fact that it is a weakly dynamism.

This problem is usually modeled as a dynamic dial-a-ride problem with time windows (DARPTW) one of the major academic problems in logistics. Other real-life examples of dynamic Dial-a-Ride Problem are Taxi sharing, Ride sharing, Elderly and Handicapped People transportation; a combinatorial optimization problem that 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.
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.

This thesis begins by introducing some concepts that are key in the problem such as defining hemodialysis, non-emergency medical transportation and the importance of the reliability and the quality of transportation for patients undergoing this treatment.

The second chapter introduces the dynamic vehicle routing problem and discusses the differences between static and dynamic VRPs as well as provides some examples of real-life examples of DVRP. In addition, a framework for classifying dynamic routing applications according to their level of dynamism is proposed. The second part of the chapter focuses more on defining Dynamic Dial-a-ride Problem.

The third and last chapter is devoted to defining and solving our optimization problem and presenting the obtained results. The problem is modeled by a linear program before being solved using the IBM CPLEX optimizer.

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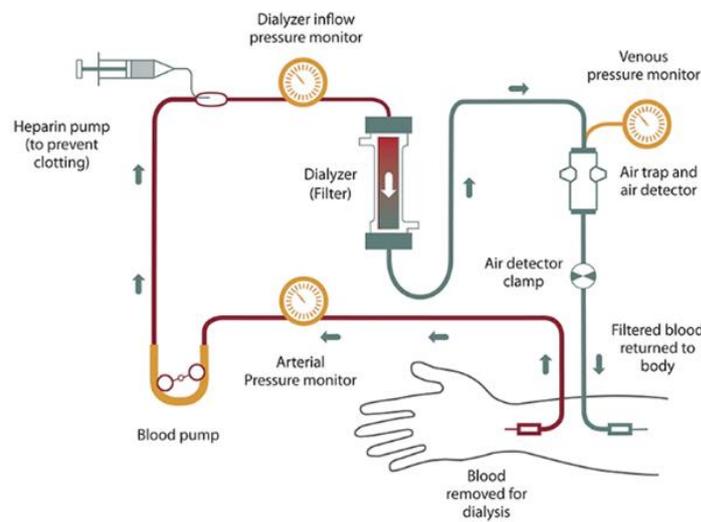
Figure 1-1: blood's Journey in the machine

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] .
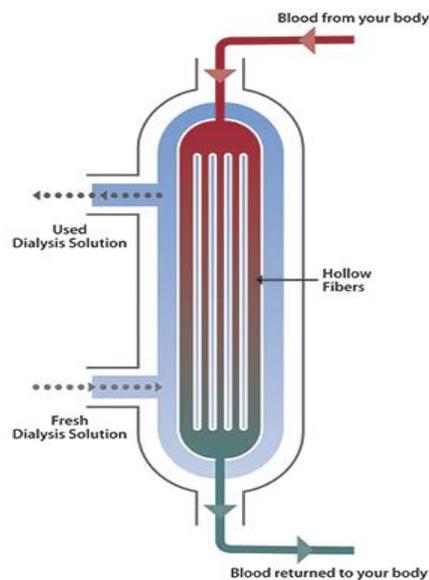
Figure 1-3: Blood in the filter

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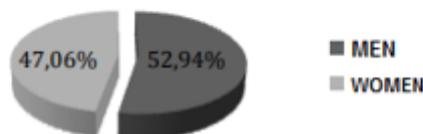
Source: "L'INSUFFISANCE RENALE CHRONIQUE TERMINALE EN ALGERIE: ASPECTS EPIDEMIOLOGIQUES ET ECONOMIQUES" Taous CHEURFA et Nouara KAÏD TLILANE

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:

Year	Public		Private	
	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.
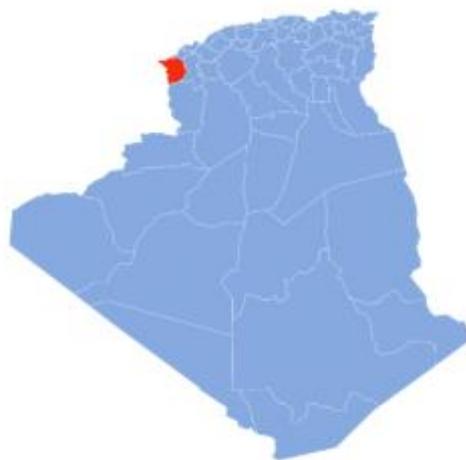
Source: Google Image

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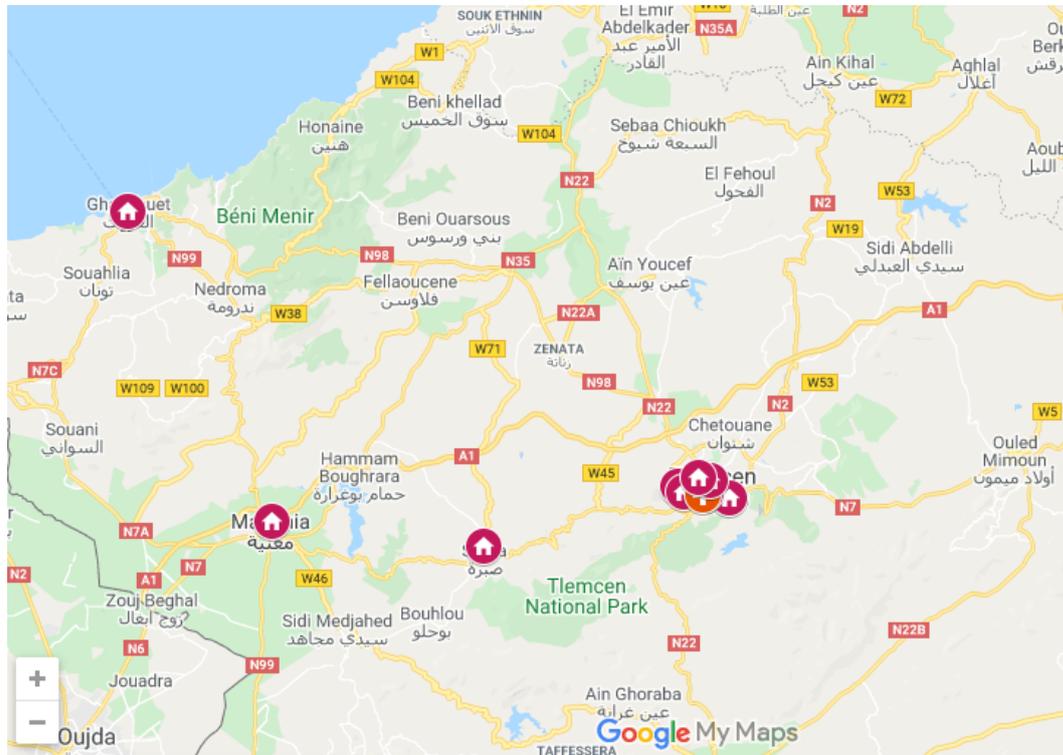
Figure 1-7: Tlemcen Map showing all 8 hemodialysis centers working with CNAS

