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InMoSion

Science Shop for Innovative Mobility Solutions for Mobility Challenged Europeans

Instrument: Specific Support Action
Thematic Priority: FP6 – Science and Society Programme

Publishable Final Activity Report

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Centre for Research and Technology Hellas/   Revision [1]
Hellenic Institute of Transport

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List of Acronyms

Geographic Information Systems (GIS)
Intelligent Transport Systems (ITS)
Very Large Scale Neighbourhood (VLSN)
Mixed Integer Linear Program (MILP)
Dynamic Programming (DP)
Dial-a-Ride problem (DARP)
Demand Responsive Transport (DRT)
Personal Digital Assistance (PDA)
Non-Governmental Organization (NGO)
Transportation Research Board (TRB)
Portable Document Format (PDF)
Directorate General for Research (DG RTD)
Directorate-General for Energy & Transport (DG TREN)

1. Project execution

1.1. Summary description of project objectives

It is a well-known fact that Europeans are rapidly aging, mainly due to the low birth-rate and the increase in people's lifespan. This creates pressing mobility problems, as older people are unable to drive but still prefer to live in low-density suburban locations or in rural areas with infrequent or no public transport service at all. In addition to this, the reduction in their income levels in the retirement period makes it harder for them to afford more private modes such as taxis. In Athens, Paris, Ankara and other mega-cities, older, poor and disabled people that do not live in areas well served by public transportation, are left with no viable transport options. In the Capodistrian Municipality of Philippi in Greece, consisting of 19 remote villages, some with fewer than 20 inhabitants, often too poor to own a car or too old to drive, there is almost no public transportation due to the low population density. For some of these Europeans, a trip to their Health Care Provider by a taxi may cost a major part of their income. Similar situations are also encountered in Cyprus, Portugal, Italy, France and other EU states, as well as Turkey and Bulgaria. As a solution, the InMoSion project has developed an innovative transport system based on the paratransit concept. Paratransit is a potentially attractive alternative to conventional transit. It constitutes the only transportation option for the elderly living in rural and suburban areas, where population density is too sparse to be supported by a schedule based transit system. Such paratransit systems were already in use in low density areas of the Province of Bologna and in Cyprus.

Furthermore, paratransit is a flexible system that can accommodate the mobility needs of elders without having to deal with the delays of the buses and the trouble of waiting in bus stops. An advantage of a paratransit system is its similarity to a taxi, in terms of service, since it also picks up a passenger from his/her origin location and delivers him/her to his/her destination location (door-to-door transportation). The proposed and developed system serves passengers using a given number of vehicles. There are no fixed routes in such a system and each passenger decides his pickup and delivery location. He can also request the observance of a time window for his pickup and delivery time. In many cases however, the passengers may not be immediately delivered to their destination point and may sometimes share the ride with other people. In this perspective, paratransit can be classified as a system that operates between large transit vehicles (buses) and single occupant vehicles (cars, taxis). It actually bridges the gap between the two systems. Similarly, the cost of a paratransit system lies generally between the cost of the bus and that of the taxi; a little more than the cost of a bus and a little less than the cost of a taxi.

The InMoSion paratransit system took advantage of the leap in communication, computational, Geographic Information Systems (GIS) and Intelligent Transport Systems (ITS) technologies (cell phones, PDAs, Internet, electronic payment, traveller information systems and other). The introduction of communication-based technologies accommodates further the development of such a system, where the passengers would not

have to plan their trip from the previous day. All vehicles could be equipped with a real time vehicle locator and a communication device, so that the dispatcher can immediately decide which vehicle should be assigned with the transportation of the passenger either through the use of an automated help system or through his/her experience. The architecture of the paratransit InMoSion system has been based on existing paratransit systems e.g. Province of Bologna, Italy and other European countries, the United States Intelligent Transportation Systems system architecture, European traveller information systems and the newly established 511 traveller information system that is spreading throughout the United States and will be available in every state by the year 2010.

In a nutshell, the InMoSion project analyzed the needs of older Europeans both in rural and urban environments, designed and developed a paratransit system that combines algorithms and GIS databases to compute the optimum mobility solutions for both passengers and system operators. The system was deployed on one location – Municipality of Philippi, Greece – and the results were disseminated through workshops on site, through the project's web, as well as through conference presentations and publications. The project can make its services available throughout Europe to municipalities and other community entities and groups to support the needs of older people. The InMoSion project can provide support any community (or municipality, government agency, NGO) that wants to provide paratransit service. Undergraduate and graduate students have been supporting these research and real-life implementation activities by getting involved from the initial steps of brainstorming and initial calculations, to the specific system design (establishment of geographical boundaries, conduction of research to obtain the needs and perceptions of potential passengers, estimation of the necessary number of vehicles, level of service provided, pricing terms, legal issues, financial issues, etc.) all the way to final deployment and support. The support can be provided free of charge in terms of system development, except any local requirements and other local deployment related expenses (after the end of the EU funding period).

The main objective of InMoSion has been the development of all the necessary know-how for effectively supporting any European community to deploy a paratransit system to meet the mobility needs of their citizens (elder or in need). While the basics of a successful paratransit application can be gathered from current experiences and technological advancement, eventually every community has a specific combination of traveller profile and paratransit potential, which require a customized paratransit service design and implementation.

The following sub-objectives of the InMoSion Science Shop have been finalized within the 30-months project duration:
- Analysis of the user needs for a demand-driven paratransit system in both rural and urban environments
- Development of an innovative transport system based on the paratransit concept
- Development and integration of the system regarding software, communication and hardware developments
- Deployment process design and documentation

- Model deployment in terms of mathematical formulation of the problem, algorithmic implementation and simulation
- Dissemination of project's ideas and results

1.2. Contractors involved

In sharing the workload, the **Systems Optimization Laboratory** (SOL) at the **University of Thessaly, Greece,** has lead the research activities, that focused on network analysis, urban networks and transportation systems. SOL provided both theoretical and practical expertise on analyzing such systems and on developing effective solution algorithms for them.

The **Centre for Research and Technology Hellas - Hellenic Institute of Transport** (CERTH/HIT) is the National Organization devoted to the promotion and execution of transport research in Greece, whose basic target is to create a centre of excellence in the field of transport with highly specialized research and policy development services offered to government and third party organizations and bodies and relevant ministries. The scope of such services covers all areas of transport, in particular the organization, operation, planning, construction of infrastructure, standardization, economic analysis, management, vehicle technology, and impact assessment, of land, maritime, air, and multimodal transport services. CERTH/HIT has performed, and is still active in, more than 70 European projects and national studies. Being the coordinator of many of these projects, CERTH/HIT has a great experience in the financial management, and raising financial support for transport infrastructure and research.

The **Middle East Technical University** (METU) is one of the finest research-oriented higher education institutions in Turkey, famous for its School of Engineering. The Department of Civil Engineering has an active Transportation group that produces research on various transportation related topics, and national and international projects for more than 40 years. More recently, interdisciplinary studies among the CE Transportation group and the Institute for Geodetic and Geographic Information Technologies at METU have started a study field focusing on better use of technology in the planning and operation of traffic network systems and development of a transportation-based database.

The **City of Paris Engineering School** (EIVP) focuses on the analysis of urban transportation networks and more exactly on one of the regions in Paris. The French research team goal was not only to serve elders, but also to serve all people in need of mobility.

The **Cyprus Transport and Logistics Ltd.** (CTL) is a private consulting company based in Nicosia, Cyprus. CTL specializes in transport modeling, transportation planning and transport logistics. Its members and associates have a 20-year experience in analyzing and modelling transport systems in the United States and more recently in Europe.

The **Public Transport Authority of Bologna, Reti e Mobilita**, (SRM) has a coordination role between conventional and alternative transport services. In Bologna an on-demand service has already been developed and implemented with success, but it is observed that it is not the right solution for a mountainous area in the southern part of the city.

The **Municipality of Philippi**, (MP) Greece, consists one of the eleven Capodistrian Municipalities of the prefecture of Kavala and has served as the main on-site demonstrator of the InMoSion project.

1.3. Work performed & end results

The activities that took place during the entire duration of the InMoSion project primarily focused on organizing and executing the work at technical, dissemination and administrative levels, thus aiming to ensure the best cooperation between the partners during the 2,5-years project period and setting the foundations for the effective execution of InMoSion. The most notable activities carried out in the first year of the project comprised the Kick-off Meeting, the elaboration of a Quality Handbook, an extensive literature review for paratransit systems, the survey design methodology and design, the actual field data collection with the surveys, the deployment process design for the paratransit system under development and an initial analysis for the development and integration of the system. Additionally, dissemination activities such as the implementation of the project's own website and publications to scientific fora took place.

In the last 1, 5 years of the project the consortium focused its work on the development of the paratransit system, by the deployment design and integration of the system (software, communications hardware etc.).

The most significant activities carried out comprised the development of the operational paratransit system, the well organized and successful implementation of the pilot project demonstrated in the Municipality of Philippi in Greece and the analysis of user's requirements.

The development of suitable algorithms for the routing and scheduling procedure, the build up of database system, the development of system interfaces and build up of communication system was the specific work performed in order to ensure the operational pilot actions of the paratransit system.

Also working issues such as the system architecture the enhancement of software and hardware configurations were performed in order to ensure the success of the pilot implementation.

The end-result of the project was an operational paratransit system, demonstrated in the Municipality of Philippi in Greece, as described previously. During the pilot actions the consortium contacted surveys (during - after) the use of the innovative transport system with the passengers, in order to indentify users preferences, needs and other important information. The evaluation of the system measures, such as performance efficiency cost and pricing, was also one of the main objectives of the consortium.

Additionally, dissemination activities such as the implementation of the project's own website and publications to scientific fora took place. UTH, METU and CERTH/HIT have presented papers concerning the outputs of the project research results in the 87th and 88th Annual TRB meeting in Washington in 2008 and 2009.

In order to disseminate the pilot action, an open conference was held in the Municipality of Philippi, where the project consortium presented the operational system and its benefit to the residents. Also, the president of the Athens Urban Transport Organization (OASA) made a presentation for the transport systems in Greece. In the actual deployment of the pilot implementation of the system, the work has focused on organizing the drivers and the call centre, on helping customers, on advertising the system, on keeping records of everyday events and complaints, on collecting questionnaires, etc.

1.4. Methodologies and approaches employed

1.4.1. Methodologies

Two methodologies comprise the main outcome of InMoSion.

The first one involves the forecast concerning the transportation needs of a specific area of application. This methodology deals with the problem of transportation needs estimation for the area of application. In the municipality of Philippi there was no way to retrieve historical data in order to estimate transportation needs. A solution to this problem was the use of survey. A survey can be formatted in many ways. It depends heavily on the information one needs to extract from its analysis. Studies concerning survey formation can be used in order to assist in its construction. In the InMoSion case, the survey technique used was the stratified sampling, where two sample size criteria were used. The first relates to the level of precision (or sampling error) and is set to be approximately 7%. The second criterion, the confidence level, is equal to 95%. In accordance with the above criteria, that are often used to produce surveys concerning public opinion, the sample size was approximately 2% of the population. The survey was used to identify:

1. Daily or weekly trip habits (origin, destination, time of transit) in order to define a trip number for every week day
2. The user perception of the most interesting trip features for the model
3. Charging Price, in relation to existing means of transport for a specific set of service quality parameters
4. Waiting time (pickup or deliver time windows)
5. Maximum trip travel time in relation to the shortest path distance (taxi time) travel time.

The second one is the estimation of the profitability concerning a proposed Paratransit system. In order to achieve an economically viable DRT system, it is important to assess whether the proposed transportation system can be profitable. Basic elements of the developed methodology are: trip data, definition of service key parameters and the convergence process. In the first survey data is gathered and then analyzed, in order to

infer the population's transportation needs and service-quality related factors. The final step is the convergence process, where a guided search is performed, in order to define the critical point where the system becomes profitable.

1.4.2. Approaches employed

For the <u>first methodology</u> concerning the transportation needs forecasting via a survey an appropriate survey for this area was conducted. The Municipality consists of 19 villages with a total population of 10,827 inhabitants, most of which are elderly. The purpose of the survey was to investigate the market potential and the potential acceptance of the system in a rural community in Greece. The questionnaire was specially designed to capture the potential acceptance of the inhabitants of the area towards the proposed system. Data was collected through face-to-face interviews, carried out by trained people that had a good knowledge of the area, the available modes of transport and the population's mobility needs. In order to ensure that the results of the survey would be reliable, a stratified sampling of approximately 2% (220 questionnaires) of the population was used. The questionnaire consisted of two parts: The first part included general questions for the respondents (such as demographics). The second part included questions that aimed to derive the basic design parameters of the proposed DRT system that would affect its profitability. In order to make the questionnaire more understandable to the people, some questions had predefined answers (multiple choices).

For the <u>second methodology</u> concerning the estimation of the profitability, the following convergence process was presented, that was used in order to identify the profitability critical points. In order to reach the desirable point where the system would become profitable, an extensive guided search sequence was conducted by running multiple iterations of various dial-a-ride algorithms. The *Convergence algorithm* has been designed to reach that point while maintaining the values of the service quality parameters unchanged.

1.5. Achievements of the project to the state of the art

InMoSion project produced a sequence of scientific dial-a-ride algorithms that have been presented in various conferences. A summary of those algorithms is presented below:

1. <u>The Simple Insertion Heuristic Algorithm</u>

The Simple insertion algorithm that has been used is a variation of the one presented by Jaw. The basic task of that algorithm is to create (specific trips assigned to specific vehicles) an initial solution that can be used as a reference by the proposed Very Large Scale Neighbourhood VLSN heuristic. VLSN heuristic needs an initial solution because that initial solution provides the associated set of assigned trips for every vehicle to be used later by the *"exact 2-vehicle"* algorithm. That solution could be easily constructed by assigning trips randomly to vehicles <u>or</u> by using a fast heuristic to produce it. In the first case the VLSN heuristic reaches the best solution with significant slower rates. Because of the random assignment, no optimized solutions were produced at all or even any feasible solutions. In the second case (the use of "*simple insertion heuristic*"

algorithm) the produced solution is at least feasible and generally speaking not far away from the optimum solution. In that case the VLSN heuristic reaches its own best solution sooner.

A short verbal description of the *"simple insertion heuristic"* algorithm follows. At the beginning, the algorithm creates empty routes for every vehicle. After that, for every trip request the algorithm finds the best position -in terms of cost- to insert by searching all vehicle routes. If that position is found, then the trip request is inserted into that position. If it is no possible to find at least one position where the trip could be inserted, then the trip request is rejected. At the end of execution, specific trips have been assigned to specific vehicles.

2. <u>The Exact 2-Vehicle Algorithm</u>

Two exact approaches have been explored in InMoSion: a Mixed Integer Linear Program (MILP) relying on the formulation of the previous section and an implicit enumeration based on Psaraftis' Dynamic Programming (DP) algorithm. The DP approach, which is used as part of the VLSN heuristic, is discussed. Due to the nature of the problem, to get the exact solution for the Dial-a-Ride problem (DARP) it is necessary to evaluate every feasible combination of trip requests and vehicles that cannot be ruled out, based on some technique. Given the problem's combinatorial nature it is obvious that the number of combinations explodes, making any exact approach meaningless for realistic size problems. If somehow that number of combinations is eliminated, then the solution space is restricted making the effort more promising of finding the solution. Memory requirements are another issue. There is a need to eliminate memory requirements in order to execute the algorithm without memory concerns. Keeping the above observations in mind, an effort has been made in order to enrich our exact algorithm with features that offer: (a) restriction of the solution space as much as possible, and (b) the independence of memory resources. For those reasons a DP implementation was developed by using recursive techniques. The heuristic part of that algorithm uses the above referenced exact 2-vehicle algorithm. The main idea is to search in a larger neighbourhood of the solution space. The basic idea is based on using the analytical 2-vehicle approach for exploring a large neighbourhood which classifies it as Very Large Scale Neighbourhood (VLSN) heuristic. The approach is continuously applying the above presented exact 2-vehicle approach for every possible combination of vehicles routes.

1.6. Impact of the project on its industry and research sector

The impact of InMoSion has been twofold.

In the area of scientific research, the main impacts included the production of:

1. Three new dial-a-ride algorithms and the implementation of these algorithms in order to be usable by a real application.

2. The convergence process and convergence algorithm which is a scientific tool to the hands of any possible investor in order to identify the profitably of a proposed transportation system.

In the area of the related industry sectors, the main impact was:
The production of a real operational system application that is being used in the
Municipality of Philippi. This application is fully operational and can be used at a fully
operational environment. In comparison to other commercial products it is:

1. Completely open source
2. Completely non depended of any propriety software and data
3. Completely web-based application

