Report Title: Optimizing mobility on demand with dynamic pickup station and drop of with time window Report Title: An

optimization algorithm for Dial a Ride problems in the context of intermodal route planning I like his one

This is a tentative title

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Contents

1 Introduction

Increasing mobility demands raise the pressure on existing transport networks. As the most used mode of transport, private cars have a particularly strong environmental impact and produce congestion.

Shared mobility concept existed before even the coloured television was invented, The first ride-sharing as in car-sharing program was established in 1948 in Zurich when a housing cooperative began a small car share arrangement, it was called “Sefage program”. In this period this solution wasn’t very attractive. Simply because the automotive production got faster and cheaper and it was more appealing to own your vehicle than to share one. Many ride-sharing initiatives re-appeared in Europe afterwards but none did last until we got to the $1990's$ when the congested traffic networks started surfacing, fuel prices risen and environmental concerns were put on the table of discussion.(Becker et al.

2015)(1), the first bike-sharing program began in 1965 in Amsterdam, Netherlands.

In the current times, the rise of smartphone applications and location data increased the feasibility of shared transportation services and mobility on demand. In the region of Ile de France there's $836km$ of accessible roads where 25% experience congestion in the peak hour(2). It is no secret that we need an effective solution. Ride sharing as in mobility on demand, can help to address these issues by increasing the number of persons per car. However, what we're experiencing now is that, although the ride-sharing solutions exist we still have a rise in the traffic congestion and traffic density is worsening (3), additionally there exists no effective method of integrating ride-sharing solutions into transport trip planners as of now, mainly due to the fuzzy and flexible nature (e.g., no fixed stops, possibility of making detours) of carpooling. Some solutions are proposed (see Stiglic et al. 2016, Alonso-Mora et al. 2017)(4)(5), some companies actually operate on this basis but none of them is contributing significantly to the traffic congestion problem. (6)(7)(3)

The numbers of fleet sizing optimization are very promising, without shared mobility almost half of the taxies in Manhattan are empty at normal times, the article in Nature magazine, written by researchers in Senseable city lab(8) shows that we only need 60% of today's taxis. additionally with autonomous shared mobility, the perfect scenario, we can move all Manhattan with $137,000$ vehicles which is half of what's on the road today, but here we're not talking about the perfect scenario, in the dynamic world we only look for the best we can do. (8)

To reduce the negative externalities of car travel, local governments encourage the use of public transit. Unfortunately, many suburban and rural areas are not adequately served as they lack the population density to justify public transit, i.e., the public transit is not economically viable. In cities with sprawling suburban areas, the utilization of public transit to commute to work is often low, e.g., less than 5% in metropolitan areas like Houston and Atlanta in the United States.(4)

This report is organized as follows, in section (2) I start by explaining the motivation in research into this subject, following by section (3) where the literature in shared and intermodal mobility is discovered with the development of a conclusion and a demonstration of the gap in research that exists. Section (5) is a documentation of the methods followed in the literature review and building a bibliography. Section (6) is a detailed taxonomy that was built around the terminologies found in research papers. In section (7) a formal problem definition is presented, with a basic diagram that shows the problem setting. In (7.4) the next steps are mentioned and finally in section (8) is the conclusion.

2 Motivation

When it comes to this subject, my readings had raised questions that need answers, the conflict between mobility on demand and public transit systems. To look into this conflict I decided to read about existing problems from both sides (Public Transport and Mobility on Demand)

In the last few years, there has been a resurgence of interest in demand-responsive shared-ride systems for the general public. (see Ho et al. 2017)(9) This has been fuelled in part by concerns for the environment; each commuter using a separate car leaves a large carbon footprint and also causes congestion in central business districts. Thus, the notion of a sharing economy that advocates a shift from car ownership to "mobility as a service"gained popularity. right now it is a billion dollar business.

My motivation is fuelled by the fact that current mobility problems require intelligent solutions, dynamic ride sharing solutions offer great help to the daily commutes especially in the big cities, public transport on the other hand helps millions everyday to get to their destination, there seem to be a relationship between both if we look into the first and last mile problem and areas underserved with public transport. We can safely say that both these modes are complementary, on one hand, public transport is quite sparse in some regions, ride-sharing or mobility on demand offers to reach areas with limited public transport connectivity, on another hand, the number of dynamic ride sharing relevant for a query increases when allowing routes which bring a passenger to a station where he can use public transport to continue his journey, this is because the passenger will be able to cover a longer distance paying less money, also gaining time because there is a reliable mobility service that will get him to the station of the public transport. (10)

This way dynamic ride-sharing as well as public transportation benefit from this combination: by offering dynamic ride-sharing to the passengers using public transport, of course multi-modal transportation has existed as long as passenger transport itself, in the suburban areas we see Park & go options were you can drive your private car to the main transportation node park the car and use the public transport service. But of course as shared mobility tries to solve many problems, I see a real motivation in integrating both modes and finding a solutions. Many researchers had already investigated this topic (see Bast et al. 2016)(11), it is going to expanded in the third part of the literature review section (4).

To begin literature had to be studied, to find the most recent findings in this topic, first starting with challenges present in shared mobility, this is where I discovered a whole world of problems. Many competent engineers and researchers are trying their best to solve and come up with solutions as this is going to be expanded in Section (3).

Mobility research is broad and can include many topics, when we talk about mobility optimization it involves the integration of information, transportation, inventory, warehousing, material handling, and packaging, and certainly security.