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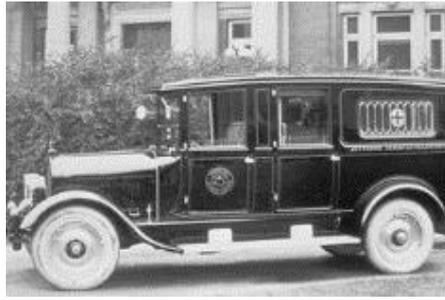
Figure 1-8: the first hospital-based ambulance service in the United States at Cincinnati Hospital 1865

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 Dynamic Vehicle Routing Problems

Chapter two: Generalities on Dynamic Vehicle Routing Problems

1.1 Introduction:

The VRP is an important sub-problem in logistics and a lot of effort has been devoted to research on various aspects of the VRP. However, in routing problems, the problem data are assumed static and not subject to change during the planning horizon plus in the real world, the VRP is subject to dynamic environments. Therefore, recent studies shifted their focus to the more complex dynamic versions of the VRP as they are closer to real-world applications.

This chapter gives an idea about the differences between static and dynamic VRPs and the degree of dynamism of different problems. The second part of the chapter defines Dynamic Dial a Ride Problem, which is a major variant of Pickup and Delivery Problems as themselves are a variant of the famous Vehicle Routing Problem, as we will focus on it in the next chapter.

1.2 Dynamic Vehicle routing problem:

Dynamic vehicle routing problem (DVRP) is an NP-hard optimization problem and a major problem in operational research. In Dynamic DVRP, the customers' demands appear with time, and the unserved customers' points must be updated and rearranged while carrying out the programming paths. The demands change from one period to another one. It is closer to a real logistic scene.

1.3 Dynamic VS static:

Below we give a brief summary of a comparison[1] between static versus dynamic routing:

1. Time dimension is essential .In a static routing problem the time dimension may or may not be important. In the dynamic counter part time is always essential. The dispatcher must as a minimum know the position of all vehicles at any given point in time and particularly when the dispatcher receives the request for service or other information.

2. The problem may be open-ended. The process is often temporally bounded in a static problem. The routes start and end at the depot. In a dynamic setting, the process may very well be unbounded. Instead of routes, one considers paths for the vehicles to follow.

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[1] Larsen, Allan. (2000). The Dynamic Vehicle Routing Problem.

3. Future information may be imprecise or unknown. In a static problem all information is assumed to be known and of the same quality. In a real-life dynamic routing problem, the future is almost never known with certainty. At best probabilistic information about the future may be known.

4. Near-term events are more important. Due to the uniformity of the information quality and lack of input updates all events carry the same weight in a static routing problem. Whereas in a dynamic setting it would be unwise immediately to commit vehicle resources to long-term requirements. The focus of the dispatcher should therefore be on near-term events when dealing with a dynamic routing problem.

5. Information update mechanisms are essential. Almost all inputs to a dynamic routing problem are subject to changes during the day of operation. It is therefore essential that information update mechanisms be integrated into the solution method. Naturally, information update mechanisms are not relevant within a static context.

6. Re-sequencing and reassigning decisions may be warranted. In dynamic routing new input may imply that decisions taken by the dispatcher become suboptimal. This forces the dispatcher to reroute or even reassign vehicles in order to respond to the new situation.

7. Faster computation times are necessary. In static settings, the dispatcher may afford the luxury of waiting fora few hours in order to get a high quality solution, in some cases even an optimal one. In dynamic settings, this is not possible, because the dispatcher wishes to know the solution to the current problem as soon as possible (preferably within minutes or seconds). The running-time constraint implies that rerouting and reassignments are often done by using local improvement heuristics like insertion and k-interchange.

8. Indefinite deferment mechanisms are essential. Indefinite deferment means the eventuality that the service of a particular demand be postponed indefinitely because of that demands unfavorable geographical characteristics relative to the other demands. This problem could for instance be alleviated by using time window constraints or by using a nonlinear objective function penalizing excessive wait.

9. Objective function may be different. Traditional static objectives such as minimization of the total distance traveled or the overall duration of the schedule might be meaningless in a dynamic setting because the process may be open-ended. If no in-formation about the future inputs is available, it might be reasonable to optimize only over known inputs. Some systems also use nonlinear objective functions in order to avoid undesirable phenomena such as the above mentioned indefinite deferment.

10. Time constraints may be different. Time constraints such as latest pickup times tend to be softer in a dynamic routing problem than in a static one. This is due to the

fact that denying service to an immediate demand, if the time constraint is not met, is usually less attractive than violating the time constraint.

11. Flexibility to vary vehicle fleet size is lower. In static settings, the time gap between the execution of the algorithm and the execution of the routes usually allows adjustments of the vehicle fleet. However, within a dynamic setting the dispatcher may not have instant access to backup vehicles. Implications of this may mean that some customers receive lower quality of service.

12. Queueing considerations may become important. If the rate of customer demand exceeds a certain threshold, the sys-tem will become congested and the algorithms are bound to produce meaningless results. Although vehicle routing and queueing theory are two very well studied disciplines, the effort to combine these has been scant.

1.4 Real-life Examples of DVRP's:

- The travelling repairman.
- Courier mail services.
- Distribution of heating oil.
- Dynamic dial a ride systems.
- Taxi services.
- Emergency services.