1.7. Diagrams and photos illustrating the work of the InMoSion project logo and reference to the project public website.

A screen capture of the application menu of the developed paratransit system of the Municipality of Philippi the "EnTAXI"
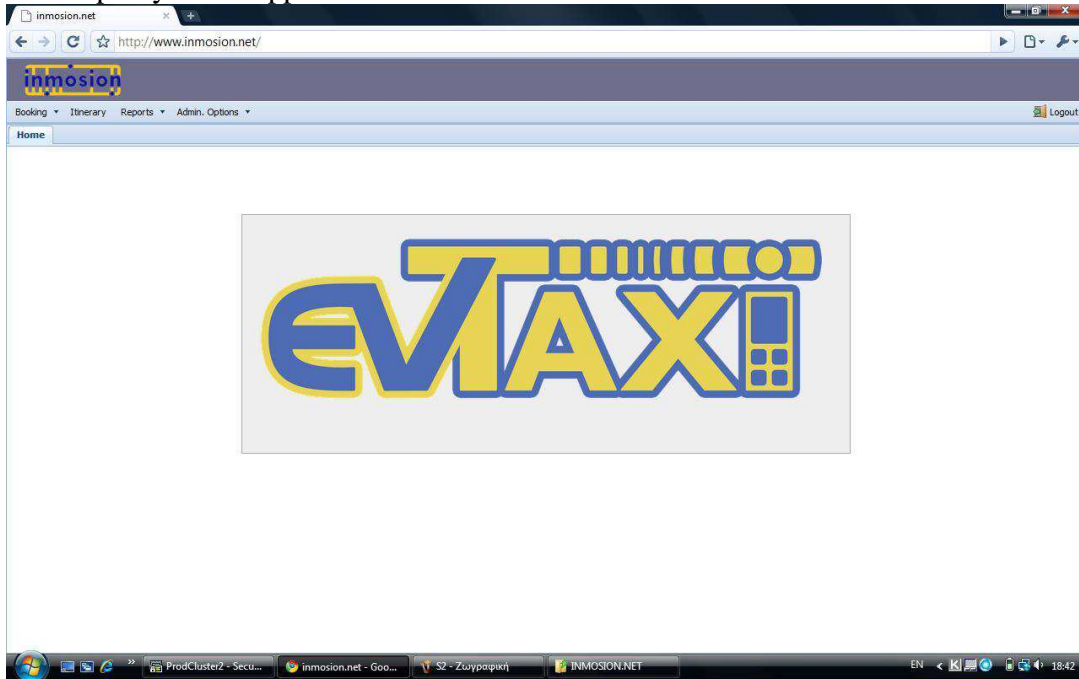
A screen capture the booking – customer selection
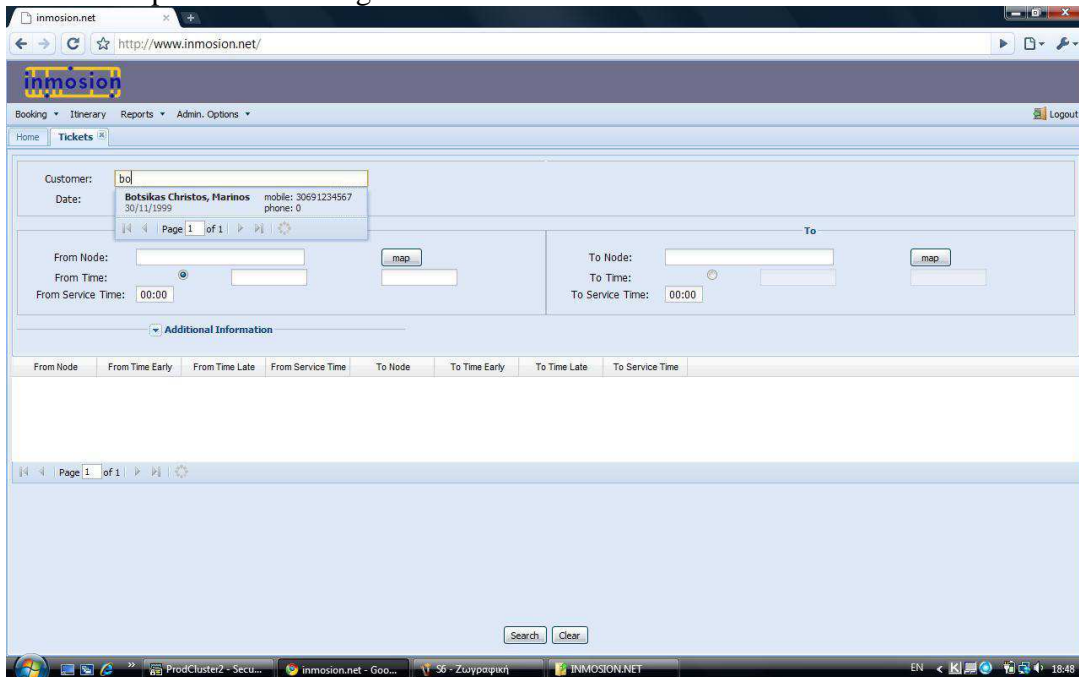
A screen capture of an origin – destination selection
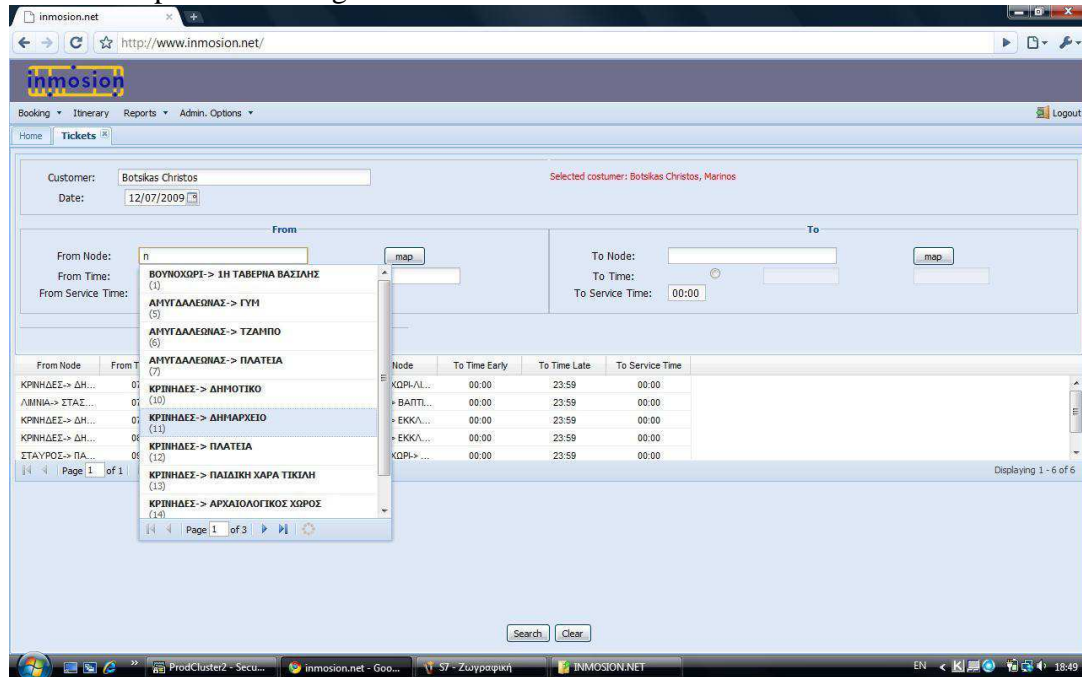
And via map
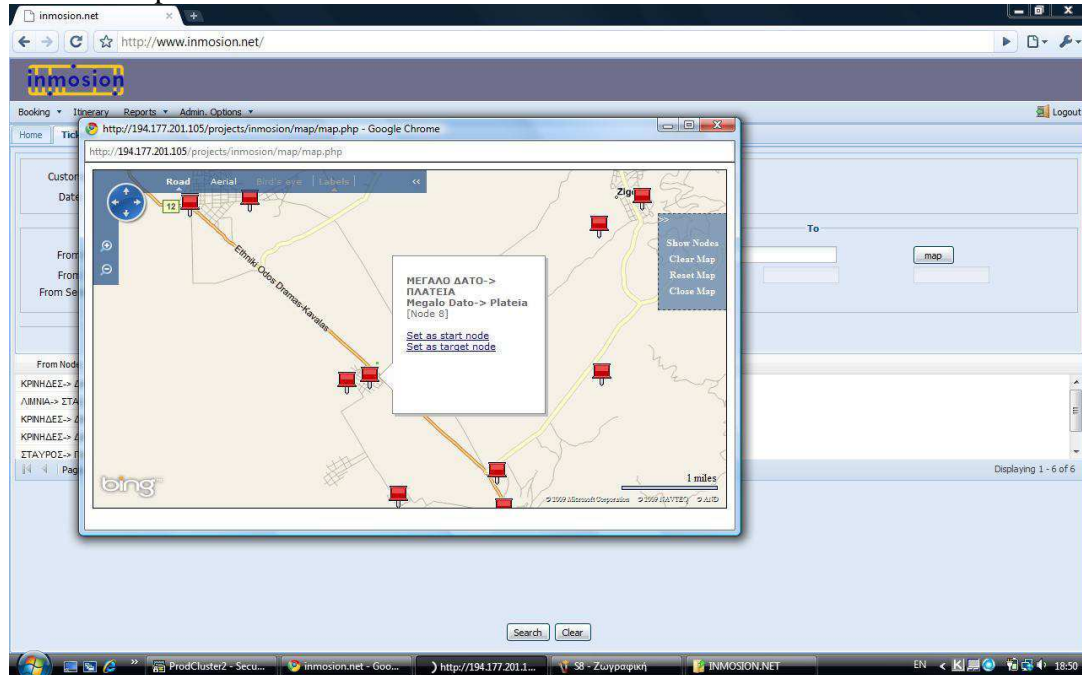
A screen capture of InMoSion paratransit system mapping Admin – options monitoring the system.
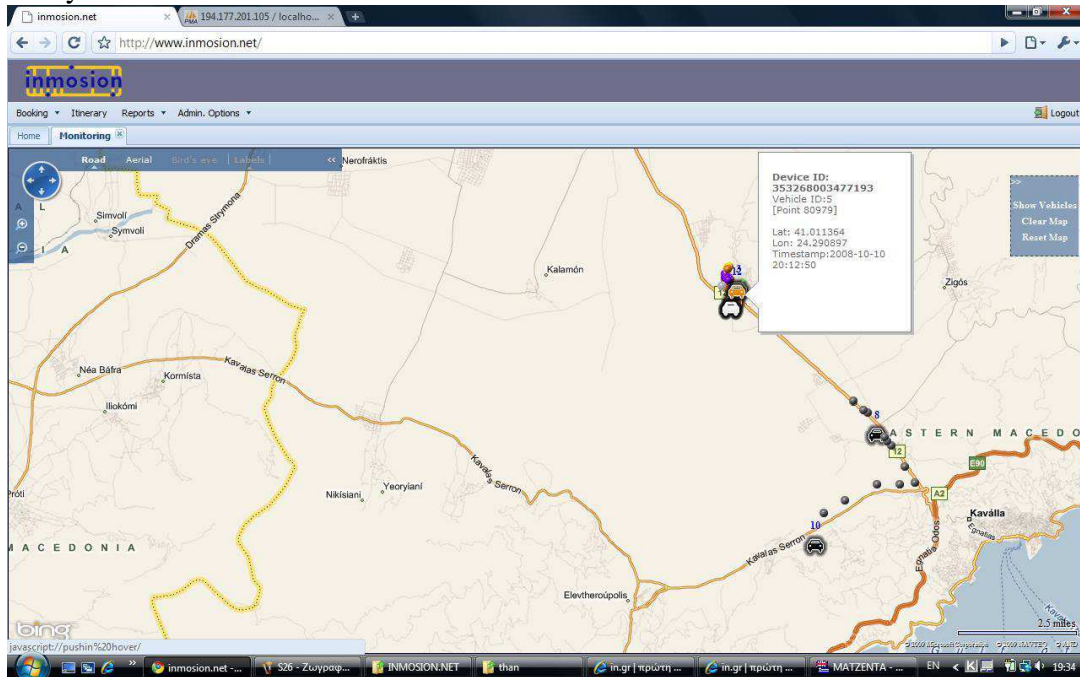
A screen capture of the InMoSion paratransit system web-based mapping tool for the graphical output of the system's results.
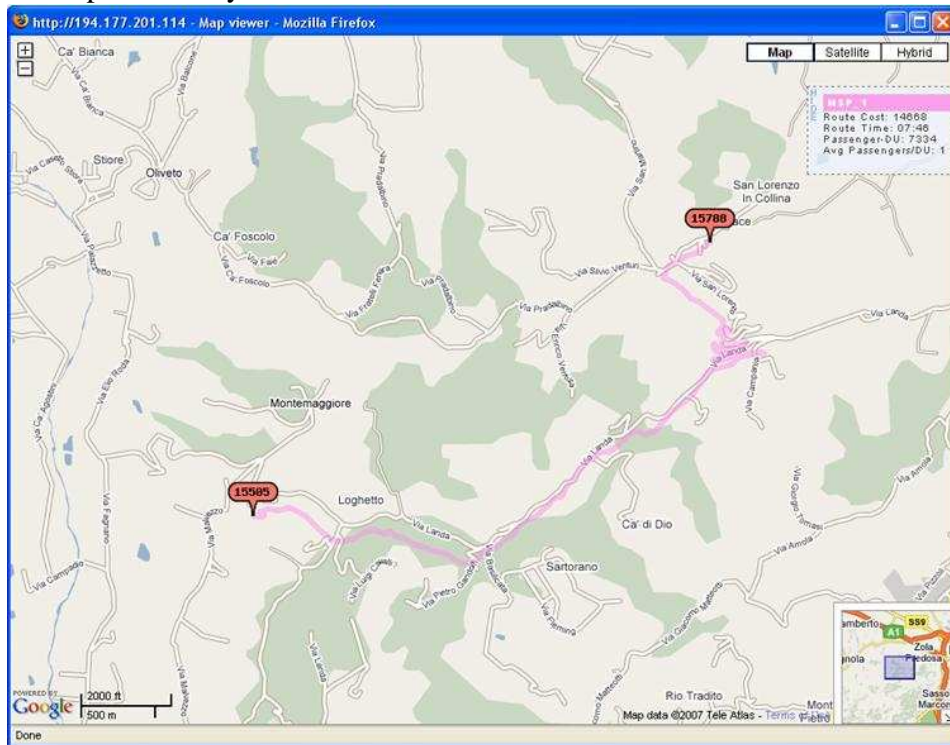
The structure and dependencies of the InMoSion Work Packages are depicted in the following figure.
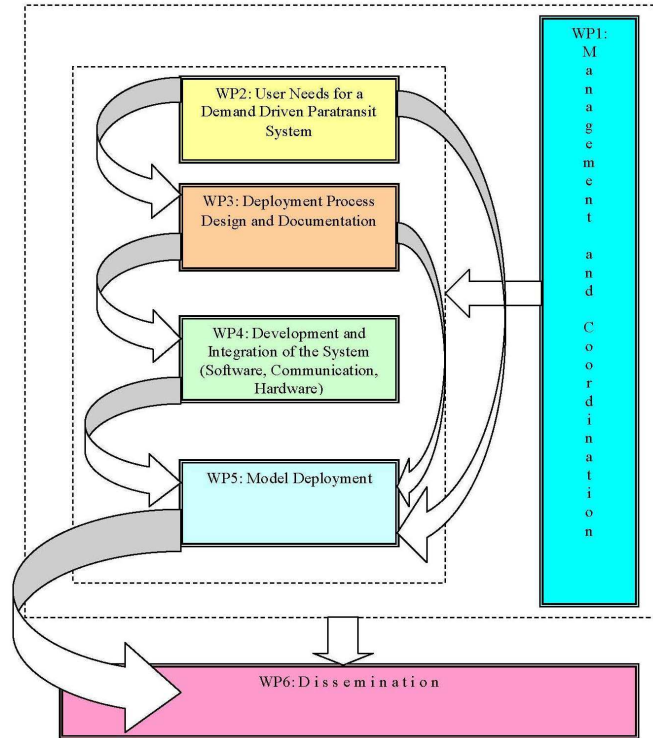
Photos of the InMoSion kick-off meeting at the premises of CERTH/HIT in Thessaloniki, Greece. February 2007.

Photos of the InMoSion open conference in the Municipality of Philippi, Greece, September 2009

Project logo:

InMoSion Science Shop website: http://www.inmosion.eu

1.8. Co-ordinator contact details

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2. Dissemination and use

2.1. Publishable results

In the end of this section four (4) publications are included, that can be disseminated to the broad public with results from the main activities of the project:
1. System Design of Paratransit Systems
2. Analysis of Questionnaires and Simulation of Data from Philippi
3. The Algorithm for the Multivehicle Dial-a-Ride with Time Windows
4. A Scenario-Based Semi-Disaggregate Market Share Estimation For A Proposed Paratransit System For Philippi Region, Greece

2.2. Final Plan for using and disseminating the knowledge

Section 1 - Exploitable knowledge and its Use
Overview table

Exploitable knowledge (description)	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
Conducting detailed surveys on mobility needs	Analysis of surveys on mobility needs	1. Transport 2.Econometrics 3. Regional Planning	n/a	none	Consortium
Architecture for paratransit systems	High-level architecture and functional specification for paratransit systems	1. Transport 2. Regional Planning	n/a	none	Consortium
Deployment process	Deployment process design for paratransit systems	1. Transport 2.Econometrics 3. Regional Planning	n/a	none	Consortium
Paratransit system modules	Detailed description of necessary paratransit system modules	1. Transport 2.Econometrics 3. Computing systems	n/a	none	Consortium
Dial-a-ride algorithms	Development of new Dial-a-ride algorithms	1. Transport	n/a	none	Consortium

		2.Econometrics 3. Computing systems 4. Mathematics			
GIS enabled database	Development of new GIS enabled databases to support paratransit systems	1. Transport 2. GIS 3. Computing systems	n/a	none	Consortium
Interfaces	Development of new, user friendly interfaces for web-based paratransit systems	1. Transport 2. Computing systems	n/a	none	Consortium
Communication	Development of new communication systems for web-based paratransit systems	1. Transport 2. Computing systems 3.Communication systems	n/a	none	Consortium
Evaluation of system measures	Evaluation of system measures (performance, efficiency, cost pricing)	1. Transport 2.Econometrics 3. Computing systems	n/a	none	Consortium
Innovative paratransit system	Development of an operational paratransit system	1. Transport	n/a	none	Consortium

Description of exploitable results

1. Conducting detailed surveys on mobility needs

The result is the creation of new methodologies for data collection and data analysis for assessing new mobility needs and mobility patterns. The leading partner of this initiative has been METU with the support of the other consortium partners. The results can be used as an indicative methodology for similar studies or as supporting academic teaching input.

2. Architecture for paratransit systems

The result is the design of High-level architecture and functional specification for paratransit systems which can be used for implementing similar systems in other areas. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

3. Deployment process
The result is the documentation of a Deployment process design for paratransit systems. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

4. Paratransit system modules
The result is a detailed documentation and description of all necessary paratransit system modules. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

5. Dial-a-ride algorithms
The result is the design and development of new advanced Dial-a-ride algorithms. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

6. GIS enabled database
The result is the development of new GIS enabled databases to support paratransit systems. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

7. Interfaces
The result is the development of new, user friendly interfaces for web-based paratransit systems. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

8. Communication
The result is the development of new communication systems and processes for web-based paratransit systems. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

9. Evaluation of system measures
The result is the formulation of an advanced evaluation methodology for system measures such as performance, efficiency and cost pricing regarding newly implemented paratransit systems. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

10. Innovative paratransit system

The result is the development of an operational paratransit system. The leading partner of this initiative has been UTH with the support of the other consortium partners. The result can be used directly or modified in order to meet local characteristics and needs.

Section 2 – Dissemination of knowledge

The following dissemination activities include all activities performed by the whole duration of the project. Dissemination activities presented in the form of a table, have been maintained and updated by the UTH, CERTH/HIT and SRM with regular input by all project partners.

Overview table

Planned/ Actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible / involved
May 2007	Project website http://www.inmosion.eu	All	All		UTH, All
May 2007	Partner's web-link to project's website http://www.srmbologna.it/FAQ.sh tm	All	All		SRM
May 2007	Partner's web-link to project's website http://www.hit.certh.gr/site/pageg enerator.php?id=262	All	All		CERTH/HIT
May 2007	Partner's web-link to project's website http://sol.mie.uth.gr/sol/website/cu rrent/index.php?page=projects/in mosion/overview	All	All		UTH
May 2007	Partner's web-link to project's website http://web.ce.metu.edu.tr/index.php ?id=5&agency=3	All	All		METU

May 2007	Partner's web-link to project's website http://www.ctranslog.com/news.html	All	All		CTL
May 2007	Partner's web-link to project's website http://www.eivp-paris.fr/?id=55	All	All		EIVP
May 2007	Project logo	All	All		SRM
Entire project duration	Give aways, Brochures, Posters Conference posters, CD-Rom	All	All		All
October 2007	Mobility Tech, the International Forum on the Technological Innovation for the Development of Mobility and Public Transport "The technological innovation in mobility sector in Emilia‐Romagna Region" (Authors: Tommaso Bonino, Dora Ramazzotti)	Academics, Scientists, Transport authorities, Transport Professionals	All	≈70	SRM
January 2008	TRB 2008 Annual Meeting - Conference presentation "Large Neighbourhood Heuristic Algorithm for Multi-vehicle Dial-A-Ride Problem with Time Windows" (Authors: Lois Athanasios; Ziliaskopoulos Athanasios; Aifadopoulou Georgia)	Academics, Scientists, Transport authorities, Transport Professionals	All	≈110	UTH, CERTH/HIT
May 2008	10th International Conference on Application of Advanced Technologies in Transportation – conference presentation " Design of a deployable paratransit system for	Academics, Scientists, Transport	All	≈170	UTH

	rural areas" (Authors: Christine Mastrogiannidou, Athanasios Lois, Athanasios Ziliaskopoulos)	authorities, Transport Professionals			
June 2008	7th European Congress and Exhibition on Intelligent Transport Systems and Services – conference presentation "EU Project InMoSion Science Shop for Innovative Mobility Solutions for Mobility challenged Europeans" (Authors: Tommaso Bonino) http://www.itsineurope.com/index.cfm?do=timetable.paper&paperID=2726	Academics, Scientists, Transport authorities, Transport Professionals	All	≈100	SRM
September 2008	Large-scale conference in Philippi	EC representatives (DG RTD, DG TREN), Academics, Scientists, Public authorities, Governmental, Ministries, NGOs, Transport authorities, Transport Professionals, Professional associations, European Transportation Research Associatio	Greece, Italy, France, Cyprus, Turkey	≈150	Municipality of Philippi, CERTH/HIT, UTH

		ns, Media (newspapers, TV, radio)			
September 2008	Conference website http://194.177.201.114/projects/inmosion/conferences/19sept08/index.php?c=inmosion	All	All		UTH
September 2008	Reference to the project via the website http://news.disabled.gr/?p=18652	All	All		Municipality of Philippi
September 2008	Reference to the project via the website http://www.uth.gr/ekdiloseis?start=18	All	All		UTH
September 2008	Reference to the project via the website http://www.express.gr/news/ellada/76448oz_2008091776448.php3	All	All		Municipality of Philippi
September 2008	Reference to the project via the website http://www.ota.gr/article/31464.html	All	All		Municipality of Philippi
September 2008	Partner's web-link to conference's website http://www.philippi.gr/index.php?option=com_content&task=view&id=35&Itemid=18	All	All		Municipality of Philippi
September 2008	Reference to the project via the website http://www.emea.gr/default.asp?ElementId=33429&pPage=10	All	All		All
January 2009	Application's video on YouTube http://www.youtube.com/watch?v=Qvw2v-UhbcA	All	All		UTH
January 2009	TRB 2009 Annual Meeting – Conference presentation "The use of dial-a-ride algorithms in the design of a profitable and flexible DRT system through a convergence process" (Authors: Lois Athanasios, Koukkos Ioannis, Ziliaskopoulos Athanasios)	Academics, Scientists, Transport authorities, Transport Professionals	All		UTH
January 2009	TRB 2009 Annual Meeting – Conference presentation "A Scenario Based Semi-Disaggregate Market Share Estimation for a Proposed Paratransit System for Philippi	Academics, Scientists, Transport authorities,	All		METU

	Region, Greece" (Authors: Hediye Tuydes, Murat Ozen)	Transport Profession als			
January 2009	EU Project Flipper: Training Course 1 "Design Flexible Transport Service : area, citizens requirements and involved actors point of view" (Dora Ramazzotti, Eugenio Margelli)	All	All		SRM
April 2009	EU Project Flipper: Training Course 1 "Flexible Transport Service schemes, dispatching and booking technologies" (Athanasios Lois, Tommaso Bonino)	All	All		UTH, SRM

Description of dissemination activities

1. Project website

A dedicated project website has been set-up, with information being updated regularly. The project's website provides information on the progress of the project work and the lessons learned. It also contains the core documents accessible to public. Links with partners' web pages are available.

2. Partner's web-link to project's website

A link to the project's website has been created on the frequently accessed main website of SRM**.**

3. Partner's web-link to project's website

A link to the project's website has been created on the frequently accessed main website of CERTH/HIT.

4. Partner's web-link to project's website

A link to the project's website has been created on the frequently accessed main website of UTH**.**

5. Project logo

A corporate project logo was created. The logo presents a "corporate image", as it was clear that a sound and consistent look and feel of the InMoSion product would help it to be perceived as more professional and contribute to an increasing visibility and traceability across different sites.

The logo is being used on the documentation, promotional and publicity literature, exhibition boards, CD-ROM and on the web site.

6. Give aways, Brochures, Posters, Conference posters, CD-Rom
Even if most communications were electronic, it was still useful to create an A4 flyer with general level information that could be circulated in printed form, e.g. to hand out at conferences or to interested stakeholders. It promoted the main objects, aims and results of the project. The electronic version (e.g. PDF file) was also circulated electronically.

7. TRB 2008 Annual Meeting - Conference presentation
A scientific paper entitled "Large Neighbourhood Heuristic Algorithm for Multi-vehicle Dial-A-Ride Problem with Time Windows" (Authors: Lois Athanasios; Ziliaskopoulos Athanasios; Aifadopoulou Georgia) has been accepted and presented at the TRB 2008 Annual Meeting in Washington DC, U.S.A.

8. Large-scale conference in Philippi
A large scale conference for the presentation of the InMoSion paratransit system was organized. The conference took place in the demonstration area of the project – Municipality of Philippi, Greece. Aim of the conference was to attract a large number of attendees from various sectors (EC representatives (DG RTD, DG TREN), Academics, Scientists, Public authorities, Governmental, Ministries, NGOs, Transport authorities, Transport Professionals, Professional associations, European Transportation Research Associations, Media, newspapers, TV, radio) and to disseminate the results of the project.

Section 3 - Publishable results

Four (4) publications are included next, that can be disseminated to the broad public with results from the main activities of the project:

1. System Design of Paratransit Systems
2. Analysis of Questionnaires and Simulation of Data from Philippi
3. The Algorithm for the Multivehicle Dial a Ride with Time Windows
4. A Scenario-Based Semi-Disaggregate Market Share Estimation For A Proposed Paratransit System For Philippi Region, Greece

Publication 1: *Design of a Paratransit System for Rural Areas*

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Design of a Paratransit System for Rural Areas

Abstract

This paper is concerned with the key stakeholders and design parameters of a deployable paratransit system with emphasis on the system users and the operator. A user survey was conducted in the municipality of Philippi in Northern Greece consisting of 19 villages to obtain potential users' perception of the key system parameters in connection with the likely market share. A heuristic pickup and delivery routing algorithm was implemented and used to evaluate alternate system designs with varying levels of provided service and pricing policies. Some computational results are provided for the network of Philippi, Greece.

Keywords: paratransit systems, travel survey

1.   Introduction

Paratransit is a flexible demand responsive transport system that aims to function at a cost of bus while providing personalized service as close as possible to a taxi. Typically, a user is expected to contact the system requesting a service between two nodes of a network and for a specific time window. The paratransit system aims to facilitate personal mobility needs and fight social exclusion while providing high quality services at a relatively low cost. The system uses a version of a pick up and delivery routing algorithm, known in the literature as Dial A Ride Problem (DARP) algorithm to group the trips of the users in such a way that the cost of the system is reduced without deviating too much from the shortest path of each user.

Paratransit started as an element of public transport services in low density areas in the early 1970's. The U.K. and the U.S. were among the countries that very early deployed systems exhibiting this service concept. During the late 1970s, the concept evolved to its present role of a specialized door-to-door service for disabled passengers who cannot use conventional public transport. The most commonly used transport vehicle for such an activity is mini-bus, usually equipped to serve disabled and elders.

In the USA and Canada paratransit services are used extensively as part of the American with Disabilities Act (ADA). In Cyprus, a paratransit taxi-based system exists, mainly for airport service and other intercity trips ranging from 50 to 100 km per trip, which offers a cheap alternative to a regular taxi. While it is not exactly a door-to-door paratransit application, a popular transit option in Turkey, called *"dolmus",* is a good application example of a new public transportation mode that is more flexible than the public bus and still more affordable compared to taxi/car option.

Many EU countries such as Italy, Finland, Sweden, Netherlands and Belgium have employed paratransit systems, mainly funded by the European Commission. Experience from Europe shows that strategically it is more straightforward to implement paratransit systems in regulated environments, as there is less conflict with other public transportation modes. In 2000, the UK Government pledged in its Ten Year Plan for transport to remove or (at least) relax constraints on the development of flexible bus services and to promote a greater role for community-based services. In addition, research commissioned by the Department of the Environment Transport and the Regions (DETR) argues that flexible public transport services— provided by local authorities and bus operators in partnerships with employers, stores and leisure centers —would help to break down social exclusion. Similar initiatives have been reported in Ireland, in 1999. More recently, in 2001, the UK Rural White Paper proposals for the extension of Bus Service Operators Grant (BSOG) –formerly Fuel Duty Rebate (FDR) – to community transport were adopted. Finally, the recent successes of local authorities in winning substantial funding under the Rural and Urban Bus Challenge programs for the implementation of demand responsive transport services confirms this new interest in flexible forms of transport.

Very little has been reported for such a service in Greece. As part of the Program Connected Cities funded by the European Commission, the deployment of such a service in remote villages in Greece is investigated. In this paper the analysis of such potential deployment is investigated. While a DARP algorithm has been developed as part of this program, the objective of this paper is not to report on the algorithm but rather on how

the algorithm in connection with a user survey can be used to perform a analysis of alternate system designs.

In the next section, the potential stakeholders involved in carrying out a paratransit system are identified and their potential role is briefly discussed. The role of the two critical stakeholders (users and the operator) is analyzed next: In Section 3, the perception of the potential users is investigated through a structured questionnaire and the critical parameters (price and level of service) are quantified. Section 4 is concerned with the role of the system operator and how the results from the survey in connection with the implemented DARP algorithm can be used to evaluate alternate system designs. Section 5 concludes this paper.

2 Definition of stakeholders

The difficulty of employing paratransit systems in most cases has proven to be the balance that should be achieved between the involved stakeholders. Those are all the entities affecting the operation of the system. The stakeholders identified are summarized below as well as the role they play in the deployment of a paratransit system.

- **Users**

The potential users of the paratransit system could be categorized into different groups based on occupation, age, gender, etc. The attitude of each user plays an important role and is affected by their mobility needs, financial situation, whether they own private means of transport, trip purpose and origins/destinations. Students, housewives, elders, disabled and retired people appear to be more willing to use such a service, while tourists appear to constitute a special category of users. The paratransit system may accommodate their mobility needs providing transportation solutions of better quality and cost. The users are obviously the most critical stakeholders and their perception will determine the market share attracted by such a system. The most important parameters determining the market share are the cost and the level of service. In the next section, the users perception is analyzed through a structured questionnaire and the parameters determining the market share are broadly quantified.

