Demand responsive transport: design of the service and examples

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Description of a Demand Responsive Transport (DRT) service

1) The user calls the operation center stating:
   - number of passengers
   - origin and destination
   - desired departure and arrival times

2) The systems allocates two time-ranges, calculated considering
   - departure and arrival times
   - a predefined level of service
   and ensures departure and arrival times within the calculated time ranges

3) The systems runs algorithms finalized to select
   1. Which vehicle of the fleet will pick up the user
   2. Which route the vehicle will make
   3. User’s departure and arrival times

4) The system advice the user whether his request has been satisfied or refused.
   If refused, the system negotiates with the user a modification of departure and arrival times. The system communicates to the selected vehicle the variations to routes or scheduled times
Two different decision problems

- Service planning (design)
  - service area
  - design of the type of service (traditional with deviations, door-to-door, …)
  - size of the fleet
  - size of the call center
  - communication technologies
  - delays procedures
  - …

- Service management
  - ACCEPTANCE or refusal of the user
  - choice of the bus to serve each user
  - management of delays and interruptions
  - …
Outline

- Service planning (design)
  A possible scheme for the design procedure exemplified with a case study: a service in a hilly area in Como during Sundays and holidays

- Service management
  An example of software for the management of the service
## A possible scheme for planning

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<thead>
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<td></td>
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<td>• costs (n° and schedule of the buses, bus*km)</td>
<td></td>
</tr>
</tbody>
</table>
Steps for the service design (1)

A. Land analysis
Analysis of the territory, the morphological shape and the mobility needs of the area. The road network, on which the demand-responsive system will operate → time-dependent graph of the road network

B. Analysis of the current supply
Assessment on how the current users use the current transportation systems and how the new service would interact with the existing ones

C. Demand analysis
Estimation of the current demand (OD matrices). Construction of the new OD matrix based on the potential demand

D. Generation of different service alternatives
Different alternatives of service with different size of the fleet, operating time, vehicle's dimensions, booking procedures are generated

E. Simulation
The service provides in each alternative is simulated with an appropriate software

F. Selection of the “best” alternative
The alternatives are evaluated and compared, possibly using a multi-criteria analysis, with several criteria: e.g. transport efficacy, economic feasibility, environmental sustainability, social acceptability
Steps for the service design (2)

- Territorial Analysis
- Demand Analysis
- Supply Analysis
- Definition of Alternatives
- Technological Availability
- Travel Demand
- Elasticity of the Demand
- Supply
- Routing & Scheduling Algorithms
- Simulation System
- Transport Efficiency
- Economic Feasibility
- Environmental Sustainability
- Social Acceptability
- Impacts
- Alternatives Comparison
- Evaluation System
- Choice
Case of Como
A - territorial analysis

Characteristics of the territory
- Limited space
- Inadequate roads network and high congestion level
- Confused urban development
- Territorial functions concentrated in the Convalle (the center of the city)
A – Urban area

<table>
<thead>
<tr>
<th>Area quartiere</th>
<th>Area urbanizzato</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Como Est</td>
<td>1,12</td>
<td>0,76</td>
</tr>
<tr>
<td>Como Nord</td>
<td>1,75</td>
<td>0,56</td>
</tr>
<tr>
<td>Camnago Volta</td>
<td>1,27</td>
<td>0,29</td>
</tr>
<tr>
<td>Garzola/Civiglio</td>
<td>3,65</td>
<td>0,32</td>
</tr>
</tbody>
</table>

Urban areas distribution
B - current transport supply (1)

- Current operator: SPT Linea and ATM
- 13 urban motorized lines + 1 funicular line
- Radial rides from the center to the suburbs
- Functioning hours: 6.00 – 21.00 (except CC1)
- Frequency between 15’ and 30’ during rush hours, double on holidays (except CC1)

