

METHODOLOGY TO OPTIMIZE RESOURCE REQUIREMENTS OF A DEMAND RESPONSIVE TRANSPORT SYSTEM FOR PERSONS WITH DISABILITIES: A CASE STUDY OF FLANDERS

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ABSTRACT

Demand responsive transport (DRT) services are frequently offered in the context of door-to-door transportation of elderly and persons with disabilities. The present study describes an optimization methodology to analyze the minimal resource requirements of a DRT system in terms of vehicles and drivers required and total distance traveled, by means of a vehicle routing plan, taking into account heterogeneous users (persons with different severity and type of disabilities), heterogeneous vehicles (regular and wheelchair adapted vehicles) and multiple geographically distributed depots (locations where vehicles are stored). The implementation of a geographically covered DRT system for the transportation of persons with disabilities in Flanders in the prediction years 2015, 2020 and 2030, was applied. A microscopic simulation of the demand of persons with disabilities for transportation, spatial and temporal effects taken into account, was applied over the whole service area, in order to obtain a detailed overview of all transportation requests that need to be processed by each individual service provider. Specific travel data of persons with disabilities (with specific disability-related attributes) were collected by means of a survey that was distributed among 344 persons with disabilities. Next, a separate vehicle routing plan was created for each service provider for both a weekday and weekend day, resulting in the required number of vehicles and vehicle kilometers. The results of the Flemish application show that the new DRT system seems unaffordable for the society, despite the applied optimization methodology.

1 INTRODUCTION

Demand responsive transport (DRT) services may be considered as transport on demand from passengers, using fleets of vehicles scheduled to pick up and drop off people in accordance with their needs (1). In order to reduce operating costs, passengers may be grouped together in a vehicle (2). Hence, DRT is an intermediate form of transport, between fixed-route fixed-schedule public transportation and personal taxi services. Several variants of DRT exist, both in literature and practice. The concept is also denominated as demand responsive transit, dial-a-ride services, or paratransit, among others.

Two main types of applications of DRT may be distinguished. On the one hand, these kinds of services are offered in rural areas with low demand for public transport. Offering traditional fixed-route fixed-schedule services in these areas would be too costly, while flexible on-demand transport systems provide a more cost-efficient alternative. On the other hand, DRT services are frequently offered in the context of door-to-door transportation of elderly and persons with disabilities (PWD). This paper focuses on the second application. PWD often cannot make use of general public transportation services because these are not adapted to their needs. Age, walking difficulties and employment status are considered as important factors in the decision to make trips with DRT (3). Besides lower employment levels and associating lower income levels, disabled persons are less likely to live in areas with easy access to social services (4) and might have an increased level of car dependence (5). As an alternative to costly taxi services, authorities might introduce (subsidized) on-demand transportation systems to provide PWD with an affordable means of transportation. This should allow PWD to participate in social life, as individuals have a personal need to perform activities, requiring travelling to the destinations of these specific activities. Such DRT projects, offering transport for PWD, have been reported in many large cities around the world already. These type of services are expected to become even more widely spread in the future due to the ageing population in many western countries (6-7), with associated potential to develop physical limitations in large numbers.

Given its increasing importance for mobility impaired people, DRT has received more research attention as well (8). Stated preference studies revealed that DRT would be considered as the most preferred travel mode above all by seniors with physical limitations. As PWD most likely have very few transport alternatives, DRT is extremely price-inelastic with a strong willingness to pay of its users. However, DRT services for PWD are expensive to provide, which makes it imperative to maximize its efficiency (9). Although a substantial proportion of the costs of DRT might be paid by society rather than by the individual consumer in some regions, this does not reduce the costs, but merely shifts the incidence of payment (10).

The present study describes an optimization methodology to analyze the minimal resource requirements of a DRT system in terms of vehicles and drivers required and total distance traveled, by means of a vehicle routing plan, taking into account heterogeneous users (persons with different severity and type of disabilities), heterogeneous vehicles (regular and wheelchair adapted vehicles) and multiple geographically distributed depots. An application in the region of Flanders is presented. A microscopic simulation of the demand of PWD for transportation is applied over the whole service area of Flanders, in order to obtain a detailed overview of all transportation requests that need to be performed by each specific service provider.

This paper is structured as follows: in the Problem statement, the context of the problem and the Flemish case study are discussed. Next, the creation of all transportation requests of PWD, and the methodology to calculate the associating resource requirements of the different types of service providers, are described. The following section describes the results of the study, while the paper concludes with discussing future research opportunities and major conclusions.