- **Operator**

The operator is responsible for the efficient operation of the paratransit system. Additionally, he is responsible to take all the decisions related to the level of service and the pricing policy. The operator may be a municipal entity, a private entity or a Public Private Partnership (PPP). The objective of the operator is obviously to ensure the financial viability of the system and depending on its corporate structure, to increase profit or social benefit. The operator will be responsible for designing, deploying and maintaining the system. The general impacts of the system on land use, environment and socio-economics are of interest from the point of view of negotiating tax breaks, subsidies and cost-sharing schemes. The operator is probably the second most important stakeholder, as he can determined the pricing policy and level of service that affects users' perception and ultimately market share. The critical design elements related to these parameters are discussed in Section 4.

- **Government**

Local governments are potential stakeholders as they can be the operator or participate in a Public-Private Partnership (PPP) and of course they have to represent the people in general. In addition, they are also responsible for the compliance with state regulations and for any potential subsidies of the system. Finally, local governments are interested in serving their constituency, especially the old and disadvantaged that have mobility problems. Paratransit can positively impact environmental problems and have important implications on land use and the economy. The system may need to be subsidized through taxation or participation from the local market, which also involves the local, regional and central government.

In most cases, because the implementation of a paratransit system requires a large amount of money to be invested, the participation of the local or national government in subsidizing the system would constitute a viable solution especially for the first years of the system's operation.

- **Drivers/Employees**

Deploying a paratransit system influences all the employees responsible for its efficient operation such as drivers, system operators and administrators. Employees may be either private employees, owner operators or even taxi drivers that can participate in the operation. The employees of the system will also be responsible for the quality of the provided services.

- **Local markets & Touristic SMEs**

Local market includes all the public and private organizations like schools, hospitals, commercial markets, etc. These entities may benefit from the increased mobility (in addition to any latent demand) and the flexibility & convenience provided by the system. The increased economic activity is of interest to these entities and they may be asked to participate in sharing the cost of the system.

- **Competition: other Transportation Service Providers**

Other transportation service providers may be the official public bus system that operates in the area, or taxis. The introduction of a new transport system will undoubtedly affect them. Additionally, because the desired service quality of the paratransit system is equivalent to taxis' while the cost remains at lower levels, comparable to those of buses, it is expected that these operators will oppose to the implementation of such a system. There is also a case, however, that the paratransit system accommodates the mobility needs of passengers in favour of the public bus system. Paratransit may be a valuable tool to increase the efficiency of the public bus system and this depends on the type of relationship that will be established between them.

On the other hand, paratransit may also collaborate with taxis. It may form contracts with taxis in order to use them in cases where the existing infrastructure cannot satisfy the requests in the system.

3. User Survey

The most important issue that should be taken into consideration in deploying a paratransit system is the perception of the users. The most obvious reason for that is the level in which the users feel satisfied by the currently operating transport systems. In the case that the users cannot see the need for the introduction of a new system, even when they have not completely understood the advantages and the disadvantages, it would be less likely to use the new system. Then, it is crucial to identify the market potential of the area in which the new system is going to be deployed.

In addition, if the results of a survey like this are positive, then the paratransit system will be easier to be deployed in terms of financial support by the local government or private entities. But mostly, the purpose of this survey is to capture all the critical elements that need to be taken under consideration in the designing phase and define some crucial steps in the phase of deploying a paratransit system in a rural area. Moreover, all these issues are of interest to the stakeholders in their decisions to deploy or not a paratransit system because finally, the viability of the system depends on these elements.

In many countries that paratransit systems have already been deployed, surveys were conducted but usually only after the system was in operation. Thus, they wanted to capture the perception of the users in terms of enhancing the existing paratransit system and provide services of better quality. The majority of these questionnaires were conducted on-board or even by phone. Additionally, many questionnaires have been presented that deal with the issue of transportation of handicapped persons and how the paratransit system can be adapted in order to provide quality services and easy access to disabled.

Till now, in the literature, there is no survey that investigates the potential acceptance of a paratransit system in any area, urban or rural, and/or independently of the profile of the user. Moreover, there is no survey that investigates the procedure for the design phase of a paratransit system, which is the objective of this paper.

The most widely used method in order to identify the market potential is to conduct a survey by questionnaire. This is the method that we are going to follow in this paper. Next, we discuss the steps that have been followed for the design of the questionnaire. In the third section, we discuss the issues that we took into consideration in the process of conducting the questionnaires in a Greek rural Municipality. The analysis of the questionnaires follows in the fourth section. Finally, in the fifth section we summarize the present work and give some useful conclusions.

3.1 Design of the questionnaire

In order to understand the potential acceptance of the system by the users, we conducted a survey. The purpose of the survey was to investigate the market potential and the potential acceptance of the system in a rural community in Greece.

As we have already discussed in the previous section, the matter of identifying the potential acceptance of the system by the users is quite crucial in deploying a public or private entity to provide paratransit services. It is also crucial because it can help securing subsidies by the government.

The questionnaire was designed in such a way that we would be able to capture the intention of the inhabitants of the area and to elicit answers that are of interest to the

stakeholders. The method of data collection that was followed is face-to-face interviews by trained people that had also a good knowledge of the area and the needs for transport. The method was stratified sampling of approximately 2% of the population.

The questionnaire is comprised by four parts. The first part includes some general questions such as the sex, the age and the occupation of the respondent. In order to understand the perception of the biggest part of the population, we divided the population into several categories according to their age. For the deviation calculations we also took into consideration whether the respondent is able to drive owns a vehicle.

The resulting categories are:
- Child in elementary school
- Child in junior high school / high school
- Male 18 – 60
- Male 60+
- Female 18 – 45
- Female 45 – 70
- Female 70+

The second part of the questionnaire asked about the usual trips he/she makes. They were asked for the day of the trip, the origin and the destination location, the time of departure and the trip duration, the cost and the purpose of the trip and finally the means of transport that he/she used and whether this were also the desirable means. From the aforementioned questions, we tried to draw some useful conclusions -mainly statistical results- about the trips of the respondents, the days and the hours they usually travel, the destination, the time it takes them and the cost of the trip. The results of these answers can provide an estimate of the cost of the system if it was to be deployed as well as the viability of the system in the target area.

The third part of the questionnaire dealt with the specific trips the respondent undertook last week. The purpose of this part was to capture the exact trips that were being made by the respondents at a specific time period, rather than capture their actual habits. This was done because at such questions people tend to exaggerate or state less real-world scenarios. Thus, comparing the answers of the second and the third parts we can draw some safe conclusions about the exact trips of the respondents.

The third part contains exactly the same questions with the second part with the only difference being that they are limited to the trips actually performed last week only.

Finally, the fourth part contains some qualitative questions, such as the amount of money that the respondent is willing to pay in order to travel faster, or the extra time that they are willing to spend travelling so that the cost is reduced. They were also asked for their opinion about the existing transport system and if they would use the proposed paratransit system.

3.2 Conducting the survey by questionnaire

The questionnaires were conducting in the rural Municipality of Philippi, Greece. The Municipality consists of 19 villages with a total population of 10,827 inhabitants. A sufficient sample was considered to be around 2% of the population. We followed a stratified sampling methodology, using 210 questionnaires that would be equally

distributed among the population subgroups or approximately 30 questionnaires per age group. The interviews were conducted by trained people that had a good understanding of the area, available modes and mobility needs.

The elaboration of the official existing public transport system (KTEL) itineraries showed some interesting results. Table 1 shows the frequency of the trips of KTEL to every village per day and the total trips for a whole week. By looking at the table it is obvious that for some villages such as Amigdaleonas and Stavros the frequency of the trips to the biggest urban centre of the area, the city of Kavala, is fairly high while in villages such as Limnia and Likostomo there are sparse. We also observe that in some villages such as Dato, Mikrochori, Kranochori there are no bus trips at all.

In order to draw useful results from the 30 questionnaires that corresponded to each age group, half of them were conducted in villages with easy access to big urban centres and the rest in villages without easy access. Problems arise during the data collection process due to the lack of inhabitants in some villages. In the Municipality of Philippi there are villages as large as three thousands inhabitants but there are also others as small as only twenty or thirty inhabitants. Another important measure was the distance of the villages from the big urban centers and the facilities provided in those villages. The Municipality of Philippi is located between two major urban centers: Kavala and Drama, which offer a range of facilities and infrastructures such as medical centers, universities and tutoring schools, gyms, parks, etc. Obviously, people prefer to live in these areas despite the substantially higher cost of housing, because they can enjoy these amenities without excessive travelling. Paratransit aims to provide an effective transport system in such rural areas so that people could maintain their residence in a village and have access to the urban area facilities.

3.3 Analysis of the results

The analysis of the questionnaires revealed some interesting finding regarding the perception of users for the proposed transport system. It also revealed the needs for transport in the target area, the acceptance the system by the users and some critical elements regarding the categories of population and trip purposes that can be mostly attracted by the paratransit system.

Some of the results were intuitive, such as that the paratransit system would be preferred by women that do not own a private car or they do not have a driving license and they are between forty-five to seventy years old, while men at the same age would not leave their cars in favor of the paratransit system. The system could also comprise an attractive solution for students that want to travel to their schools or tutoring schools, take part to extracurricular activities, etc.

The first and most interesting result from the elaboration of the questionnaires was the perception of the users regarding the level of service and its pricing policy. We define as the optimum level of service the one provided by taxis, because they drive you directly to the desired destination location, following the potential shortest path route. The lowest level of service is that of the bus, which usually makes a lot of stops before delivering the passenger to the desired location and usually is associated with walking and waiting. Furthermore, we define the cost of the taxi to be the highest while the cost of bus the

lowest. The expected output would be the users to answer that they want the level of service equal to taxi and the system to be free of charge or cost the price of the bus ticket. On the contrary, as can be seen in figure 1, the users do not demand a transport system free of charge while providing the service level of the taxi. The majority of the respondents would be happy with a system that would cost half of the price of the taxi and taking twenty-five percent more travel time than the taxi.
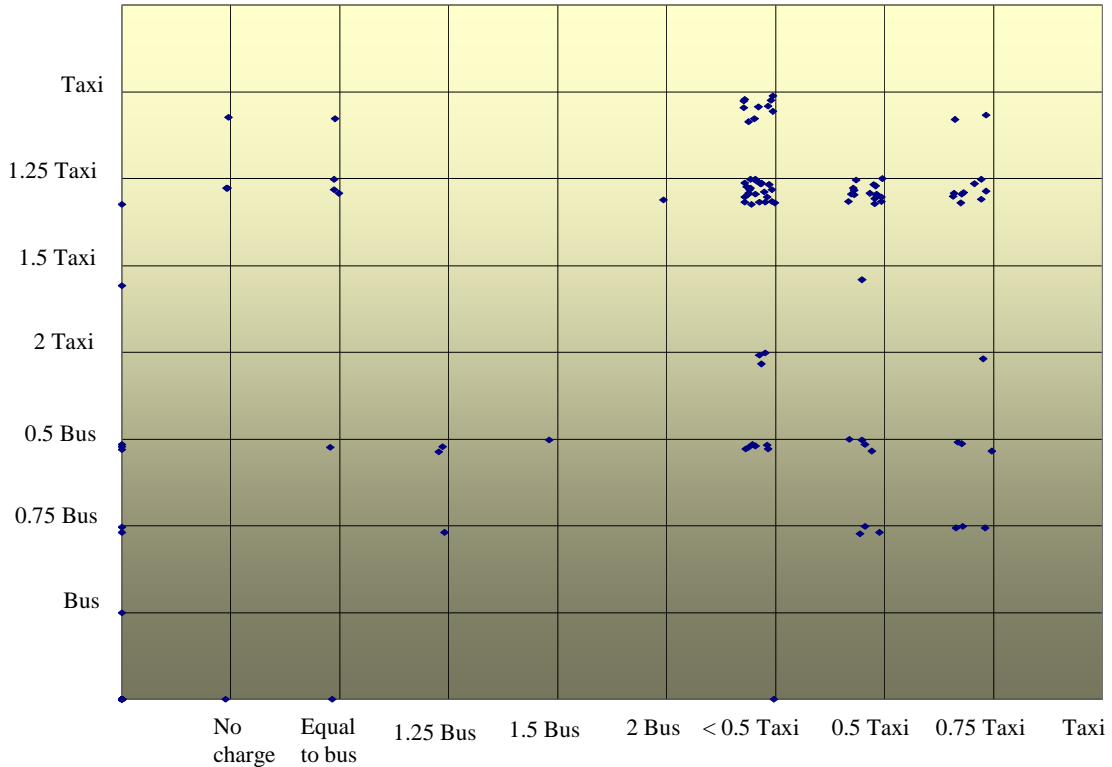

Figure 1: Level of service vs. price

Another important result is that the majority of the trips were accomplished by unemployed / pensioners and housewives / housebased employees while the greatest part of trips was made by women between eighteen and forty-five years old (Figure 2). The most frequent purposes of transport are shopping, business and social reasons (Figure 3).
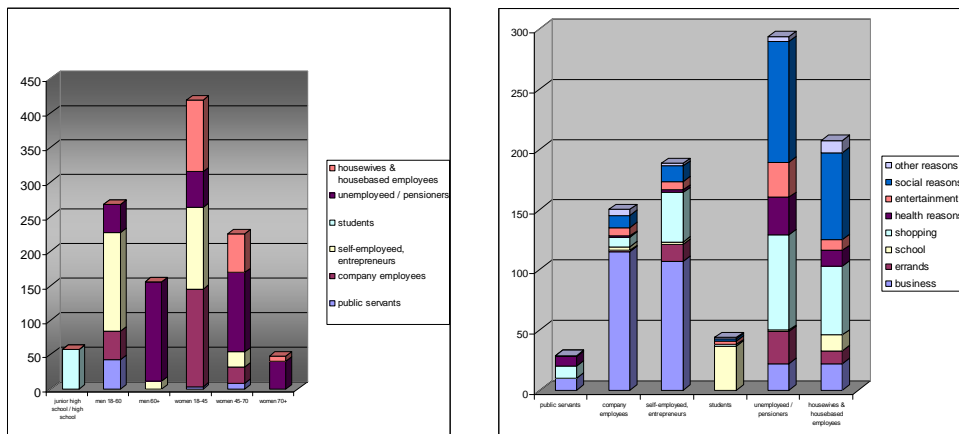
Figure 2: Number of trips vs. age and occupation   **Figure 3: Trip purpose**

We also examined the number of respondents that use bus and taxi for their transportation needs. The results revealed that mostly women use bus for shopping and children to go to school. Taxi is also used by women when there are health reasons for the trip and for shopping but the number of respondents that use taxi are much less than those using bus.
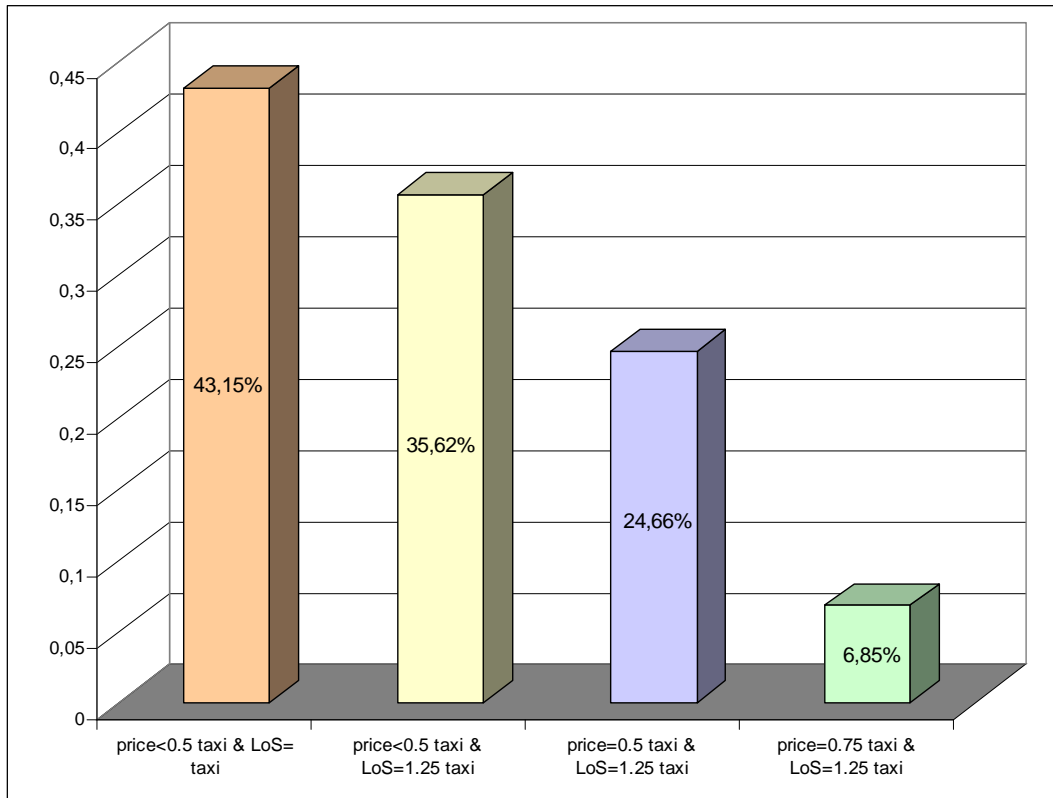
Figure 4: Paratransit market share versus price and level of service

The potential market share of the paratransit system, as shown in Figure 4, depends on the level of service and the price. It is extremely interesting that about forty percent of the surveyed is willing to use the paratransit system if it costs less than the half price of the taxi while providing the exact level of service with taxi. For a system like this it is often difficult to achieve the same level of service with taxi due to its purpose to transport simultaneously more than one passenger. But, looking carefully at the plot, we observe that the next column which is about thirty-five percent of the examined sample would uses the proposed system if it was half the price of the taxi and the travel times were twenty-five percent more than the taxi. If we translate the above percentage into the number of passengers per week it is almost four thousands passengers per week which is large enough.

4 Design of a paratransit system

One of the most useful benefits of the above study is to help the operator of the paratransit service to identify the key operating elements of the system. The components that are critical in the design of the system are as follows:

1. The number of vehicles
2. The capacity per vehicle
3. The level of service, in terms of time and distance deviation compared to that of taxi
4. Basic operating costs
5. The minimum charge per kilometer per passenger in order for the system to be profitable

Providing that the operator of the system is aware of the above elements, it would be easy to develop the feasibility study of the system and finally to decide whether to invest or not.

In order to produce specific numbers for the aforementioned key elements, we followed the procedure described below:

First step: we specified the main user groups depending on pricing policy and level of service. The following table gives the demands defining these groups. Attention must be given that those numbers are not mentioned on the total demand of the area, but are related to the sample size of the survey; the demand that is based on the sample size is simply extrapolated for the whole population, which is the best that can be done given the available information.

Table 1: Market share groups

Group Name	Level of Service	Pricing Policy	Demand
GRP01	1.25*(Taxi Time)	=0.75*Taxi cost	**78**
GRP02	1.25*(Taxi Time)	=0.5*Taxi cost	**48**
GRP03	1.25*(Taxi Time)	<0.5*Taxi cost	**114**
GRP04	Taxi time	<0.5*Taxi cost	**28**
GRP04+GRP03	<= Taxi time	<0.5*Taxi cost	**142=28+114**
GRP04+GRP03+GRP02	<= Taxi time	<=0.5*Taxi cost	**190=28+114+48**
GRP04+GRP03+GRP02+GRP01	<= **Taxi time**	<=**0.75*Taxi cost**	**268=28+114+48+78**

For example group GRP04 is willing to pay less than half of the taxi charge while the respondents that belong to GRP04 are not willing to travel more than a taxi does. Group GRP03 is willing to pay less than half of the taxi charge and likes the travel time to be no more than 25% longer than the taxi time.

The combined group GRP03+GRP04 is willing to pay less than half of the taxi charge and likes the travel time to be no more than the exact taxi time.

In the same way we combine groups GRP02+GRP03+GRP04 and GRP01+ GRP02+GRP03+GRP04.

The various groups added because it is obvious that the responders willing to pay the most will also use the system on the assumption that the level of service will be at least equal with the accepted level of service.

Second step: identify and run specific experiments in order to simulate the real demand requests for every market share.

Each experiment is a combination of the group (or group combinations), the number of vehicles and the different capacity.

Table 2 shows the exact concepts behind the experiments.

Table 2: Experiments specification

Fleet size	Capacity of each vehicle	Group(s)	Number of Demands
2	8	GRP04	28
2	8	GRP03+GRP04	142
2	8	GRP02+GRP03+GRP04	190
2	8	GRP01+GRP02+GRP03+GRP04	268
2	12	GRP04	28
2	12	GRP03+GRP04	142
2	12	GRP02+GRP03+GRP04	190
2	12	GRP01+GRP02+GRP03+GRP04	268
2	16	GRP04	28
2	16	GRP03+GRP04	142
2	16	GRP02+GRP03+GRP04	190
2	16	GRP01+GRP02+GRP03+GRP04	268
4	8	GRP04	28
4	8	GRP03+GRP04	142
4	8	GRP02+GRP03+GRP04	190
4	8	GRP01+GRP02+GRP03+GRP04	268
4	12	GRP04	28
4	12	GRP03+GRP04	142
4	12	GRP02+GRP03+GRP04	190
4	12	GRP01+GRP02+GRP03+GRP04	268
4	16	GRP04	28
4	16	GRP03+GRP04	142
4	16	GRP02+GRP03+GRP04	190
4	**16**	**GRP01+GRP02+GRP03+GRP04**	268

Third step: identify for every experiment the critical results that are useful for the operator. Such critical results could be:

1. Total distance (in kilometers) covered by the vehicles
2. Total passenger distance (in passenger kilometers) covered by all vehicles
3. Average number of passengers per kilometer
4. Shortest path distance for all the demands
5. Average Percentage of distance Deviation per passenger from the corresponding shortest path.

Using these results, the operator can identify the operating costs in such a way to be useful to balance the service levels and operating costs.

In the following table we give the results produced by the experiments.

Table 3: Experiments Results

N of V	CAP	MARKET SHARE	Demand Num	Total Distance	Total Passenger-kilometers	Avg Passengers /km	Total SP Distance	Avg Distance Deviation	Avg Time Deviation Percentage %	Avg Distance Deviation Percentage %
2	8	GRP04	28	75,4	75.4	2	75,4	0	186	0
2	8	GRP03+ GRP04	142	263,74	515.9	2.292	311,66	7.043	125	65
2	8	GRP02+ GRP03+ GRP04	190	295,06	537.43	2.048	371,81		114	44
2	8	GRP01+ GRP02+ GRP03+ GRP04	268	307,1	608.14	2	360,32	6.044	133	68
2	12	GRP04	28	75,4	75.4	2	75,4	0	186	0
2	12	GRP03+ GRP04	142	263,74	515.9	2.292	311,66	7.043	125	65
2	12	GRP02+ GRP03+ GRP04	190	295,06	570.23	2.173	346,59	6.044	137	64
2	12	GRP01+ GRP02+ GRP03+ GRP04	268	307,1	608.14	2	360,32	6.044	133	68
2	16	GRP04	28	75,4	75.4	2	75,4	0	186	0
2	16	GRP03+ GRP04	142	263,74	515.9	2.292	311,66	7.043	125	65
2	16	GRP02+ GRP03+ GRP04	190	295,06	570.23	2.173	346,59	6.044	137	64
2	16	GRP01+ GRP02+ GRP03+ GRP04	268	307,1	608.14	2.200	360,32	6.044	133	68
4	8	GRP04	28	75,4	75.4	2	75,4	0	186	0
4	8	GRP03+ GRP04	142	282,86	513.18	2.187	321,22	6.399	118	59
4	8	GRP02+ GRP03+ GRP04	190	424,9	675.98	2	472,62	4.519	137	43
4	8	GRP01+ GRP02+ GRP03+ GRP04	268	497,36	882.23	2.066	506,35	6.712	146	74
4	12	GRP04	28	75,4	75.4	2	75,4	0	186	0
4	12	GRP03+ GRP04	142	282,86	513.18	2.187	321,22	6.399	118	59

4	12	GRP02+ GRP03+ GRP04	190	399,78	650.9	2.095	441,36	4.762	136	47
4	12	GRP01+ GRP02+ GRP03+ GRP04	268	505,7	852.51	1.958	506,35	6.181	139	68
4	16	GRP04	28	75,4	75.4	2	75,4	0	186	0
4	16	GRP03+ GRP04	142	282,86	513.18	2.187	321,22	6.399	118	59
4	16	GRP02+ GRP03+ GRP04	190	399,78	650.9	2.095	441,36	4.762	136	47
4	16	GRP01+ GRP02+ GRP03+ GRP04	268	505,7	852.51	1.958	506,35	6.181	139	68

For example, we examine the experiment where 2 8-seat vehicles are used, and the market share is GRP02+GRP03+GRP04, while the total number of demands is 190. The experiment gives the following results for that combination of vehicles, capacity and market share: Total Distance covered by all vehicles, 295.06 km (the demands in this area were quite short in terms of distance, 2-3 kilometres on average) while the straight shortest path distance (as if the passengers using taxis) is 371,81 km. The averaged distance deviation was 44% (0.9 – 1.2 kilometres) more than the pure shortest path distance.