3 Literature

Some leading laboratories already have a remarkable research output. In the beginning I didn't need to go very far in my research and started with literature from the Industrial Engineering Lab in our school, some strong research was conducted on many mobility problems, benchmark studies and surveys.

What came most useful in the start is the survey on model and algorithms in shared mobility (by Mourad et al. 2019)(12). That was a comprehensive survey to the most recent variants of the shared mobility problems, and a study of their different features and modelling approaches, not only that but the survey also explained all the constraints researchers consider into their shared mobility problems such as Time Constraints and Capacity Constraints, the relationship between transporting goods and people, pick up and delivery problems and the potential merge between both worlds.

Strong research also came from the lab in the social and economic impacts of autonomous shuttles for collective transport (see Antonialli & Attias 2019) (13), some strong research also came from the lab in vehicle routing problems and new mobility services (see Vosooghi et al. 2019)(14)(15).

In this topic some notable researchers had a significant contribution, one of them is: Gilbert Laporte who is currently a Full Professor of Operations Research at HEC Montréal. He has a notable contribution to the vehicle routing problem (VRP) & Dial-a-Ride Problem (DARP). His work has been cited over $60,000$ times (16).

However, in many countries around the world there are strong research entities, operational research and mobility companies and individuals that are solving transportation optimization problems. Starting from the west, in the United States, the origin land of Uber & Lyft, the number of research output in the mobility and transportation research is very high, in Europe we have many labs and institutes focusing on this subject with the goal of optimizing freight a people transport in the old continent especially because we're going to witness an increase of +42% in passenger mobility and +60% in freight transport by 2050 (17). In Asia the research output is very high as well.

3.1 Shared mobility

Shared mobility concept as mentioned before contains many variants and characteristics, in (Mourad et al. 2019) (12) a great visual representation of the characteristics of the problem. In this report, we're interested in Dial-a-Ride problems that are concerned with the following variants; goods transport, mobility on demand (MoD), pre-arranged and real-time bookings. To be more specific we're interested in DARP problems concerned with the first and last mile problems in multimodal commutes. A survey of dial-a-ride problems (Ho et al. 2018) (9) presented an up-to-date review of recent studies on dial-a-ride problems (DARPs) with their different variants and solution methodologies.

What is the Dial-a-Ride Problem? The dial-a-ride problem (DARP) generalizes a number of well studied vehicle routing problems such as the Vehicle

Routing Problem with Time Windows(VRPTW) and the Pickup and Delivery Problem (PDP). The DARP is a demand responsive transportation service, which arises for example in the context of patient transportation. It is a service for elderly or handicapped people, where patients have to be delivered to medical facilities or carried back home leading to specified

pickup and delivery locations. The transportation requests have to be completed under user inconvenience considerations by a given fleet of vehicles. Assigning vehicles of a fleet to given transportation requests is usually modelled in terms of a static DARP, which has obtained noticeable attention in the literature in recent years.(see Ritzinger et al. 2016)(18).

Another variant of the ride-sharing problem is the shared-taxi problem introduced by Hosni et al. (2014) as a multi-vehicle dynamic DARP. In the shared-taxi problem, passengers indicate their desired pickup and drop-off locations, their earliest/latest acceptable pickup/drop-off time, and a maximum trip time. Which means this problem shares the same characteristics, such as demand-responsiveness, as the DARP. However, the main difference is that most shared-taxi services aim to minimize the response time to passenger requests whereas dial-a-ride systems aim to minimize vehicle operating cost by reducing the number of vehicles used to serve given passenger demands

Many approaches are adopted to solve the dial a ride problem, each with a specific design that makes each problem different than the other. The most popular objectives of DARPs are to minimize service provider's operating costs (e.g., total transportation time, total distance travelled by the vehicles, total route duration, the number of vehicles required, and driver working time) and/or users' inconvenience metrics (e.g., total ride time, user waiting time, and deviations from requested pick-up/drop-off time windows).; this can be done by cutting down the number of fleet and maximize the occupancy rate. However, some solutions take in to consideration the social welfare and the balance of affecting ride to drivers which makes the optimization relative to the context. A small proportion of work considers vehicle emissions as well. Other more problem-specific objectives include optimizing passenger occupancy rate, cost-effectiveness metric, operator's profit, staff workload, and the reliability of the system.

In (Ritzinger et al. 2016)(18) The proposed hybrid solution framework for solving the DARP includes two algorithmic components: dynamic programming (DP) and Large Neighbourhood Search (LNS). In (Cordeau et al. 2006)(19) they used Branch & Cut algorithm to find an exact solution using an LP model, in (Bertsimas et al. 2018)(20) using re-optimization and an efficient network mixed-integer optimization formulation along with simple heuristics, they were able to find solutions for large scale problems with 5000 taxis and $26,000$ bookings.

To read more into the history of DARP related problems in (Ho et al. 2018) (9) a comprehensive survey of the journal papers published since 2007. Additionally the survey has a detailed taxonomy of the problem variants, and discussion on subtleties of the classification that is going to be investigated in section 6.

More on the survey side (Cordeau & Laporte 2008)(21) presented a summary of the most important models and algorithms, their work and LP model was an inspiration to the model presented in section 7.2. In (Hame 2011)(22) used an insertion algorithm for a DARP problem with narrow time windows. The consideration of narrow time windows means that the vehicle route is restricted by relatively strict time limits for pickup and delivery of each customer. Narrow time windows emerge in real-time dial-a-ride services, in which each customer is given an estimate or guarantee regarding the pickup and delivery times in the form of time windows. These time windows are examined as hard limits to be met by the vehicle, which is not the case for most of the existing mobility on demand services.