2 PROBLEM STATEMENT

Given the increasing importance of DRT, with social participation enhancement of PWD as ultimate goal, some governments have committed to a more coherent approach regarding the organization of DRT services, in order to offer affordable adapted transport. Since DRT are expensive to provide, there is a need to organize them in a cost effective way in order to be able to meet this commitment. The present study describes a methodology to optimize the resource requirements to offer round the clock DRT services in a region, using a large number of individual service providers.

Previous studies on calculating the resource requirements of DRT systems have mainly focused on the required fleet size (number of vehicles) (7, 11-13). For an overview of literature on this topic, the reader is referred to (7) and (12). The majority of research has focused on estimating resource requirements based on a limited set of parameters which are assumed to be constant and applicable to all users (service area size, demand density, time window length, maximum ride time, average ride length, and others). Hence, spatial and temporal dependencies between user requests are mostly not taken into account, i.e. requests are distributed uniformly over space and time. Recently, Markovic et al. have proposed a model which takes into account peak and non-peak demand periods (7). Their results demonstrate the need to model DRT operations of an entire day instead of only during a peak period, due to the existence of route duration limits in practice. To the best of our knowledge, only Deflorio (14) and Kuo et al. (15) consider both spatial and temporal effects of demand for DRT services. Finally, Luo et al. (13) indicate that existing models often suffer from the limitation of using manual or very simple vehicle routing algorithms (e.g. insertion algorithms) and neglecting user time constraints.

In this paper, resource requirements are measured in terms of vehicles and drivers required and total distance traveled. Distance traveled is taken into account since it has a large impact on the operating costs of the service providers. Estimation of minimal requirements is based on a model which optimizes the transportation planning of each individual service provider. In contrast to other papers, this vehicle routing and scheduling step for each service provider is optimized using a state-of-the-art meta-heuristic algorithm instead of using a simple insertion algorithm. This way, better solutions are obtained. In order to solve the vehicle routing problem, detailed data about the demand and supply of DRT services are necessary. Spatial and temporal effects of demand are of importance, as these effects greatly influence the ability to combine requests of several users into a single route, which clearly has a large impact on the required resources and the service cost-efficiency (14-15). As well, specific personal disability-related data (e.g. type and severity of disability of each PWD, probability of making trips) need to be taken into account, as the activity system and the weekly rhythms of PWD are different from those of the general population (16), and the disability-related characteristics can influence the mode choice of each individual trip. Therefore, a microscopic simulation of the demand of PWD for transportation is applied. The input of this vehicle routing problem is a detailed list of all transportation requests that need to be performed by each specific service provider, containing for each request the specific pick-up and drop off location, desired timing, capacity requirements (wheelchair, accompanying person), and others. Using aggregated data would not reveal such detailed data, causing that the spatial, temporal and disability-related effects would not be taken into account.

This paper describes the application of the optimization methodology to analyze the minimal resource requirements of a new DRT system for PWD in the region of Flanders (the northern, Dutch speaking part of Belgium). Flanders is characterized by an area of 13.521 km², a population of six million inhabitants and a population density of 470 inhabitants per km². The need for a more coherent approach was recognized by the Flemish government, and a new Decree about DRT services was issued: the 'Decree to compensate the public service obligation of the transport of persons with a disability or seriously limited mobility' (17), approved in December 2012. The idea behind this Decree is that a mobility system will be developed by which subsidized adapted transport will be offered, geographically covering the whole of Flanders. Hereby, on the one hand, PWD can make use of voluntary organizations, denoted as 'Less Mobile Services' (LMS), relying on volunteers who use their own passenger car to offer transportation services in their neighborhood. This type of service is only available for persons in low income classes (income constraint of 2x the current living wage), and persons in a wheelchair cannot be accommodated. On the other hand, if PWD do not meet these conditions, they can rely on a limited set of geographically dispersed 'Adapted Transport Services' (ATS) that are compensated by the Flemish government. These ATS services generally use a heterogeneous fleet of vehicles with at least one adapted vehicle, and are suitable for persons in a wheelchair. The (predetermined selection of) 'compensated' service providers may apply for a compensation of the government for their driven kilometers with a wheelchair user or person with seriously limited mobility, and therefore they can offer payable adapted transport to PWD.