1.5 Degree of dynamism:

It is possible to categorize the vast majority of routing systems found in practice as they do not share the same degree of dynamism[2] by using three echelons; weakly, moderately, and strongly dynamic systems:

1.5.1 Weakly Dynamic Systems:
Routing environments with a weak degree of dynamism include the distribution of heating oil or liquid gas to private households. In this example, most customers (more than 80 %) are known at the time of the construction of the routes. These are 'automatic replenishment' customers for whom the company uses their demand profile and "degree days" to schedule deliveries. Requests may also be received during the day from "on call" customers. They are serviced as a function of their level of inventory, the available time, and unused tank capacity. The reaction time is considerably longer in such a problem compared to that in a taxi dispatching system. Other examples include residential utility repair services, such as cable television and telephone. The transportation of elderly and handicapped people - usually referred to as **the dynamic dial-a-ride problem** – is yet another example of a routing system that

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[2] Larsen, Allan. (2000). The Dynamic Vehicle Routing Problem.

can be classified as weakly dynamic. The traditional approach for solving such problems has been based on adaptation of static procedures. A static vehicle routing problem is solved every time an input update occurs.

1.5.2 Moderately Dynamic Systems:

Practical examples of such systems include long-distance courier mail services and appliance repairs. In the latter setting, for instance, scheduled customers are interspersed with dynamic ones that need immediate attention due to the gravity of their request (e.g., a broken refrigerator will take precedence over an already scheduled partly broken stovetop). Compared to weakly dynamic systems, in moderate ones the number of immediate requests account for a substantial part of the total number of customers who have to be serviced. For a wide range of applications, re-searchers have also included stochastic elements, such as unknown customer demands, and used stochastic programming models. However, these tend to become extremely hard to solve due to their combinatorial nature. Solution strategies have often been based on deferring decisions until the latest possible moment. Ideally, this will improve the quality of the decisions made because the level of uncertainty decreases as time elapses. Yet, the frequent updates of the available information severely limit computation time. As an alternative approach, one could use a model, which utilizes the time between input updates to perform improvements of potential routes. This, of course, requires detailed information on future requests.

1.5.3 Strongly Dynamic Systems:

Emergency services, such as police, fire and ambulance departments exhibit strong dynamic behavior. Another example is taxicab services in which only a negligible number of the customers have ordered their ride in advance. The importance of especially the first of these problems has motivated numerous strategic and tactical analyses of their associated costs and quality of service since the early 1970s. In particular, ways to decrease response times have been studied with continued interest. Strongly dynamic systems are characterized by the fast pace of changes in the data and the urgency of almost all requests received. Furthermore, the quality of a-priori information is often relatively poor concerning data such as the locations of the customers, their demands, etc. If, on the other hand, a-priori information or even expectations were available, it would be evident to try to incorporate them into the algorithms used. For example, this could involve moving an idle vehicle currently situated in a low traffic area to a central location. Another characteristic of these systems is that queueing begins to occur in relatively heavy traffic. Therefore, handling aspects related to it often plays a central role. This is especially true given the type of systems found in practice and the importance of reaction time.

1.6 Dial a Ride Problem with Time Window:

The Dial-a-Ride Problem (DARP) 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.

Non-emergency medical transportation is a DARP, multiple users or patients make their requests for transportation from their specific origins generally their homes to destinations locations, which are the dialysis centers. The two nodes are also known as pick-up and drop-off or delivery points, respectively.

The medical transportation service provider receives the requests of the patients and then arranges with its fleet of vehicles based on the requested time and the area of service.

 The transportation service is shared in the sense that multiple patients (with different origins and same destination) may be in the same vehicle at the same time. The typical features of the problem include the following:

- Request: Each patient has to be delivered from the origin to the destination.
- Time window: Each patient has an earliest and a latest time of pick-up and/or delivery, representing the departure time from the origin and the arrival time at the destination.
- Depot(s): The starting and ending points of a route of a vehicle.
- Trip: A vehicle finishes a trip once it returns to its initial point (depot).
- Vehicle capacity: The maximum number of patients seating in a vehicle at the same time.
- Ride time: The time a user spends seated in a vehicle. It is the difference between the scheduled times of pick-up and delivery.
- Route duration: The time a vehicle travels in a single trip. It is the difference between the time of leaving from and returning to the depot.

A typical DARP assigns the vehicles to the requests and determines the vehicle routes for transportation services, with the consideration of the above features.

The objective of the problem is to improve users' experience, for example reducing waiting time or to minimize service provider's operating costs, for example the total distance traveled by the vehicles. The total distance of each trip. The goal is to

optimize the objective function subject to constraints related to the above features such as capacity of the vehicle or time window constraints.

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.

1.7 Dynamic Dial-A-Ride Systems:

The Dial-A-Ride Problem (DARP) consists in finding the cost optimal route through a number of customers; each of which has an origin location (pick-up location) and a destination location (delivery location). The objective to be minimized is usually a function of the number of vehicles in the solution, the distance driven and the level of service provided to the customers. The conventional DARP could be divided into the following three broad categories[3]:

•Many-to-one (MTO): MTO is the simplest type of the DARP to provide and it is relatively easy to construct high quality routes. As an example of a real-life application of the MTO, one could mention the transport of customers from a residential area to for instance the local shopping mall.

•Many-to-few (MTF): MTF is harder to provide because this system services more than one attraction center. However, the quality/cost ratio is relatively high in an MTF, because a considerable amount of the transit goes from home to some attraction center. Again, a real-life example could for instance be three different stops at the same large shopping mall.

•Many-to-many (MTM):The MTM service could be thought of as a taxi cab system in which multiple passengers could be in the vehicle at the same time. Passengers are being picked up at several different locations and dropped off at several different locations. The MTM problem is therefore similar to transportation of elderly and handicapped people.

1.8 Resolution Approaches:

When solving an optimization problem such the problem treated in this thesis, we can choose between different optimization methods: Exact optimization methods, which

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[3] Larsen, Allan. (2000). The Dynamic Vehicle Routing Problem.

find an optimal solution, and heuristic optimization methods that do not promise to find an optimal solution.

1.8.1 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:

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

1.8.1.2 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.

1.8.2 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.

1.8.3 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[4] 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 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.

1.9 Conclusion:

In this chapter, we begins by introducing the dynamic vehicle routing problem and theirs resolution approaches, we also discuss the differences between static and dynamic VRPs as well as pro-vides some examples of real-life examples of DVRP and categories VRPs into three echelons based on theirs degree of dynamism. Later on, we define Dynamic Dial a Ride Problem as a weakly dynamic system.