In (Garaix et al. 2010) (23) used standard column generation scheme applied it with a classical linear objective function minimizing the total travel cost but with the objective to maximize the passenger occupancy rate. Much more work has been published with very significant results.

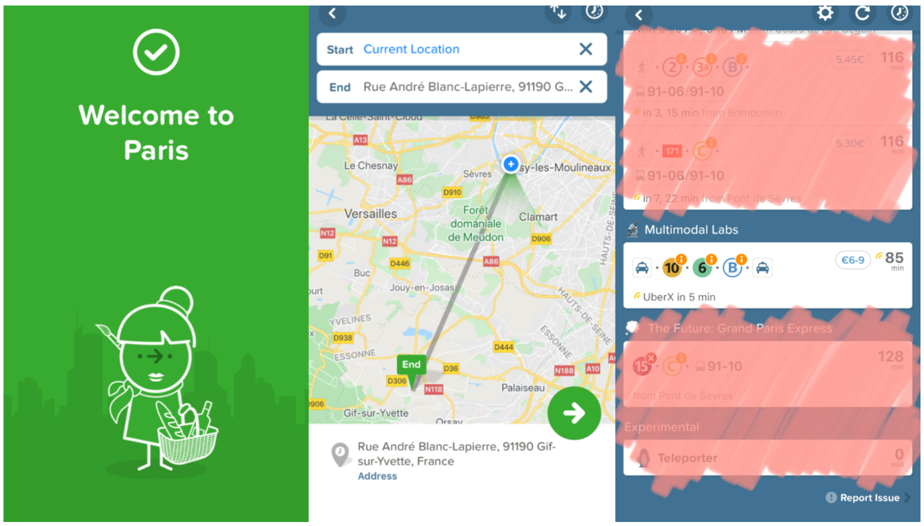
In the assembly of the work, there was no clear correlation between the nature of the trip or tours in the characteristics of Dial-a-ride problems, some work displayed the context of optimization to the elderly (see Stiglic et al. 2016)(4), the pick-up and delivery of the passengers is completely abstract from the context in most of the articles I have read.

This nevertheless was a turning point in the literature review to start studying the nature of the problem when put into different contexts.

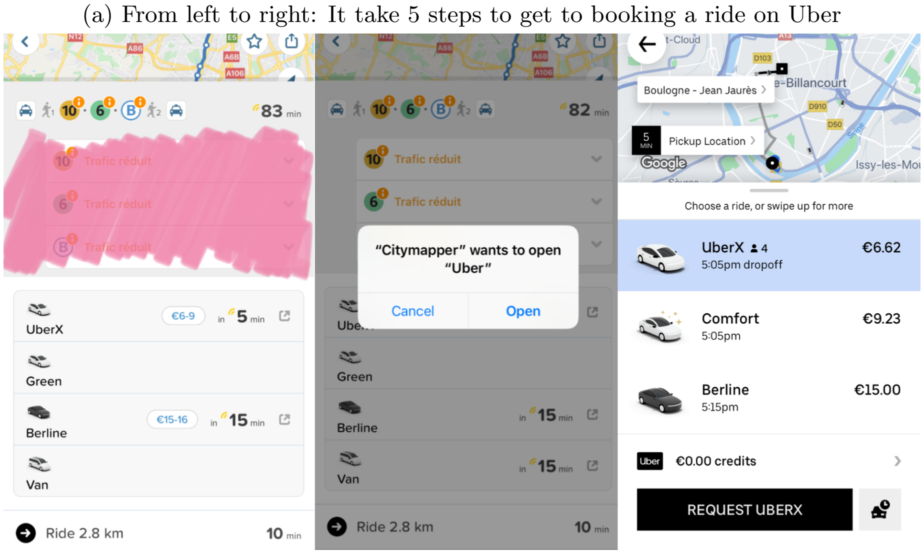
To conclude this point in one sentence we can say that Inter-modality and multimodality exist in literature but none of the literature mixes between dial a ride problems and multimodal transport although it exists in real life. Each service has a specific context, there's a clear lack of research output in DARP optimization problems when it comes to intermodal trip planning, it comes as a responsibility to the user to manage all the bookings. Of course there's research in multimodal trip planning, there are also very famous mobile applications such as "CityMapper"that we use everyday to find the best transportation mode to go from point A to point B. These apps (the ones similar to CityMapper) are the closest to planning an multimodal trip in real life.

Although some of these apps will allow you to book your ride that will get you to the train station, neither the app nor the mobility on demand service provider will be responsible if you arrived late for the train. (in fig. **??**) a little application to the situation described where I want to go back to my residence in Gif-sur-Yvette because the confinement is over and we need to go back for an exam, so it is very important to be there on time, I know that I will use more than one transportation mode to get there, I choose CityMapper to plan the trip for me and choose the best multimodal trip. It turns out to get there fast, I can take an Uber from my current location to the nearest metro station of line 10, the trip planner shows it will take $85min.$ given how Uber works it will surely take longer than that.

Time window pick up in Uber is not a hard constraint (check section 6) the service will choose for you the closest option, also Uber Pool option will add an additional times to the wait $T > 2min.$ to find a match, we should also consider the fact that despite that the driver might be late because of many reasons, the driver can also choose to cancel the trip, Uber will surely find a replacement within minutes or even seconds but that all adds up to the wait time. Also here shows the disadvantage of competition to the customer, simply because Citymapper only shows you Uber as an option at the same time there maybe a Kaptain that is much closer.