Disaggregated data are used to simulate the transportation requests of PWD in Flanders. Disability-related data (e.g. type and severity of disability of each PWD) and travel behaviour data of

PWD (e.g. probability of using adapted transport) are collected, as these characteristics influence the use of a specific transportation service. Figure 1 shows the specific conditions of both types of transportation services (LMS and ATS), and their relation to the disability-related characteristics of PWD. The objective of this study is to determine the minimal resource requirements to offer round the clock on-demand transportation services in the whole region, using a large number of individual, local, voluntary service providers as well as selected compensated service providers of this Decree. These resource requirements are calculated for the start-up year 2015, as well as for the medium term (2020) and for the long term (2030).

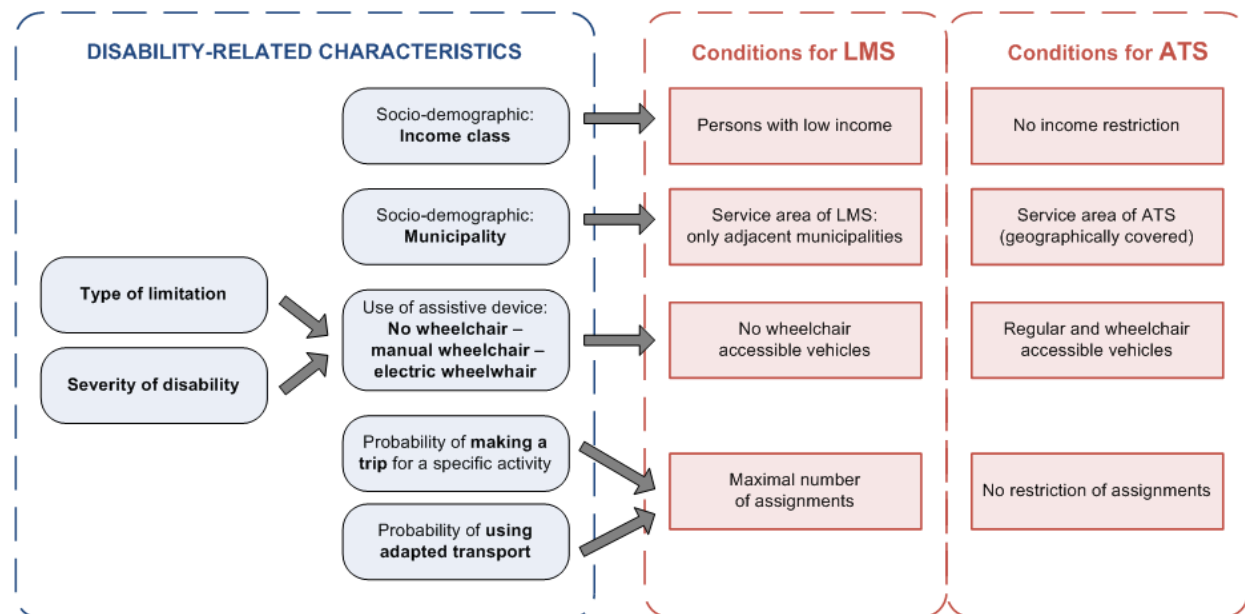


FIGURE 1 Conditions of using LMS and ATS services, and their relation to disability-related characteristics of PWD.

3 METHODOLOGY

3.1 Overview of procedure

To determine the minimal resource requirements of this geographically covered DRT system, a detailed overview of all transportation requests that need to be performed by each specific service provider, is necessary. Figure 2 shows the procedure to determine the minimal resource requirements. The first step consists of creating a synthetic population of all PWD in Flanders (3.2), representing individual actors (so-called ‘agents’) which are statistically equivalent to the real population of PWD in Flanders. Next, the transportation requests of these PWD are generated with specific travel-related characteristics (3.3). Each simulated transportation request is first assigned to a specific service provider (3.4), after which a separate vehicle routing plan is created for each provider (3.5) for both a weekday and weekend day. This plan results in the minimal required number of vehicles and vehicle kilometers in order to perform all transportation requests assigned to this specific provider.

3.2 Building a synthetic population of PWD in Flanders

Aggregate data at population level in Flanders are available by means of the ‘General socio-economic survey 2001’, where the full Flemish population (about 6 million) was obligatory surveyed on several socio-demographic variables (age, gender, etc.) (18). Official sources about disability are consulted, such as the Flemish Agency for Disabled Persons and the Federal Public Service of Social Security. As well, a survey is distributed among PWD in Flanders between June and July 2012. A total of 344 internet-based questionnaires are completely filled out by persons with various types and severity of disability, e.g. persons with physical limitations, intellectual limitations, visual limitations, and others.

