POTENTIAL DEMAND AND PRELIMINARY DESIGN OF DOOR TO DOOR DIAL A RIDE SYSTEMS

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ABSTRACT. The paper aims to provide a framework for the preliminary design of dial a ride system. In this context we have carried out a stated preference survey to evaluate the potential demand of service, taking into account a sample of citizens with limited disability to move. Thus, we have submitted a questionnaire to users of some clinics of Palermo, considering in the choice competitive scenario the dial a ride system. Furthermore a multinomial logit model has been calibrated. Finally a preliminary design of service has been proposed.

INTRODUCTION

Historically, dial-a-ride services were large-scale systems designed in the seventies to serve the general population of large urban metropolitan areas. The original objective of dial-a-ride were to cater for widely dispersed trip-patterns and to provide a service in low density suburban areas for mainly non work journeys. Interested users would telephone in their requests some days before they intended to travel and the operator would plan the service the day before the trip. Dial-a-ride or demand responsive transport services are undertaken on a variety of modes, i.e. buses, coaches, taxis, adapted taxis and minibuses and can be supplied by a variety of service providers (including bus, taxi and private hire operators, community transport, local authority and ambulance vehicles and even car club members). Services can be free-standing or integrated between different modes, for example as feeder services for bus, tram and rail services. The development of communications and optimisation systems has enabled the evolution of new forms of flexible public transport services which can be placed at intermediate position between conventional fixed route bus and highly flexible private vehicle or taxi. The key characteristics that delineate service types are the route (by flexibility and density of linkages between origins and destinations), the schedule (fixed or flexible), the method of collecting passengers and quality factors. These systems, met with financial problems and were either dismissed or radically transformed. Recently, they are almost exclusively used in particular situations, for example for services in rural areas or for users with particular needs: disabled and older citizens. There are significant contributions in

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the literature on scheduling and routing dial-a-ride systems. In fact, the Dial-a-Ride Problem is similar to the Pickup and Delivery Problem with the added constraint of restricting the maximum passenger ride time (Savelsbergh and Sol 1995, Daganzo, 1978). Recent papers focus on the design of dial-a-ride services on a technologically advanced basis. Dial (1995) proposes the implementation of a decentralized control strategy for a fleet of vehicles. Diana et al., (2004) includes the heuristics to solve dial-a-ride problems on large scale and evaluates the reduction emissions of the service (Diana et al. 2007). Conversely there are few scientific papers on the potential demand estimation of the dial a ride service and the preliminary design. Daganzo (1984) presents a preliminary feasibility study of checkpoint dial-a-ride systems and compares its effectiveness with fixed route systems.
The main contribution of the paper is to provide a framework for the preliminary design of dial a ride system. We have carried out a stated preference survey to evaluate the potential demand of service, taking into account a sample of citizens with limited disability to move. Thus, we have submitted a questionnaire to users of some clinics of Palermo, considering in the choice competitive scenario the dial a ride system. Furthermore a multinomial logit model has been calibrated. Finally a preliminary design of service has been proposed. The paper is divided as follows: section 2 architecture and typologies of service, section 3 describes the survey and the questionnaire, section 4 reports the estimation of service demand by stated preference analysis, section 5 reports the preliminary design of service and, finally, section 6 discusses concluding and remarks.

ARCHITECTURE AND TYPOLOGIES OF SERVICE

The development of communications and optimisation systems has enabled the evolution of telematics-based systems. These are based on organisation by Travel Dispatch Centres using booking and reservation systems which have the capacity to dynamically assign passengers to vehicles and to optimise the routes. Automated vehicle location systems are used to provide real-time information on status and location of the fleet for route optimising software (Nelson et. al. 2003 and 2007). The main architectural components of dial-a-ride system can be identified as follows:

- the travel dispatch centre;
- devices for users to access the service;
- on board units;
- the communication network.

The booking process generally adopted is based on interested user calls by phone the travel dispatch centre pointing out the origin, the destination and the time of the trip. The task of travel dispatch centre is to assign the user to a vehicle of fleet and to define the route which vehicle has to run in order to satisfy the user require. Thus the user is informed by dispatch centre providing on the time window when he/she will be pick up by origin and brought to destination. Figure 1 shows the architecture of systems. Users of service can book their reservation by phone, multimedia kiosk, internet. In vehicle on board system allows the management of call service by:

- ticketing machines;
- in vehicle terminal;
- long range communication for voice and data;
- location devices e.g. GPS and odometer;
- short range communication devices (for communication inside the depot);
- external and internal passenger information display;
- video for security.