(a) From left to right: It take 5 steps to get to booking a ride on Uber



(b) As the figure shows only Uber is an option

That's why the literature review took a natural turn into multimodal trip planning and routing problems.

3.2 Multimodal Trip Planning

Inter-modality, also called mixed-mode commuting, involves using two or more modes of transportation in a journey. However, the research that is going to be displayed in the next paragraph doesn't tackle the the optimization of mobility on demand with public transport, it does mention studies that mix ride-sharing with public transport nevertheless from routing problems point of view and feasibility studies. One of the early notable investigation done in this area is the report "Ride-sharing as a Complement to Transit"(Murray et al., 2012)(24), this report was published in TRB, highlights ride-sharing as an important opportunity for transportation agencies to address the "last mile problem", the last mile problem can be generalized to include first and last mile problems. It shows a comprehensive survey on transit agencies in the United States that are trying to close gaps in service and penetrating difficult to serve areas using ride-sharing to complement their services. The report also shows that despite these important reasons for integrating ride-sharing into transit services, only a modest number of public transit agencies is involved in ride-sharing.

Notable research in this part is done by (Stiglic et al. 2016)(4) who investigated the possibility of realizing a seamless integration of ride-sharing and public transit as it may offer fast, reliable, and affordable transfer to and from transit stations in suburban areas thereby enhancing mobility of residents, they investigated the potential benefits of such a system by means of an extensive computational study. In the paper they mentioned the ride matching technologies that are required to make it a reality, in the paper they consider a centralized system that automatically establishes matches between drivers and riders, and finally turn it into a matching rides problem where they evaluated the benefits of this integration by comparing instances of ride-matching with and without the ride-sharing service.

(Fahnenschreiber et al. 2016) (10) also worked on combining dynamic ride sharing and public transport. In their work they address two problems in multimodality; the first is to connect public transport stations by dynamic ride-sharing and the second is connecting start and destination of a query to public station routes by dynamic ride-sharing routes, although their contribution to the subject is more on the route planning the paper proposes very good methods for ride-matching and finding connections, they also showed better connections using ride-sharing and two modes of transport in terms of travel duration and cost. Their matches are added to their global travel information system.

In (Huang et al. 2019)(25) the paper proposes a new method to merge public transport and carpooling networks for multimodal route planning, considering the fuzziness and flexibility brought by carpooling. It is based on the concept of drive-time areas and points of action, they started by creating a model for both mode of transportation, to study the feasibility they studied all the 5-minute drive time areas computed around all train stops in Switzerland. (Salazar et al. 2019)(26) studied the same public transport feeding challenge but with autonomous mobility on demand in highly dense cities not rural areas,they presented a network flow optimization model that captures the joint operations of autonomous mobility on demand systems and public transit, their results show that an autonomous mobility on demand systems can significantly reduce travel times, pollutant emissions, total number of cars, and overall costs compared to an autonomous mobility on demand system operating in isolation. To conclude this part all the studies show that the integration of a ride-sharing system and a public transit system can significantly enhance mobility and increase the use of public transport which is an expected result.

4 Conclusion of literature review

As previously mentioned, no study captures the interplay between multiple externalities arising from the synchronization of different modes of transportation. To date, there exist no optimization frameworks that capture optimal coordination policies for I-AMoD systems whilst assessing their achievable performance. (26)

We can safely establish that the maturity of this subject is stagnant, this means that the topic is on the table now for a significant amount of time but the improvements and contributions don't seem to serve the area of first and last mile problems when using public transportation.

One of the common integration options between a fixed-schedule system and an on-demand feeder systemis the so-called Demand Responsive Connector (DRC) (Stiglic et al. 2016)(4). We can find an example of DRCs in several US cities and observes that it is one of the most popular types of flexible transit services. Such systems typically operate within a service area and move passengers to and from a transfer point that connects to a major fixed-route transit network.

Although a research gap has been identified, and despite the fact that in (Ho et al. 2018) (9) they recommended a unified method for solving different DARP variants. Each DAR system has problem-specific constraints due to its underlying motivating application. DARP algorithms may need to be adaptable to different problem variants. For example, in this report the DARP is adapted to match rides with public transport and respect timetables.

The literature review goes beyond this report. In (27) I built an online bibliography that is up-to-date with, in addition to that you can also find an excel sheet that sorts down all the articles reviewed and their importance, authors, publishing journal, year and more detailed description such as the use of time constraints.

5 Methodology

The literature review can be divided into two categories, the first one is a general discovery to search for the current research trends in the intelligent transport community and research boards. The second category is more precise and technical to look into the mathematical and scientific problem definitions and identify the problems where there is need and requires research force.

The key contributions are the following:

1. A comprehensive surveys that were published on topics of interest
2. An overview of application areas of DARPs
3. A detailed taxonomy of the problem variants
4. Identification of potential research gaps

Thanks to the free access that is granted by the school network I was able to reach the targeted articles without difficulties. My method of looking for information consisted on three main sources:

- Scientific journals
- Books
- Online Material

5.1 Scientific Journals

My main sources of research were the journals, more specifically Transportation Research Journal, this journal that is published regularly is divided into 6 parts, ranging from policy and practice, emerging technologies to Transport and Environment, the parts that significantly contributed to my literature review are Parts B & C.