A questionnaire to the bus driver → strengths and weaknesses

- Strong lines: CC1 and CC6
- Strong influence of the market
- line CC10: load equally distributed
- lines CC4 and CC5: underused in the moderate flow hours and on holidays
B - current transport supply (2)
C – current transport demand (Como)

Source
- O/D survey, Regione Lombardia 2002
- Traffic Urban Plan, Municipality of Como
- On bord survey, SPT line

Area of the prospective DRT service

- Como is a strong attractive pole in the morning rush hours
- 80% of the rides is done with private vehicles, also due to the inadequate public transport system

The municipalities around Como
Public transport in this area is currently offered by 2 urban bus lines (lines CC4 and CC5) and by an extra-urban one (line C43 Como – Tavernero)
B - current transport supply (4)

Number of passengers served by line CC4

Number of passengers served by line CC5
D – Service configuration (1)

A DRT service in a hilly area during Sundays and holidays
- Needs: current lack of public transport (weak demand areas)
- Functioning days: Sundays and holidays, replacing lines CC4 and CC5
- Functioning hours: 9.00 – 22.00
- Lines length:
  - CC4 6.4 km
  - CC5 7.2 km

Two different kind of service

Door to door in a 10 km² area

Traditional with 10 fixed stops in the city center
D – Service configuration (2)

The ten stops along the path cover an ample part of the urban area surrounding the historical center.
C - Estimation of the current travel demand

- Survey of the traffic flow
- Survey on the current trips characteristics
- Origin/Destination (O/D) matrices of the current travel demand
C - Estimation of the current travel demand

Models based on stated preferences

An example of SP survey for a mountain tourist area
C – Comments on SP models (1)

Problems in the calibration

- Because of the low numbers, the models’ coefficients can be not statistically significant
- Use of revealed preference in similar situations to correct the models
What to do with the results of SP demand models?

- Classical models return the expected value $E$ of passengers that would use the Dial-a-Ride (DaR) service. Then, a program is applied using $E$ to model the DaR system. Problem: the numbers are low and working with the expected value is not correct, because the model of the Dial-a-Ride is not linear.

- Another approach: simulation. $N$ possible instances of the number of passenger are simulated, for instance with a Montecarlo method. The DaR program models the services for each of the $N$ instances, and an expected value is calculated afterwards.
C – Potential demand estimation

Volume of moving

From the SPT survey on board → find out the load of transported passengers and the main motivations of the trip

Addresses of origin/destination

area involved in the door to door service

Random extraction from the data base

(Montecarlo method)

200 daily trip requests

Fixed city center path

Fixed stops CC4/CC5
D - a DRT simulation software
D – Simulation

Trade-off among different objectives

We need a decision support system to choose among service alternatives, which have conflicting effects on different evaluation criteria.
E – A decision support system

Effects of the alternatives

Utility functions

Importance of the points of view

Scores of the alternatives (ranking)

\[ V(k) = \sum_{i=1}^{n} w_i \cdot v_i(g_i(k)) \]

Efficient alternatives

Dominated alternatives

refused users

costs

Scores of the alternatives

\[ W \]

\begin{array}{c|c}
\text{cr. 1} & w_1 \\
\text{cr. 2} & w_2 \\
\vdots & \vdots \\
\text{cr. i} & w_i \\
\end{array}
E - Actors of DRT services

The organization involves *actors* with their own *objectives*:

- **USERS** \(\rightarrow\) *quality* of service (e.g. Level of service, LoS)
- **MANAGERS** \(\rightarrow\) fleet *rationalization* (plant and operating costs)
- **URB. PLANNERS** \(\rightarrow\) territorial *coverage* and scheduling
E - Simulation of the service

<table>
<thead>
<tr>
<th>Level of service</th>
<th>n° buses</th>
<th>accepted requests</th>
<th>refused requests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n°</td>
<td>%</td>
</tr>
<tr>
<td>SPT (current) quality</td>
<td>3</td>
<td>192</td>
<td>96%</td>
</tr>
<tr>
<td>Better quality</td>
<td>4</td>
<td>194</td>
<td>97%</td>
</tr>
</tbody>
</table>

