Vehicle Sharing Services Optimization Based on Multi-Agent Approach

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Abstract: Nowadays, in transport sector, more researches are established in order to find solutions for the existing problems such as the future shortage of oil, the global warming… Most of these researches are turning to innovative alternative of private car like carsharing and carpooling. These means of transport represent a promising answer for economic and environment problems. In fact, total cost and gas emission quantities are considerably reduced if they are divided by the number of passengers. In this paper, we propose an evolutionary optimization method based on multi-agent approach which takes into account all possible means of transport, including carsharing, carpooling and multimodal common transport in order to satisfy transport user itineraries demands, respecting environment state. Our work is financed by the ademe (Agence de l’Environnement et de la Maîtrise de l’Energie) and the regional council NPdC.

1. INTRODUCTION

Recently, the spatial dispersion of habitat and activities contribute to a considerable growth of the use of cars and traffic. Private car has become the most popular and the preferred mean of transport seducing people by its flexibility, efficiency, speed and comfort. It represents freedom and technical progress (Ballet et al., 2007)(Clavel et al., 2008). In 2008, statics shows that the private car is the dominant mean of transport by 60% of urban travel while the others means like walking, multimodal common transport, bicycle and motorcycle represent recursively 27%, 9%, 2% and 2% (Ballet et al., 2007). However, it has many drawbacks which deteriorate the quality of life : atmospheric pollution (important emission of CO₂ and different other greenhouse gases), noise pollution, monopolization of the public place, accidents, considerable costs (fuel, insurance, repairing, maintenance, parking, etc.). In order to find out a solution to these problems, communities are now turning to innovative alternative of private car. Thus to complete the classic offers of common transport (bus, metro, tram…), some solutions of public transport are implemented like transport on demand, vehicle-sharing services (carpooling, car sharing) and cycling (Velib for example). These solutions are complementary and respond to each specific need. It allow a significant decrease of the cost and the gas emissions since it divides these criteria by the number of concerned passengers.

Knowing that our target is to satisfy transport user demands, respecting environment state, we propose in this paper a vehicle-sharing services system. This system combines all possible means of transport including private cars, vehicles on service and multimodal common transport, which remains a remarkable solution for the environment and the streets obstruction. The adopted method is an evolutionary optimization approach in terms of total cost, time and gas emission volume, taking into account passenger constraints and preferences.

The reminder of this paper is organized as follows: a brief presentation of the state of the art about existing systems is described in section 2. The problematic of our paper is illustrated in the section 3. The adopted approach to resolve the described problem is presented in section 4. The global architecture of multi-agent system is proposed in section 5 where we detail the behavior of each agent. Then we evaluate our approach by a simulation example in section 6. Finally, conclusion and prospects are addressed in section 7.

2. STATE OF ART

The transport sector is under pressure across the world. Overloaded roads lead to both economical and ecological problems. In order to resolve these problems, researchers and industrialists combined their efforts to find out a solution. Some of them have treated the problem of multimodal common transport. They proposed systems that optimize in real time user itineraries in term of cost and travelling time (Kamoun, 2007)(Zidi, 2006). On the other side, carsharing and carpooling services continue to appear all over the world. Car sharing services consist on bringing into service a fleet of cars available 24hours/24 and 7 days/7. Generally, the software employed in these systems provides the management of reservations, billings, databases and communication between system and vehicles. It is a simple static management of reservations without incorporating any optimization1.

1 www.lilas-autopartage.com ; www.communauto.com;
Carpooling services consist on meeting websites where we offer or search a ride. Then, we simply contact the person in order to agree about the place and the travel time. The travel must be planned at least 24 hours before. However another type of carpooling, which is more interesting, is taking place: dynamic carpooling. Its great flexibility and less interdependence led to the development of many projects. All these systems and projects remain incomplete without any optimization aspect neither a valid real time reservation assignment. In this paper, we propose a vehicle-sharing services system which satisfy efficiently user itinerary demands especially in real time and based on an optimization and multi-agent approach. It combines all possible means of transport including private cars, vehicles on service and multimodal common transport.

3. PROBLEM DESCRIPTION

The main concern of our system is to satisfy the users by providing their itineraries and respecting their priorities criteria. At a time \( t \), as shown in Fig. 1, a transport user uses a medium of communication (e.g. laptop, PDA) in order to express his demand and provide a departure and arrival points and the correspondent earlier and later schedules. In a short time interval, many transport users can formulate simultaneously a set of requests. So the system should find feasible decompositions in terms of independent sub-itineraries called Routes recognizing similarities. Departure and arrival time of user’s requests can belong to a same cover zone or different zones. In each case, the system has to identify all the zones which will intervene in the Routes identification. For a given Route, we can have several possibilities with different vehicles, which are available to ensure this Route through the same time window. Then, from these identified Routes, we have to recognize the different possibilities of Routes Combinations to compose each itinerary demand, thanks to a junction process. The problem is how to choose the most effective Vehicle for this Route to a given user, taking into account his constraints and preferences in terms of total cost, total travelling time and total greenhouse gas volume.