Part B publishes papers on all methodological aspects of the subject, particularly those that require mathematical analysis while part C addresses development, applications, and implications, in the field of transportation, of emerging technologies from such fields as operations research. In Transportation Research Part B I found the article that was recommended by my supervisor "A survey of models and algorithms for optimizing shared mobility"(Mourad et al. 2019)(12).

It was very hard to choose between articles, this is why my main reference to the articles in shared mobility was the survey by (Mourad et al. 2019)(12). Then I started using some keywords into my search such as: "DARP", "Multimodal", & "Last mile problem".

5.1.1 Books

Books are the main reference if you want to understand correctly a scientific topic, in this survey I stumbled upon many references such as "The Handbook of Transportation Science"and ...

5.2 Online Tools

The literature review process wouldn't have been possible without the very powerful online tools such as ScienceDirect that helped me widen my research by suggesting 6 related articles to the paper I am currently investigating. Google Scholar is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines this tool helped me to find many articles, know where it has been cited and published this tool also shows me the researcher profiles and who they have collaborated with, their most cited work and their research topics of interest, in conclusion it is the Facebook for researchers. Finally researchGate that helped me by suggesting papers of interest and follow the updates of the researchers in the field. Semantic Scholars also helped my literature review because it shows a number of scientific papers and articles that were highly influenced by the actual paper I am reading.

5.2.1 Conferences

I can safely state that the mobility program was a bootloader for my research project, this conference ...

5.3 Online Material

Thanks to the open source material online, we can easily find the tools that can help advance in the topic.

I was advised by the program director to start a class online on the queuing theory, "Queuing Theory: from Markov Chains to Multi-Server Systems "Queuing theory aims at modelling waiting or blocking phenomena. To be more precise, in queuing theory, those phenomena are characterized by mathematical models. This makes it possible to compute average system performance such as an average delay or a blocking probability. Reciprocally it is possible to dimension system resources in order to reach a given performance level.

This online class gave me a better understanding of the queuing modelling and applications in mobility problems, this basic understanding helped me working on my first project to simulate the traffic on a road with three lane and tolling stations and then study the possibility of creating a traffic jam based on the rate of generation of vehicles.

In addition to this, the program I am into fits perfectly the technical knowledge I need to advance in my research, just in this first semester I was able to recognize and deal with many optimization and operational research problems. What's even better is that most of the work we do in the class most of the times is on a subject related to mobility as an example in the modelling class the project was on traffic modelling using a hydromatic analogy and the law of conservation of flow.

Attending the class of "Optimization for Transportation"the lectures were very helpful to have a wider understanding of the modelling of the transportation problems, the dynamism of the problems and the algorithms used to find an exact or heuristic solution. The project of this course was one of the most interesting projects I worked on with Yue Su. This project gave me an insight on how to practically solve these transportation problems using powerful optimization tools such as CPLEX, the goal was to find the optimal solution of a capacitated vehicle routing problem (G-VRP) to minimize the total distance covered by the fleet. In this project I implemented my first Clarke & Wright Savings Algorithm.

6 Taxonomy

funny citation you found

To introduce and clarify basic terminology is called setting. Besides indicating where a transportation request needs to be picked up and where it should be transported to, a shared trip must also indicate when this process can take place. This is usually done by associating a time window with each transportation request, whether for a passenger or freight. In ride-sharing systems, this time window is usually given by each passenger indicating the earliest departure time from his origin and the latest arrival time at his destination. In intermodal itineraries, the goal of the passenger is to use on demand mobility service (e.g. van-pooling service) to get to the main transportation method (e.g. a train)

AMOD I-AMOD CRT MAAS MOD

7 Problem Definition

7.1 Introduction & Overview

Before defining the problem (writing the problem statement) I will present here a brief description in few lines of the actual optimization problems that exist in the literature, for works please refer to the literature review. Travelling Salesman Problem, minimum cost flow problem, vehicle routing problem, Dial a ride problem.

The Dial-a-Ride Problem (DARP) consists of designing vehicle routes and schedules for n users who specify pickup and delivery requests between origins and destinations. The aim is to plan a set of m minimum cost vehicle routes capable of accommodating as many users as possible, under a set of constraints. Several local authorities are setting up dial-a-ride services or are overhauling existing systems in response to increasing demand such as BVG BerlKönig [Add ref here], and Flinc ride-sharing smartphone, to better describe the problem as illustrated in (fig. 2) the dial a ride problem often receives the pick up and drop-off time windows as inputs from the users, most of the trip planners such as Citymapper [], for mobility on demand the pick up location is usually the nearest point to the customer, in the problem we're going to introduce dynamic pick up locations taking into consideration the drop-off time windows and fair walking distance between customers. In this problem the drop-off time window is defined by the timetable of the destination and not by the user, which makes the whole experience more reliable and seamless.

7.2 Problem setting

We can start by finding an exact optimization method using linear programming we can define the problem as the following: In this part we will describe the problem only at peak hours when the mobility on demand is only serving a many-to-one (Many pick up stations to one drop-off station), in the case of normal operating hours, the service runs a basic mobility on demand service where its mathematical model can be found in the following paper. (Laporte et al. 2007) [add ref here] We have n number of users, m number of vehicles in the fleet and s is the number of stations the customers can be dropped-off at (These stations must have clear and predefined timetables such as train stations and school) $P = \{1, ..., n\}$ is the set of pick up requests and $l = \{1, ..., n\}$ are the respective locations. $D = \{1, ..., s\}$ is the set of drop-off stations, $B = \{1, ..., b\}$ is the set of vehicles available, in this basic problem the capacity of the fleet is unlimited and the travel cost will no be considered in the optimization problem.