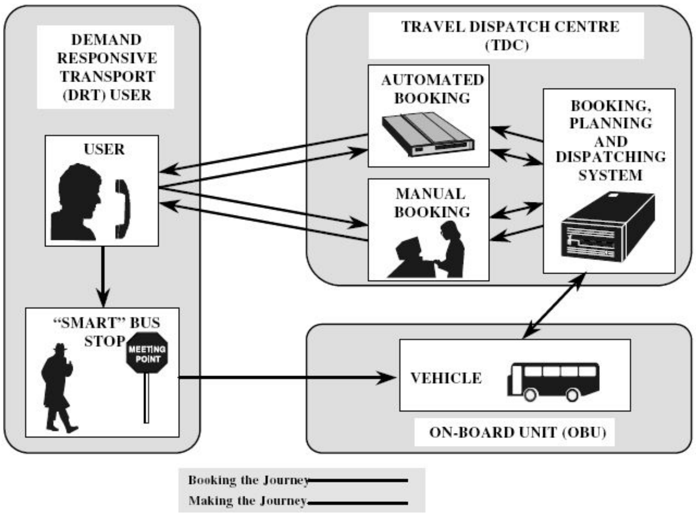


Figure 1. Representation of telematics based dial-a-ride service.

The macro functions of a public transport company can be divided in three main functional areas as follows:

- *management of requires*, the main task is to manage the collection and processing of trip bookings;
- *operations control*, checks and plans the transport operations (management of deviations from scheduled route) by communication system;
- *user information*, provides user information both for booking (pre trip information) and for trip (on trip information).

By these macro functions, the service management scheme is organized in four different steps (figure 2):

1. the user calls the dispatch centre for booking;
2. the generation and change of route;
3. the negotiation of service between the operator and user (confirmation/refusal of proposed service);
4. the update and broadcast of service to vehicle driver.

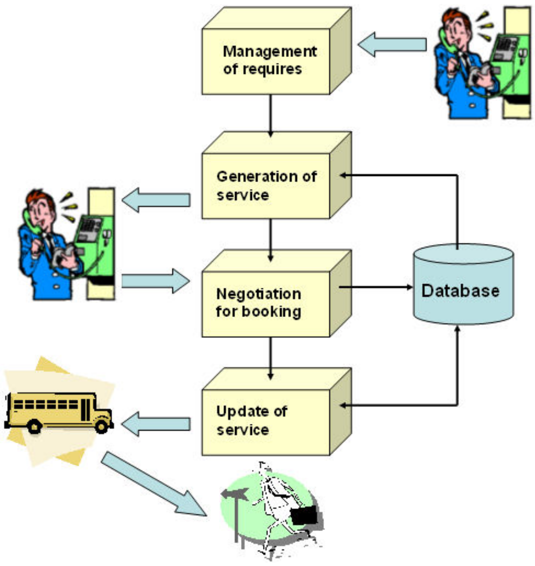


Figure 2. The service management scheme

The dial-a-ride service introduces a certain level of flexibility in comparison with traditional public transport. Typologies depend on some service concepts based around careful definition of stopping points and route flexibility, booking, intermodal integration and vehicle allocation. Stopping points may be end stop points (terminals), fixed intermediate stop points such as conventional bus stops, predefined stop points (recognised meeting places) and non-predefined stop points which are generally the doorstep of the user—the latter two requiring pre-booking. Route flexibility is characterised by either semi-fixed routes or flexible routes for which the service departs from an end stop point (possibly a terminal) at prescribed times; or virtual flexible routes with no fixed end or intermediate stop points and no fixed times (Westerlund et al., 2000). Some examples of dial-a-ride service route concepts are shown in Fig. 3.