Current SPT service

- 2 buses with 64 seats on CC4
- 2 buses with 40 seats on CC5

4 buses

3 buses with 15 seats
Outline

- **Service planning (design)**
  
  A possible scheme for the design procedure exemplified with a case study: a service in a hilly area in Como during Sundays and holidays

- **Service management**

  An example of software for the management of the service
A possible scheme for **planning**

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**Input**

**Decision variables**

**Estimated scenarios**

**Simulation**

**Solution choice**
A possible scheme for **management**

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<th>Bookings through the website or the call center</th>
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| Fleet | bus to serve each user, schedule of the pick-ups and deliveries, routes |

| Algorithms | routing and scheduling |

| Evaluation elements: | • covering (% served users) |
| | • quality (wait time or travel time) |
| | • costs (n° and schedule of the buses, bus*km) |

**Input**

**Real requests**

**Decision variables**

**Compute the solution**

**Monitoring parameters**
A sw example: the DREAMS project

An integrated information and management system for traditional and demand-responsive mobility services in the city of Milan

Financed by the Italian Ministry of the Environment and by the Municipality of Milan.
The travel planner request

origin

day and time

destination
The travel planner output

Available services

<table>
<thead>
<tr>
<th>Servizio</th>
<th>Tempo</th>
<th>Costi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Privata</td>
<td>17-20'</td>
<td>3-4 €</td>
</tr>
<tr>
<td>Taxi</td>
<td>16-17'</td>
<td>6-7 €</td>
</tr>
<tr>
<td>Trasporto pubblico urbano</td>
<td>17-22'</td>
<td>1 €</td>
</tr>
<tr>
<td>Servizio a chiamata DREAMS</td>
<td>17-40'</td>
<td>3 €</td>
</tr>
</tbody>
</table>

Servizi svolti in orari o data diversi da quelli richiesti:

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<th>Servizio</th>
<th>Tempo</th>
<th>Costi</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADIOBUS</td>
<td>16-25'</td>
<td>2,5 €</td>
</tr>
</tbody>
</table>

Route with the private car

Cost

Travel time
Time-dependent network model

Different levels of congestion during the day

Modeling time-dependent speed on a link

\[
\begin{align*}
V &= 30\text{km/h} & \text{(period 1)} \\
V &= 20\text{km/h} & \text{(period 2)} \\
V &= 40\text{km/h} & \text{(period 3)}
\end{align*}
\]

time of the day

In the software, time-dependency can be assigned as follows

- Free assignment
  - The speed of each link is modified directly for each period (small network), or
  - A database already calibrated, for instance, by the mobility agency of the city is imported.

- Proportional assignment
  1. A parameter is associated to each period
  2. The speed of each link is multiplied for that parameter and a factor that depends on the class of the link (small road, highway, …)
The network editor
The DREAMS Dial-a-Ride

A web-based software that manages:

- off-line as well as on-line passenger requests;
- several transportation companies;
- several territorial areas;
- different categories of users (students, disabled, elderly, ...).

Users

- the customers → trip requests
- the companies → fleet operations
- the mobility agency → planning and monitoring
DaR - The architecture

Customer → Call center → Demand side web-interface

Demand side web-interface → Routing and scheduling module

Routing and scheduling module

Network model

Requests

Fleet operation

Schedule

Schedule dispatcher → Vehicles

Transportation company → Supply side web-interface
DaR - The reservation

**Origin**

**Destination**

**Day**

**Earliest departure time**

**Latest arrival time**

**Number of people**
Characteristics of service requests

- The service requests can be performed:
  - before the start of the service (offline problem)
  - during the service (online problem)