If the salary of drivers and employees, vehicle maintenance costs and fuel costs were known, we would be able to produce the exact charge per kilometre in order to make the system profitable. The customer is charged for the distance that he/she travels according to the shortest path route to their destination, regardless of whether this is the route that he/she will actually travel or not.

Assuming known fuel prices, salaries and vehicle maintenance costs, we compute the appropriate charge per kilometre in our case.

The values assumed concern the costs in Greece and they are as follows:
1. Salary costs: 1200€ per driver per month
2. Fuel + maintenance costs: 0.5€ per kilometre
3. Vehicle purchase cost: 30000€ and should be writtenoff in 5 years
4. Other operating costs: 1000€ per month
5.

Table 4 summarizes these results under the specific assumptions given below.

Table 4: Final Charges Table

N of V	CAP	MARKET SHARE	Demand Num	Taxi charge per kilometer	Paratransit charge per km with initial costs	Paratransit charge per km without initial costs
2	8	4	28	1,30	2,09	0,98

2	8	3+4	142	1,47	0,81	0,54
2	8	2+3+4	190	1,58	**0,72**	0,49
2	8	1+2+3+4	268	2,05	0,76	0,53
2	12	4	28	1,30	2,2	0,98
2	12	3+4	142	1,47	0,85	0,54
2	12	2+3+4	190	1,66	0,8	0,53
2	12	1+2+3+4	268	2,05	0,79	0,53
2	16	4	28	1,30	2,28	0,98
2	16	3+4	142	1,47	0,88	0,54
2	16	2+3+4	190	1,66	0,81	0,53
2	16	1+2+3+4	268	2,05	0,8	0,53

5 Conclusions

This paper introduces an approach for analyzing, designing and deployingparatransit systems in rural areas. We identified the potential stakeholders, the critical parameters and the impacts related to the deployment of paratransit systems and comprise critical elements in the designing and the operating phases of the paratransit system. The users and the operator appear to be the most critical stakeholders for a successful deployed paratransit system. A survey was used to identify the users' perception and the potential market share of the system. These two elements are critical for the viability of the system. The data collected were analyzed and the results showed that for specific user groups the expected penetration of the system would be large enough. The results in conjunction with an implemented DARP algorithm were used to evaluate alternative system designs taking into account the market share as revealed from the survey.

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Publication 2: The use of simulation in the design of flexible on demand bus transportation systems

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ABSTRACT. In many European areas transportation services are inadequate because of spatial restrictions and unsatisfied user needs. In order to achieve **a sustainable transportation system** it is very important to assess if the proposed transportation system could be beneficial or not in terms of sustainability and profitability. In this paper we propose a new methodology for defining or evaluating critical system operational parameters, in order to formulate a sustainable and profitable transportation system. The main focus of that methodology is the use of **an innovative simulation process**, which utilizes data and conclusions drawn from user surveys and their subsequent analysis. A user survey is used in order to track customers' transportation habits and unsatisfied transport needs. Survey analysis is made so as to obtain potential customers' perception of key system parameters such as travel cost, travel time, travel pickup & deliver time windows. User demands are projected on a **3-d model** where axis-x represents the cost range, axis-y represents the travel time range (in relation to the absolute shortest path travel time) and axis-z represents the pickup time window range. The basic feature of that projection model is that demand, is a monotonic cumulative increasing function as we move towards the axis' starting points. The simulation proccess begins from a starting point, where all demands are included, and eventually reaches (or **converges to**) a point where a specified number of demands is satisfied and the system turns from "non profitable" to "profitable". The simulation software uses "Dial-a-Ride with Time Windows" algorithms, which are the result of recent research achievements on this scientific field (also presented in this paper).

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INTODUCTION AND LITERATURE REVIEW

A great number of European areas are faced with substantial demand for mobility services. A typical state-run transportation system does not always offer adequate transportation services because of high operational costs. On the other hand, countries like the USA, by introducing the Americans with Disabilities Act, created a market for on-demand transportation systems. On demand transportation systems aim to facilitate personal mobility needs and fight social exclusion while providing high quality services at a relatively low cost. The ideal on-demand transportation system aims to provide personalized service, similar to the services provided by a taxi, while suppressing operational costs and retaining them on the same level as a bus would cost to run. The scheme's typical operation is described as follows: a user is expected to contact the system requesting transportation between two nodes of a network in a specific time window. On-demand transportation services provided by private enterprises should be profitable so as to be attractive to investors. In order to investigate if an investement of the kind is profitable or not, a specific methodology that could provide the appropriate information is necessary. To our knowledge, no specific studies have been presented addressing this issue. On the other hand, simulation tools have been used extensively in order to provide some knowledge concerning the various parameters that affect the operation of on-demand transportation systems. Simulation tools are very powerful in evaluating system performance and have been extensively utilized in the literature in a variety of fields including transportation. Wilson et al (1) pioneered the use of simulation to compare different heuristics to assess the influence of the service area, the demand density and the service quality on the fleet size requirements. Ali Haghani et al (8) presented a study about a real problem concerning bus transit vehicle scheduling within the Mass Transit Administration (MTA) in Baltimore USA. He showed that the proposed models for Multiple Depot Vehicle scheduling problems (MDVS) and Multiple Depot Vehicle scheduling problems with route time constrains (MDVSRTC) improve over MTA schedlules by decreasing 5.77% operational costs. Fu (2) used simulation in order to track the behavior in paratransit systems that are subject to tight service time constraints and time-varying, stochastic traffic congestion. The main focus in that study was on high uncertainty that characterized travel time due to traffic conditions. The same author presented general concepts, models and computational techniques that can be applied in the simulation, focusing on how various components are modeled and how they interact with each other in the overall simulation process. In another study, Sinoda (7) focused on the usability of paratransit systems in large towns, especially in comparison with fixed route transportation systems. Simulation results showed that a) The usability of the dial-a-ride system with a fixed number of buses drops very quickly when the number of requests (demands) increases. b) When we increase the number of buses proportionally to the number of demand, the usability of the dial-a-ride system is improved more significantly than that of the fixed-route system. c) When frequency of demands is sufficient, the dial-a-ride system is a reasonable solution, from the perspective of both usability and profitability. Sinoda used a generic algorithm in order to achieve the aforementioned results. Luca Quadrifoglio *et al* (3,4) used simulation in order to propose an innovative concept that merges the flexibility of Demand Response Transit (DRT) systems with the low cost operability of fixed-route systems. The same author (5) used simulation tools to study the impact specific operating practices currently used by

demand responsive transit providers have on productivity. They investigated the effect of using a zoning vs a no-zoning strategy in Los Angeles County and time-window settings on performance variables such as total trip miles, deadhead miles and fleet size. They demonstrated that by using a no-zoning strategy instead of a zoning strategy we can decrease the total number of vehicles and the number of deahead miles. Simulation has been used in above studies in order to present the usefulness of the proposed algorithms in terms of cost reduction or solution improvement.

In the present study we propose an innovative methodology that can guarantie that our insight on a paratransit system can help us declare it profitable or non profitable in advance. A specific number of steps and some simulations should follow in order to achieve the final result which is the ticket charging cost vs real vehicle cost. In the following paragraphs we present that specific methodology that should be applied. In section 2 we provide a short description of the Methodology steps. In Section 3 we present the data source analysis, In section 4 we present the converge process and the underlying DARP algorithms. In section 5 we present the computational experience, and finally in section 6 we derive some conclusions.

1. METHODOLOGY STEPS

In this methodology we propose a "how to" guide to build a procedure that will help define basic parameters that could affect the system profitability.

In short, we can describe those steps as follows:

Step 1: **Production of trip demand data**. Before we start simulating the system we need data. Data can be acquired through various ways. We can use historical transportation data from other transportation services in the specific area, although that data can't be characterized as definitely reliable. The best way to acquire reliable data is to conduct a survey. We use surveys to:

1. Track current user mobility needs and habits. For example, a survey could contain questions about users' current week trips, trip duration e.t.c
2. Track main factors that affect the service quality vs tickets pricing. These factors are critical in the overall process. Through these factors we can measure user perception of the proposed system, its pricing policy and service quality. These factors include pickup (deliver) time windows, maximum ride times, trip pricing e.t.c.
3. Track potential trip demands, in case that the transportation system under investigation is on-demand.

This survey – typically conducted at 2% of the whole population - is analyzed and then projected to the full population. The more detailed the survey is, the more precise information we can extract.

Step 2: **System Simulation and the convergence proccess**. This step gives us the neccecary information about system performance. Some good DARP algorithms should be used in order to derive the exact system state in terms of costs and benefits. We use a **convergence process** so as to define the critical point at which the system reaches

profitability. More Details concerning the simulation and convergence process can be found at section 4.

2. DATA SOURCE ANALYSIS

The most important issue that should be taken into consideration when deploying a DRT system is the perception of the users. The most widely used method in order to identify the market potential is to conduct a survey by questionnaire. While some of the studies on DRT provide results of survey analysis, few provided the full survey questionnaires. A representative yet thorough set of key parameters from different DRT surveys is collected and can used as a backbone for the requsted survey. Survey data analysis should be kept to a be minimum in order to create the questionnaire to be used. This questionnaire is applicable in all cases, whether the survey site is an urban or a rural area.

2.1. The Survey

The survey can be formatted in many ways. It depends heavily on the information we like to extract for the survey analysis. Studies concerning survey formation can be used in order to assist in the survey construction. In this paper we don't provide an extensive study of the optimal creation survey policy. On the other hand, some key features, some construction parameters and a minimum data analysis concerning the survey should be satisfied. In the following paragraph we present the survey to identity:

- Minimum construction parameters. As construction parameters we refer to the sampling size (typically, 2% of the population), the sample kind (simple random sample, stratified random sample, cluster random sample, systematic sample).

- Minimum question set. This minimum set of questions should include questions about :
  o Daily or weekly trip habits (origin, destinations, trip times)
  o User perception concerning <u>ticket price</u>, in relation to existing means of transport for specific quality of service parameters of DRT system, like:
    ▪ Waiting time (pickup or deliver time windwows) before the trip begins
    ▪ Maximum "trip" travel time in relation to the shortest path distance (taxi time) travel time.
    ▪ Reservation interval (how soon ahead would they be willing to place a reservation)
  o User willingness to use the proposed system (the posible market penetration of the proposed system).

  Other questions can be included concerning some general issues like:
  o Sex
  o Age
  o Occupation / attribute (i.e. student, housewive)
  o Residence location (Suburbs, town, small village)
  o Special needs / mobility disabilities

  Additionally, minor transportations issues like:
  o Nature of trips (work, education, healthcare, shopping, leisure)
  o Frequency per kind of trip
  o Trip dependency on sex (male, female)

- o Trip dependency on vehicle type
- o Trip dependency on date and time
- o Trip dependency on subjects profession
- o Trip dependency on markets

Of course, the complete survey can include more questions, depending on the desirable analysis.

2.2. The Survey data analysis

The first step is the projection of the sample to the entire population, i.e. if the sample size is 2% of the whole population then we have to multiply the number of trips that have been reported in the survey by a factor of 50. The following table presents this concept.

TABLE 1 "Trip Number Projection based on survey data"

Origin	Dest	Trip Time Interval	Pickup(deliver) Time Window	Max Trip Ride accorring to SP	Ticket Price	Survey trips number	Projected to whole population trips number
i	j	k	l 6-10 minutes	m	n	X_{ijklmn}	$X_{ijklmn}*50$
		(11:00-12:00)		2 times the SP travel time	Double the price of the bus ticket		

The trip distribution among time intervals is considered to be Normal. This simple procedure shows how we use the survey in order to produce the trip demands to be used later during the simulation process. More sophisticated routines can be used, in order to generate the number of trip demands, but it is out of the scope of this study to provide more details.

3. THE CONVERGENCE PROCCESS

3.1. An Introduction

The basic process can be characterized as a continuous process that attempts to locate the critical point where the transportation system becomes profitable. We use three key parameters that affect the profitablity. Those parameters are:

Travel cost. Travel cost (or ticket fee) represents the charging costs that users are willing to pay for a specific trip. It can be proportional to distance covered, fixed for each specific trip or fixed for all trips.

Travel time. Travel time represents how much time customers spend in-vehicle in comparison with the time the customer would spend with the same transportation medium if his travel path between pickup and deliver points was the shortest path.

Pickup (deliver) time windows. Pickup (deliver) Time windows represent the typical time windows for the pickup and deliver time.

3.2. The 3d Model

The model we use in order to obtain a visual perspective of the system parameters is a 3-d model where **axis-x** represents the charging cost range, **axis-y** represents the travel time

range (in relation to the absolute shortest path travel time) and **axis-z** represents the pickup time window range.

Trip demands are projected in this model in a specific way.

The corner in the opposite site of point (0,0,0) (point D) contains trip demands corresponding to minimum trip requirements (maximum charging price – axis x , maximum time window axis-y, maximum ride time axis-z)
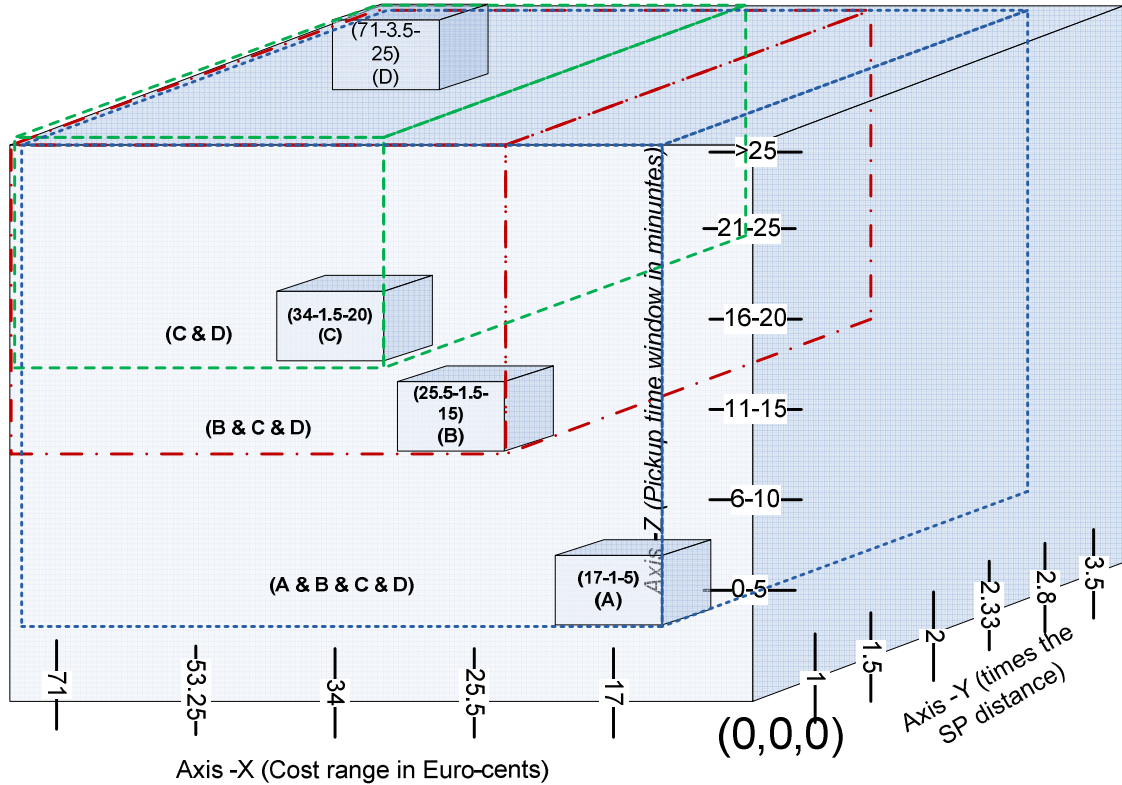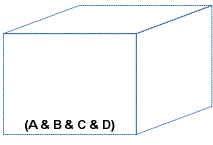

FIGURE 1 : System parameter 3d Model

The meaning of this point is that customers are willing to pay the maximum price (71 euro-cents per KM), to use the widest time window (>25 minutes), to tolerate the maximum ride time (3.5 times the time for the shortest path). On the other hand, point (A) represents the customers that are willing to pay the minimum price (17 euro-cents), to use the minimum pickup (deliver) window, to tolerate ride time that is 1.5 times the minimum ride time (the shortest path time). The same holds for every point (small cube) inside the wrapping cube. We can observe that if a transportation system satisfies user demands at point (B) (X=25.5, Y=1.5, Z=15), then that system satisfies every point

inside the cube $\quad$ (B & C & D) $\quad$ that has as starting at point (25.5-1.5-15). The same holds

for cube $\quad$ (C & D) $\quad$. Based on that observation we can create a number of wrapping cubes, for every small cube. The total number of demands of every wrapping cube is the

sum of all included small cube. For example, the number of demands of the wrapping cube at point (A) is the **sum** of small cubes (A), (B), (C), (D).

3.3. The Convergence algorithm.

In order to reach the desirable point where the system becomes profitable, we conduct an extensive sequence of simulations. The profitability of a DRT system is not the only factor we are interested in. One of the most intriguing issues concerning DRT systems is service quality versus price. The Convergence algorithm is designed to reach the point where the system turns from no profitable to profitable, while the service quality remains the same. The Algorithm follows a sequence of simulations in order to reach that point. That sequence is constructed by a specific way. The first course of action is to decide what the desired service quality is. This can be decided either by finding what are the most common service quality features for the trips, or by system provider strategic decision. Service quality features – for this specific study, since many other features could be defined – are pickup (deliver) time windows and maximum ride time. Our scale of time windows begins from 5 minutes and ends to >25 minutes. The scale of maximum ride time has 1 as the beginning point and 3.5 as the ending point. Max ride time means the time that a customer spends on the vehicle in comparison with the taxi time which is always considered as the time for the Shortest Path Distance. These values represent the multiple factor of the taxi time. The following notation helps us distinguish each point for each axis of the the 3-d model. Let X_i $(i=1,2,...M)$ represent distinct points for axis X, Y_j, $(j=1,2,3...N)$, for axis Y, Z_k $(k=1,2,3...K)$ for axis Z. The total number of all discrete possible points is $MxNxK$. As a first step we find where the biggest concentration of trip demands is in terms of time window time and max ride time. If there are other concentrations (in terms of number) near the largest one, then we select the point related to the concentration that has the tightest restrictions in terms of time window and maximum ride time. For example, if the largest concentration of trip demands has a time window of 20 minutes and the ride time is 2 times and there is no other major trip concentration near that concentration point then we select that time window and that maximum ride time as reference point for service quality. If the largest concentration of trip demands has time window 20 minutes and ride time 2 and there is another big concentration that has time window 15 minutes and max ride time 1.5 then we select the latest one as service quality indicators. Of course, the system operator can use his own estimation of the appropriate or desirable offered service quality and define these indicators. After that we start the simulation sequence by using the following rule: Use the wrapping cube that has point $(X_i$ - Y_i - $Z_i)$ where $i=a=1, j=\beta, k=\beta$ represent the predefined indicators concerning time windows and maximum ride time, as the start point. We run the simulation for that point $(X_\alpha$ - Y_β - $Z_\gamma)$ that represents the total trip number TN_{ijk} included in that cube, without any restriction for the number of vehicles. After the simulation has been executed, the algorithm returns the numbers of vehicles used in order to satisfy all trip demands and the total distance $(TD_{ijk}, i=a, j=\beta, k=\gamma)$ covered by all vehicles. By using these results we can easily calculate:

1. The total cost (TSC_{ijk}, $i=a$, $j=\beta$, $k=\gamma$) of the system, where $TSC_{ijk}=f(TD_{ijk})$ Suppose that the cost *cost_per_distance_unit* per distance unit is known , then the function $f(TD_{ijk})=TD_{ijk}*cost\_per\_distance\_unit$. (function $f(TD_{ijk})$ is not always linear)

2. The total charging fees (TCF_{ijk}, $i=a$, $j=\beta$, $k=\gamma$) where $TCF_{ijk}=g(TD_{ijk})$. Suppose that the charge *charge_per_distance_unit* per distance unit is known , then the function $g(TD_{ijk})=TD_{ijk}*charge\_per\_distance\_unit$. (function g($TD_{ijk}$) is not always linear)

3. Profit or (loss) ($P_{ijk} = TCF_{ijk} - TSC_{ijk}$,$i=a$, $j=\beta$, $k=\gamma$)

If the simulation produces loss for that X_i ($i=\alpha$) then we recalculate the charging fee by using the following formula *new_charge_per_distance_unit*= TSC_{ijk}./ TD_{ijk} After that we select the first appropriate X_i ($i=p$) (where $p > \alpha$) with a value bigger than the *new_charge_per_distance_unit* value. By using a new point X_i ($i=p$) we have to deal with a new wrapping cube (X_p - Y_a - Z_β). It is obvious that, at that new point (X_p - Y_a - Z_β), the wrapping cube contains less trip demands that the previous one.

If the simulation produces profit for that X_i ($i=\alpha$) then we follow the same procedure mentioned above, but in that case we select the new appropriate X_i ($i=p$) (where $p< \alpha$) with a value smaller than the *new_charge_per_distance_unit* value.

Next step is to run the simulation again. That process continues until we find the point where the calculation produces not profit or loss. If we identify that point then we know that this point is the systems' point of equilibrium. The Convergence algorithm could be presented by pseudo code as follows:

Step 0:   *Define service quality indicators (time windows & ride time) either by using data analysis either by manual definition.*
Step 1: *Start at that point which is: closest to the axis-x start while keeping fixed service quality indicators*
Step 2: *Run the simulation and calculate total operating costs(TSC_{ijk})and total charging fees (TCF_{ijk})*
Step 3:
   Step 3.1: if there is a loss then calculate the new charge value that produces profit if it is applied to the current itinerary.
   Step 3.2: Identify the point on axis-x that has the first bigger value close to the previous calculated new charge value.
   Step 3.3: if there is a profit then calculate the new charge value that produces loss if it is applied to the current itinerary.
   Step 3.4: Identify the point on axis-x that has the first lower value close to the previous calculated new charge value.
   Step 3.5: if there is no profit or loss go to step 5:
Step 4: *Move to that point and Go to Step 2:*
Step 5: *Exit*

3.4.   The Underlying DARP Algorithms

In order to run the simulation we used specific DARP algorithms in order to achieve feasible solutions. The DARP algorithm that will be used for the purposes of that simulation is a hybrid algorithm that consists of a pure heuristic part and a pure exact part. That algorithm is called "Very Large Scale Neighborhood heuristic" (VLSN) that uses:

1. An *"simple insertion heuristic"* at the initial phase to get an initial solution for the problem

2. An *"exact 2-vehicle"* approach as a sub module to perform the search in order to reach more optimized solutions

The aforementioned algorithm has been presented on the 87th TRB conference in USA and can be found on the TRB site (11).
A short description of that algorithm should be given for a better understanding of the process.

Simple Insertion heuristic algorithm
The Simple insertion algorithm that has been used is a variation of the one presented by Jaw(15). The basic task of that algorithm is to create an initial solution (specific trips assigned to specific vehicles) that can be used as a reference by the VLSN heuristic. VSLN heuristic needs an initial solution because that initial solution provides the associated set of assigned trips for every vehicle to be used by the "exact 2-vehicle" algorithm.