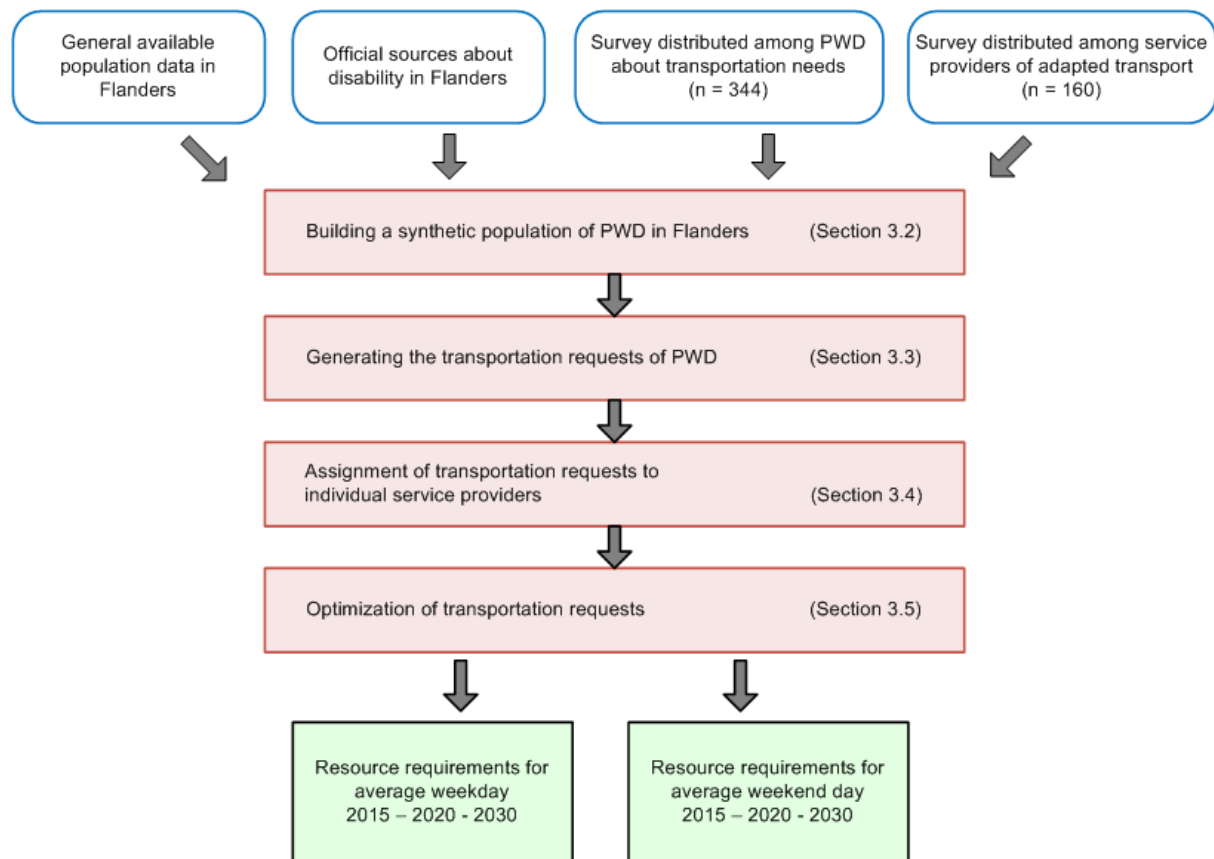


FIGURE 2 Flowchart of the procedure to determine the minimal resource requirements of the DRT system.

The distribution of allowances of PWD in Flanders offers detailed information about the number of PWD in each municipality, by age group and gender. Information about the *type of limitation* (or combination of types) is needed as this influences the assignment to a specific service provider (and associating fleet of vehicles). For example, persons with severe motor impairments likely need a wheelchair accessible vehicle, while the vehicle type to transport individuals with an intellectual impairment is less relevant. The *severity of the disability* is based on information about the level of independence of PWD in Flanders, which is generally determined by a medical assessment in order to calculate the amount of allowance the disabled person may claim. Based on the previous variables, the *probability of using an assistive (ambulatory) device* is determined, influencing the decision whether not wheelchair accessible vehicles could be used or not. Persons with a high level of independence are less likely to use a manual or electric wheelchair, while this probability increases in persons with a lower level of independence. For an overview of the influencing factors of the assignment to a specific service provider, the reader is referred to Figure1.