- The requests performed by phone or on the website need an answer (acceptation or negotiation) during the same call:
  - we need an insertion algorithm very fast (< 1 minute)
Vehicle routing and scheduling problems are \textit{NP-hard} (=no one knows a good way to solve them optimally):

- Exact algorithms cannot deal with large problems
- Heuristic methods required
  - Simple heuristics: constructive or improvement methods
  - Metaheuristics: genetic algorithms, ant systems, neural networks, simulated & deterministic annealing, tabu search

The tail node request 4 of arc (4,2) is moved to the route of the head node request 2

The head node request 2 of arc (4,2) is moved to the route of the tail node request 4
Realized algorithm structure

Off-line algorithm

On-line algorithm

- Requests
- Initial solution generation
- Optimization
- Initial solution
- Optimization
- Feasible insertion?
- Yes
- No
- Request
- New current solution
- Optimization
The algorithm

- **Insertion (first solution)**
  - Insertion of the new customer’s request in the first feasible position, between the already booked requests
  - Answer to the customer in a few seconds

- **Optimization of the insertion**
  - Improvement of the solution, without modifying the positions of the booked requests
  - Objective function: max the level of service and min the number of vehicles
  - If a new request is made, the optimization stops and lets the new request to be inserted before continuing

- **Post-optimization**
  - In the idle time, the system optimizes the schedule of all the inserted requests, using a meta-heuristic
## DaR - The vehicle schedule

<table>
<thead>
<tr>
<th>ID Prenotazione</th>
<th>Username</th>
<th>T. Minimo</th>
<th>T. Effettivo</th>
<th>Massimo Operazione</th>
<th>Passeggeri Caricati</th>
<th>Indirizzo</th>
</tr>
</thead>
<tbody>
<tr>
<td>3327</td>
<td>alex</td>
<td>10:02</td>
<td>10:14</td>
<td>10:48</td>
<td>Parcoaggio</td>
<td>0</td>
</tr>
<tr>
<td>3328</td>
<td>alex</td>
<td>10:55</td>
<td>10:56</td>
<td>10:55</td>
<td>Salita</td>
<td>2</td>
</tr>
<tr>
<td>3329</td>
<td>andreao</td>
<td>11:00</td>
<td>11:08</td>
<td>11:30</td>
<td>Salita</td>
<td>1</td>
</tr>
<tr>
<td>3330</td>
<td>andreao</td>
<td>11:04</td>
<td>11:11</td>
<td>11:34</td>
<td>Discesa</td>
<td>-1</td>
</tr>
<tr>
<td>3331</td>
<td>andreao</td>
<td>11:05</td>
<td>11:35</td>
<td>11:95</td>
<td>Discesa</td>
<td>-2</td>
</tr>
<tr>
<td>3332</td>
<td>ale</td>
<td>11:09</td>
<td>11:29</td>
<td>11:99</td>
<td>Salita</td>
<td>1</td>
</tr>
<tr>
<td>3333</td>
<td>andreao</td>
<td>11:11</td>
<td>11:21</td>
<td>11:11</td>
<td>Salita</td>
<td>1</td>
</tr>
<tr>
<td>3334</td>
<td>gianni</td>
<td>11:17</td>
<td>11:37</td>
<td>11:17</td>
<td>Salita</td>
<td>3</td>
</tr>
<tr>
<td>3335</td>
<td>andreao</td>
<td>11:22</td>
<td>11:41</td>
<td>11:22</td>
<td>Discesa</td>
<td>-1</td>
</tr>
<tr>
<td>3336</td>
<td>gianni</td>
<td>11:24</td>
<td>11:44</td>
<td>11:24</td>
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<td>-1</td>
</tr>
<tr>
<td>3337</td>
<td>gianni</td>
<td>11:29</td>
<td>11:36</td>
<td>11:30</td>
<td>Discesa</td>
<td>-3</td>
</tr>
<tr>
<td>3338</td>
<td>sere</td>
<td>11:34</td>
<td>11:31</td>
<td>11:34</td>
<td>Salita</td>
<td>1</td>
</tr>
<tr>
<td>3339</td>
<td>Diego</td>
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<td>11:34</td>
<td>11:40</td>
<td>Salita</td>
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</tr>
<tr>
<td>3340</td>
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<td>11:41</td>
<td>11:57</td>
<td>11:43</td>
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<td>-1</td>
</tr>
<tr>
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<td>11:48</td>
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<tr>
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<td>12:03</td>
<td>11:58</td>
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</tr>
<tr>
<td>3343</td>
<td>ale</td>
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<td>12:10</td>
<td>12:15</td>
<td>Discesa</td>
<td>-1</td>
</tr>
<tr>
<td>3344</td>
<td>ale</td>
<td>12:14</td>
<td>12:16</td>
<td>12:50</td>
<td>Parcoaggio</td>
<td>0</td>
</tr>
<tr>
<td>3345</td>
<td>sere</td>
<td>13:00</td>
<td>14:52</td>
<td>13:00</td>
<td>Deposito</td>
<td>0</td>
</tr>
</tbody>
</table>