Exact 2-vehicle
Due to the nature of the problem, to get the exact solution for the DARP problem it is necessary to evaluate every feasible combination of trip requests and vehicles that we cannot rule out based on some technique. Given the problem's combinatorial nature it is obvious that the number of combinations explodes, making any exact approach meaningless for realistic size problems. The DP implementation was developed by using recursive techniques. Recursive techniques offer tracking of the last execution point in the algorithm. The algorithm starts with an initial combination. Based on that combination, it finds the next one, which contains the parent--previously produced combination. The process continues that way, till to find the "final" or "bottom" combination. The cost produced from the first full trip solution is used as a reference point to the next searches. If a trip combination is not feasible or the produced cost until that time is larger than the previous calculated one, the search using that combination is discontinued.

The Heuristic – Exact Algorithm
The heuristic part of that algorithm uses the above referenced exact 2-vehicle algorithm. The main idea is to search in a larger neighborhood of the solution space. The basic idea is based on using the analytical 2-vehicle approach for exploring a large neighborhood which classifies it as Very Large Scale Neighborhood (VLSN) heuristic (Ahuja)(12). The approach is continuously applying the above presented exact 2-vehicle approach for every possible combination of vehicles routes. For example, if we use 4 vehicles (Vi,

i=1,2,3,4), all possible 2-vehicle combinations are: V1-V2, V1-V3, V1-V4, V2-V3,V2-V4,V3-V4. For every combination we execute the exact algorithm that provides a better solution (in terms of cost if that is objective function) than the pervious calculated cost, because of the exact evaluation. As the process continues the algorithm reaches a point where no more optimization can be found. At that point algorithm terminates because further execution could not produce more optimized results. Prior to that algorithm running, the "simple insertion heuristic" algorithm should be executed. That step is required in order to feed the algorithm with an initial solution.

4.   TEST CASE – THE MUNICIPALITY OF PHILLIPI

The rural Municipality of Philippi, Greece, was chosen for the test case. The Municipality consists of 19 villages with a total population of 10,827 inhabitants, most of which, as at most Hellenic villages, are elderly. In the Municipality of Philippi, there are villages with as many as three thousand inhabitants and others with only twenty to thirty inhabitants. That was an important factor in selecting the specific Municipality. Another important factor was the distance of the villages from the big urban centres and the facilities provided by these villages. At the initial area evaluation, the elaboration of the official existing public transport system ("KTEL") itineraries showed some interesting results. In some villages, the frequency of the trips to the largest urban centre of the area, the city of Kavala, was fairly high, while in other villages it was sparse. Moreover, in some villages there were no scheduled buses at all. Also, a few major villages house institutions such as schools, medical centers, municipality offices etc, thus attracting most of the outgoing travels from smaller villages.

In order to understand the potential acceptance of the system by the users, a survey was conducted, by means of a carefully outlined questionnaire. The purpose of the survey was to investigate the market potential and the potential acceptance of the system in a rural community in Greece. As already mentioned, identifying the potential acceptance of the system by its users is quite crucial in deploying a public or private entity to provide DRT services, because the level of acceptance and the profitability of DRT transportation system will depict the need and the potential for its introduction. It is also crucial because it can help secure subsidies by the local or general government.

In this case, the questionnaire was specially designed to capture the intention of the inhabitants of the area towards the proposed system. The method of data collection that was followed was face-to-face interviews by trained people that had a good knowledge of the area, the available modes of transport and the population's mobility needs. In order to ensure that the results of the survey would be reliable, stratified sampling of approximately 2% (220 qustinaries) of the population was used. The questionnaire consists of two parts.

The first part includes some general questions for the respondents, such as their sex, their age, their permanent place of residence, their employment status, their main occupation, their education level, the number of people that live in their household, their average annual household income, the kind of communication systems they use, whether they experience any kind of disabilities, their main mode of transport and finally, the frequency and the main purposes of their trips.

The second part includes questions that are required to figure out the basic design parameters of the proposed DRT system that affects its profitability. In order to get the questinarie more undestandable to the people some questions had specific answers. So the responded had to choose of one of the proposed answers. Those questions (and the possible answers) were:

1. The specific days when their trips are conducted (every day of week)
2. Their origin and destination locations (every combination between 19 vilages)
3. Their time of departure

(Possible answers)

1. 06:00 - 09:00
2. 09:00 - 12:00
3. 12:00 - 16:00
4. 16:00 - 21:00
5. 21:00 - 23:59

4. The time they are willing to wait for pick-up on the average

(Possible answers)

1. 0 – 5 minutes

2. 6 – 10 minutes

3. 11 – 15 minutes

4. 16 – 20 minutes

5. 21 – 25 minutes

6. > 25 minutes

5. The amount of money that they are willing to pay in order to travel faster

(Possible answers)

1. Bus Price (17 euro cents / per KM)
2. 1.5 more than bus price (25.5 euro cents / per KM)
3. Twice the bus price (34 euro cents / per KM)
4. 0.75 taxi price (53.25 euro cents / per KM)
5. Taxi price (71 euro cents / per KM)

6. The maximum travel time that they are willing to spend travelling in comparison of taxi travel time for the same distance.

1. Same as taxi *(1 time the SP travel time)*
2. 1.5 the taxi time*(1.5 times the SP travel time)*
3. Twice the taxi time*(2 times the SP travel time)*
4. 0.5 Bus Time*(2.33 times the SP travel time)*
5. 0.75 Bus Time *(2.8 times the SP travel time)*
6. Bus time *(3.5 times the SP travel time)*

7. If they were willing to use the new DRT system.

1. Yes
2. No

8. If they are satisfied by the existing transportation system.
1. Very Good
2. Good
3. Mediocre
4. Bad

Additionally, in what way they like to schedule their trip and finally, if they have any special service needs, how long in advance they are willing to schedule their trip, what benefits they foresee from the proposed system.

The statistical analysis of the answers helped draw useful conclusions. Since the total population of the 19 villages is not normally distributed, a representative sample of both sexes and all age groups was taken, in order to acquire a more indicative picture of the common perception of the new system.

For all possible combinations of charging cost (ticket fare), times the SP travel time (maximum travel time), pickup time window for those users who wish to use the system and they are not satisfied by the existing transportation services we have:

1. The number of the projected trips to whole population as they producted from the survey
2. The accumulated number of projected trips for that wrraping cube that described by those specific coordinations accrording to 3-d model.
   Following table presents in detail the way in which the data are organized

Table 2 Number of projected trips and the accumulated number of trips (according to the 3-d model)

Charging Cost(cents/per KM)
1. (17)
2. (25.5)
3. (34)
4. (53.25)
5. (71)

Times the SP travel time
1. (1)
2. (1.5)
3. (2)
4. (2.33)
5. (2.8)
6. (3.5)

Time window In minutes
1. (0–5)
2. (6–10)
3. (11 – 15)
4. (16 – 20)
5. (21 – 25)
6. (> 25)

Charging Cost(cents/per KM)	Times the SP travel time	Time window In minutes	#of projected trips	Wrapping cube accumulated number of trip demands
1	1	1	0	**1112**
	1	2	65	**954**
	1	3	0	**528**
	1	4	0	**38**
	1	5	0	**0**
	1	6	0	**0**
	2	1	0	**838**
1	2	2	0	**773**
	2	3	71	**477**
	2	4	0	**38**
	2	5	0	**0**
	2	6	0	**0**
..	..	..	..	**..**
2	2	2	27	**525**
..	..	..	..	**..**
3	2	2	76	**185**
..	..	..	..	**..**
..	..	..	..	
4	2	2	0	**38**
..	..	..	..	**..**
..	..	..	..	**..**
5	6	1	0	**0**
		2	0	**0**
		3	0	**0**
		4	0	**0**
		5	0	**0**
		6	0	**0**

5. COMPUTATIONAL EXPERIENCE

By use of the above statistical analysis, we can design our experiments. Before we proceed it is <u>necessary to define </u>the real operational cost per KM for a DRT transporation system. To the knowledge of the authors, there is no such study that calculates costs like that in a generally applicable way. This seems quite logical taking into consideration the variance of the different factors that affect the cost. In the current study we used the taxi cost as the operational cost. This cost has been estimated by taxi drivers as 34 euro cents per KM for distances above 300 KMs /per day, 40 euro cents for distances between 200-300 KMs /per day, and 45 cents for distances below 200 KMs/per day. Next step was the definition of the desired service quality. By data analysis we found that **the most desired service quality parameters** were:

Waiting Time Window: 6-10 minutes
Max Ride Time in comparison to SP Travel Time: 1.5 times the SP travel time
Experiment design included also the vehicle capacity definition. For our experiments we have chosen three different seat vehicle capacities (8,12,16)

The following table (Table 3) presents the convergence algorithm behavior during various tests. Columns explanation is presented in the following list.
1st first column is the number of the experiment – as they were referenced above.
2nd column is the accumulated (wrapping cube) number of demands,
3rd the third column is the charging cost per KM that we charge customers
4th column is real vehicle cost per KM in Euros
5th is the number of vehicles that should be used in order to satisfy all trip demands
6th is the total distance in KM's covered by all vehicles
7th is the total passengers distance, is which means the sum of all Shortest Path distances for all customer trip demands.
8th is the total vehicle cost which the product of 4th and 6th column
9th is the total charging cost for all trip demands
10th is the pure profit in Euros
11th is the percentage profit to total vehicle cost
12th is the average time number the shortest path ride time
13th is the converge algorithm correction value concerning the charging cost per KM
14th is the converge algorithm next value according to survey
15th is the average number of passengers per KM
16th is the logical value indicating if there is an equilibrium point for the convergence algorithm.

Table 3 Experiment Set Results (Vehicle capacity 8, 12, 16 seats)

# of Experiment	Number of accumulated (projected) trip demands	Charging Cost	Real Vehicle Cost Per KM in euros	Number of Vehicles	Total Vehicle Distance in KMs	Total Passengers Distance in KMs	Total vehicles Cost (Euros)	Total Charging Cost (Euros)	Profit (Euros)	Profit (Loss) percentage to real vehicle cost	Times the Max trip Ride Time(Actual Value)	Converge Algorithm Correction Value	Converge Algorithm Next Value	Average Number of passengers per KM	Critical Point for "break even"
1(8-seat) vehicle	773	0.17	0.34	13	4997	8539	1698.98	1451.63	-47.35	-14.56%	1.3	0.19896709	0.255	2.008	No
	525	0.255	0.34	9	3407	5933	1158.38	1512.92	354.54	30.61%	1.38	0.19524355	0.17	2.18	**Yes**
	185	0.34	0.4	4	1171	1738	468.40	590.92	122.52	26.16%	1.4	0.26950518	never reach that point	1.83	no
	38	0.5325 0.71	0.45	2	369	671	166.05	357.31	191.26	115.18%	1.16	0.24746647	0.17	1.81	No
2 (12-seat) vehicle	773	0.17	0.34	10	4477	8539	1522.18	1451.63	-70.55	-4.63%	1.41	0.17826209	0.255	2.42	No
	525	0.255	0.34	9	3281	5933	1115.54	1512.92	397.38	35.62%	1.39	0.18802292	0.17	2.25	**Yes**
	185	0.34	0.4	4	1172	1738	468.80	590.92	122.12	26.05%	1.4	0.26973533	never reach that point	1.83	no
	38	0.5325 0.71	0.45	2	369	671	166.05	357.31	191.26	115.18%	1.16	0.24746647	0.17	1.82	No
3 (16-seat vehicle)	773	0.17	0.34	10	4403	8539	1497.02	1451.63	-45.39	-3.03%	1.41	0.17531561	0.255	2.45	No
	525	0.255	0.34	9	3276	5933	1113.84	1512.92	399.08	35.83%	1.39	0.18773639	0.17	2.26	**Yes**
	185	0.34	0.4	4	1172	1738	468.80	590.92	122.12	26.05%	1.4	0.26973533	never reach that point	1.83	no
	38	0.5325 0.71	0.45	2	369	671	166.05	357.31	191.26	115.18%	1.16	0.24746647	0.17	1.82	No

From table 3 we can derive that when the charging cost is minimum (17cents), the system is always non-profitable, whereas it is profitable for all other charging cost levels higher than that, to reach dramatic profit <u>percentages</u> for the highest charging cost (53cents). Nevertheless, we found that the highest real profit is found where the charging cost is 25.5 euro cents per KM. That means that the numbers of demands affects heavily also the profitability. Vehicle capacity is another factor that affects profitability. From table 3 we conclude that the increased vehicles capacity increases profits and puts a burden on the average duration of a single trip, but this slight increase in duration is insubstantial compared to the profit increase. The columns 13 and 14 also show us that whatever the starting point is for the algorithm, algorithm always converge at a single point with is the charging cost of 25.5 euro cents. The system's charging policy remains a strategic decision, depending on whether the operator's goal is high profitability <u>percentages</u> or high profitability <u>in absolute figures</u>.

6. CONCLUSIONS

In this paper we presented a methodology that could assist private or governmental entities in order to establish a DRT system. That methodology focuses in:

1. The way we setup a survey with minimum requirements in order to get the necessary raw data concerning a possible installation of a DRT system
2. The way we process raw data concerning trip demands
3. The convergence algorithm that finds the **critical point** concerning the charging value (ticket fair) where the proposed DRT system turns from non profitable to profitable.
4. The way we identify critical service quality parameters

In order to get solutions – with good quality- for those Dial-a-Ride problems we have been using some brand new algortihms like the VLSN algorithm which is based on large neighborhoud search in order to over come local optimal.

The results of this study provide some general insights about the behaviour of a DRT system concerning its profitability. Factors like pickup time windows, demand maximum ride time; heavily affects the profitability while other factors like vehicle capacity affects in smother way profitability.

For the test of municipal of Philipi we found that the critical charging cost was 25.5 cents per KM. That price was fair enough for that area profile. Finally, we conclude that the proposed DRT system would be an economically viable solution to the specific area.

Future research could focus to the study of a more general framework that takes in consideration many other factors (social-economic, market penetration factors, more complex charging schemas, more complex -incoming rate- demand models, number of vehicles, vehicles capacity) and can be applied to urban, suburban and rural areas.

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Publication 3: A Large Neighborhood Heuristic Algorithm for the Multivehicle Dial a Ride with Time Windows

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A Large Neighborhood Heuristic Algorithm for the Multivehicle Dial a Ride with Time Windows

Abstract

This paper is concerned with the static dial–a–ride problem; it introduces an exact approach for the 2-vehicle problem, which then is used for designing an efficient multivehicle large neighborhood heuristic. The exact algorithm is based on Psaraftis' Dynamic Programming pionnering design but computationally improved for memory management. The very large neighborhood heuristic algorithm iteratively redistributes requests between any two vehicles at a time until no more improvements cane be achieved. The computational results demonstrate the efficiency of the approach and quality of the produced solutions.

INTRODUCTION AND LITERATURE REVIEW

The Dial a Ride Problem (DARP) is the generalization of the well known capacitated Traveling Salesperson Problem (TSP) and of course it was proven by Healy and Moll *(1)* to be an NP-Hard Problem. Despite its intractability many efforts were made to produce exact algorithms. Pioneering approaches were presented in the early 80's by Psaraftis *(2)* Psaraftis' Dynamic Programming (DP) approach is limited to a single vehicle. Later Dumas *(3)* presented a combination of branch-and-bound and column generation, which solved exactly some multi vehicle problems. Another approach is introduced by Desrosiers *(4)* who solved the problem of one vehicle and almost 40 trip requests. Due to great demand of transportation systems, where the DARP problem plays a critical role, research was oriented to heuristics approaches in order to solve large scale problems. First attempts presented by Jaw *(5)* can be characterized by the "sequential insertion" orientation. Sexton and Bodin *(6)* introduced the concept of "cluster first and route second" where customers who are close together forming a cluster by the use of a heuristic algorithm. At the second phase, they applied Bender's decomposition and solved the scheduling and routing problem for every cluster. Newer trends introduced the concept of the secondary optimization phase. That concept which requires a construction phase, where an initial solution found and the optimization phase by the use of intra-trips, inter-trips exchanges try to improve the solution as presented by Savelsbergh *(7)* Stopping criterion was the no more optimization for a certain execution cycle of algorithm. Final result is a local optimal solution, where algorithm cannot overcome. Last trends concentrated on the TS approach *(8), (9)*. Where there is a construction phase that produces an initial solution – feasible or not - and a refinement phase where the initial solution is refined continuously. The refinement is based on a set of empirical parameters that can be self corrected during the execution. The idea is based on the fact that the algorithm can eventually overcome local optimum crossing worst "areas" in term of solution quality and can reach better solutions. Closeness to the optimal solution can't be quarantined or estimated somehow. Regret and simulated annealing techniques have been introduced also. The reader can be referred to the study by Cordeau JF and Laporte G *(10).*

In this paper we introduce a very large neighborhood heuristc algorithm that uses a 2 vehicle exact approach to solve the dial-a-ride problem. A very large scale neighborhood (VLSN) heuristic algorithm is one that searches a considerably larger

neighborhood of feasible solutions than the typical local optimum algorithms. There are three main categories of such approaches that are outlined in Ahuja, Ergun, Orlin and Punnen (2002): variable depth methods, network flow based methods, and restrictions on NP hard problem methods. The introduced in this paper approach falls under the third category; it performs cyclic exchanges of all requests between any two vehicles by using the exact approach. The computational results indicate that it produces near optimum solutions in small problem instances for which exact solutions exist. This algorithm is a part of paratransit system that has been designed to provide transportation services.

The paper is organized as follows: The problem is defined and formulated in Section 2. The solution approach in Section 3. Numerical Results are presented in Section 4. The closeness to the optimal solution is assessed in Section 5. Section 6 concludes this paper and provides pointers for future research.

PROBLEM FORMULATION, DEFINITIONS AND NOTATIONS

The typical DARP problem is defined as follow: Given a set of vehicles and a set of trip requests compute the optimum (for passengers and/or the operator) itinerary for every vehicle, without violating certain constraints. For every vehicle, it is typically defined a depot location ("start", "end" that may not be necessarily the same), a capacity and a maximum vehicle drive time. Trip requests are characterized by pickup and deliver sites, time windows for pickup and delivery, maximum trip drive time. Those features are primary features for a trip request. More features can be considered, such as "customers type". i.e for persons with disabilities. At the current study we stay to the primary features.

The basic notation concerning Vehicles and Trip Requests presented in Table 1:

TABLE 1 Basic Notation

$V = \{1,2,3, \quad ,|V|\}$ = Set of Vehicles
$Q_v = \{ Q_1 .. Q_{|v|} \}$ Vehicles capacity for all v in V
$VSD = \{1, 2, \ldots , |V| \}$ = Set of "start" depots for all vehicles.
N = is the number of trip requests. Each trip request is consisted by one pickup and one deliver node.
$VED = \{ 2N +|V|+1, 2N+|V| +2, \ldots ,2N +2|V| \}$ = Set of "end" depots for all vehicles.
$Mvrt_V = \{ Mvrt_1 .. Mvrt_{|V|} \}$ = is the maximum vehicle ride time for every $v \in V$
$VSED = \{ 1, 2, \ldots , |V|, 2N +|V|+1, 2N +|V|+2, \ldots , 2N +2|V|\}$ = Set of "start" & "end" depots for all vehicles.
$P^+ = \{|V|+1, |V|+2,\ldots |V|+N \}$ = Set of pickup nodes in the network. $P^- = \{ |V|+N +1, |V|+N +2,\ldots |V|+2N\}$ = Set of deliver nodes in the network.
$P = P^+ U P^-$ = Set of pickup and deliver nodes in the network.
$P^{all} = P U VED U VSD$ = Set of total nodes (pickup, deliver, "start depot", "end depot") in the network.
$[e_i l_i]$ = time windows [earlier, late] for each node (pickup, deliver, "start", "end" depot nodes) $i \in P^{all}$.
$DRT_i = \{ DRT_1, .. DRT_N\}$ Set of requests maximum ride time for every trip request, $i \in P^+$

drt_i = index of the DRT_i set.

τ_{ij} = travel time from node i to j where $i,j \in P^{all}$, .

c_{ij} = travel cost from node i to j where $i,j \in P^{all}$, .

s_i = service time at node (pickup or deliver) $i \in P^{all}$.

d_i = load at node (pickup or deliver) $i \in P^{all}$. (+1 for pickups, -1 for delivers, 0 for "start", "end" depots)

$x_{ij}^v, i, j \in P^{all}, i \neq j$ = 1, if i^{th} request is served by vehicle v. 0 in another case.

$T_i^v, i \in P^{all}$ Is the time variable which describes the time that the service begins at node i.

$L_i^v, i \in P^{all}$ Is the load variable which describes the vehicle load on every node.

A commonly used objective function minimizes total travel cost as follows:

$$\sum_{v \in V} \sum_{i \in P^{all}} \sum_{j \in P^{all}} x_{ij}^v c_{ij} .$$

Clearly, we need another set of constraints concerning:

1. Trip time window constraints ($[\mathbf{e}_i\ l_t]$)
2. Maximum vehicle ride time constraints ($Mvrt_V$)
3. Maximum trip request ride time (DRT_i)
4. Maximum Vehicle load restriction (Q_v)

The above results in the following Mixed Integer Linear Program

$$\min \sum_{v \in V} \sum_{i \in P^{all}} \sum_{j \in P^{all}} x_{ij}^v c_{ij} \tag{1}$$

ST:

$$\sum_{i,j \in VSED} x_{ij}^v = 0, v \in V \tag{2}$$

$$\sum_{j \in P^{all}} x_{ij}^v - \sum_{j \in P^{all}} x_{(i+N)j}^v = 0, i \in P^+, v \in V \tag{3}$$

$$\sum_{v \in V} \sum_{j \in P^{all}} x_{ij}^v = 1, i \in P^+ \tag{4}$$

$$\sum_{j \in P^{all}} x_{ij}^v - \sum_{j \in P^{all}} x_{ji}^v = 0, i \in P , v \in V \tag{5}$$

$$\sum_{j \in P^+} x_{ij}^v = 1, i \in VSD, v \in V \tag{6}$$

$$\sum_{i \in P^-} x_{ij}^v = 1, j \in VED, v \in V \tag{7}$$

$$\sum_{j \in P^{all}} x_{ij}^v = 1, i \in P^{all}, v \in V \tag{8}$$

$$\sum_{i \in P^{all}} x_{ij}^v = 1, j \in P^{all}, v \in V \tag{9}$$

$$\sum_{i \in P^{all}} x_{ii}^v = 0, i \in P^{all}, v \in V \tag{10}$$

$$\sum_{i \in P^{ved}} x_{ij}^v = 0, j \in VSD, v \in V \tag{11}$$

$$\sum_{j \in P^{vsd}} x_{ij}^v = 0, i \in VED, v \in V \tag{12}$$

$$T_i^v + s_i + \tau_{ij} \le T_{(i+N)}^v, i \in P^{all} \tag{13}$$

$$x_{ij}^v = 1 \Rightarrow T_i^v + s_i + \tau_{ij} <= T_j^v, i, j \in P^{all} \tag{14}$$

$$x_{ij}^v = 1 \Rightarrow T_i^v + s_i + \tau_{ij} <= T_j^v, i \in VSD, j \in P^+ \tag{15}$$

$$x_{ij}^v = 1 \Rightarrow T_i^v + s_i + \tau_{ij} <= T_j^v, j \in VED, i \in P_t^- \tag{16}$$

$$x_{ij}^v = 1 \Rightarrow L_i^v + d_j \le L_j^v, i \in P^{all}, j \in P^+, v \in V \tag{17}$$

$$x_{ij}^v = 1 \Rightarrow L_i^v + d_j \ge L_j^v, i \in P^+, j \in P^-, v \in V \tag{18}$$

$$x_{ij}^v = 1 \Rightarrow L_i^v + d_j \ge L_j^v, i \in P^-, j \in P^-, v \in V \tag{19}$$

$$x_{ij}^v = 1 \Rightarrow L_i^v + d_j \le L_j^v, i \in P^-, j \in P^+, v \in V \tag{20}$$

$$e_i \le T_i^v \le l_i, i \in P^{all}, v \in V \tag{21}$$

$$T_i^v \le drt_i, i \in P^+, v \in V \tag{22}$$

$$T_i^v \le drt_{i-N}, i \in P^-, v \in V \tag{23}$$

$$T_i^v \le mvrt_v, i \in P^{all}, v \in V \tag{24}$$

$$L_i^v \le Q^v, i \in P^+, v \in V \tag{25}$$

$$L_i^v = 0, i \in VSED \tag{26}$$

$$x_{ij}^v, binary$$

The Objective function (1) minimizes the total cost produced by all vehicles.
Constraint (2) ensures that no vehicle moves empty from "start" to "end" depot.
Constraints (3 and 4) guarantee that each request is served exactly once and pickup, deliver nodes are visited by the same vehicle.