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[4] 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.

Chapter Three:
Problem modelling

1 Chapter Three: Problem Modelling

1.1 Introduction:

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 cost of transit, while respecting some constraints. The problem is then resolved using IBM CPLEX optimizer for a case study and the optimization results are presented by the end of the 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. Each patient undergo treatment three times per week. Treatments are separated by one day for every patient. The requests that must be transported in the first day are different from the requests of the next day. There is a certain dynamism in this problem; therefore, the problem is modeled as a Dynamic Dial-a- Ride Problem.

1.3 Problem Description and Definition

We suppose that we have a pickup and delivery requests for a set of patients to be transported to dialysis centers. Both the patients' origins and the centers' locations are geographically indicated. The requests are satisfied by using vehicles having the same capacity of three patients at once.

The problem is obviously NP-hard because it reduces to the PADP, known to be NP-hard.

The problem is defined on a graph $G = (N, A)$ where:

N includes depot (0) plus a set of pickup nodes $N_c = \{1, \dots, n\}$ and a set of delivery nodes $N_d = \{n + 1, \dots, 2n\}$.

A is the set of arcs such that $A = \{(i, j) \mid i, j \in N, i \neq j\}$.

Each arc (i, j) is associated with:

- $C_{i,j}$ The routing cost between two nodes where $C_{i,j} \neq 0$.
- dij : Distance between nodes i and j.
- r_{ij} A request, $r_{ij} = 1$ when j is the destination of the origin i.

Each ambulance is represented by k, where K is the set of available ambulances. $K = \{1, \dots, m\}$. All the vehicles of the fleet has the same capacity, with a route that starts by leaving the depot, visiting a subset of patients, picking them up from i and transporting them to j.

D The set of days in a period, where $p \in D$ represent a day in the time horizon.

Each patient has three days every week in which he must be transported to the dialysis center.

1.4 Mathematical modelling:

We make the following assumptions:

- Vehicles start and end at depot labeled 0.
- Each patient must be serviced the required number of times (three days) over a period (a week).
- Each node must be served by exactly one vehicle a day.
- Vehicles pickup and give a ride to three patients at most.
- There is a pairing constraint, meaning a patient must be delivered to only his destination at the end.
- There is no time window in this model; we are only interested in satisfying the requests of multiple treatments per week.
- There is no return trip from the dialysis center in the model, but the objectif function is multiplied by two referring that the cost is doubled because the vehicles travel the same route twice.

The problem that we want to solve has:

- To decide which vehicle to send to a patient.
- To assign routes to vehicles.
- To minimize the maximum total cost of routes.

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

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

- **element sets**
  - ✓ (i, j)：Pair of nodes.
  - ✓ k：Index of vehicles.
  - ✓ p: Index of days.
- **Sets:**
  - ✓ N_c：Set of origin nodes $N_c = \{1, \dots, n\}$.
  - ✓ N_d: Set of destination nodes $N_d = \{n + 1, \dots, 2n\}$.
  - ✓ $N = N_c \cup N_d \cup \{0\}$: Set of all the nodes.

- ✓ K: Set of vehicles.
- ✓ D: Set of days.
  - • **Parameters**
- ✓ n : Number of requests (origin and destination nodes).
- ✓ m: Number of vehicles.
- ✓ l: Number of days in a period.
- ✓ $C_{i,j}^k$: Cost per kilometer traversed by vehicle$k$.
- ✓ dij: Distance between nodes i and j.
- ✓ $r_{i,j,p}$: Request of i to be transported to j in day p.
- ✓ q_{ik}^p: Load of vehicle k at node i in day p.

Let us define the following decision variables:

- ✓ $X_{ijk}^p = \begin{cases} 1 \ if \ some \ vehicle \ k \ travels \ from \ i \ to \ j \ on \ day \ p. \\ \quad 0 \ otherwise \end{cases}$

- ✓ $Y_{ik}^p \begin{cases} 1 \ if \ patient \ at \ node \ i \ is \ served \ by \ vehicle \ k \ in \ day \ p \\ \quad\quad\quad 0 \ otherwise \end{cases}$

- ✓ 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

$$\min Z = 2 * \sum_{i\in N}\sum_{j\in N}\sum_{k\in K}\sum_{p\in D} C_{ij} * d_{ij} * X_{ijk}^p$$

$$\sum_{p\in D}\sum_{k\in K} Y_{ik}^p = 3 \quad \forall i \ \in N_c \ (2)$$

$$\sum_{k\in K} Y_{ik}^p \leq 1 \ \forall i \ \in N_c , \forall p \ \in D \ (3)$$

$$\sum_{p\in D}\sum_{k\in K} Y_{jk}^p \geq 3 \quad \forall j \ \in N_d \quad (4)$$

$$\sum_{k\in K} Y_{0k}^p = 3 \ \forall p \ \in D \quad (5)$$

$$\sum_{p\in D}\sum_{k\in K}\sum_{j\neq i,j\neq 0} X_{ijk}^p = 3 \ \forall \ i \ \in N_c \quad (6)$$

$$\sum_{p\in D}\sum_{k\in K}\sum_{i\in N_c} X_{ijk}^p = 3 \ \forall \ j \ \in N_d \quad (7)$$

$$\sum_{j\neq i, j\neq 0} X_{ijk}^p = Y_{ik}^p \quad \forall i \in N_c, \forall p \in D, \forall k \in K \quad (8)$$

$$\sum_{\substack{i \in N_c \cup (0) \\ i \neq j}} X_{ijk}^p = Y_{jk}^p \quad \forall j \in N_c, \forall p \in D, \forall k \in K \quad (9)$$

$$\sum_{j \in N} \sum_{k \in K} X_{ijk}^p = 0 \quad \forall j \in N_d, \forall p \in D \quad (10)$$

$$\sum_{i \in N_c} X_{ijk}^p = Y_{jk}^p \quad \forall j \in N_d, \forall p \in D, \forall k \in K \quad (11)$$

$$\sum_{j \in N_c} X_{0jk}^p = Y_{0k}^p \quad \forall p \in D, \forall k \in K \quad (12)$$