**Image:**
- Diego: Salita 1 + 0
- Gianni: Salita 3
- Sere: Discesa -1 + 1
DaR - The communication (1)

The driver receives a pick-up job
The driver is picking up the passengers
DaR - The communication (3)

The driver communicates that he is 20 minutes late, due to traffic congestion.
## DaR - Statistics

Statistiche delle Flotte

Interrogazione Temporale

![Calendar and input fields for selecting date range]

<table>
<thead>
<tr>
<th>Tipo Giorno</th>
<th>Lunedì</th>
<th>Sabato e Festività</th>
<th>Martedì</th>
<th>Domenica</th>
<th>Mercoledì</th>
<th>Atri Festa</th>
<th>Giovedì</th>
<th>Venerdì</th>
</tr>
</thead>
</table>

### Bus

<table>
<thead>
<tr>
<th>Bus</th>
<th>Fermate</th>
<th>Distanze</th>
<th>Pass. x Km</th>
<th>Utenti Serviti</th>
</tr>
</thead>
<tbody>
<tr>
<td>bucaneve</td>
<td>5</td>
<td>1,7179 Km</td>
<td>0,00 Km</td>
<td>0 + 0</td>
</tr>
<tr>
<td>cisternino</td>
<td>5</td>
<td>0 Km</td>
<td>0,00 Km</td>
<td>0 + 0</td>
</tr>
<tr>
<td>gessola</td>
<td>5</td>
<td>1,8019 Km</td>
<td>0,00 Km</td>
<td>0 + 0</td>
</tr>
<tr>
<td>ilg</td>
<td>5</td>
<td>0 Km</td>
<td>0,00 Km</td>
<td>0 + 0</td>
</tr>
<tr>
<td>marcella</td>
<td>5</td>
<td>2,4616 Km</td>
<td>0,00 Km</td>
<td>0 + 0</td>
</tr>
<tr>
<td>otricella</td>
<td>63</td>
<td>14,6002 Km</td>
<td>28,25 Km</td>
<td>25 + 3</td>
</tr>
<tr>
<td>primula</td>
<td>5</td>
<td>0,3624 Km</td>
<td>0,00 Km</td>
<td>0 + 0</td>
</tr>
<tr>
<td>rosa</td>
<td>57</td>
<td>21,6175 Km</td>
<td>40,85 Km</td>
<td>22 + 4</td>
</tr>
<tr>
<td>tulipano</td>
<td>63</td>
<td>15,7027 Km</td>
<td>45,50 Km</td>
<td>27 + 2</td>
</tr>
<tr>
<td>viola</td>
<td>6</td>
<td>0 Km</td>
<td>0,00 Km</td>
<td>0 + 0</td>
</tr>
</tbody>
</table>

Bus 1 - 10 di 10