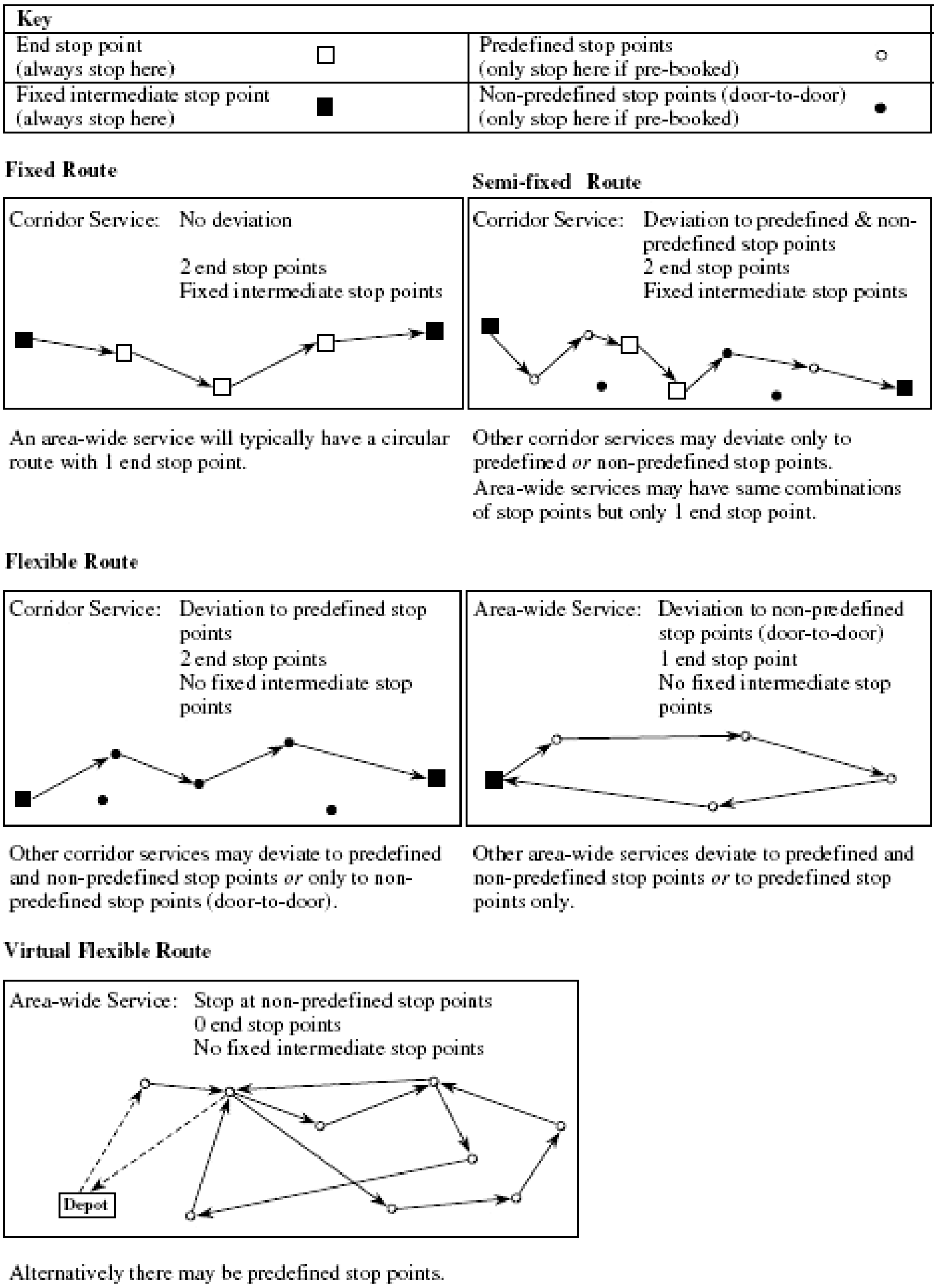


Figure 3. Dial-a-ride service route concepts (Mageean and Nelson, 2003)

A crucial element for dial-a-ride service is the booking of the trip request. Normally three phases can be identified:

1. a request to make a trip with a particular origin and destination (stop or address) and an arrival or departure time;
2. a proposal of a feasible service by the service operator;
3. a booking confirmation (or refusal of proposed service) by the user.

Nowadays enabling information technologies tools and systems (e.g. interactive voice response systems, internet and web service, GSM phones and SMS etc.) allow for a higher degree of automation of booking process.
Dial-a-ride services can have different roles in the general public transport supply. The feeder service avoids time-consuming deviations of the direct service that often connects two important centres in the region. The stand alone service is mainly employed in rural areas with low density of population.
The operator of the dial-a-ride service will ideally have a fleet of vehicles (with different types of vehicle for capacity, accessibility and special facilities) that can be used to realise the service. The user requests can be answered in the most efficient way using the most appropriate vehicle for each request, and the vehicles can be allocated for a service which fits best to the characteristics of the vehicle.