Constraints (6 and 7) guarantee that the route of each vehicle *v* starts at the origin depot and ends at the destination depot.

Constraints (5, 8 and 9) is the system "mass" equilibrium

Constraint (10) ensures that we don't use the same node as source and destination

Constraint (11) ensures that every vehicle, during the trip is not going to reach the "start" depot.

Constraint (12) ensures that the vehicle will stop its trip at the "end" depot node.

Constraints (13 through 16) ensure that for each request, the pickup node is reached before deliver node. Time variables concerning the time that the service begins - on every node - is calculated here.

Constraints (17 through 20) ensure the consistence of load variables for every request

Constraint (21) ensures that each request time windows is not violated

Constraints (22 through 23) ensure that each request maximum drive time is not violated

Constrain (24) ensures that each vehicle maximum drive time is not violated

Constrain (25) Ensures that each vehicle maximum load capacity is not violated
.

SOLUTION APPROACH

The proposed Solution is a Very Large Scale Neighborhood (VLSN) heuristic that uses an exact 2 vehicle approach as a submodule to perform the search. Before presenting the heuristic part, we present the exact part which works as a sub-problem to the heuristic part

The Exact 2-Vehicle Algorithm

In order to get the exact solution for the DARP problem it is necessary to evaluate every possible and feasible combination of trip requests and vehicles. Given the problem's combinatorial nature it is obvious that the number of combinations explodes making the approach meaningless. If somehow we eliminate that number of combinations, then the solution space is restricted making the effort more promising of finding the solution. Memory requirements are another issue. We need to eliminate memory requirements in order to execute the algorithm without to worry of running out of memory resources. Initial attempt for the exact solution for one vehicle was introduced by Psaraftis *(2)* in 1980. He calculated that the required memory locations in order to keep track of all states are of the order $O(3^N)$. Keeping the above observations in mind, we tried to enrich our exact algorithm with features that offer: a. restriction of the solution space as much as possible, b. the independence of memory resources. For those reasons a DP implementation was developed by using recursive techniques. Recursive techniques offer tracking of the last execution point in the algorithm. Every time we have a recursive return we know exactly what is the next point to go further. It works like the Depth First Algorithm (well known graph algorithm). Algorithm starts with an initial combination. Based on that combination algorithm finds next combination, which contains the parent, previously produced combination. The process continues that way, till to find the "final" or "bottom" combination. For example: given one vehicle (denoted as V1) and 2 trip requests (denoted as P1,D1 for picking and delivering trip request 1, P2,D2 for picking and delivering trip request 2). Possible combinations are:
Starting with trip request #1

V1P1 (1+)
V1P1->V1P1V1D1 (2+)
V1P1->V1P1V1D1->V1P1V1D1V1P2
V1P1->V1P1V1D1->V1P1V1D1V1P2-> V1P1D1V1P2V1D2
V1P1->V1P1V1P2 (2-)
V1P1->V1P1V1P2->V1P1V1P2V1D1 (3+)
V1P1->V1P1V1P2->V1P1V1P2V1D1V1D2
V1P1->V1P1V1P2->V1P1V1P2V1D2 (3-)
V1P1->V1P1V1P2->V1P1V1P2V1D2V1D1
Or Starting with trip request #2
V1P2 (1-)
V1P2->V1P2V1D2 (2+)
V1P2->V1P2V1/D2->V1P2V1D2V1P1
V1P2->V1P2V1D2->V1P2V1D2V1P1-> V1P2D2V1P1V1D1
V1P2->V1P2V1P1 (2-)
V1P2->V1P2V1P1->V1P2V1P1V1D2 (3+)
V1P2->V1P2V1P1->V1P2V1P1V1D2V1D1
V1P2->V1P2V1P1->V1P2V1P1V1D1 (3-)
V1P2->V1P2V1P1->V1P2V1P1V1D1V1D2
Specific signs such (1+), (1-) (2+),(2-) (3+),(3-) shows track points that algorithm put in order to remember where to backtrack, after the recursive return.

Trip combination V1P1D1V1P2V1D2 is a fully trip, satisfying all trip requests. That combination is checked for feasibility and if feasible, is evaluated producing travel cost. Above example shows how algorithm produce possible trip combinations. By using track points there is no need to store all combinations because every time we know exactly where to go. That cost produced from that solution is used as a reference point to the next searches. If a trip combination is not feasible or the produced cost until that time is larger than the previous calculated one, the search using that combination is discontinued. The term "feasible" means that there is no violation for:

1.   Time windows concerning trip requests
2.   Time violation concerning maximum trip request ride time
3.   Time violation concerning maximum vehicle ride time
4.   Violation concerning maximum vehicle capacity

As a result, the search is limited in a more restricted solution space. Of course the number of possible combinations is combinatorially increasing as parameter of the trip requests and vehicles number. That technique can't be used in order to solve large problems. Obviously, knowing an initial feasible solution we could substantially improve the search process. To achieve an initial feasible solution we run a simple insertion heuristic algorithm just to produce an initial solution that can be used as a starting point of our exact algorithm. Figure 1 sketches the overall approach.
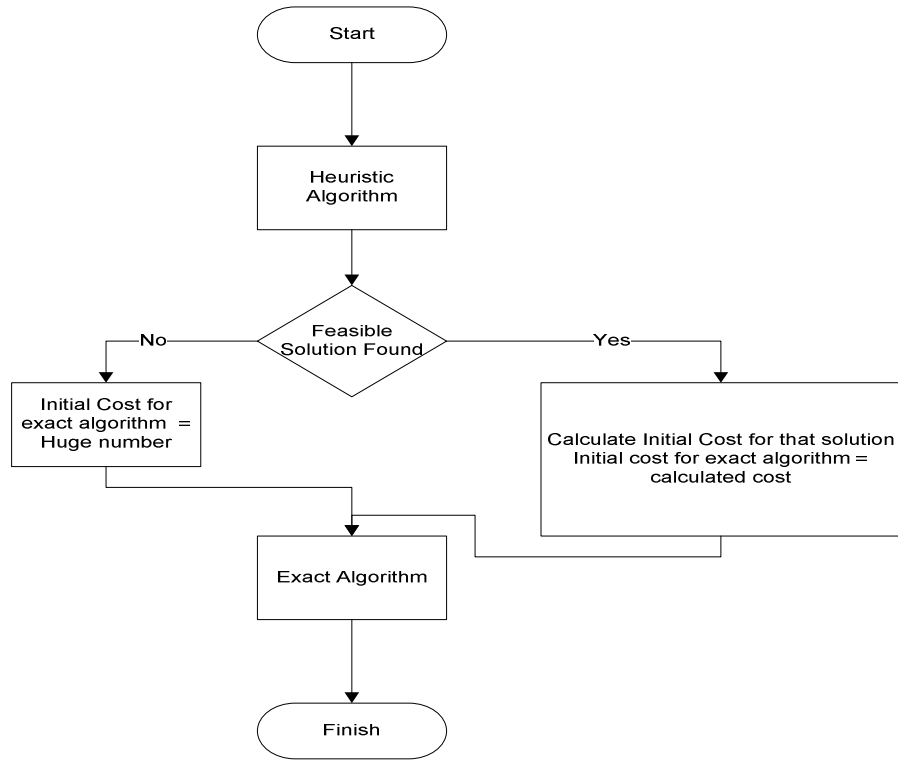
FIGURE 3 Search for initial cost in order to feed exact algorithm

The following example deals with a case where we use 2 Vehicles and 2 trip requests. Each vehicle is denoted as Vx (x=1,2) and each trip request is denoted as Px (x=1,2) for pickups and Dx (x=1,2) for delivers accordingly.

Before executing the exact algorithm, we use a simple insertion heuristic algorithm to produce some initial feasible solution. The heuristic finds a feasible solution with cost of 193.861 distance units. This cost is used as a bound for the exact algorithm. The exact algorithm produces the following output where it is clear on how it works. Not all possible combinations are presented here, because for some cases is useless to search more. (Consider combination case **V1P1V1D1V1P2** where there is no meaning to search for further combinations because already that combination is not feasible). As the algorithm executes finally finds the best combination which is **V1P2V1D2V1P1V1D1** with cost 191.941 distance units.

TABLE 2 Exact Output Example

Combination : V1P1
Combination : V1P1V1D1
*Combination : **V1P1V1D1V1P2** Not feasible solution. (further search is useless)*
Combination : V1P1V1D1V2P2
Combination : V1P1V1D1V2P2V2D2 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V1P1V1P2 Not feasible solution. (further search is useless)
Combination : V1P1V2P2
Combination : V1P1V2P2V1D1
Combination : V1P1V2P2V1D1V2D2 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V1P1V2P2V2D2 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V2P1
Combination : V2P1V2D1
Combination : V2P1V2D1V1P2 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V2P1V2D1V2P2 Not feasible solution. (further search is useless)
Combination : V2P1V1P2
Combination : V2P1V1P2V2D1 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V2P1V1P2V1D2
Combination : V2P1V1P2V1D2V2D1 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V2P1V2P2 Not feasible solution. (further search is useless)
Combination : V1P2
Combination : V1P2V1P1
Combination : V1P2V1P1V1D1
Combination : V1P2V1P1V1D1V1D2 Not feasible solution. (further search is useless)
Combination : V1P2V1P1V1D2 Not feasible solution. (further search is useless)
Combination : V1P2V2P1
Combination : V1P2V2P1V2D1 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V1P2V2P1V1D2
Combination : V1P2V2P1V1D2V2D1 Feasible solution but over current best cost (further search is useless): 193.861
Combination : V1P2V1D2
Combination : V1P2V1D2V1P1
Combination : V1P2V1D2V1P1V1D1
*Combination : **V1P2V1D2V1P1V1D1** New best cost found :191.941*
Combination : V1P2V1D2V2P1
Combination : V1P2V1D2V2P1V2D1 Feasible solution but over current best cost (further

search is useless): 191.941
Combination : V2P2
Combination : V2P2V1P1
Combination : V2P2V1P1V1D1
Combination : V2P2V1P1V1D1V2D2 Feasible solution but over current best cost (further
search is useless): 191.941
Combination : V2P2V1P1V2D2 Feasible solution but over current best cost (further
search is useless): 191.941
Combination : V2P2V2P1
Combination : V2P2V2P1V2D1
Combination : V2P2V2P1V2D1V2D2 Not feasible solution. (further search is useless)
Combination : V2P2V2P1V2D2 Not feasible solution. (further search is useless)
Combination : V2P2V2D2
Combination : V2P2V2D2V1P1 Feasible solution but over current best cost (further
search is useless): 191.941
Combination : V2P2V2D2V2P1
Combination : V2P2V2D2V2P1V2D1 Feasible solution but over current best cost (futher
search is useless): 191.941
Algorithm Ended : (MIN)V1P2V1D2V1P1V1D1 With Cost : 191.941
Time Elapsed in secs : 0.094
Total Combs : 46 Reject Combs : 21

 This exact approach –limited only by the execution time- can solve any DARPTW problem. It can run for days or for months. However combinations number especially in large problems, degrade the usefulness of that algorithm only to small problem instances. (1 vehicle up to 10 trip requests, 2 vehicles up to 8 trip requests, 3 vehicles up to 7 trip requests, 4 vehicles up to 6 trip requests s)**.** A short description of the exact algorithm follows.

***Function** Build_Exact_Combs(current combination)*
If** no_more_requests **then
> *Update Current Best Cost*
> *Update Current Best Trip Combination*
> ***Return** from Build_Exact_Combs (recursive return)*

Else
> **For** *every Vehicle*
>> ***For** Every Trip Request*
>>> *Build_current_combination*
>>> ***If** not a feasible_combination **then***
>>>> ***Continue** next comb*
>>> ***Else if** not produced cost < than current best cost **then***
>>>> ***Continue** next comb*
>>> ***Else***
>>>> ***Call** Build_Exact_Combs(current combination)// recursive*
>>>> ***Return** from Build_Exact_Combs (recursive return)*
>>> ***End if***
>> ***End for***
> ***End for***
End if
End

A graphical description of that algorithm depicted in the following figure
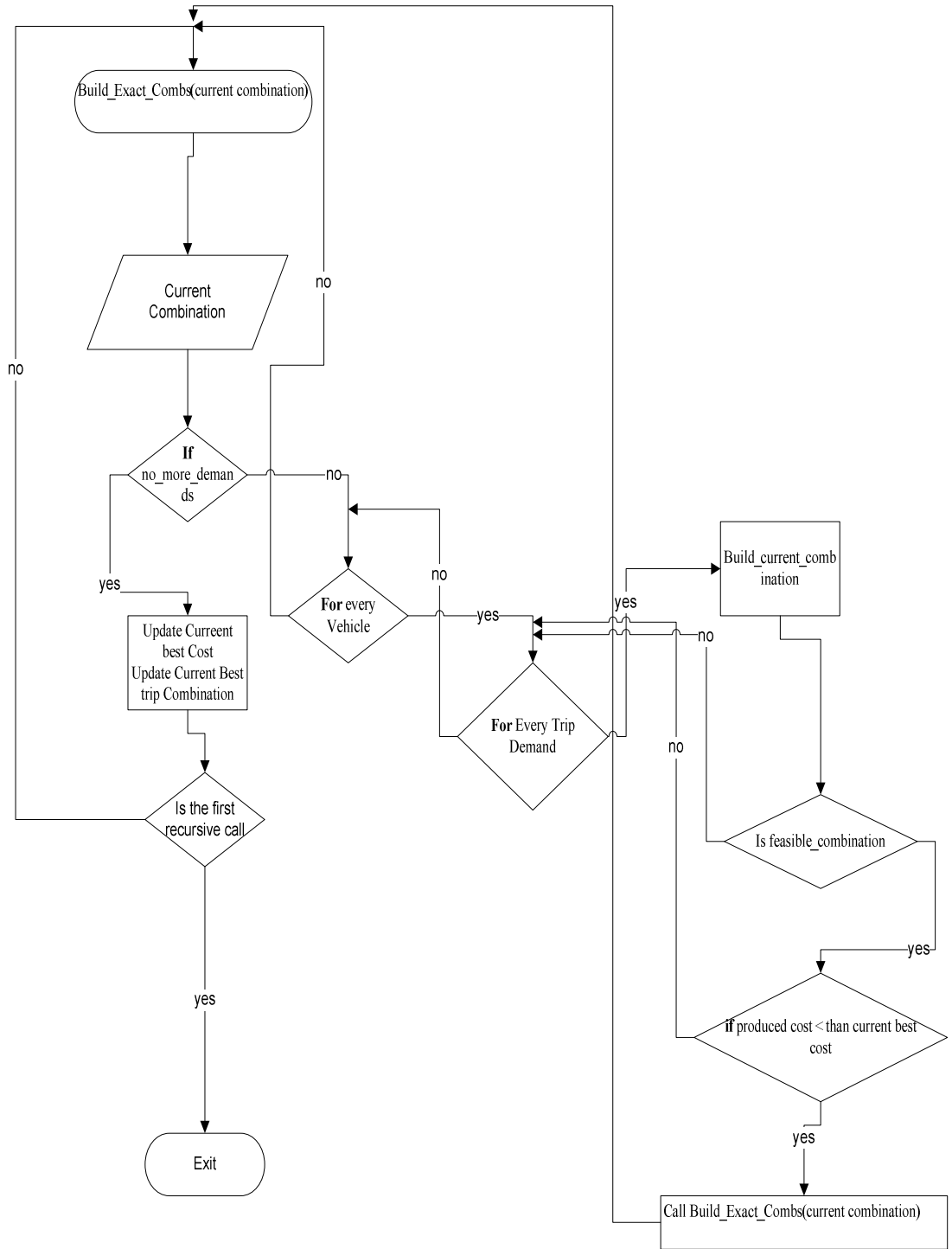

FIGURE 4 Search for initial cost in order to feed exact algorithm

Correctness of the proposed exact algorithm

The above exact algorithm has been tested extensively in order to prove results correctness. We choose to compare that algorithm with the MILP implementation of the DARP problem. The mathematical formulation presented in Section 2 has been used to implement the MILP in AMPL. Both implementations DP and MILP gave always the same results concerning objective function and trips pickup and deliver sequence. Following table shows results of the comparison between two implementations.

TABLE 3 Comparison Results Between DP and MILP implementations

Vehicle Number	Trip Requests	CPU Time for the DP Implementation of Exact Algorithm	CPU Time for the MILP Implementation of Exact Algorithm	Difference between objective functions of DP and MILP implementations
1	4	0.120	0.295	0
1	5	1.030	0.400	0
1	6	22.480	9.124	0
1	7	263.000	267.973	0
1	8	578.964	3527.330	0
2	4	1.150	3.560	0
2	5	15.450	58.280	0
2	6	493.000	1728	0
2	7	1559.000	1193	0
3	4	1.260	7.827	0
3	5	155.910	169.659	0
3	6	604.653	2039.370	0
3	7	8149.000	13649.600	0
4	4	2.450	39.923	0
4	5	17.620	567.857	0
4	6	3583.000	12022.000	0
5	4	2.040	119.407	0
5	5	149.420	2464.070	0
5	6	459.850	2276.190	0
5	7	19592.000	36554.000	0

Execution times show clearly that DP implementation is faster than MILP implementation. For that reason DP implementation has been chosen to be used as sub-problem in the heuristic – exact algorithm implementation.

The heuristic Part

Heuristic part of that algorithm uses the above referenced exact algorithm. The main idea is to search in a larger neighborhood of the solution space. The basic idea is based on the combination between exact part and heuristic part. Exact part is based on the exact evaluation of two vehicles. Heuristic part is based on the continuous appliance of the above 2-vehicle exact evaluation for every possible combination of vehicles. For example, if we use 4 vehicles, all possible 2-vehicle combinations are: 1-2, 2-3, 3-4, 1-3, 1-4, 2-4. For every combination we execute the exact algorithm that provides a better solution (less cost) than the pervious calculated cost, because of the exact evaluation. As the process continues algorithm reaches a point where no more optimization can be found. At that point algorithm terminates because further execution could not produce more optimized results. Prior to that algorithm running, a simplest heuristic algorithm should be executed. That step is required in order to feed the algorithm with an initial solution. A short description of the heuritstic-exact algorithm follows.

Function Hybrid_Exact()
      Build Vehicle Pair Combinations
      While *(no cycle with all vehicle pair combinations completed without optimization)*
         Select next vehicle pair combination
        If *not all vehicles pairs have been examined* **then**
         Run exact algorithm for 2 vehicles
      End if
    End While
End

A graphical description of that algorithm depicted in the following figure
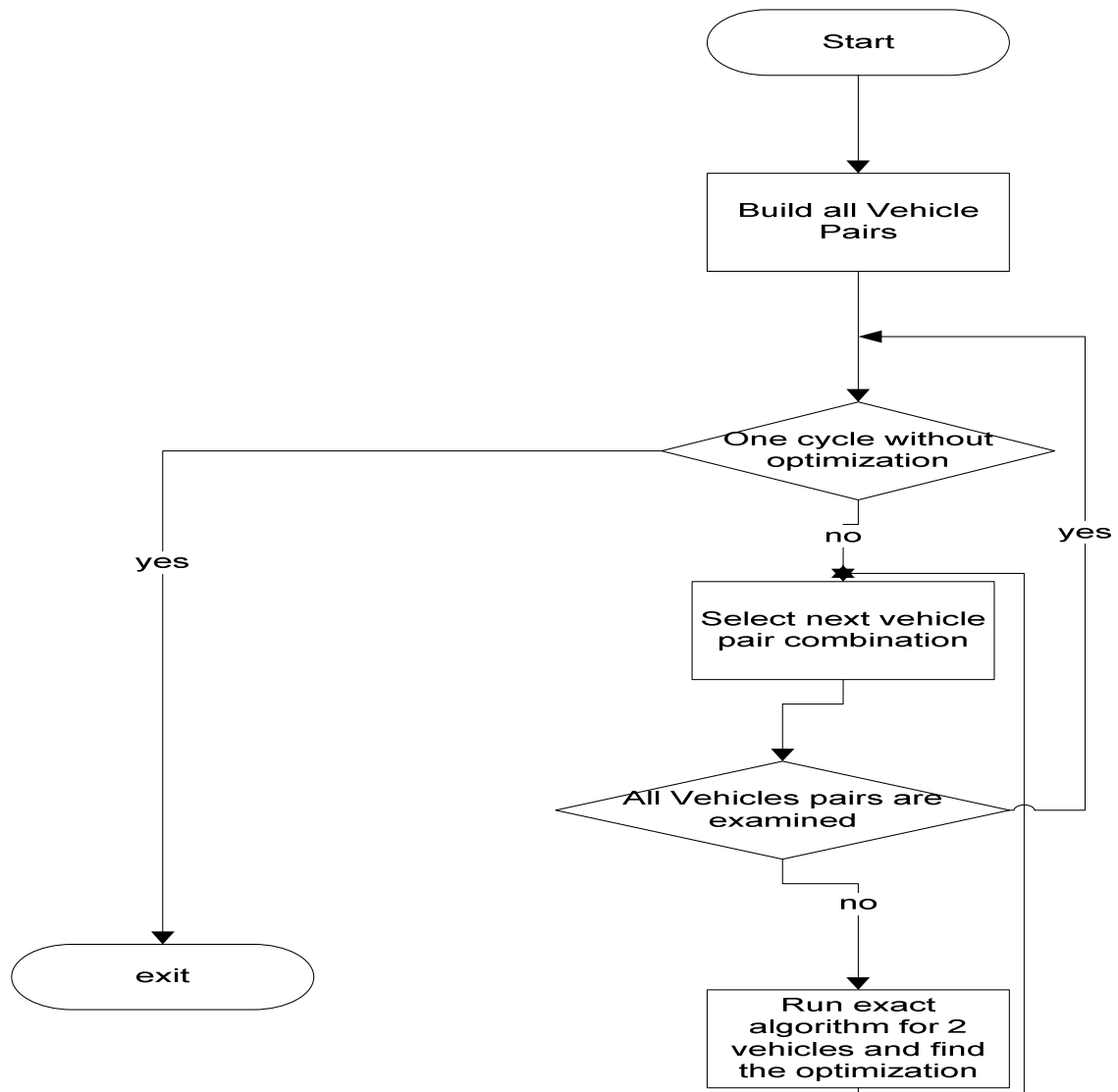

Figure 3 Heuristic - exact algorithm

NUMERICAL RESULTS

The Proposed algorithms exact, heuristic-exact were developed in C++ and tested on a Linux machine with dual core processor. A variety of problem configurations where solved in order to test algorithm extensively. As referenced already, the main algorithm stopping criteria is "one combination cycle without optimization". But the 2 vehicles exact algorithm which is used as sub problem it suffers – concerning the execution time - when trip requests are more than 8. That is why we added an additional stopping criterion which is the execution time for the exact algorithm to take no more than 7200 seconds. Problem instances produced randomly. The test field was a square area 100X100 Kilometers. Pickup and deliver positions of every trip request selected randomly over that area. Vehicle "Start", "End" depots are selected randomly over that area. Time windows for pickup was randomly selected between 0–1440, time windows for delivers produced from pickups time windows plus the 1.5*Cartesian distance between those points. Maximum vehicle ride time was 480.

TABLE 4 Computational Results for Small Instances

Problem	Vehicle Number	Vehicle Capacity	Trip Requests	CPU Time in Sec's	Cost (Heuristic Initial cost)
1	3	4	6	18.28	688.057 (708.166)
2	3	4	7	110.5	539.661 (566.256)
3	3	4	8	3002.22	827.165 (845.014)
4	3	4	9	6108.24	566.066 (578.211)
5	3	4	10	10710.6	843.97 (959.223)
6	5	6	12	567.82	943.145 (1043.34)
7	5	6	14	31139.6	1385.29 (1500.38)
8	5	6	16	76412.8	1588.61 (1774.05)
9	5	8	12	567.82	943.145 (1043.34)
10	5	8	14	3830.84	1321.7 (1425.91)
11	5	8	16	86619.8	1483.95 (1756.4)
12	5	8	20	165650	1692.49 (1988.71)
13	5	8	24	102995	1991.97 (2041.72)
14	5	12	28	144001	2191.74 (2394.34)

Cost is the objective function that is produced by the heuristic-exact algorithm. Cost in parentheses is the objective function that is produced by the insertion heuristic algorithm. Clearly the new heuristic-exact algorithm improves the objective function. For those problem instances that the execution time is larger than 6000 sec's stopping criterion of 7200 sec's for the 2-vehicle exact algorithm has been activated.