Based on this information, the synthetic population of all PWD in Flanders is created, which aims at reproducing the human behaviour of PWD at the individual level (e.g. *how many activities and trips are made by PWD or which transport mode do they use?*). The population is created by means of the Iterative Proportional Fitting (IPF) technique (19). Population projections from the Federal Planning Bureau (20) are used as marginals to generate the population data for the prediction years 2015, 2020 and 2030 respectively. As a result, each person of the synthetic population is simulated on a microscopic scale, with specific socio-demographic and disability-related characteristics: municipality, gender, age, income class, type of limitation, severity of disability, and use of an assistive device (e.g. walking cane, manual or electric wheelchair, electric scooter). For the future prediction years (2020 and 2030), the percentage of persons with disabilities in each age category, the severity of disability and all other socio-demographic and disability-related characteristics are supposed to be constant. As well, the activity and travel patterns are assumed unaltered.

3.3 Generating the transportation requests of PWD

All individuals of the synthetic population are also simulated with a number of travel-related characteristics, using probability distributions of the characteristics based on the results of the survey that was distributed among PWD. The conditional *probability of making a (specific) activity-related trip* is based on the queried number of performed trips (for each type of activity). Based on the frequency of the use of different transport modes, the conditional *probability of using adapted transport* for a specific type of activity is estimated for each individual. As well, the acceptable maximum user ride time of trips with adapted transport (i.e. the maximum time a person would accept to spend in the vehicle) is obtained by means of this survey. The study area is divided in 2386 transportation analysis zones (TAZ), of which attractiveness measures are available via the General socio-economic survey 2001 (3.2), resulting in the conditional *probability of going to a specific TAZ* while making a trip with adapted transport.

All individuals' personal and travel-related attributes are used as inputs to generate the list of transportation requests (i.e. the demand of transport) of PWD in Flanders, for an average weekday and weekend day. Table 1 shows the (generated) number of PWD in the synthetic population and their trips made by DRT.

TABLE 1 Number of PWD, and Trips by DRT by PWD in Flanders of 1 Weekday, by Assistive Device

	No wheelchair	Manual wheelchair	Electric wheelchair	Total
Number of PWD in Flanders				
2015	154,094	23,032	7,792	184,918
2020	164,320	24,398	8,159	196,877
2030	185,589	27,644	9,122	222,355
Number of trips by DRT by PWD in Flanders				
2015	27,718	4,044	1,376	33,138
2020	29,628	4,274	1,396	35,298
2030	33,126	5,038	1,670	39,834

3.4 Assignment of transportation requests to service providers

The objective of the Decree about DRT services, which was recently issued by the Flemish government, is to provide affordable adapted transport in the whole of Flanders. On the one hand, services will be provided by LMS (voluntary organizations) for those who are eligible, and on the other hand by a selected set of compensated ATS service providers. However, the practical implementation process of the Decree, and the actual selection of compensated service providers, is still being evaluated at the moment.

A (second) survey was distributed among current individual service providers of adapted transport in Flanders, which provided information about the demand (e.g. timing of the trips, travel times) and supply of transport (e.g. service area, capacity and number of vehicles) in their specific organization. Since the average radius of the service area of an individual service provider in Flanders currently is 20-25 kilometers, we assume service areas of similar size in this paper for the compensated service providers. This approach leads to 26 compensated ATS service providers in Flanders. Another assumption is that the amount of volunteers, offering inexpensive transport by LMS, will increase in the future, as the proportion of young retirees will increase the coming years (due to the ageing population). Since these people are still (physically) active, no longer work and as a consequence have more time available, it may be expected that a portion of them is willing to sign up as a volunteer for these services. Therefore, we assess that a doubling of the current number of volunteers is realistic, and consequently a doubling of the current supply of transport by LMS will occur.

To estimate the minimal resource requirements for this system of DRT services, a vehicle routing problem is solved for each of the service providers individually (3.5). To do so, each

transportation request as simulated in 3.3 should first be assigned to a specific service provider. Therefore, for each service provider the following attributes are estimated based on the survey that was distributed among the individual service providers of adapted transport in Flanders:

- Average number of seats in regular vehicles;
- Average number of seats in adapted vehicles (if there are any);
- Average number of wheelchair places in adapted vehicles (if there are any);
- Number and locations of vehicle depots;
- Service area.