A request is a couple (i, j), where $i \in P \& j \in D$ the travel time of this couple will be denoted t_{ij}.

As we can see this is an optimization problem that requires a lot of pre-processing, simply because the pick up will be realised by a cluster of demands sharing the same geographical area, there will be a designed algorithm that calculates the location of the best virtual pick-up station, for this algorithm we will introduce a distance limit denoted by l_i which is the maximum distance the customer is willing to make to reach the pick up station, because when transporting passengers, reducing user inconvenience must be balanced against minimizing operating costs.

The algorithm will then introduce m the number of pick up stations defined $m \leqslant n$, $M = \{1, ..., m\}$ is a THERE IS SOMETHING WRONG HERE set of pick up stations, (k, j) is a couple of a pick up station M_k and a drop-off station D_j, this couple will be represented by a vertex $v_i \in V$ to each vertex associated the pick up time at the station. Let R_k the pick up time from the station and R_j the drop off **predefined**, $R_k + t_{ij} \leqslant R_j$.

This model should also serve as a normal shared mobility service, unlike services provided by Mobility on Demand services, the requests are not served as soon as possible. However, the customer is only picked up when to ensure his arrival to destination, if we have a request P_i it should happen before the pick should have place M_k, which leads us to introduce the time variant, since there are a lot of times involved we will introduce a multidimensional set $T = \{x\}_{x \in \{P,M,D\}} \{1, ..., y\}_{y \in \{n,m,s\}}$, with this logical development we can express the following inequalities:

$$
\begin{aligned}
& T_{x \in P, y \in [1,n]} + W < T_{x \in M, y \in [1,m]} + C < T_{x \in D, y \in [1,s]}, \\
& W \in [0, Time_{l_i}], \\
& C > 0
\end{aligned}
\tag{1}
$$

In equation 1, W is a variable that represents the time for the client to leave his actual location and reach the pickup station, W can be equal to zero if the pick up station is right where the customer is located, it can be $W : W = maximum(l_{i_1}, ..., l_{i_n})$ where n here is the number of the people that will be picked up from the pickup station. C is a contingency variable that takes into consideration many factors:

Pick up duration that is proportional to the number of clients being picked up at the station

Transfer time which is the time from the drop-off station until reaching the destination,

This problem can be represented using a three index formulation. The three index variable x^b_{kj} is a binary variable that is equal to 1 only if the couple (i, j) is going to be served by vehicle k.

$$
\begin{array}{lll}
\text{Minimize} & \sum_{b \in B} \sum_{k \in V} \sum_{j \in V} x^b_{kj} & \\
\text{subject to} & \sum_{b \in B} \sum_{j \in V} x^b_{kj} & (k = 1, ..., m) \\
\text{add rest} & \text{of constraints here} &
\end{array}
$$

7.2.1 Algorithm

As already mentioned, the problem complexity imposes the use of some heuristic procedure. The adopted approach is structured into two stages, the Pre-Processing Phase and the pickup virtual station phase.

Different solution approaches have been proposed for the DARP and its variants. Some solution approaches can apply to more than one problem type. For example, heuristics or metaheuristics can be applied to solve both static-deterministic DARPs and dynamic-deterministic DARPs

Algorithm 0: How to write algorithms

```
Result: Write here the result
initialization;
while While condition do
    instructions;
    if condition then
        instructions1;
        instructions2;
    else
        instructions3;
    end
end
```

7.2.2 The matching problem

As in Stiglic et al. [2015], we create a node for each driver i 2 D and each rider j 2 R and an edge connecting node i and j if there is a feasible match between driver i and rider j. We also introduce nodes that represent pairs of riders (j;k), where j;k 2 R and j 6= k. We add an edge connecting node i and (j;k) if there is a feasible match between driver i and rider pair (j;k). Each edge e has two weights: number of riders in the match, ne, and the additional driving distance for drivers, de (note that this value may be negative in park-and-ride matches because the driver uses public transit to reach his destination from the park-and-ride station). Note that a transfer match between a driver and a rider (or a driver and a pair of riders) may not be unique, because there may exist a number of feasible transfer matches involving different stations and different departures. Similarly, a park-and-ride match between a driver and a rider (or a driver and a pair of riders) may not be unique. We only consider the match with the lowest driving distance for that combination of the driver and rider(s). Let E represent the set of all edges in the bipartite graph and let the binary decision variable xe for edge e 2 E indicate whether the edge is in an optimal matching (xe = 1) or not (xe = 0). Furthermore, let Ei and Ej represent the set of edges in E associated with driver i and rider j, respectively. Then, our ride-share matching problem with the objective of maximizing the number of matched riders can be formulated as the following integer program:

The question here, why are we doing all this? reason #1 is because people had shown the incapacity to manage their time correctly, this is due to the fact that we're unaware of the all the fluctuations happening that might be a changing factor in our trip time, if we want to make sure we don't miss our train we always put a contingency additional time that will allow us to reach before the time limit within a safety margin, this safety margin differs from one person to another, some people exaggerate and arrive too early, some people get lucky and arrive on time, other people fail to make it in time. The system will help the three types. reason #2 is because if we optimize this we might prove that we don't need all these shared mobility services, shared mobility research in big cities [show references here] such as Berlin and New York showed us that we don't need all these taxis circulating around, numbers showed we need [insert number here] less taxis in New York and [insert number here] in Berlin. Planning these first and last mile commutes for the customers will help them gain time and save money.