THE SURVEY

Palermo is the main Sicilian city, with an area of 158 squared km and a population of about 700.000 inhabitants, with a large historical centre (about 2,7 squared km) This area is the centre of the main directional and administrative functions of the island. The mobility system, inside the metropolitan area of Palermo, is characterized by a strong lack of railways transport systems, lack of an efficient public transport system, lack of suitable parking areas. The urban railway system operating in Palermo has been derived from the traditional railway infrastructures crossing the town. In particular, the railway system connects the Central railway station, the harbour inside the town and Trapani (a town far from Palermo about 100 km). The main bound of the actual urban railway system is the single track. This implies a maximum frequency at the stations equal to 2 trains per hour. Another bound is the decentralised position of the railway stations respect to the main activities in the city. These characteristics penalize the citizen in the railway mode choice. The public transport by bus covers almost all area of the city, but only few lines run reserved lane. Thus, its performances are influenced by congestion of private mobility causing inefficiency in the level of service (travel and waiting time and scheduling). Furthermore the city has few parking areas and has not parking area of interchange with other transport modes.
The main purpose of survey is to estimate the potential demand of dial-a-ride service in the urban area by stated preference analysis. The survey was carried out in Palermo in March/April 2007, considering in the choice competitive scenario the dial a ride system. We submitted the questionnaire to a sample of citizens with limited disability to move in some clinics of Palermo.
Main tasks of analysis are:

- to reduce congestion in the road network close to the clinic and thus to rationalise the stream of people to hospital services;
- to improve the accessibility to hospital services of citizens with limited disability to move.

In particular the survey was carried out in the Clinic “Palermo Centro” in G. Cusmano Street 10^{th} district. This Clinic is the most important diagnostic centre for Palermo, and has several

specialist branches (as such: cardiology, angiology, surgery, haematology, endocrinology, urology, oncology, neurology, etc.)
A questionnaire was constructed and submitted to the sample chosen of citizens. A part of the questionnaire was devoted to the decision maker's socio-economic and physic characteristics, useful for identifying him or her, like: sex, age, household income and type of disability to move. Moreover interviews aimed to identify the non occasional user of dial-a-ride service by the travel habits as frequency of medical visits, place of origin, used transport mode, parking place (whether the decision maker went by private transport). Citizens that living not too far from clinic and then could go by walk were excluded by interview since they were not potential users of dial-a-ride service. The second part of the questionnaire was aimed to identify the decision maker's preferences by the submission of transport scenarios taking into account in the context choice the dial a ride system. The modal choice alternatives were: private car, bus, metro/bus and dial-a-ride service (table 1). In order to maintain the scenario realistic, the quantitative attributes able to explain the choice demand model and their values were also identified by a pilot survey. These attributes were: the average running time for trip (RT), the average waiting time for parking/at bus stop (WT), the average cost for trip and parking (C) and the average distance from parking (D). The average time spent to travel by car for trip. In particular, the average running time from different origins to the Clinic was estimated elaborating a D.U.E. (Deterministic User Equilibrium) process of assignment of the private car O/D matrix (related to the rush hour and the average working day) to the urban network (Comune di Palermo, 2006). The values of the levels of the public transport travel time were individuated using a public transport network modelling by a hyperpath minimum algorithm. Established the number of the attributes (t = 4) and the number of levels of every attribute (n = 2), it was therefore possible to determine the complete factorial plan (composed by $n^t = 2^4 = 16$ scenarios). Thus, assuming the irrelevance of interactions between attributes we reduced, in according to the technique of Kocur *et al.* (1982), in 10 different scenarios (fractional factorial design) in order to avoid fatigue effect in respondents as the literature of sector suggests. Each decision-maker has reported on the questionnaire the choice between the competitive alternatives for each scenario. Among choice modalities (choice, ranking and rating) available to the designer of the experiment has been chosen the *choice* because it is simpler in the elaboration and also in the indication of the preference.

Table 1. Alternatives, attributes and levels of scenarios.

Alternatives/Attributes	Private car	Bus	Metro/bus	Dial-a-ride
The average running time for trip (RT)	15 min	20 min	15 min	20 min 30 min
The average waiting time for parking/at bus stop (WT)	15 min	15 min	20 min	5 min 10 min
The average cost for trip and parking (C)	5,5 €	2 €	2 €	3 € 4 €
The average distance from parking (D)	100 m	100 m	100 m	10 m 50 m

The Universe is composed by about 6,000 users per month of the Clinic. We assumed that for large population (infinite) the size of the sample can be estimated by *bernoulli* sample.
Let φ be the successful probability equal to 0.5; z the confidence degree at 95%; δ the range of the error equal to 0.1. The size of the sample is give as follows:

$$n \geq \frac{\varphi(1-\varphi)z^2}{\delta^2} \qquad (1)$$

We achieved a size of the sample about $n \simeq 100$ interviews.