![Fig. 1. Global system description](image)

Our problem is defined by:

- \( N \) itineraries demands formulated through a short interval of time \( \Delta t \), waiting for responses at the same instant \( t \), is the set of these requests.
- \( I_k(t_{kd},t_{ka},W_{gd,ga}) \in I \), is an itinerary request formulated by a user \( k \) at a time \( t \) from a departure point \( x_{kd} \) to an arrival point \( x_{ka} \) through a time window \( W_{kd,ka}=[t_{kd},t_{ka}] \); \( t_{kd} \) and \( t_{ka} \) correspond respectively to the most earlier (minimum departure time from \( x_{kd} \)) and the most later (maximum arrival time to \( x_{ka} \)) possible schedules with \( t_{kd} < t_{ka} \).
- \( Z = \{ Z_m \} \) is the set of \( M \) cover zones to explore in order to identify different Routes with \( m \in \{ 1...M \} \).
- \( R_{g,t}(x_{gd},x_{ge},W_{gd,ge}) \) is a route identified to response to \( I_k \), where we need a mean of transport available to move from the departure point \( x_{gd} \) to the arrival point \( x_{ge} \) through a time window \( W_{gd,ge}=[t_{gd},t_{ge}] \) with \( t_{gd} \) and \( t_{ge} \) correspond respectively to the most possible earlier departure time to leave \( x_{gd} \) and the most possible later arrival time to attend \( x_{ge} \). This set of available vehicles to assure \( R_{g,t} \), is noted by \( \xi_{g,t} \) (obtained by \( R_{g,t} \)) and concerns users whose this route belongs to a possible Route Combination to their itineraries. The set of such users itineraries corresponds to the \( I_k \) scope of \( R_{g,t} \) and obtained by \( R_{g,t} \).
- \( R_t \), the set of all identified routes to response to \( I_k \).
- Due to the paper goal, we focus on three criteria of optimization: Cost, Time and Gas emission. When a user \( k \) formulates his itinerary request \( I_k \), he also has to mention his priorities criteria expressed by weights. A weight corresponding to an optimization criterion \( C_r \) for the user \( k \) is real numbers \( \alpha_k \in [0,1] \) (1\( \leq C \)) with \( \sum_{r=1}^{C} \alpha_r = 1 \). An optimization criterion has a label obtained by \( C_r \).
- In a time \( t \), a vehicle \( V_h \) ensures only one Route \( R_{h,t}(x_{gd},x_{ge},W_{gd,ge}) \) and by the way \( V_h \) is characterised by a value for each criterion \( C_r \) (dynamic character obtained by \( V_h \)). So at a time \( t \), a vehicle has a single departure time and a single value per criterion. A vehicle \( V_h \) is also characterised by a type (obtained by \( V_h \)) knowing that we distinguish three types of vehicles (static character):
  - Type A: private vehicles (e.g. carpooling). The vehicle \( V_h \) is characterized by three dynamic properties according to the assured Route \( R_{h,t} \) at the time \( t \) : the number of real remaining places in the Vehicle \( (V_h,nb) \), the maximum authorized places \( (V_h,nbMax) \) so we have \( V_h,nbMax-V_h,nb \) the total number of passengers and finally the departure time \( (V_h,dep) \). According to a given Route, a vehicle \( V_h \) is characterized by a type (obtained by \( V_h \)) knowing that we distinguish three types of vehicles (static character):
    - Type B: free use vehicles (e.g. VLIB AUTOLIB). In this case, the vehicle \( V_h \) is characterized by a single dynamic property \( nb \) (\( V_h,nb \)) corresponding to the real number of available vehicles in the departure node of the assured Route in the correspondent time window;
    - Type C: multimodal transport vehicles (bus, tramway...). A vehicle of type \( C \) is characterized by the departure time like type A.

4. THE ADOPTED STRATEGY

To the problem described above, we propose a Multi-agent based evolutionary approach to optimize vehicle sharing services. This strategy follows three essential stages. Firstly, when the system receive simultaneously a set of requests, all the zones including the initial and final points of the itineraries demands have to be located. Then, the system has
to identify all possible routes able to satisfy these requests. Secondly, we have to generate all the routes combinations and finally apply an optimization approach in order to give an optimized solution based on the priorities and the weight criteria of the demander.