Each transportation request is assigned to a specific service provider as follows. It is analyzed whether the user that initiated the transportation request is allowed to make use of a LMS service. This is the case when the user is not in a wheelchair, his income is below a certain threshold, the transportation request takes place within the service area of a LMS service provider and the maximum number of assignments to LMS's is not reached (Figure 1). The maximum number of assignments is imposed because the number of volunteers is limited to twice the current level. When one of the conditions is not met, the request is assigned to the closest of the 26 compensated ATS service providers. The distribution of trips during the day is derived from the survey among the service providers. Both types of service providers are providing shared-ride trips, and are therefore different from commercial taxi services.

3.5 Optimization of transportation requests

For each service provider, a separate vehicle routing plan is created, both for a weekday and for a weekend day. A vehicle routing plan is a schedule that determines which transportation requests are performed by which vehicle and, for each vehicle, the respective order in which the requests are performed. This plan gives an indication on how many vehicles and vehicle kilometers are required on an average weekday or weekend day in order to perform all transportation requests assigned to this specific provider. The detailed input list of transportation requests is derived from the microscopic simulated synthetic population, with associated travel characteristics, taking into account the spatial and temporal effects of demand. In order to take into account the variability of travel times during a day, each weekday is divided into five time intervals: morning peak (6-9am), day (9am-4pm), afternoon peak (4-7pm), evening (7-22pm) and night (10pm-6am). Transportation requests are assigned to the appropriate interval, based on the desired timing. A separate planning is made for each interval, using appropriate travel times. A similar approach is used for weekend days, but only a day (6am-22pm) and a night period (22pm-6am) are assumed.

To obtain an efficient vehicle routing plan for a given service provider and time interval, a dial-a-ride problem (DARP) is solved. Dial-a-ride problems are a generalization of the classical capacitated vehicle routing problem (VRP). They are closely related to the Vehicle Routing Problem with Pickup and Delivery (VRPPD), in which goods have to be transported from a specific pick-up to a specific delivery location (21). A major distinction is the fact that dial-a-ride problems deal with transporting people rather than goods. Hence, user inconvenience should be accounted for. This is generally done by imposing additional constraints to restrict user inconvenience or by introducing some quality of service aspects in the objective function of the problem. In this paper, the first approach is followed.

Most research on DARP considers a homogeneous set of users and a homogeneous fleet of vehicles located at a single depot (22-23). However, in the application described in this paper, two types of users are considered (non-wheelchair and wheelchair). Besides, service providers may operate both regular and adapted vehicles, located at several depots in the service area. For an overview of research on DARP taking into account such heterogeneous aspects of users and vehicles, the reader is referred to (23) and (24). General overviews of literature on DARP are provided by Cordeau et al. (25-26), and Parragh et al. (27).

To the authors' knowledge, the Multi-Depot Heterogeneous Dial-A-Ride Problem (MD-H-DARP) introduced by Braekers et al. (22-23) is the only problem that simultaneously deals with heterogeneous users, heterogeneous vehicles and multiple depots. Hence, in this paper this problem definition is adopted. The MD-H-DARP is defined as follows. Users specify a set of transportation requests between specific pick-up and drop off locations. With each request a time window at the pick-up location (inbound requests) or at the drop off location (outbound requests) is associated (see

3.4). This time window indicates the time interval between which service (picking up or dropping off the user) should start. Furthermore, each request has a service time (time needed to pick-up/drop off the user) and a capacity requirement for regular vehicle seats and for wheelchair places. Finally, a maximum user ride time is defined, indicating the maximum time the user may spend in the vehicle. Transportation is performed by a set of vehicles with limited capacity for both vehicles seats and wheelchair places. Each vehicle is assigned to a depot where it should start and end its route. To take into account maximum shift durations of drivers, a maximum route duration is imposed. The objective is to minimize total distance traveled, while satisfying all transportation requests without violating time window, ride time and maximum route duration constraints.

A slight adaptation to this problem definition is made in this paper. The number of vehicles to be used is an objective rather than a constraint. Hence, an unlimited fleet of vehicles is assumed, together with a hierarchical objective function which first minimizes the number of vehicles used and second total distance traveled.

Braekers et al. (23) propose two algorithms to solve the MD-H-DARP: an exact branch-and-cut algorithm and a deterministic annealing meta-heuristic. The exact algorithm can only be used to solve relatively small problems in terms of number of transportation requests, while the meta-heuristic approach provides near-optimal solutions within a couple of minutes even for large problems (≥ 100 requests). Experimental results on several sets of benchmark instances have indicated that the meta-heuristic algorithm outperforms other state-of-the-art solutions methods on homogeneous and heterogeneous dial-a-ride problems. Therefore, in this paper the meta-heuristic approach is used to solve the routing problem of each service provider. The algorithm is implemented in C++.