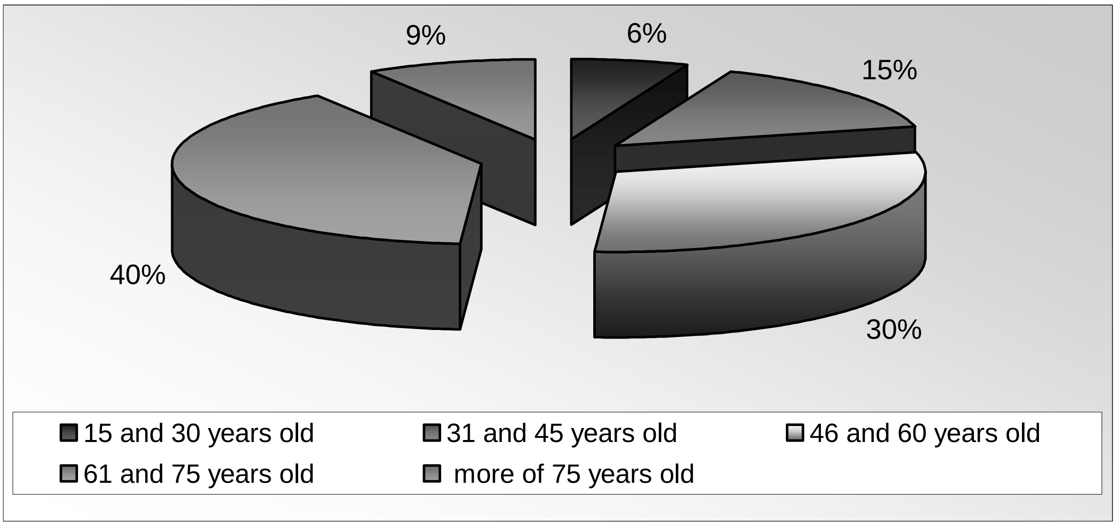


Figure 4. Age of the interviewed sample

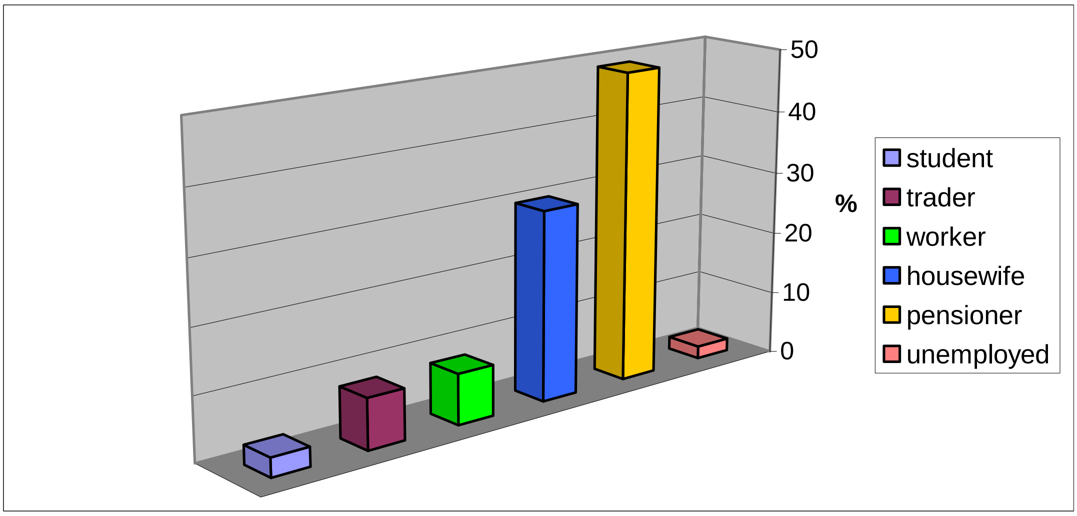


Figure 5. Job of the interviewed sample

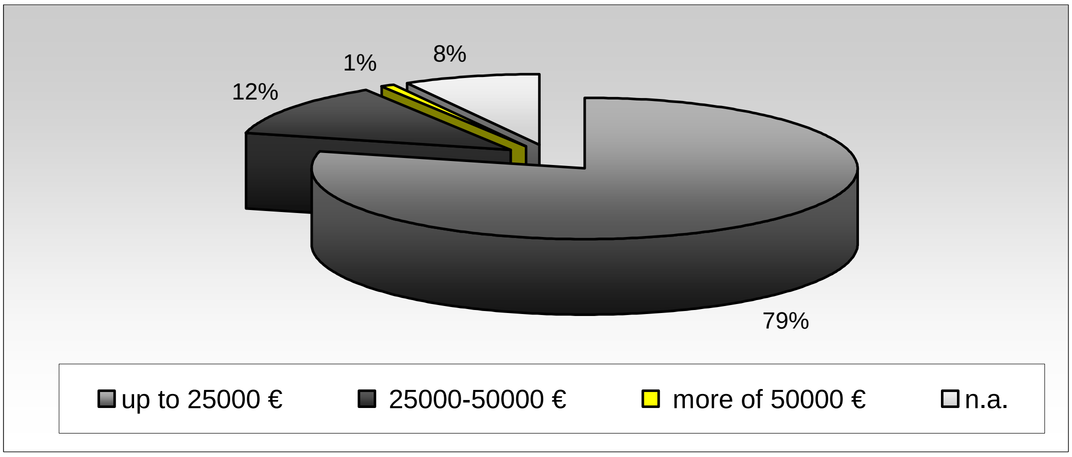


Figure 6. Household income of the interviewed sample

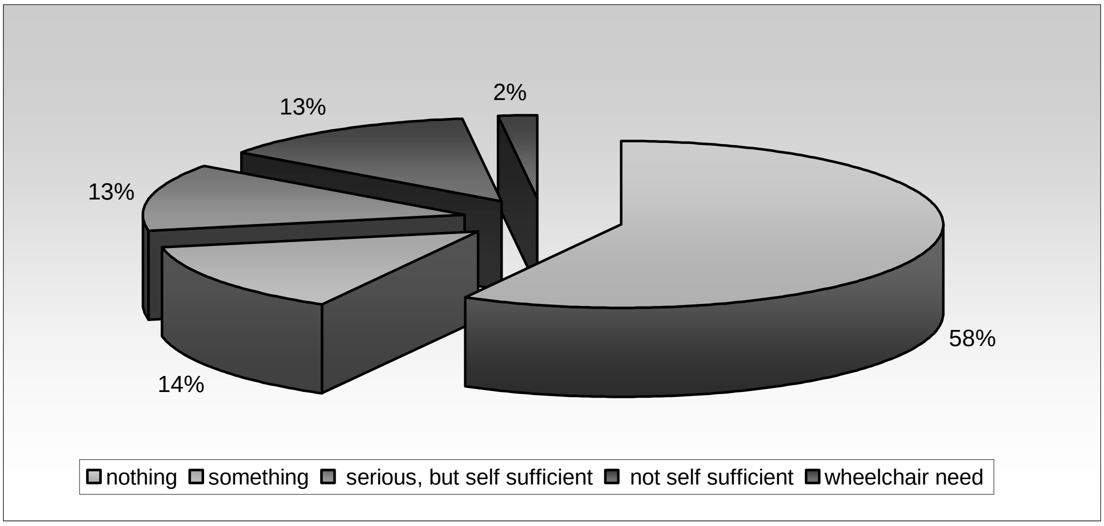


Figure 7. Difficulties to move of the interviewed sample

Figures from 4 to 7 show respectively the age, the job, the household income and the difficulties to move of the interviewed sample. It should be noted that about 80% of the interviewed sample is older than 45 years, about 48% is pensioner, about 80% has an income less than 25,000 euro and about 48% has difficulties to move. Furthermore 25% of the interviewed sample does not own a car, 80% has an attendant and 73% uses the private car (whose 45% as driver and 28% as passenger) and 25% uses the bus to go to Clinic.

THE ESTIMATION OF SERVICE DEMAND

The main aim of this study was the calibration of a demand multinomial logit model able to estimate the potential demand of the dial-a-ride service. In order to calibrate the demand model, the stated preference technique was used carrying our a survey on the individuated sample.

Let V_a be the private car utility function; V_b the bus utility function; V_{mb} the metro/bus utility function; V_{bc} dial-a-ride service utility function; C the average cost for trip and parking; D the average distance from parking; Na /Nc the number of cars per person; *Age* the decision-maker's age; *FR* the household income; A_A the car specific attribute; A_B the bus specific attribute; A_{MB} the metro/bus specific attribute; $b_1 \div b_5$ coefficients of the utility functions achieved by calibration process.