4.1 Zones Identification

With our approach, we use a grid cutting in order to divide the geographical map into several zones \( Z_m \), \( m \in \{1, M\} \). The granularity of this grid is a parameter which must be adjusted according to experimental results. It can be a department, a city, a municipality… In this paper, we proceed by a municipal division: one zone is a municipality. To each zone \( Z_m \), we associate an agent responsible called Zone Agent. Each agent is able to suggest an optimized itinerary for the user’s request \( I := \{I_{k,t}\}_{k \in N} \), if this request is dealing with a departure place \( x_{kd} \) and an arrival one \( x_{ka} \) which are included in the agent’s zone. Otherwise, if \( x_{kd} \) and \( x_{ka} \) are included in two adjacent zones, the responsible agents should cooperate to respond to the user’s request. In addition, \( x_{kd} \) and \( x_{ka} \) can be managed by two Zone Agents which are not adjacent. These agents should cooperate with other agents adjacent to them, in an optimal way to be able to suggest an \( x_{kd} \) to \( x_{ka} \) itinerary. The cooperation of the Zone Agents is not handled in this paper but will be specified in the future works.

So, for an itinerary response, one or many Zone Agents are involved. Then, they consult the agents responsible of the different transport operator existing in that zone. In fact, for each operator in each zone, we associate one Transport Information Agent. These agents send a response to the Zone Agent’s request which mentions the availability of one or more vehicles for an existing Route \( R_{g,t} \) in this zone. They can be related to a multimodal common transport operator, carsharing or carpooling operator. The agent connected to the carpooling service communicates with special software “CARTOCOM”. It is a geo-localization software able to communicate with mobile phones and locate them in real time. The conductor or the passenger, who wants to use the carpooling, has in the first time to be connected with adequate software for this application. Then, he has to choose his destination and his status. The status shows the state of the user who can be a passenger needing a car, then his status will be, for example, “need car” status. Also, the user can be conductor searching for passengers, so his status will be “Available car” status. Then, this software facilitates the location and the identification of passengers and conductors who want to share a Route in the demanding zone.

Thus, after identifying each possible vehicle moving in the zone through a useful time window, we associate a vehicle \( V_h \) to a Route \( R_{g,t} \), if the departure time of the itinerary (or a part of the itinerary) from the first departure point of this vehicle \( V_h \) is greater or equal than the at least the most earlier departure time of user demand. So we add \( V_h \) and all the others vehicles assuring the same route within the same window time to the set possible vehicles \( \xi_{g,t,g,b} \).

4.2 Routes Combinations

Once the possible routes are identified, we generate the possible combinations of routes (RC) for each itinerary request \( I_{k,t} \in I \). The Route Combination (RC) is the result of the junction of different routes. So, we can formulate a possible route combination \( RC_{k,l,p} \) of the itinerary request \( I_{k,l}(x_{kd},x_{ka},W_{d,k,l}) \in I \) as follows:

\[
RC_{k,l,p} = \bigcup_{i=0}^{n} \left( x_{k_i} \right) \text{ with } x_{k_0} = x_{kd} \text{ and } x_{k_n} = x_{ka} \text{ and } \right.
\]

\[
\bigcup_{i=0}^{n} \left( x_{k_i} \right) = x_{k_0} \big| \xi_{k_0,k_1} \big| x_{k_1} \big| \xi_{k_1,k_2} \big| x_{k_2} \big| \ldots \big| x_{k_{n-1}} \big| \xi_{k_{n-1},k_n} \big| x_{k_n}
\]

The junction process can propose a Route combination with empty part if the set of identified routes don’t compose a RC to a given route. This is means that there is no available vehicle to traverse a Route \( R_{g,t} \) in a given time window (i.e. \( \xi_{g,t,g,b} = \emptyset \)).

4.2 Optimization Approach

In order to optimize user’s itineraries in terms of several criteria taking into account their preferences and constraints, we are in front of a combinatorial multi-objective problem. The target of this type of problem is to find the single solution giving the best compromise between multiple objectives. The use of metaheuristics seems to be the most promising to generation of approximately efficient solutions (Jasckiewicz)(Ulungu, 1994). So we choose to adopt an evolutionary metaheuristic in order to generate randomly solutions and we propose an efficient coding for the chromosome respecting our problem’s constraints (Jeribi, 2009). The chromosome is represented by the Route Agent (RAgent) and is a matrix \( CH(|R_{g,t}|,|R_{g,t}|,\xi_{g,t,g,b}) \) where rows correspond to Persons (transport users) and columns correspond to different identified vehicles which are available to transport these persons through the same time window \( W_{g,t,g,b} \) to serve the route \( R_{g,t}(x_{gd},x_{ga},W_{g,t,g,b}) \).