Explain how will they gain time:

Explain how will they save money:

Better planning comes with better data, the idea is to have the most amount of input to the problem the earliest possible, in order to be able to better allocate clients to drivers and better choose the pick up stations, the will affect globally the operation cost ... the cost saved will reflect in the total ride cost, which will be a great incentive for the customers to book their rides earlier. ELABORATE & EXPAND

7.3 Problem Visualisation

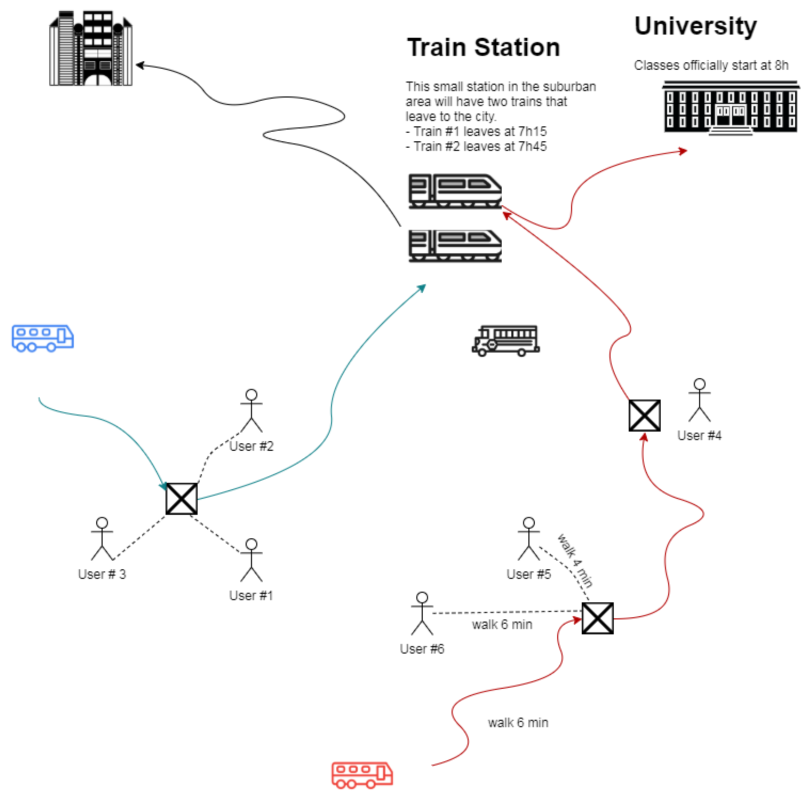


Figure 2: A small description of the optimization problem

In Figure 2 a visual representation of the problem is displayed. In this small example we have a fleet of three vehicles $\{blue, red, black\}$, a total of 6 *users* and two possible drop-off destinations $\{TrainStation, University\}$ the capacity of the vehicles are unlimited so the best scenario is to pick up all 6 clients with one vehicle. This setting represents a basic dial-a-ride problem in the morning in a small suburban city, Users $\{1, 2, 3\}$ work in the city and they start work at $8:00am$ so they all need to catch $train\#1$ that leaves the station at $7:15am$, they all live nearby so the blue vehicle will pick them up from one pick up station that is within walking distance between the three of them. Users $\{5, 6\}$ go to the university that is not very far from where they live so the vehicle can drop them off right at the destination, classes start at $8:00am$ so the red vehicle will pick them up from another pick up station that is within walking distance between the two of them, another user $\{4\}$ requests a ride to go to the train station, $train\#2$ leaves at $7:45am$, the red vehicle can pick user $\#4$ on the way to the university a drop him off before that $train\#2$ leaves the station, for user #4 if there are many possibilities to pick him up we choose the one that will affect the least the initial planned trip, we can measure this disturbance with a distance deviation or additional ride time added to the trip.

Of course with this small example the solution can be done on paper, but let's imagine the same situation with 50 bookings and a fleet of 8 vehicles it then becomes a quite challenging task, this type of ride is called many-to-one which describes the rides from many pickup locations to one final destination. However, in this problem there's a chance we have more than one drop off station as in the case of the red vehicle.

7.4 Next Steps

The first step in the problem definition statement is to be able to present the work in a mathematical formulation, the LP model and Algorithm in 7.2 are a preliminary representation of the work

CPLEX will be used to find a solution for a basic problem formulation with 1 vehicle, 3 customers and one arrival station.

8 Conclusion

We often forget that the most valuable asset for humans is time...

write what you conclude from the readings

What I noticed a month into readings is that is is very easy to get lost into the articles, you can start searching for a specific topic but 30 minutes into the search you find yourself on

References

[1] H. Becker, F. Ciari, and K. W. Axhausen, "Comparing car-sharing schemes in switzerland: User groups and usage patterns," *Transportation Research Part A: Policy and Practice*, vol. 97, pp. 17 – 29, 2017.

[2] *ILE-DE-FRANCE - UNE ÉTUDE DÉMONTRE L'AGGRAVATION DES EMBOUTEILLAGES*, 2018. Available at `https://www.cnews.fr/france/2018-05-13/ile-de-france-une-etude-demontre-laggravation-des-embouteillages-781509`.

[3] *Can Shared Rides Reduce Traffic Congestion*, 2019. Available at `https://www.forbes.com/sites/forbestechcouncil/2019/07/11/can-shared-rides-reduce-traffic-congestion/#e4b2ad56f146`.