CLOSENESS TO OPTIMAL SOLUTION

Although, there is no methodology proposed till now to provide the ability of estimating the closeness to optimal solution of any solution produced by a heuristic, we can provide some computational results that shows that the produced solution by that algorithm and the fully solution provided by the exact algorithm. Of course problem size is limited to small instances because of the limited ability of the exact algorithm to solve large problem sizes. However it is worthwhile to present those results.

TABLE 5 Comparison between Heuristic-Exact produced Solution and the fully Exact Solution

Problem	Vehicle Number	Vehicle Capacity	Trip Requests	Exact Execution Time	Heuristic Execution Time	Objective function Difference
1	3	3	**5**	1587.03	20.55	0
2	3	3	**5**	1819.85	1.12	0
3	3	3	**5**	1635.13	1.74	0
4	3	3	**5**	1779.86	14.59	6.742
5	3	3	**5**	1183.11	13.29	0
6	3	3	**6**	2038.55	80.6	0
7	3	3	**6**	2064.41	4.42	0
8	3	3	**6**	1336.86	242.57	0
9	3	3	**6**	3133.78	18.58	0
10	3	3	**6**	2049.84	245.66	0

CONCLUSIONS

This paper introduces another solution approach concerning the dial-a-ride problem. As it can been seen in the above section (closeness to the optimal solution) it produces results very close to the optimal solution. This algorithm can be used as main-algorithm in paratransit systems where is critical to provide good routes in order to provide better customer service. Further research fields could be: a. improvement of the exact algorithm in order to solve larger problems (at least 16 trip requests, 2 vehicles) by using more problem specific characteristics, b. study for the closeness to optimum solution between heuristic-exact and exact algorithms, c. algorithm solution sensitivity analysis as parameter of the exact algorithm time stopping criterion, d. use of that heuristic-exact algorithm to online algorithms based on the concept of space-time discretization where the number of trips is not so large and can be solved near to optimum..

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Publication 4: A Scenario-Based Semi-Disaggregate Market Share Estimation For A Proposed Paratransit System For Philippi Region, Greece

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Abstract

Paratransit systems are designed to increase the mobility in a region where public transit systems fail to satisfy the demand, specific user needs (mostly for disable people or elderly) or are not sustainable, as in low population density regions. Recently a research project, titled InMoSion, is focused on determination of the user needs and preferred modal attributes, and gathering know-how to help municipalities to develop their own paratransit systems. The project included a survey design and a pilot study in the rural Philippi region in Greece. The following step in the project was the determination of paratransit market share and characteristics to support the system design process. This paper first briefly introduces the scope of the InMoSion project and focuses on the determination of traveler level mobility and modal preferences that led to the design of a scenario-based semi-disaggregate market share estimation approach developed for the pilot region. A price and travel time sensitivity of the forecasted paratransit ridership revealed the price and travel time intervals that mostly impact the paratransit preference in the region.

Keywords: Paratransit, Mode Choice Estimation, Market Share Estimation, Price Sensitivity

1. INTRODUCTION

Paratransit means "alongside" transit. It includes all public and private mass transportation in the spectrum between private automobile and conventional transit [1]. More specifically "paratransit" is defined as "any type of public transportation that is distinct from conventional transit, which provides door-to-door or curb-to-curb service combining the cost advantage of transit with flexibility of more private modes, such as taxi or car" [2]. The terms "demand-driven" or "demand-responsive" are also commonly used interchangeably/in association with paratransit in paratransit literature.

In a study by the Adam Smith Institute [3], paratransit operations in major metropolitan cities in the world, such as Hong Kong, Kuala Lumpur, Istanbul, Cairo, etc., are defined as "light vehicle operations", where "light vehicle" refers to midsize vehicles (8 to 16-passenger capacity) used in such flexible services. In the evaluation of paratransit systems in the developing countries, Cervero [4] uses the term "informal transportation services", which includes paratransit as well as minibuses, microbuses, motorcycles, etc. In this context, paratransit plays a role of filling the service void left by formal public transport operators. The term "dial-a-ride" is also used to refer to paratransit or demand responsive transit (DRT) services, which refers to the fact that people have to call or make a reservation in advance. The in-advance reservation is a critical attribute which supports cost sharing and gains advantage over taxi. Common applications of such systems are airport shuttle services and services for people with disabilities and mobility challenges. In urban locations, paratransit mostly supports the transit system, such as "jitney" service in Cairo (starting in the late 1970s permitted on fixed routes) and "dolmus" services in Istanbul, which were originally shared cab with a 5 to 7 seats, but transformed to minibuses with 8 to 14-seat capacity over time.

The paratransit systems can be an optimal mode to provide the following four general types of services: a) special services for the disable people: If the paratransit system is offered for the disabled, who cannot use stairs and escalators, board or alight from transit vehicles, in an area without regular transit system, it provides opportunity to increase their mobility and make them available to the general public. b) In rural areas, where paratransit has a potential to provide mobility that cannot be sustainable or efficient, when served by traditional transit services, due lack of demand and long routes and travel times. c) Late-night and off-peak period service which substitutes very lightly traveled bus routes in low density areas and d) as an independent permanent service in small cities; as transit service in suburban areas coordinated with regular bus routes serving the central city (Ann Arbor), or as feeders to suburban rail transit stations (Toronto region) [5].

Price and travel time level of service are again two main attributes of paratransit, as in the

case of transit services. Thus, any policy decision on these attributes would affect the market share of paratransit directly. Another factor affecting the success of a paratransit system is whether it be route- based or door-to-door services (or curb-to-curb); while the former has a better chance for sustainability, if the routes are designed to serve along the high demand relocations (as in the case of "dolmus" services in Turkey), the latter requires a more vigorous vehicle routing tool that would combine nearby trips in an effective and efficient order, which can be achieved by specially developed vehicle routing algorithms supported by real-time information exchange.

A new generation paratransit systems is being developed by assisting paratransit services with Intelligent Transportation Systems (ITS), where not only booking is done in a computerized manner, but also the vehicle routing would be supported by algorithms using recently developed methods and technologies, such as dynamic traffic assignment, real-time guidance with GPS and navigation systems, and communications systems. Design of such a system is explained by Mastrogiannidou et. al. [6] with more details on the key stakeholders and technologies required. This study also included a survey in the rural Philippi region of Greece, asking participants about their preferences and willingness to use a proposed paratransit system in their region. A basic cost-travel time analysis of the stated preferences for the proposed system showed that most of the participants would use the system, if it costs half of taxi price and takes not much longer than taxi. A heuristic routing algorithm was also employed to estimate alternate system designs for fleet size for different level of service and pricing policies. The results of this study formed a basis for a follow-up research project funded by the European Union Framework 6 titled "Innovative Mobility Solutions for Mobility Challenged Europeans – InMoSion" that aimed development of an innovative paratransit concept to address the needs of a portion of European population: the elderly and mobility-challenged people. The project details and methods developed in this project are explained in the following sections.

2. INMOSION PILOT STUDY IN THE RURAL PHILIPPI REGION

InMoSion is a research project exploring a new approach to meet the mobility needs of mobility challenged population (such as elderly, disabled people or people in rural areas) via new technologies. Crossing the gap between science and society, the partners of the project consortium include both technical groups such as universities and research companies (University of Thessaly, Hellenic Institute of Transportation, Greece; Middle East Technical University, Turkey; The City of Paris Engineering School, France; CTL Cyprus Transport and Logistics, Cyprus) and local authorities as Municipality of Philippi, Greece and SRM -Reti e Mobilita (P.T. authority), Italy. The project foresees two pilot applications: first, a paratransit application in the rural Philippi Region in Greece, and the other one in a mountainous region of Bologna, Italy. Currently the survey analyses are finished for both locations and system is being tested in the Philippi region.

To gather the necessary know-how for establishment of a paratransit system for a municipality, InMoSion approach requires the steps of a) design of a paratransit questionnaire, b) analysis of the survey results to estimate potential paratransit market share and c) design of the paratransit system (fleet size, service hours and characteristics, etc.). The first step is briefly summarized here to form a basis for the market share analysis step, which is the main focus of this study, while the last step is not discussed here due to limitations.

2.1 Paratransit Questionnaire Design

To better estimate the market share and design criteria of a proposed paratransit system first requires understanding of the traveler and trip characteristics in a region which can be mostly captured via a survey study. A thorough review of transit and paratransit systems is done to capture all the elements that are critical in the design and deployment phase of a paratransit system for both urban and rural areas. While the details can be found in the deliverables of the project [2], the main aspects are summarized here as follows:

A paratransit survey should include questions addressing a) user characteristics, b) trip characteristics, c) available transit system characteristics, d) proposed paratransit system characteristics and

preferences, e) technological aspects and f) perception assessment.

As the value of time of each traveler may vary for different trip durations and lengths, questions regarding "willing to use the system" and "willing to pay" should be asked separately for long and short trips. Limits on the definitions of "short trip" and "long trip" should be defined based on the regional characteristics. For example, for Philippi Region "short trips" are defined as trips shorter than 5 km or 15 minutes.

Another key parameter in preferability of paratransit mode -and also transit-is found to be the total number of stops, which is related to "in-vehicle-waiting time", and desired limits on this can be sought in the survey and used in the development of operational policies.

Though not directly used in market share estimations, technical system details, such as reservation options and reminder services (i.e. SMS messages prior to pick-up), are found to be system attributes directly impacting out-of-vehicle waiting time and design of the ITS application to support the system.

2.2 Philippi Region Survey

The developed paratransit questionnaire is again used in the survey conducted in the Municipality of Philippi in Northern Greece to obtain potential users' perception of the key system parameters in connection with the potential market share. The Philippi Region consists of 19 villages with a total population of 10,827 inhabitants. Community of Krinides and Zigos are the larger villages in the regions, with a population of 3,323 and 2,103 inhabitants, respectively. The majority of the population is known to be local people (mostly farmers, retired and elderly people). The average yearly income level of the participants is found as approximately 18,000€. Theaverage car availability of the participants is also found as 76%; while taxi is available everywhere transit bus services covered very limited parts of the regions, discouraging mobility in general. As the questionnaire included a weekly stated trip table, a more detailed mobility analysis is performed and described below.

Based on a prior survey experience in the same region, the interviews were conducted by trained people that had good knowledge of the area, the available modes of transport and the population's mobility needs. To encourage higher and more complete participation, the developed paratransit questionnaire had to be simplified and shortened by excluding some of the revealed trip attributes, such as trip purpose, trip cost, mode choice, number of travelers, etc; but some attributes are sought at traveler level, such as "main trip purpose", and "main mode of transportation". As a result, a conventional disaggregate mode choice modeling and market share estimation approaches could not be used; instead, a semi-disaggregate scenario-based approaches are developed that use both the traveler and trip level data, as well as mobility pattern information in the region, which is discussed in Section 3.

3. MODAL AND TRAVELER CHARACTERISTICS IN PHILIPPI REGION

Due to limitation in funding and time, paratransit survey study is done with a sample 221 people that is approximately 2% of the population, with 128 are male and 93 are female participants corresponding to 2.4% and 1.7% of the male and female population in the region respectively. The analysis of the revealed weekly trip patterns showed that 221 participants made 2146 trips in a week, resulting in an average weekly mobility of 9.71 trips/person/week. Majority of the these trips made by people of age 26 to 60 years old, which has a large share in the sample as well, resulting in an average mobility of 11.81 trips/person/week for this age group; however the elderly (>60 years old) have a mobility of 6.44 trips/person/week on average, that is significantly lower than the overall average. Alternatively distance-based mobility measures are calculated as a) average weekly total trip distance traveled and b) average trip distance per trip, which showed average values of 125.71 km/week and
12.95 km/trip, respectively.

"Home-based trips" are identified as those which have one-end of the trip as the permanent location of the traveler. An analysis showed that 2,070 out of 2,146 weekly trips are home-based trips. The departure time based distribution of these trips shows the majority departing in the early morning period (T1: 6-9am) and returning back home in the afternoon period (T3: 12-4pm) with a total of 748 weekly trips made by 80 travelers (see Table 1). Second major trend is observed among 68 travelers with 436 weekly trips made between late morning period (T2: 9am-12pm) and with a return in T3. A relatively weaker trend is observed among 26 travelers making 192 weekly trips departing in the evening (T4: 4-9pm) and returning home after 9:00pm (T5). Day of the week information of the late night return trips (134 trips after 9:00 pm) indicated that most of these trips are made on Friday and Saturday, suggesting non-work trips.

TABLE 1 Departure time distribution of weekly home-based and five-day commute (C5) trips

Departing Trips	Return Trips									
	T1 (6-9am)		T2 (9am-12pm)		T3 (12-4 pm)		T4 (4-9 pm)		T5 (9 pm-6am)	
	No. of Travelers	No. of Trips	No. of Travelers	No. of Trips	No. of Travelers	No. of Trips	No. of Travelers	No. of Trips	No. of Travelers	No of Trips
T1 (6-9am)										
Home-based	1	20	9	56	80	748	8	90	1	14
5-Day Commute	1	20	3	40	57	570	4	40		
T2 (9am-12pm)										
Home-based			14	126	68	436	12	104	2	24
5-Day Commute			5	80	15	180	7	70	1	10
T3 (12-4 pm)										
Home-based					7	34	17	76	1	14
5-Day Commute					2	20	1	10		
T4 (4-9 pm)										
Home-based							21	112	26	192
5-Day Commute							3	30	4	40
T5 (9 pm-6am)										
Home-based									6	24
5-Day Commute										

Determination of commute trips, which have a strong repetitive pattern and constitutes a significant potential for paratransit, is crucial in designing a paratransit system, especially in case of fixed route services. In the literature commute trips are defined as "trips that are taken on a regular basis between permanent location of the traveler and work" [7]; however, due to lack of trip purpose information at trip

level in the Philippi survey results, the distinction between home-based work and home-based non-work trips could not be made. But, using the departure time information and trip origin and destination data, all home-based trips with the same trip ends departed at the same time of the day for 5 days or more in a week, are accepted as "commute trips" in this study, which is a more flexible definition but still capturing the repetitive pattern. The commute patterns are further classified as a) a 5-day commute pattern (C5), if commute trips are repeated at the same time intervals during only the weekdays (Monday to Friday), b) a 6-day commute (C6), if these trips continue during 6 days, and c) a 7-day commute (C7), if continue all week. The results showed that 118 out of the 221 participants made total of 1466 weekly commuting trips, out of which, 1110 are C5, 72 are C6, and 294 are C7. It is also observed that some participants have more than one commute pattern a week to different destinations. As shown in Table 1, majority of the C5 trips take place between T1-T3 and T2-T3 time intervals, which follows the general travel pattern in the region. When the trip ends of C5 commute trips are investigated, it is seen that communities of Krinides and Kavala are attracting most of these trips, acting as major attraction zones in the region, which is expected due on their high populations and economical activities.

3.1 Determination of Personal Mode Choice Preferences

In the absence of trip level mode choice information, other trip characteristics are used in combination with traveler characteristics to develop a semi-disaggregate method to estimate the modal splits in the Philippi region. The proposed method first, determines personal mode choice preferences between three main modes: public transit (PT), taxi (TX) and private car (PC). This process includes utilization of total number of revealed trips, stated TX and PT use frequencies and car availability results for each traveler with cross-checking for consistency (see Figure 1).

For a traveler, stated PT and TX use frequencies are converted to number of weekly travel days using average values of 0, 0.5, 1, 3 and 6 days for frequencies of "once in a month or less", "about every other week", "weekly", "2-4 days a week", "5-7 days a week", respectively. The PT and TX travel days are checked against the revealed weekly number of travel days from the survey results; if the stated days of PT and TX travel are bigger than revealed values, they are corrected as the revealed values. For example, Traveler 16 reports a PT use of "2-4 days a week", which means a PT use for 3 days/week on average (see Table 2). Similarly, stated taxi use preferences of his/her is "5-7 days a week", corresponding to a taxi use of 6 days/week. However, the weekly revealed days of travel for Traveler 16 is only 3 (calculated from the revealed trips); thus, weekly TX use frequency is corrected as 3 days/week. Later, the corrected PT and TX travel day values are converted to an estimated number of trips by assuming a traveler makes an average of 2 trips per day (i.e. the return will also have the same mode). The difference between the total trips and total PT and TX trips gives us the total number of private car trips. If the traveler does not have a car, the estimated monthly PC trips are distributed among the PT and TX trips. For the sake of simplicity in trip numbers, total trip numbers are calculated monthly where a month is assumed to have four weeks. For example, "Traveler 16" has a total of 56 trips, 48 of which are expected to be done by PT and TX, leaving 8 monthly PC trips. But, the "Traveler 16" does not own a car, thus, estimated 8 car trips are distributed between PT and TX modes, resulting in 28 PT and 28 TX trips in a month.
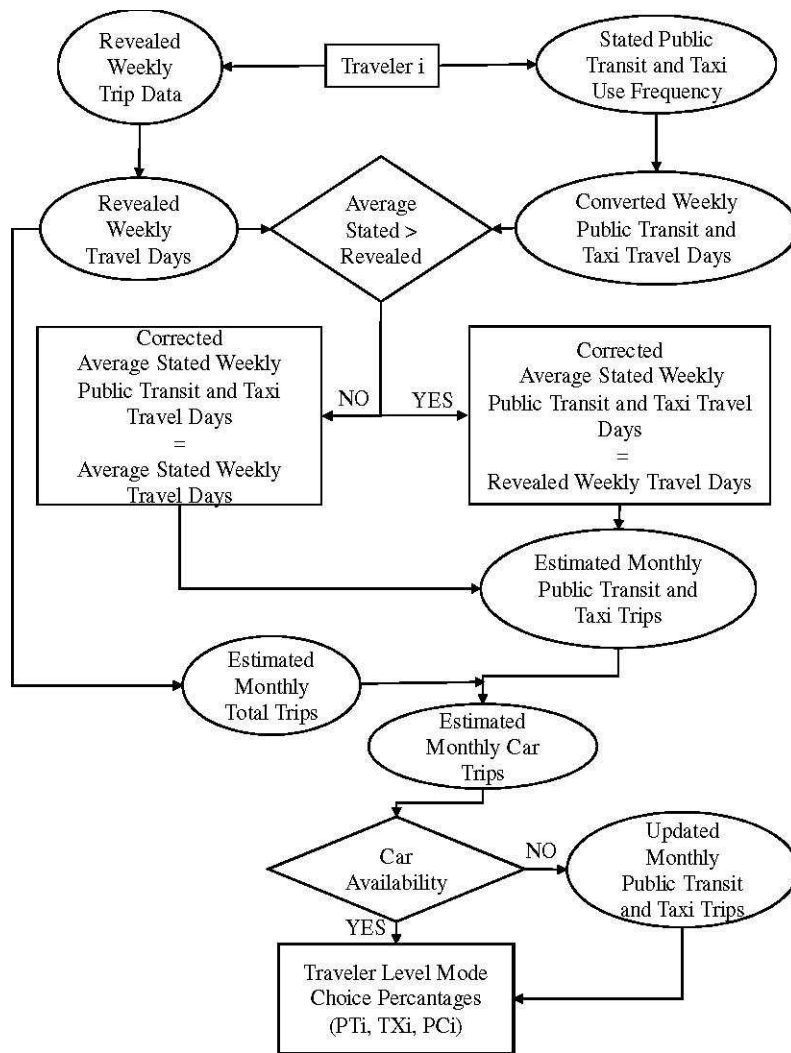
FIGURE 1 Travel Level Choice Determination Process

TABLE 2 Traveler Level Mode Choices for Selected Travelers

Traveler Id	Public Transport (PT) Use			Taxi(TX) Use			Revealed Weekly Days of Travel PT	Private Car (PC) Availability	Monthly Trips							Traveler Mode Preferences %		
	Stated Frequency	Converted Weekly Travel Days	Corrected Weekly Travel Days	Stated Frequency	Converted Weekly Travel Days	Corrected Weekly Travel Days			Total Trips(1)	PT		TX		PC		PT	TX	PC
										E(2)	U(3)	E(2)	U(3)	E(2)	U(3)			
4	"5-7 days a week"	6	5	"Weekly"	1	1	5	Yes	60	40	40	8	8	12	12	**0.67**	**0.13**	**0.20**
8	"About every other week"	0.5	0.5	"One in a month or less"	0	0	6	Yes	48	4	4	0	0	44	44	**0.08**	**0.00**	**0.92**
16	"2-4 days a week"	3	3	"5-7 days a week"	6	3	3	No	56	24	28	24	28	8	0	**0.50**	**0.50**	**0.00**
17	"One in a month or less"	0	0	"One in a month or less"	0	0	5	Yes	40	0	0	0	0	40	40	**0.00**	**0.00**	**1.00**
18	"2-4 days a week"	3	3	"About every other week"	0.5	0.5	5	Yes	40	24	24	4	4	12	12	**0.60**	**0.10**	**0.30**
60	"One in a month or less"	0	0	"2-4 days a week"	3	3	5	Yes	80	0	0	24	24	56	56	**0.00**	**0.30**	**0.70**

[1] Total Number of Monthly Trips Estimated From Revealed Weekly Trips [2] E: Estimated Monthly Trips [3] C: Updated Monthly Trips

Finally, the percentages of use of each mode (PT, TX and PC) for each traveler are calculated based on the estimated and updated trips for each mode. The travelers with only PC trips are labeled as "strong car users" with "occasional TX/PT" use as in the case of "Traveler 17" in Table 2. In the Philippi sample, 88 of the 221 travelers are assigned as a "strong car user". If the traveler is not a "strong car user", his/her mode choices are accepted as their mode choice percentages, instead of assuming a definite PT or TX or PC user.

3.2 Estimation of Modal Attributes

Once the modes preferences of each traveler are estimated, cost and travel times of the available modes are needed to estimate potential switch to paratransit for a given price and travel time scenario. The attributes for the available modes (PT, TX and PC) are calculated as follows:

• **Modal Costs**

Although it is generally flat rate for most public transit trips at a fare of 1.2€ per ticket, it is observed that some villages with longer distances have slightly higher rates going up to prices of 1.7€ or even 2.3€. Based on the existing PT ticket prices between certain villages, a distance based cost function is assumed for transit as shown below:

$$Cost_{PT} = \begin{cases} 1.2€ \text{ for distance} < 12 \text{ km} \\ 1.2€ + (distance-12)*0.1€ \text{ for } 12 \text{ km} < distance < 17 \text{ km} \\ 1.7€ \text{ for } 17 \text{ km} < distance < 25 \text{ km} \\ 2.3€ \text{ distance} >25 \text{ km} \end{cases}$$

Cost of a car trip is estimated with only the gasoline cost of the trip using the average gas consumption of 0,07 lt/km and an average gasoline price of 1.119 €/lt.

Cost of taxi trips are priced as follows in the region:

$$Cost_{TX} = \begin{cases} 3.85€ + 0.34*distance \text{ before midnight} \\ 3.85€ + 0.64*distance \text{ between } 12:00\text{-}5:00 \text{ am} \end{cases}$$

Since the trip information is asked for 9:00 pm to 6:00am as one time interval, an average taxi cost for this time interval is assumed with the following values:

$Cost_{TX} = 3.85€ + 0.50*distance$ The distances between villages are used as the map distances for the region, disregarding any distance traveled within a village.

• **Modal Travel Times**

Taxi and Private Car modes are assumed to have the same travel times, which is calculated as the time required when traveled at an average speed of 70kph. Public transit travel times for this mode is estimated as the time it takes when traveled at a speed of 50kph with an average waiting time of 10 minutes.

4. A SCENARIO-BASED MARKET SHARE ESTIMATION

Market share estimation is a procedure to forecast the potential ridership/use of a mode in a multi-modal transportation market. There are many approaches to calculate the percentages of different modes, varying from aggregate ones using basic modal attributes such as travel time and cost, and to disaggregate ones working at the trip and traveler level characteristics. Due to the fact that mode choice and cost information were not available at the trip level for the reasons explained earlier, developing disaggregate mode choice models were not possible.