The utility functions of the competitive alternatives were:

$$V_a = b_1 \cdot C_a + b_2 \cdot D_a + b_3 \cdot Na / Nc + A_A \quad (2)$$

$$V_b = b_1 \cdot C_b + b_2 \cdot D_b + A_B \quad (3)$$

$$V_{mb} = b_1 \cdot C_{mb} + b_2 \cdot D_{mb} + A_{MB} \quad (4)$$

$$V_{bc} = b_1 \cdot C_{bc} + b_2 \cdot D_{bc} + b_4 \cdot Age + b_5 \cdot FR \quad (5)$$

The calibration of the logit model was made using the maximum likelihood technique using the Limdep® 8.0 software. The results of the calibration process are reported in table 2.The results of the calibration process show the correctness of the signs and the p-value shows the significance of each attribute. The total significance of the demand model is shown by χ^2 test. Attributes average running time for trip and average waiting time for parking/at bus stop were not significant; probably because more 80% of the interviewed sample is older than 45 years (composed by almost 30% housewives and 50% pensioners). For them the value of time is very low, also the transportation and medical visit are considered an opportunity to meet and hence to speak with someone.

Table 2. Logit model calibration process.

Attribute	Coefficient	Standard Error	t-Student	P-value
C	-.5472392569	.13654595	-4.008	.0001
D	-.1558238548E-01	.33433147E-02	-4.661	.0000
Age	.2312514321	.67358239E-01	3.433	.0006
FR	.7109760646	.15193318	4.680	.0000
Na/Nc	1.457697570	.19853928	7.342	.0000
A_A	2.761481984	.47763870	5.782	.0000
A_B	.3521425441	.43648147	0.807	.4198
A_{MB}	-2.676379552	.59086227	-4.530	.0000
Number of observations = 1000 ρ^2 = .06401				
χ^2**[5]**= 128.77697 Significance (χ^2) = 1.00000				

Furthermore useful information are provided by the elasticity of the attribute cost. The direct elasticity is the effect due to a change of the independent variable on the change of the dependent one.

Table 3. The direct elasticity in term of the dial-a-ride service cost.

Alternative	Elasticity
Private care	**9,061**
Bus	**3,459**
Metro/Bus	**0,167**
Dial-a-ride service	**-12, 429**

We estimated by the calibrated logit model, a reduction of 12,5 % of the dial-a-ride choice probability for an increase of 1% of the service cost. Figure 8 shows the probability choice of different modes in term of the dial-a-ride service cost. Furthermore, figure 9 shows the probability choice of different modes in term of the users' age class. It should be noted an important aspect, for older users than 60 years, the dial-a-ride choice probability is more than 69%.

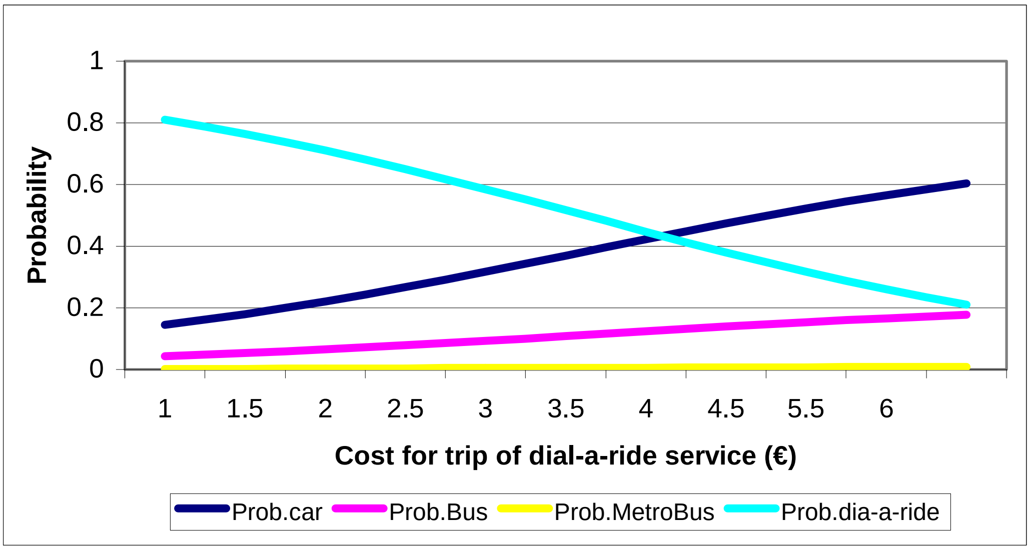
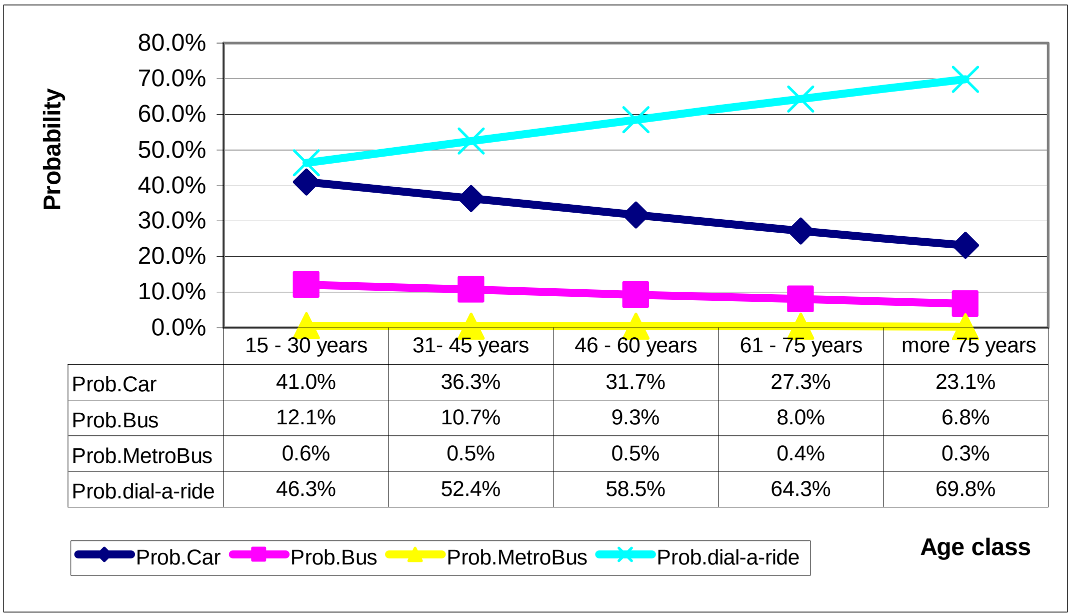