4 RESULTS

The model described in Section 3 is applied for three prediction years (2015, 2020, 2030). Results for an average weekday and weekend day are reported in Table 2. Next to total results, results for both types of service providers (LMS and ATS) are shown separately. The number of vehicles required for a service provider is calculated by taking the maximum number of vehicles used over all time intervals of the day.

The results show that a large number of resources are required to offer DRT services, given the fact that e.g. a fleet of 3285 vehicles is needed to perform all transportation requests on an average weekday (Table 2). This resource requirement is expected to increase considerably in the coming years, as indicated by the results for 2020 and 2030. For all service providers together, the number of transportation requests is expected to increase by 20% from 2015 to 2030. This increase is solely an effect of the ageing population and the associated probability of developing physical limitations. As a result, minimal resource requirements in terms of vehicle and kilometers increase almost proportionally by respectively 19% and 20%.

Transportation requests and hence resource requirements are considerably higher during weekdays than during weekend days in our model. This can be explained by the fact that recurrent trips to the fitness, physiotherapist or rehabilitation center, trips for day care, or trips to the doctor or hospital, of which the frequencies are based on the self-collected data of PWD of the survey, are mostly performed on weekdays. This pattern is similar to persons without disabilities, as they also make significantly fewer trips on Sunday compared to weekdays (28), but the specific activity types of PWD in our model are different compared to persons without disabilities.

Finally, from Table 2 it is clear that for this case study, most transportation requests will be performed by the ATS service providers. Only about 11% of all requests are carried out by LMS service providers, due to their strict acceptance rules and limited number of volunteers.

More detailed information on the number of requests per service provider and on route characteristics for the year 2015 is shown in Table 3. While LMS operate on a local scale with few requests per day (given on average 16 requests per provider per day, Table 3), the 26 compensated ATS service providers operate on a larger area with a huge number of requests per day (1128 requests per provider). Furthermore, results indicate that average route length is considerably smaller for LMS. The reason is that the maximum route duration is generally much lower for these services (e.g. 4h instead of 8h) since they rely on volunteers which are often only available for a couple of hours per day. Average trip length is on average 17 kilometers (almost similar for LMS and ATS during weekdays), and on average about 1.2 passengers are present in a vehicle at a given time.

1 **TABLE 2 Results for an Average Weekday and Average Weekend day, by Type of Service providers**

		LMS Less Mobile Services		ATS Adapted Transport Services		Total	
			%		%		%
Results for an average weekday							
Total number of requests	2015	3,806	-	29,332		33,138	-
	2020	4,068	+ 6.9	31,230	+ 6.5	35,298	+ 6.5
	2030	4,572	+ 20.1	35,262	+ 20.2	39,834	+ 20.2
Total number of vehicles required	2015	690	-	2,595	-	3,285	-
	2020	722	+ 4.6	2,730	+ 5.2	3,452	+ 5.1
	2030	797	+ 15.5	3,114	+ 20.0	3,911	+ 19.1
Total number of kilometers traveled	2015	128,987	-	869,574	-	998,561	-
	2020	129,947	+ 0.7	928,086	+ 6.7	1,058,034	+ 6.0
	2030	155,281	+ 20.4	1,040,911	+ 19.7	1,196,192	+ 19.8
Results for an average weekend day							
Total number of requests	2015	2,206	-	18,118	-	20,324	-
	2020	2,512	+ 13.9	19,126	+ 5.6	21,638	+ 6.5
	2030	2,804	+ 27.1	21,584	+ 19.1	24,388	+ 20.0
Total number of vehicles required	2015	441	-	1,592	-	2,033	-
	2020	472	+ 7.0	1,742	+ 9.4	2,214	+ 8.9
	2030	556	+ 26.1	1,968	+ 23.6	2,524	+ 24.2
Total number of kilometers traveled	2015	68,789	-	525,014	-	593,803	-
	2020	86,189	+ 25.3	555,980	+ 5.9	642,169	+ 8.1
	2030	100,857	+ 46.6	630,391	+ 20.1	731,248	+ 23.2

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4**TABLE 3 Detailed Results for Prediction Year 2015**