$$\begin{cases} \sum_{j \in N_d} \sum_{p \in D} r_{i,j,p} = 3 & \forall i \in N_c \\ \sum_{i \in N_c} \sum_{p \in D} r_{i,j,p} \geq 3 & \forall j \in N_d \end{cases} \quad (13)$$

$$\sum_{k \in K} Y_{ik}^p = \sum_{j \in N} r_{i,j,p} \quad i \in N_c, \forall p \in D \quad (14)$$

$$Y_{ik}^p = \sum_{j \in N} Y_{jk}^p * r_{i,j,p} \quad \forall k \in K, i \in N_c, \forall p \in D \quad (15)$$

$$q_{ik}^p = \sum_{j \in N_d} Y_{ik}^p * r_{i,j,p} \quad \forall k \in K, i \in N_c, \forall p \in D \quad (16)$$

$$q_{jk}^p = -Y_{jk}^p \quad \forall k \in K, j \in N_d, \forall p \in D \quad (17)$$

$$\sum_{i \in N} q_{ik}^p \leq 3 \quad \forall k \in K, \forall p \in D \quad (18)$$

$$X_{ijk}^p, Y_{ik}^p \in \{0,1\} \quad k, i, j, p \in N$$

$$q_{ik}^p \in \{-1,1\}$$

Equation (2) ensures that each pickup node is visited three times per week; equation (3) ensures that the pickup node must be visited at most once a day. If the node is a delivery or a destination node, equation (4) guarantees that it can be visited more

than three times a week. The three vehicles visit node (0) or the depot every day in equation(5).

Equations (6) and (7) establish that arc (i, j) is traversed three times a week, while equations (8)(9) (11)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 (10) guarantees that the routes are ending at a delivery node. Equation (12) ensures that the number of pickup nodes visited after departing from depot is the same number of vehicles visiting the depot.

Equation (13)specifies that the number of requests for pickup nodes is exactly three while delivery nodes can receive multiple requests. Equation (14) establishes that only one vehicle satisfy a request for a pickup node, while (15) specify that for a request to be satisfied, the same vehicle must visit both the pickup and the delivery node.

Equations (16)(17) indicate 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. The capacity constraint is guaranteed in equation (18).

The last constraint (19) defines the domain and the nature of the variables and parameters used in this problem.

1.5 Optimization using CPLEX:

The linear program is suitable for solving mathematical problems that consist of optimizing (maximizing or minimizing) a linear function of several variables which are linked by linear relationships called constraints.

For our problem, we present a mathematical model with an objective function and constraints. The CPLEX solver will be used for the resolution of this problem.

1.5.1 IBM CPLEX Optimizer

CPLEX is a computer optimization tool marketed by IBM. The name refers to C programming language and the simplex algorithm.

IBM ILOG CPLEX Optimizer is a tool for solving linear optimization problems, commonly referred to as Linear Programming (LP) problems. It is a high-performance mathematical programming solver for linear programming, mixed-integer programming and quadratic programming.

CPLEX optimizer[1]models mathematically all kind of problems and solves them with powerful algorithms, which can produce precise and logical decisions. It creates files

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[1] Hélène Toussaint, IBM ILOG CPLEX Optimisation Studio : une introduction à OPL et CPLEX Studio IDE
http://fc.isima.fr/~toussain/doc/introOPL.pdf

according to the OPL language (Optimization Programming Language). This mathematical programming technology enables decision optimization for improving efficiency, reducing costs and increasing profitability. In addition, OPL offers the user the ability to separate the model from the data, so that the same model can be easily tested with different data sets

CPLEX Optimizer provides flexible, high-performance mathematical programming solvers for linear programming, mixed integer programming, quadratic programming and quadratically constrained programming problems. These solvers include a distributed parallel algorithm for mixed integer programming to leverage multiple computers to solve difficult problems.

Therefore, the files created by CPLEX studio can model:

- Continuous linear optimization.
- Linear optimization with integer or mixed numbers.
- Constraint programming.

On the other hand, CPLEX does not model non-linear programming problems.

Figure3-1: CPLEX's logo

1.5.2 Structure of an OPL Project:
An OPL project consists of five types of[2]:

- A project file (.project)
- One or more template files (.mod)
- One or more optional data files (.dat)
- One or more optional parameter files (.ops)
- One or more runtime configuration files (.oplproject)

1.6 CPLEX execution:

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[2] (PDF) CPLEX Tuto- OPL et l'environnement CPLEX Studio, quelques bases.

```
 6  int L=...;
 7  int V=...;
 8  int P=...;
 9
10  range location=1..L;
11  range vehicle=1..V;
12  range period=1..P;
13
14  //data
15  float TML[location]=...;
16  float TME[location]=...;
17  float s[location]=...;
18  //float w[location]=...;
19
20  float request[location][location][period]=...;
21  float distance[location][location]=...;
22  float time[location][location]=...;
23  float cost[location][location]=...;
24
25  //variables de décision
26  dvar boolean X[location][location][vehicle][period];
27  dvar boolean Y[location][vehicle][period];
28  dvar float A[location][vehicle][period];
29  dvar int q[location][vehicle];
30
31  //fonction objectif
32  minimize(sum(i in location,j in location, k in vehicle, d in period)(distance[i][j]*cost[i][j]*X[i][j][k][d]));
33

    //constraintes
    subject to{

    forall(i in location:i!=1 && i<=12)
      each_patient_is_visited_three_times_per_week:
      sum(d in period,k in vehicle)Y[i][k][d]==3;

    forall(i in location:i!=1 && i<=12, d in period)
      sum(k in vehicle)Y[i][k][d]<=1;

    forall(j in location: j>12)
      each_center_is_visited_multiple_times_per_week:
      sum(d in period, k in vehicle)Y[j][k][d]>=3;

    forall(i in location:i!=1 && i<=12,d in period)
      sum(k in vehicle)Y[i][k][d]==sum(j in location)request[i][j][d];

    forall(i in location:i!=1 && i<=12, k in vehicle,d in period)
      each_vehicle_picks_patient_and_deliver_to_destination:
       sum(j in location)request[i][j][d]*Y[j][k][d]==Y[i][k][d];

    forall(d in period)
      depot_is_visited_by_all_three_vehicles:
      sum(k in vehicle)Y[1][k][d]==3;

    forall(i in location:i!=1 && i<=12)
     ars_are_traversed_three_times:
     (sum(d in period,k in vehicle,j in location:j!=1 && j!=i)X[i][j][k][d])==3;

  forall(j in location:j>12)
   ars_are_traversed_hree_times:
   (sum(d in period,k in vehicle,i in location:i!=1 && j!=i && i<=12)X[i][j][k][d])==3;

  forall(i in location: i!=1 && i<=12,k in vehicle,d in period)
    sum(j in location: j!=1  && i!=j)X[i][j][k][d]==Y[i][k][d];

  forall(j in location: j!=1 && j<=12, k in vehicle, d in period)
    sum(i in location: i<=12 && i!=j)X[i][j][k][d]==Y[j][k][d];

  forall(i in location: i>12, d in period)
    sum(k in vehicle, j in location)X[i][j][k][d]==0;

  forall(j in location: j>12, k in vehicle,d in period)
    sum(i in location: i!=1 && i<=12)X[i][j][k][d]==Y[j][k][d];

  forall(k in vehicle, d in period)
    sum(j in location: j!=1 && j<=12)X[1][j][k][d]==Y[1][k][d];

  forall(i in location: i<=12, k in vehicle, d in period)
    q[i][k][d]== sum(j in location:j>12)request[i][j][d]*Y[i][k][d];

  forall(j in location: j>12, k in vehicle, d in period)
      q[j][k][d]== -Y[j][k][d];

  forall(k in vehicle, d in period)
    sum(i in location)q[i][k][d]<=3;
```