[4] M. Stiglic, N. Agatz, M. Savelsbergh, and M. Gradisar, "Enhancing urban mobility: Integrating ride-sharing and public transit," *Computers Operations Research*, vol. 90, pp. 12 – 21, 2018.

[5] J. Alonso-Mora, S. Samaranayake, A. Wallar, E. Frazzoli, and D. Rus, "On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment," *Proceedings of the National Academy of Sciences*, vol. 114, no. 3, pp. 462–467, 2017.

[6] S. Consult, *Empty Seats, Full Streets*, 2018. Available at `http://schallerconsult.com/rideservices/emptyseats.htm`.

[7] S. Consult, *The New Automobility: Lyft, Uber and the Future of American Cities*, 2018. Available at `http://www.schallerconsult.com/rideservices/automobility.pdf`.

[8] *Minimum Fleet :: MIT Senseable City Lab*, 2018. Available at `http://senseable.mit.edu/MinimumFleet/` Senseable City Lab `https://www.nature.com/articles/s41586-018-0095-1#citeas`.

[9] S. C. Ho, W. Szeto, Y.-H. Kuo, J. M. Leung, M. Petering, and T. W. Tou, "A survey of dial-a-ride problems: Literature review and recent developments," *Transportation Research Part B: Methodological*, vol. 111, pp. 395 – 421, 2018.

[10] S. Fahnenschreiber, F. Gündling, M. H. Keyhani, and M. Schnee, "A multimodal routing approach combining dynamic ride-sharing and public transport," *Transportation Research Procedia*, vol. 13, pp. 176 – 183, 2016. Towards future innovative transport: visions, trends and methods 43rd European Transport Conference Selected Proceedings.

[11] H. Bast, D. Delling, A. Goldberg, M. Müller-Hannemann, T. Pajor, P. Sanders, D. Wagner, and R. F. Werneck, "Route planning in transportation networks," *Lecture Notes in Computer Science*, p. 19–80, 2016.

[12] A. Mourad, J. Puchinger, and C. Chu, "A survey of models and algorithms for optimizing shared mobility - see page 16 for a summary of ride sharing systems articles and their charcteristics," *Transportation Research Part B: Methodological*, vol. 123, pp. 323 – 346, 2019.

[13] F. ANTONIALLI and D. ATTIAS, "Social and economic impacts of Autonomous Shuttles for Collective Transport: an in- depth benchmark study," in *Paper Development Workshop – RBGN*, (Madrid, Spain), May 2019.

[14] R. Vosooghi, J. Puchinger, M. Jankovic, and A. Vouillon, "Shared autonomous vehicle simulation and service design," *Transportation Research Part C: Emerging Technologies*, vol. 107, pp. 15 – 33, 2019.

[15] R. Vosooghi, J. Kamel, J. Puchinger, V. Leblond, and M. Jankovic, "Robo-Taxi Service Fleet Sizing: Assessing the Impact of User Trust and Willingness to Use," in *98th Annual Meeting of the Transportation Research Board*, (Washington, D.C., United States), Jan. 2019.

[16] *Gilbert Laporte Google Scholar Profile*, 2020. Available at https://scholar.google.ca/citations?user=o4nOKvgAAAAJ.

[17] *Shaping the future of mobility: making vision a reality*, 2018. Available at https://ec.europa.eu/transport/sites/transport/files/mobility-package-factsheet-overall.pdf.

[18] U. Ritzinger, J. Puchinger, and R. F. Hartl, "A survey on dynamic and stochastic vehicle routing problems," *International Journal of Production Research*, vol. 54, no. 1, pp. 215–231, 2016.

[19] J.-F. Cordeau, "A branch-and-cut algorithm for the dial-a-ride problem," *Operations Research*, vol. 54, no. 3, pp. 573–586, 2006.

[20] D. Bertsimas, P. Jaillet, and S. Martin, "Online vehicle routing: The edge of optimization in large-scale applications," *Operations Research*, vol. 67, no. 1, pp. 143–162, 2019.

[21] J.-F. Cordeau and G. Laporte, "The dial-a-ride problem (darp): Models and algorithms," *Annals OR*, vol. 153, pp. 29–46, 06 2007.

[22] L. Häme, "An adaptive insertion algorithm for the single-vehicle dial-a-ride problem with narrow time windows," *European Journal of Operational Research*, vol. 209, no. 1, pp. 11 – 22, 2011.

[23] T. Garaix, C. Artigues, D. Feillet, and D. Josselin, "Optimization of occupancy rate in dial-a-ride problems via linear fractional column generation," *Computers Operations Research*, vol. 38, no. 10, pp. 1435 – 1442, 2011.

[24] T. R. Board, *Ridesharing as a Complement to Transit.* Washington, DC: The National Academies Press, 2012.

[25] H. Huang, D. Bucher, J. Kissling, R. Weibel, and M. Raubal, "Multimodal route planning with public transport and carpooling," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, pp. 3513–3525, Sep. 2019.

[26] M. Salazar, F. Rossi, M. Schiffer, C. Onder, and M. Pavone, "On the interaction between autonomous mobility-on-demand and public transportation systems," *ITSC2019*, 04 2018.

[27] *Ayman MAHMOUD personal bibliography*, 2020. Available at https://drive.google.com/drive/folders/1BefD6ZgD7GBdEpLz1IXsWSz-Fq8DgVpD.