Figure 8. The variation of the modal split versus the dial-a-ride service cost.



	15 - 30 years	31- 45 years	46 - 60 years	61 - 75 years	more 75 years
Prob.Car	41.0%	36.3%	31.7%	27.3%	23.1%
Prob.Bus	12.1%	10.7%	9.3%	8.0%	6.8%
Prob.MetroBus	0.6%	0.5%	0.5%	0.4%	0.3%
Prob.dial-a-ride	46.3%	52.4%	58.5%	64.3%	69.8%

Figure 9. The variation of the modal split versus the age of users.

THE PRELIMINARY DESIGN OF SERVICE

The preliminary design of the dial-a-ride service requires the determination of:

1. the estimation daily average running;
2. the optimal distance between stops;
3. the size of vehicle fleet.

We assumed a service area of size *A*, which is to be served by *M* buses on a fixed rout having Δ stops per unit area. Buses are assumed to travel at a constant speed *v* and to spend *t* seconds at every stop. The bus runs its route on a grid. The transport demand per unit area λ is uniformly distributed over *A*. The service is assumed to be continuously in operation the headway *H*, whereas the average waiting time is *H/2.*
Daganzo (1984) shows how, by a swath of width *w* and length *L*, which cut the region, and the bus moves along the swath visiting sequentially the checkpoints that are active, the estimation daily average running and the optimal distance between stops are respectively:

$$\overline{S} = n \cdot d(w) \qquad (6)$$

$$d^* \cong 0.9 r (\pi \Delta)^{-\frac{1}{2}} \qquad (7)$$

where: *n* is the number of activated stops; *d(w)* is the average distance between two consecutive stops; π the probability that a checkpoint stop is active. Thus the number of buses *M*, considering 90° percentile of the random variable daily average running, is achieved by:

$$M = \frac{2\overline{S}}{T} \qquad (8)$$

where: *T* is the maximum travel time.
Assuming: *w* = 2km; *L*=5km; *n*=180 (achieved by demand model); *r*=1.27; π=0.865; *T*=25min; *H* = 1 km; $\lambda = \Delta$ (without to lose of generality), we achieved respectively d^* = 300 m, *S* =54 km and $M \cong 5$.

CONCLUSIONS

The main contribution of the paper is to provide a framework for the preliminary design of dial a ride system. We have carried out a stated preference survey to evaluate the potential demand of service, taking into account a sample of citizens with limited disability to move. Thus, we have submitted a questionnaire to users of some clinics of Palermo, considering in the choice competitive scenario the dial a ride system. Furthermore a multinomial logit model has been calibrated. Finally a preliminary design of service has been proposed. The results of the calibration process show the correctness of the signs and the p-value shows the significance of each attribute. We estimated the elasticity by the calibrated logit model, achieving a reduction of 12,5 % of the dial-a-ride choice probability for an increase of 1% of the service cost. The age of users is an important factor since older users are more willing to use this service.

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