Figure 3-2: Our program in CPLEX

1.6.1 Input data in CPLEX:

We will consider a study case with 11 patients, 3 dialysis centers and 1 depot. So, our model will contain 15 nodes. Between every two nodes, we have a distance matrix and a cost per distance travelled matrix.

We have three vehicles travelling between the nodes in order to satisfy the requests. Each patient node (origin node) has a request and a timetable, where each one has to be served three days per week. The period is 7 days.

The input data in CPLEX are as follows:

```
distance=
[
[0,   4,   7,   7,   9,   10, 8,   14, 7,   6,    4, 9,   6,   5,   11],
[4,   0,   4,   3,   7,   9,  6,   12, 7,   10,   4, 9,   4,   3,   8],
[7,   4,   0,   3,   7,   10, 3,   10, 9,   10,   8, 8,   5,   3,   6],
[7,   3,   3,   0,   4,   7,  6,   8,  7,   8,    6, 5,   4,   5,   4],
[9,   7,   7,   4,   0,   4,  10,  5,  5,   8,    7, 3,   3,   9,   2],
[10,  9,   10,  7,   4,   0,  13,  6,  3,   6,    6, 10,  4,   11,  8],
[8,   6,   3,   6,   10,  13, 0,   14, 12,  12,   9, 8,   9,   2,   9],
[14,  12,  10,  8,   5,   6,  14,  0,  9,   12,   10, 3,  7,   13,  5],
[7,   7,   9,   7,   5,   3,  12,  9,  0,   3,    3, 8,   4,   10,  9],
[6,   10,  10,  8,   8,   6,  12,  12, 3,   0,    2, 9,   6,   10,  12],
[4,   4,   8,   6,   7,   6,  9,   10, 3,   2,    0, 9,   4,   8,   9],
[9,   9,   8,   5,   3,   10, 8,   3,  8,   9,    9, 0,   8,   11,  5],
[6,   4,   5,   4,   3,   4,  9,   7,  4,   6,    4, 8,   0,   7,   6],
[5,   3,   3,   5,   9,   11, 2,   13, 10,  10,   8, 11,  7,   0,   9],
[11,  8,   6,   4,   2,   8,  9,   5,  9,   12,   9, 5,   6,   9,   0],
];
```

Figure 3-3: Input distance Matrix

In order to estimate the cost matrix, we had to fix a cost for each distance travelled by the vehicles.

```
cost=
[     [0,  9,  9,  9,  9,  9,  9,  12, 9,  9,  9, 9,  9,  9,  12],
      [9,  0,  9,  9,  9,  9,  9,  12, 9,  9,  9, 9,  9,  9,  9],
      [9,  9,  0,  9,  9,  9,  9,  9,  9,  9,  9, 9,  9,  9,  9],
      [9,  9,  9,  0,  9,  9,  9,  9,  9,  9,  9, 9,  9,  9,  9],
      [9,  9,  9,  9,  0,  9,  9,  9,  9,  9,  9, 9,  9,  9,  9],
      [9,  9,  9,  9,  9,  0,  12, 9,  9,  9,  9, 9,  9,  12, 9],
      [9,  9,  9,  9,  9,  12, 0,  12, 12, 12, 9, 9,  9,  9,  9],
      [12, 12, 9,  9,  9,  9,  12, 0,  9,  12, 9, 9,  9,  12, 9],
      [9,  9,  9,  9,  9,  9,  12, 9,  0,  9,  9, 9,  9,  9,  9],
      [9,  9,  9,  9,  9,  9,  12, 12, 9,  0,  9, 9,  9,  9,  12],
      [9,  9,  9,  9,  9,  9,  9,  9,  9,  9,  0, 9,  9,  9,  9],
      [9,  9,  9,  9,  9,  9,  9,  9,  9,  9,  9, 0,  9,  12, 9],
      [9,  9,  9,  9,  9,  9,  9,  9,  9,  9,  9, 9,  0,  9,  9],
      [9,  9,  9,  9,  9,  12, 9,  12, 9,  9,  9, 12, 9,  0,  9],
      [12, 9,  9,  9,  9,  9,  9,  9,  9,  12, 9, 9,  9,  9,  0],
];
```

Figure 3-4: Calculated input cost matrix

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

Origin nodes	Timetables	Destination nodes
2	Sat>Mon>Wed	14
3	Sun>Tue>Thu	14
4	Sun>Tue>Thu	15
5	Sat>Mon>Wed	15
6	Sat>Mon>Wed	13
7	Sat>Mon>Wed	14
8	Sun>Tue>Thu	15
9	Sun>Tue>Thu	13
10	Sat>Mon>Wed	13
11	Sun>Tue>Thu	13
12	Sat>Mon>Wed	15

Table 3-1: Requests input data

1.7 Computational Results:

The outputs of our model are:

The decision variable $Y(i, k, d)$ which is the one responsible for assuring that all the patients are visited in theirs suitable days and that the same vehicle that carries the patient is the one visiting his destination.