However, the survey included many traveler and trip level data, as well as paratransit preferences of each traveler asked based on two main paratransit attributes (cost and travel time) in terms of PT and TX prices and travel times, such as "50 % more than taxi travel time" or "twice the bus ticket", etc. Furthermore, desirability of the proposed paratransit system is sought through

questions on level of willingness to wait, acceptable number of stops during the ride, and in-advance scheduling requirements, which could be easily used to design a paratransit system and estimate its market share, if a scenario-based semi-disaggregate approach is developed. A scenario would be created based on two attributes: paratransit cost and paratransit travel time. As willingness to pay for a paratransit trip may change with distance and travel time, the users' preferences are asked for short trips (i.e. trips less than 5 km or trips takes less than 15 minutes) and longer trips separately. An aggregate analysis of the results shows that people stated preferences for the following paratransit scenarios: a) "50% more than bus price and 50% more than taxi time", b) "bus price and taxi time", c) "Bus price and 50% more than taxi time", d) "50% more than bus price and taxi time" (see Figure 2). Although the majority answered within the expected answer groups, it is notable that, particularly for long trips, there was a reasonable dispersion towards slower service times. This means that they would generally not mind if it took a little longer to arrive to their destination, but they would certainly prefer transit times shorter than the bus system. On the other hand, the population sample showed greater sensitivity to cost issues. A small dispersion towards the right side of all charts, which refers to higher prices, can be also observed.
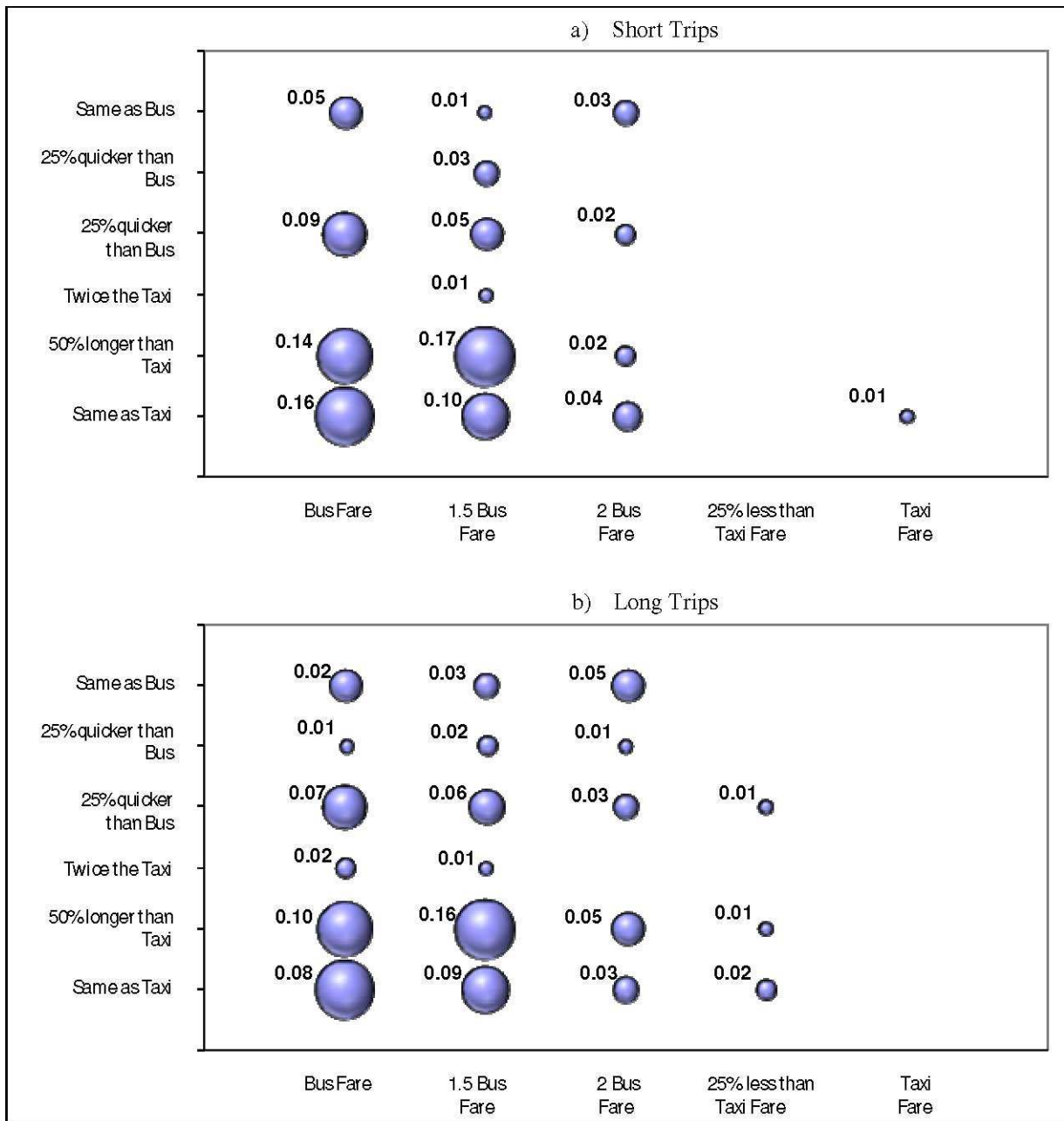
FIGURE 2 Travel Time and Cost Preferences a) Short and b) Long Trips

In particular, it can be seen that very few people answered that they would be willing to pay prices close to taxi fares, even if the transit time was equal to that of taxis.

Based on these aggregate assessment and PT fares in the Philippi region, 6 flat paratransit ticket price scenario are developed up to approximately twice the average bus ticket price as 1.7€, 2€, 2.3€, 2.5€, 2.7€ and 3€. For each price scenario, a second subset of scenarios are developed based on assumed paratransit travel time level of services used in the survey as "50% quicker than bus", "25% quicker than bus", "bus travel time", "taxi travel time", "50% longer than taxi" and "twice the taxi". Thus, a total of 36 different paratransit price vs. travel time scenarios are generated. The overall methodology of the estimation procedure is presented in Figure 3 and explained shortly as follows: For a given paratransit scenario (e.g. paratransit cost=C=1.7€ and paratransit travel time = PTTT= "taxi travel time"), for each trip i of a traveler j (t_{ij}), paratransit travel time ($PTTT_{ij}$) is calculated. Following

this, t_{ij} is classified as either a "short trip" or a "long trip" based on two different sets of definitions (short trips are those shorter than 5km or 15 minutes in Philippi). The desired paratransit cost and travel time preferences of the traveler (for both short and long trips) are used to calculate average desired values of these attributes, C_{ij} * and $PTTT_{ij}$*, respectively. Finally, scenario based paratransit travel time ($PTTT_{ij}$) and cost (C_{ij}) of the trip are compared with the average desired preferences C_{ij} * and $PTTT_{ij}$*. If both measures of the given scenario are better than the average desired preferences, the trip is assumed to be "a potential paratransit trip".
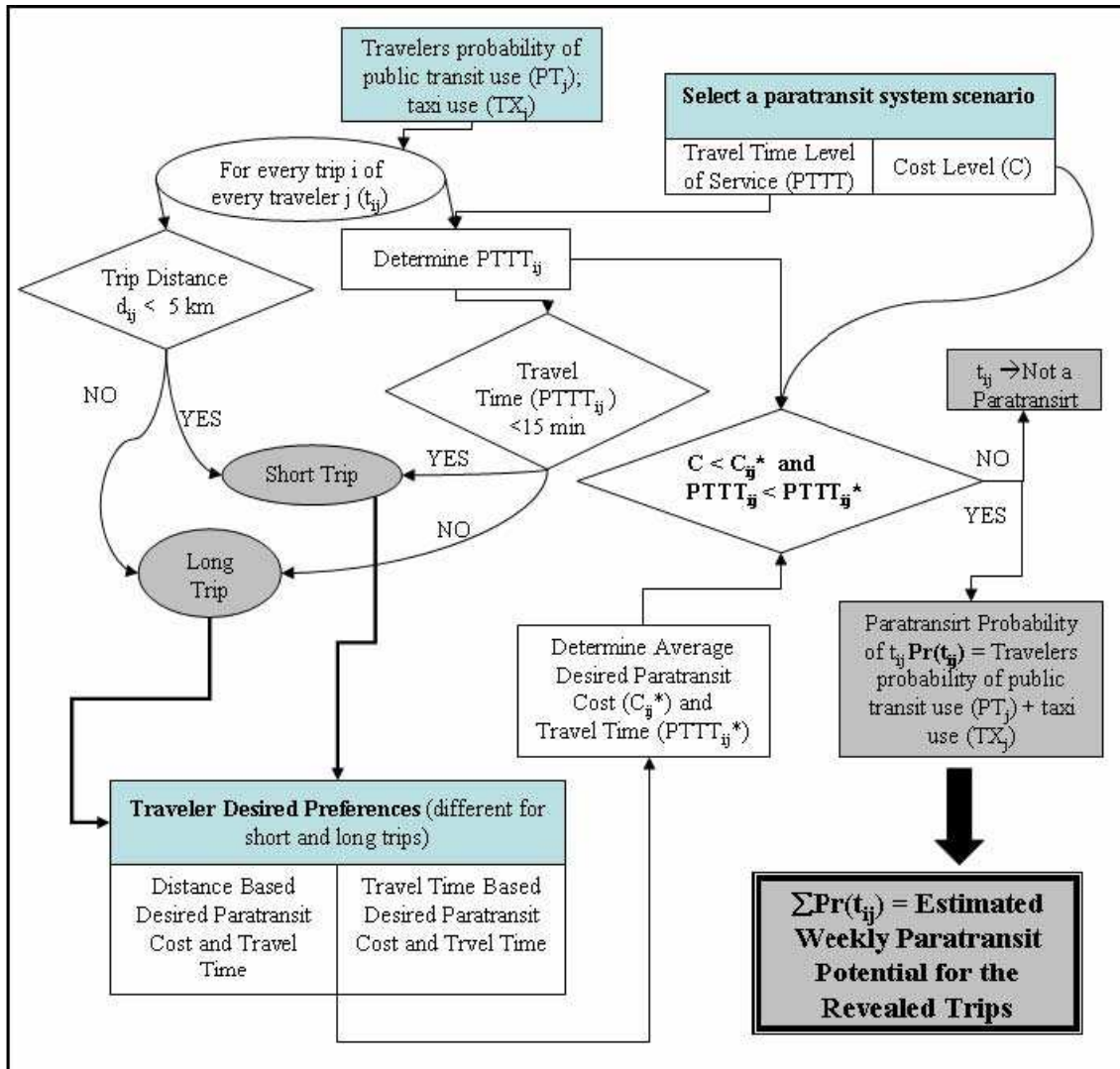

FIGURE 3 Methodology for Estimation of Potential Trip Numbers

If the selected trip is not a definite PT or TX trip, only the sum of PT and TX mode preferences of the traveler are assumed to hold a paratransit potential in the trip. When this procedure is repeated for all weekly trips of all the travelers, the sum of the paratransit potential gives the weekly estimated potential paratransit use within the sample, which is later projected for the population. There may be different approaches to get the population projection from the sample (sub-sample) values as some of the villages would attract or generate more paratransit trips, and this had been addressed in the market share estimation study in the InMoSion reports, but excluded here for the sake of shortness.

To better illustrate this part of the methodology, a list of decision and intermediate level parameters for 6 different trips by 3 different travelers are presented in Table 3. "Traveler 173" has two different trips with trip IDs of 1781 and 1794, having lengths of 18.8 km and 9.8 km, respectively. The traveler level

mode choice preferences for PT, TX and PC are obtained as 0.25, 0.04 and 0.71 using the approach discussed in Section 3.1. PT, TX and PC costs and travel times calculated as discussed in Section 3.2. The scenario travel time for the proposed paratransit is selected as "0.5 Public Transit Travel Time". For this scenario, "Trip 1781" is assumed to be completed in 16.27 minutes which corresponds to half of the PT travel time. Based on both the distance (trip length > 5km) and paratransit travel time (PTTT_173_1781 > 15 min), this trip is classified as a "long trip". As the desired cost preference of this traveler for long trips is stated as "1.5 public transit fare", it corresponds to an average desired cost limit of 2.55€. In addition, the desired travel time preference of this traveler for long trips is stated as is "1.5 taxi travel time" which corresponds to 24.15 minutes. Since the paratransit scenario travel time of 16.27 minutes is better than the desired limit of 24.15 minutes, Traveler 173 is tempted to switch from PT and/or TX to paratransit. The probability of Traveler 173 to use paratransit for this trip is ultimately the his/her total PT and TX use probability of 29%. It should be noted that, in estimating the market share of paratransit in the Philippi region, it is assumed to capture ridership from PT or TX, not PC, as a lower limit estimation.

A more complicated situation can be observed for the decision game of Traveler 97 for Trip ID 114, which is a long trip based on distance but a short one based on paratransit scenario travel time. The distance based "long trip" and "short trip" paratransit preferences of the "Traveler 97" are "2 public transit fare" and "1.5 public transit fare", respectively. Thus, Traveler 97 is willing to pay 2.60€, if he/she perceives this trip a "long" one based on distance, while 1.95€, a "short" one based on travel time. As a result, an average desired paratransit cost of 2.28€ is calculated as the average of these two limits. The desired travel time preference of this traveler is reported as "taxi travel time" for both long and short trips. As result, the average desired paratransit time preference is 11.14 minutes. In short, this traveler is willing to use paratransit for this trip, if a trip scenario has a travel time shorter than 11.14 minutes and cost less than 2.28€. But, a travel time scenario of "0.5 Public Transit Travel Time" corresponds to 12.80 minutes, Traveler 97 will not be tempted to use paratransit for Trip ID 114 in any case.

5. SENSITIVITY ANALYSIS FOR PARATRANSIT PRICE AND TRAVEL TIME

At the end of such a scenario-based game, the total number of potential paratransit trips is calculated using probability of switch to paratransit for each trip, giving also the time-dependent origin-destination matrix for paratransit demand. However, as mentioned before, this demand will vary based on the selected price and travel time level of service. The sensitivity of the total number of weekly potential paratransit trips, an aggregate measure for the market share, for the Philippi region is presented in Figure 4. As expected, the total number of paratransit trips increases as the cost of paratransit gets smaller, thus more people are attracted.

However, the change in the price sensitivity is not linear, thus demand remains almost constant for certain price ranges, while cost changes. For better level of service in travel times, such as taxi travel time or 0.5 bus travel time, cost is the main factor affecting paratransit demand until 2€ limit, while the demand remains almost constant (around 6,700 and 8,200 trips per week for "taxi travel times" and "0.5 bus travel times", respectively) for the price range of 2€ to 2.3€. As this insensitivity to price is observed in all other scenarios, it is possible to charge the upper limit without significant level of loss of demand. After this price level, a second trend of negative linear relation stage is observed between demand and price up to 2.7€, which shows that expected ridership can be changed by pricing policies effectively. Beyond 2.7€ limit people are not sensitive to cost change,

TABLE 3 Trip Level Paratransit Potential Estimation FIGURE 4 Weekly Potential Paratransit Trips for Different Price vs. Travel Time Scenarios

Traveler Id	Trip Id	Trip Distance (km)	Mode Preferences			PT Fare (€)	Taxi Fare (€)	Car Cost (€)	PT Travel Time (min)	Taxi Travel Time (min)	Private Car (PC) Travel Time (min)
			P(PT)	P(Taxi)	P(Car)						
173	1781	18.8	0.25	0.04	0.71	1.70	10.24	1.47	32.54	16.10	16.10
173	1794	9.8	0.25	0.04	0.71	1.20	7.18	0.77	21.76	8.40	8.40
56	591	9.8	0.67	0.06	0.28	1.20	7.18	0.77	21.76	8.40	8.40
56	592	7.0	0.67	0.06	0.28	1.20	6.23	0.55	18.40	6.00	6.00
97	114	13.0	0.50	0.05	0.45	1.30	8.27	1.02	25.60	11.14	11.14
97	115	21.0	0.50	0.05	0.45	1.70	10.99	1.64	35.20	18.00	18.00

Traveler Id	Trip Id	(PTTT) Scenario Paratransit Travel Time (min)	Distance Based Desired Paratransit Cost (€)	Travel Time Based Desired Paratransit Cost (€)	Average Desired Paratransit Cost (€)	Distance Based Desired Paratransit Time (min)	Travel Time Based Desired Paratransit Time (min)	Average Desired Paratransit Time (min)	Paratransit Fare Scenarios					
									3 €	2.7€	2.5€	2.3€	2 €	1.7€
173	1781	16.27	2.55	2.55	2.55	24.15	24.15	24.15	0	0	0.29	0.29	0.29	0.29
173	1794	10.88	1.80	1.80	1.80	12.60	12.60	12.60	0	0	0	0	0	0.29
56	591	10.88	5.38	5.38	5.38	12.60	12.60	12.60	0.73	0.73	0.73	0.73	0.73	0.73
56	592	9.20	4.67	4.67	4.67	9.00	9.00	9.00	0	0	0	0	0	0
97	114	12.80	2.60	1.95	2.28	11.14	11.14	11.14	0	0	0	0	0	0
97	115	17.60	3.40	3.40	3.40	18.00	18.00	18.00	0.55	0.55	0.55	0.55	0.55	0.55
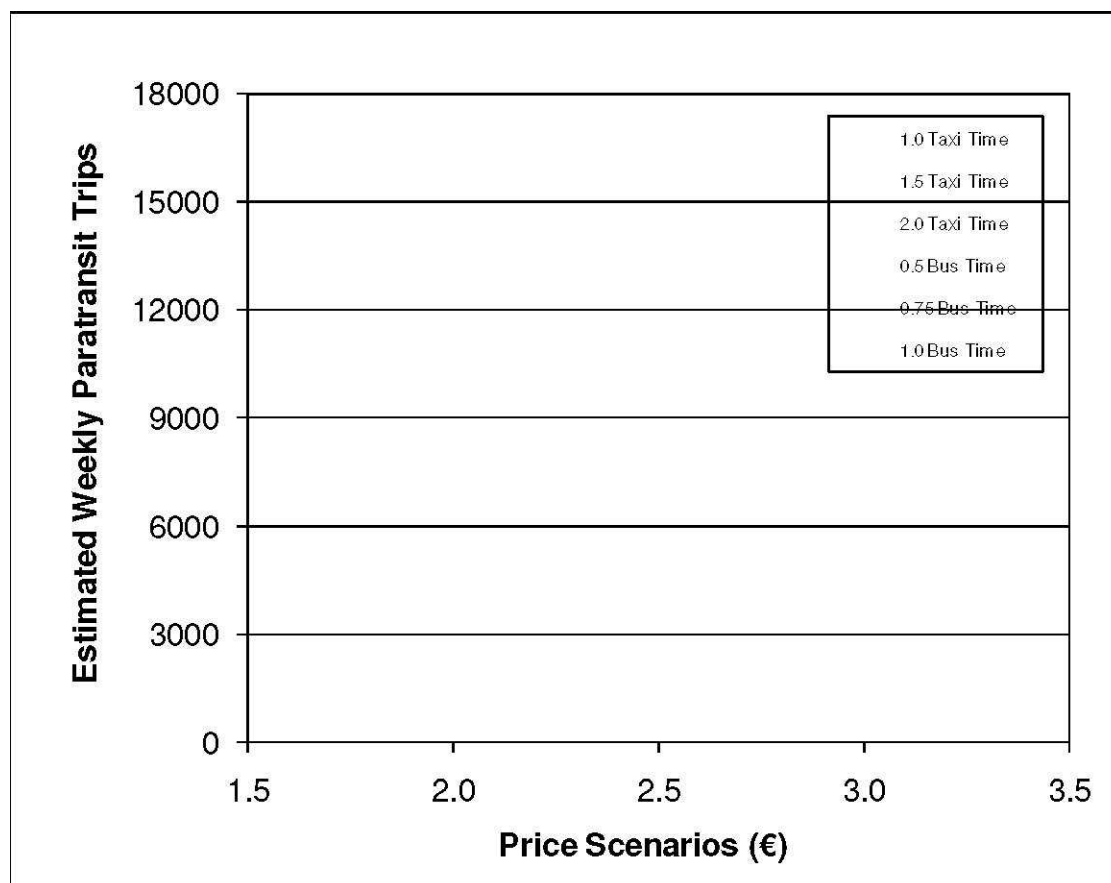
suggesting that they are willing to pay again even the higher limit (3€) for the proposed service. But of course, the level of this constant demand is significantly smaller than the almost demand attracted at 2-2.3€ (almost two thirds of the latter). Though price scenario larger than 3€ is not tested in this study, a certain decrease in demand is expected with the increase of price, but rate of decrease cannot be estimated from this graph directly.

The second dimension of this analysis is the sensitivity of the demand to travel time. As the travel time increases, the potential number of paratransit decreases as expected. The fact that "0.5 bus" travel times generate more potential than the "1.5 taxi" level scenarios is due to the relatively shorter trips in the region. Since the average taxi and bus trip travel times are calculated as approximately 10 minutes and 25 minutes, respectively, "0.5 bus" corresponds to approximately 12 minutes which is smaller than "1.5 taxi" level corresponding to 15 minutes. As can be seen in the Figure 4, there is a significant drop (almost by two thirds) in the paratransit demand when travel times increase up to 1.5 taxi level. This shows that people in the Philippi region state show sensitivity to travel time for the selected price scenarios. This may seem as a conflict with a prior finding based on the traveler level stated preferences on the cost and travel time scenarios. This can be explained by the difference in general perception of the proposed mode by the traveler versus trip level decision making based on the desired limits on modal attributes. If the proposed paratransit system works at the level of service of PT, very low demand shows that it will not be very a significant alternative for the people.

It should be noted that price and travel time impact on the paratransit ridership shown in Figure 4 is somewhat expected trend, which shows that the semi-disaggregate scenario-based approach and decision making parameters proposed in this study are sound and capable of capturing the price and cost sensitivity of the market share and ridership, as expected from any market

share model.

6. CONCLUSIONS

This paper briefly introduces a research project titled InMoSion supported by European Union that aims to develop solutions for mobility challenged people, such as elderly, disabled or rural populations. Paratransit services with ITS support is one of the alternatives that may increase or enable mobility of such people, but it is important to lay out the steps of estimation of potential paratransit market share and design aspects for municipalities or local authorities and provide the required know-how before such applications. This study mainly focuses on discussion of the market share estimation for a paratransit system in a region. Due to the trade-off between a full household travel survey and funding and time budget limitations, a customized paratransit survey results are used to develop a semi-disaggregate scenario-based approach for a pilot study in the rural Philippi Region of Greece. As the proposed methodology uses disaggregate traveler and revealed trip information, first the mobility patterns in the region are needed. Most of the trips in the region are found to home-based trips, half of which is 5-day commute trips, where the term "commute" is used in a more general context to represent repetitive travel behavior between the same origin-destination pairs at the same time of the day during all week days regardless of the trip purpose. Later mobility and modal preferences of each traveler is calculated at a disaggregate level, which are used to estimate first to traveler mode preference probabilities for the existing three modes, public transit, taxi and private car. For the market share estimation part, probability of use of paratransit for each trip of each traveler is calculated based on a) the probability of use of public transit and taxi use and b) the stated paratransit cost and travel time preferences of the traveler. At this point, it is assumed that paratransit would capture only from public transit and taxi, not private car, to get a lower limit on estimation. As the survey included the paratransit preferences of each traveler (asked based on cost and travel time level of service of the proposed paratransit system), 36 scenarios are developed based on 6 different cost and 6 different travel time levels for the proposed paratransit services. In a given scenario, the assumed paratransit cost and travel time values are compared with the cost and travel time of each trip for each traveler to decide whether he/she would prefer paratransit for this trip, leading to an expected total paratransit trip number for the region. Finally a sensitivity analysis based on different price and travel time levels is presented, showing that travelers in the Philippi will be willing to use paratransit at high interest, if cost is kept under 1.7€, while a lower but a constant demand is estimated for a price range of 2€-2.3€, which will be again sensitive to change in the cost beyond 2.3€ limit. As significant as cost, maybe even more, is the travel time of the paratransit that will affect the potential ridership.

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