	Weekday			Weekend day		
	LMS	ATS	Total	LMS	ATS	Total
Number of service providers	240	26	266	240	26	266
Average number of requests per provider per day	15.9	1128.2	124.6	9.2	696.9	76.4
Average number of kilometers per route	78.5	121.5	113.4	71.7	130.6	119.3
Average number of kilometers per request	17.0	17.4	17.3	14.6	16.9	16.6
Average number of requests per route	2.3	4.1	3.8	2.3	4.5	4.1
Average number of passengers in vehicle	1.2	1.2	1.2	1.2	1.2	1.2

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8**5 DISCUSSION**

From the results of the Flemish application, it is clear that an enormous amount of resources are required to implement a region-wide system of transportation services adapted to PWD in Flanders,

e.g. a necessary number of 3285 vehicles and a total of almost 1 million kilometers for an average weekday (Table 2). Solely relying on volunteers and a limited number of compensated ATS service providers seems not feasible. In the future, these requirements will even be much larger as the demand for adapted transport will increase because of the ageing population, making the proposed results completely unaffordable for the Flemish government, given that the necessary number of vehicles will even increase to 3911 in 2030. Furthermore, implementing such a system would exclude all current commercial service providers, as a geographically covered DRT system of compensated service providers is assumed. Clearly, this would be a sensitive policy measure.

To overcome these problems, the idea has emerged to only offer compensated DRT services for a realistic, limited number of transportation requests, based on e.g. the traveler's mobility restriction, the availability of accessible public transport, the type of activity, and the financial possibilities. All other requests could then be performed by commercial service providers in Flanders. Our model can easily be applied to calculate the effect of such a combined system on the minimal resource requirements. In the assignment step, only those transportation requests passing the objective selection criteria should be assigned to a specific compensated service provider. All other transportation requests may either be removed from the model, or may be used to model the service requirements of the commercial service providers.

In the present study, disaggregated data are used to simulate the transportation requests of PWD on a microscopic scale, taken into account spatial, temporal and disability-related characteristics of the transport demand. This is an important advantage compared to formerly used four step models, based on aggregate data and neglecting these detailed behavioral information. Additional improvements could be made by using activity-related travel diaries, instead of surveys about the frequencies of making trips for each activity type in this study, in order to gather exact information of the *individual activity patterns* of PWD.

Regarding the destination choice of the trips by adapted transport, our model is an improvement over similar models, as other models mostly assume a uniform distribution of origin and destination locations, instead of taking into account the availability and attractiveness of zones for specific activity types (13). In the present study the destination choice of the trips by adapted transport was determined by the attractiveness of the different TAZ for each activity type, based on the General socio-economic survey (3.2). Future research may take into account the attractiveness of specific care related facilities mostly used by PWD.

In this study, it was assumed that geographically covered transport in Flanders was provided by 26 individual ATS service providers (with an average service area of 20-25 km), and that the number of volunteers would double (with consequently a doubling of the current supply of transport by LMS). These assumptions are input parameters of the model, and can easily be modified to analyze the effects of changes of these parameters. For example, the model can also be calculated if assuming a smaller or larger service area and consequently a smaller or larger number of service providers; or if the number of volunteers would decrease. Modifying the size of the service areas could lead to additional optimization, as economies of scale (e.g. higher occupancy rates of the vehicles) influence the minimal resource requirements.

Future research may also focus on analyzing the effects of changing the service attributes of the vehicle route planning (e.g. longer maximum user ride times), causing that more passengers could be grouped together in a vehicle per route. Because of budget constraints, it is important to establish what service attributes would have the greatest impact for PWD as well as for the society as a whole, and what tradeoffs can be made among them (3). A social cost-benefit analysis could facilitate the weighing up of all social advantages and disadvantages of the various service attributes changes, not only in monetary terms (vehicles and drivers required, total compensated distance), but also in terms of participation enhancement, quality of life of PWD, and others. Our model can be applied to calculate the impact of changed service attributes.

6 CONCLUSION

- The present study shows that the proposed optimization methodology can easily be applied to determine the minimal resource requirements of a specific DRT system, while taking into account heterogeneous users, heterogeneous vehicles and multiple depots.

- The microscopic simulation of demand of PWD offers various advantages: a high spatial and temporal resolution of the transport demand (which allows to combine requests of several PWD into a single route), knowledge about specific disability-related characteristics (influencing the mode choice of individual trips), and knowledge about specific travel behaviour patterns of PWD.
- The results of the Flemish application show that the new Decree about DRT services, by which affordable adapted transport will be offered for PWD, geographically covering the whole of Flanders, seems unaffordable for the society as a whole, despite the applied optimization methodology.

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