The decision variable $X(i, j, k, d)$ gives an idea about the order of visit for every vehicle and in every day. The routing of the three vehicles is given below for all the periods:
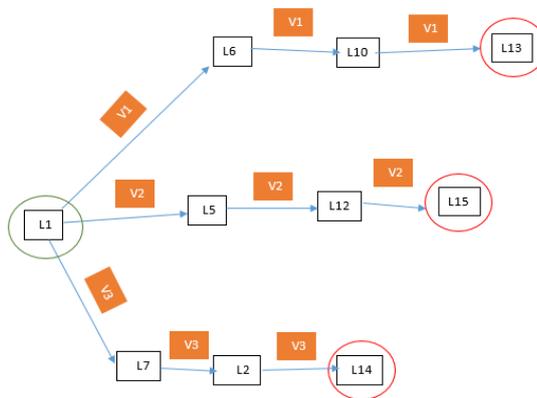

Figure 3-5: vehicle routings/the first day
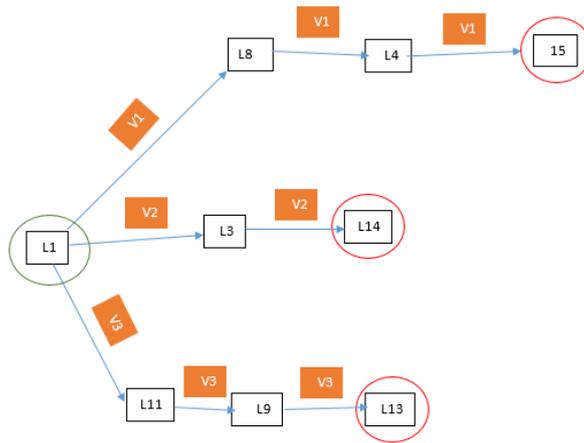
Figure 3-6: Vehicle routings/ second day
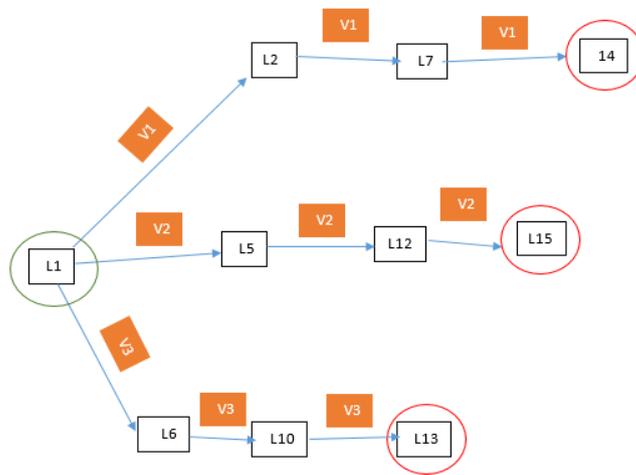
Figure 3-7: Vehicle routings/ third day
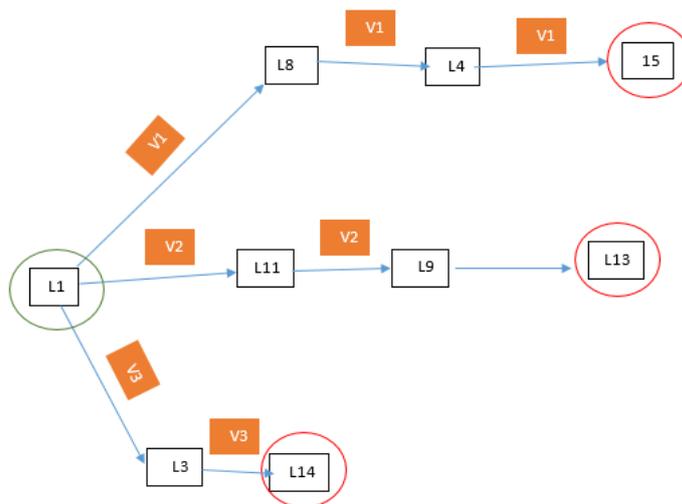

Figure 3-8: vehicle routings/4th day
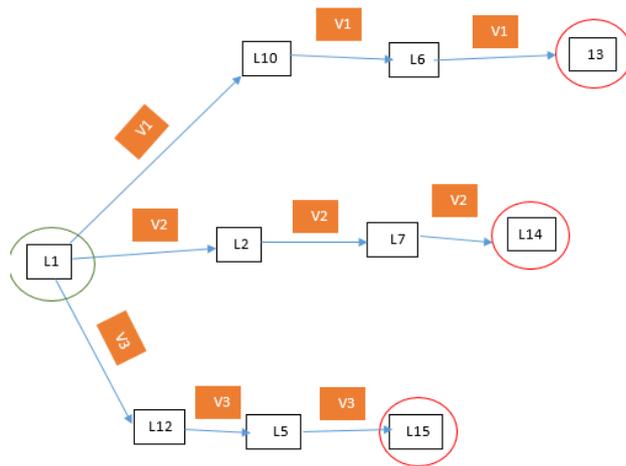
Figure 3-9: vehicle routings/ 5th day
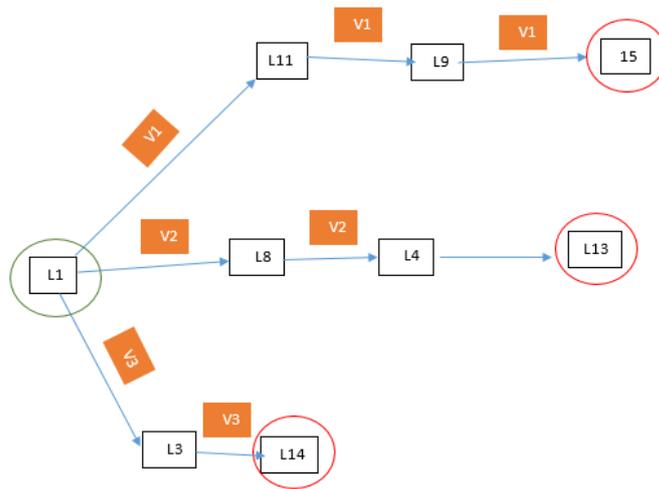
Figure 3-10: Vehicle routings/ 6th day

Location	Vehicle	Days
L2	V3	Day1
L2	V1	Day3
L2	V2	Day5
L3	V2	Day2
L3	V3	Day4
L3	V3	Day6
L4	V1	Day2
L4	V1	Day4
L4	V2	Day6
L5	V2	Day1
L5	V2	Day3
L5	V3	Day5

L6	V1	Day1
L6	V3	Day3
L6	V1	Day5
L7	V3	Day1
L7	V1	Day3
L7	V2	Day5
L8	V1	Day2
L8	V1	Day4
L8	V2	Day6
L9	V3	Day2
L9	V2	Day4
L9	V1	Day6
L10	V1	Day1
L10	V3	Day3
L10	V1	Day5
L11	V3	Day2
L11	V2	Day4
L11	V1	Day6
L12	V2	Day1
L12	V2	Day3
L12	V3	Day5

Table 3-2: output results of Y by CPLEX

1.7.1 Results interpretation:

The output results of CPLEX for our model shows that the requests of patients are respected wither to be transported to their destinations or to be transported on their specific days of treatment. The problem is that different vehicles visit the patients in different days. Again, if this model was designed for the transportation of goods, the problem might be ignored. However, our problem is designed for individuals, and being transported by different vehicles every time you need to go to your treatment is quite inconvenient, as people tend to always choose maximum of comfort and they like to be used to their transportation agents. In addition, since different vehicles carry patients, the vehicles have different routings even though they must pass by the same stops. This is also an inconvenient for the drivers.

1.8 Conclusion:

In this chapter, we have mathematically modeled our problem to optimize the transportation of hemodialysis patients. We established a mixed integer mathematical model whose objective function is used to minimize the costs of transit. This problem was solved using the CPLEX solver based on a real case and a sample of data. Resolution of the problem with the CPLEX solver is limited to 11 patients. If this limit is exceeded, CPLEX will no longer produce results.

General Conclusion

This thesis focuses on the transportation of patients undergoing the hemodialysis, as they request rides to theirs treatments. Each patient has two trips per day, three days a week, which leaves us with six trips every week for every patient. These requests differentiate from one day to another, resulting in a routing problem with a certain degree of dynamism. The rides must also respect some real-life constraints such as the maximum vehicle capacity, availability of the vehicle …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.

The following chapter introduces the dynamic vehicle routing problem and discusses the differences between static and dynamic VRPs as well as provides some examples of real-life examples of DVRP. In addition, a framework for classifying dynamic routing applications according to their level of dynamism is proposed. The second part of the chapter focuses more on defining Dynamic Dial-a-ride Problem.

The third and last chapter starts with detailed description of the studied problem. It defines and solves our optimization problem and presents the obtained results. The problem is modeled by a linear program before being solved using the IBM CPLEX optimizer.

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 of one week. 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. In the same spirit, the degree of dynamism must be augmented so, it should be possible to update a partially built solution to deal with cancellations or receiving new requests and other unforeseen events such as traffic delays and vehicle breakdowns.

References

Hemodialysis. National Kidney Foundation. https://www.kidney.org/atoz/content/hemodialysis. Published 2020. Accessed October 19, 2020.

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

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

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.

Tahar R, (2003). « Epidémiologie et aspects thérapeutiques de l'insuffisance rénale chronique en Algérie ». Communication au colloque Maghreb-France, Marseille.

Tahar R, Benabadji M & Moussaoui H, (2005). « Stratégies pour la prise en charge de l'insuffisance rénale chronique (IRC) : expérience algérienne ». Colloque France-Maghreb ; Rabat.

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

Larsen, Allan. (2000). The Dynamic Vehicle Routing Problem.

Hélène Toussaint, IBM ILOG CPLEX Optimization Studio : une introduction à OPL et CPLEX Studio IDE http://fc.isima.fr/~toussain/doc/introOPL.pdf

 (PDF) CPLEX Tuto- OPL et l'environnement CPLEX Studio, quelques bases.

Abstract:

This dissertation focuses on the dynamic dial a ride problem for the transportation of hemodialysis patients, which is a type of the famous vehicle routing problem. DARP is 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 this paper introduces the problem studied which is the optimization of the transportation for patients receiving hemodialysis treatment in centers, the plan is to define hemodialysis, non-emergency medical transportation and talk about the importance of transportation for the patients. After that, we describe the type of the routing problem in this thesis and provide a mathematical model for it. The final step is to optimize the model using CPLEX.

Keywords: transportation, dynamic Dial-a-ride problem**, Optimization, CPLEX,** hemodialysis.

ملخص

تركز هذه الأطروحة على مشكلة الركوب الديناميكية (DARP) لنقل مرضى غسيل الكلى ، وهو نوع من مشكلة توجيه المركبات الشهيرة. DARP هي مشكلة تحسين اندماجية معقدة تتعلق بالنقل ، حيث يجب اختيار مجموعة من المستخدمين من موقع المنشأ ويجب تسليمهم إلى موقع الوجهة. يقدم الجزء الأول من هذه الورقة المشكلة التي تمت دراستها وهي تحسين النقل للمرضى الذين يتلقون علاج غسيل الكلى في المراكز ، والخطة هي تحديد غسيل الكلى ، والنقل الطبي غير الطارئ والتحدث عن أهمية النقل للمرضى. بعد ذلك ، نصف نوع مشكلة التوجيه في هذه الأطروحة ونقدم نموذجًا رياضيًا لها. الخطوة الأخيرة هي تحسين النموذج باستخدام CPLEX.

كلمات مفتاحية : مشكلة الركوب مع نافذة الوقت الديناميكية، CPLEX، تصفية الدم

Résumé

Ce mémoire porte sur le problème du "dial a ride" dynamique (DARP) pour le transport des patients hémodialysés, qui est un type du fameux problème de routage des véhicules. Le DARP est 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 mémoire présente le problème étudié qui est l'optimisation du transport des patients recevant un traitement d'hémodialyse dans les centres, le plan est de définir l'hémodialyse, le transport médical non urgent et de parler de l'importance du transport de ces patients. Ensuite, nous décrivons le type de problème de routage et fournissons un modèle mathématique pour celui-ci. L'étape finale consiste à optimiser le modèle en utilisant le CPLEX.

Mots clés : transport, Dial a ride dynamique, CPLEX, hémodialyse.