Each element of the matrix is an assignment of the person \( P_{ep} \) to the vehicle \( V_{ck} \) as follows:

\[
CH(c_{p,c_{lk}}) = \begin{cases} 
1 & \text{if } P_{ep} \text{ is assigned to } V_{ck} \\
* & \text{if } P_{ep} \text{ can be assigned to } V_{ck} \\
\times & \text{if } P_{ep} \text{ can not be assigned to } V_{ck} 
\end{cases}
\]

After this first assignment, genetic operators can be applied to improve results rapidly in real time.

5. THE SUGGESTED MULTI-AGENT ARCHITECTURE

Thanks to its autonomous, reactive and/or proactive nature, the software-agent paradigm (Florez-Mendez, 1999)(Green, 1997)(Woolridge, 2002) was adopted in real time and dynamic systems. Furthermore, software agents can incorporate coordination strategies, thus enabling them to operate in distributed environments and perform complex tasks. Generally speaking, software-agent technology is considered as an ideal platform for providing data sharing, personalized services, and pooled knowledge.

Since we study an organization composed of dynamic and independent routes interacting together and optimizing their possibilities in real time, we propose a multi-agent system
based on the coordination of six kinds of software agents (Fig. 2)

Fig. 2. System architecture

The behavior of each agent is described below:

- **Interface Agents (IAgent):** An IAgent interacts with a system user allowing him to formulate his request choosing his preferences and constraints and finally displays the correspondent results. When an IAgent handles a user request, he sends it to an identifier agent. This one relates to the same platform in which several users can be simultaneously connected, thus he can receive several requests formulated at the same time.

- **Identifier Agent (IdAgent):** This agent identifies the cover area or the zones where the departure and arrival points are included. The IdAgent send a request to the concerned Zone Agents. After reception of the possible routes from the Zone Agents, IdAgent generates all possible Routes Combinations from simultaneous Itinerary requests. This generated data is transferred to an Optimizer Agent who decides of best Combinations thanks to his interaction with the autonomous Routes Agents.

- **Zone Agent (ZAgent):** A ZAgent is a Zone Agent existing in that zone for possible routes available and satisfying the user’s request in the according time window. These routes are transferred to the Identifier Agent. Many ZAgents should cooperate together when the departure and arrival points are situated in different zones.

- **Transport Information Agent (TIAgent):** For each multimodal common transport, carsharing and carpooling service, we associate a TIAgent. Many TIAgents should cooperate together when the departure and arrival points are available and satisfy the user’s request in the according time window. These routes are transferred to the Identifier Agent.

- **Route Agent (R-Agent):** an R-Agent is created in real time by the IdAgent for a given Route Rg with itineraries. This agent represents a generated chromosome scheme for an identified useful Route in order to assign concerned users to possible vehicles. A multi-agent coalition is then created regrouping all R-Agents corresponding to a possible Route Combination for a given Itinerary. Therefore we have as many coalitions as combinations knowing that an R-Agent can belong to many different coalitions according to combinations overlapping. Coalitions appear and disappear dynamically according to requests receptions and responses. As soon as each R-Agent assigns persons to vehicles, updating the number of passengers in vehicles of Type A and the number of available vehicles of type B, he computes all values criteria of each vehicle for each assignment thanks to the Criteria_eval function below:

```
function Criteria_eval
In: VS-FcTAR instance
Out: Criterion evaluation according to the Rg-Agent assignment
begin
for each IAgent (1≤k≤|I|) do
    if ∃ s where CH|ck,cs|=1 (1≤s≤|Rg|, c∈{p, b, t}) then
        begin
            for each Cr (1≤|C|) do
                begin
                    C<ref> if Vc,Type=A and Cr.label≠“Time” then d<ref>
                        (Vc,NbMax-Vc,Nb) Yc,Cr<ref> Vc,Cr/d</ref>
                    end
                end
            end
        end
    end
end
```

- **Optimizer Agent (OAgent):** this agent computes the best Combination Route for each Itinerary demand and sends it to the correspondent IAgent. Knowing that we have three criteria corresponding respectively to Time, Cost and Gas emission volume and that, as it was mentioned previously, each criterion is weighted by a real number αi∈[0,1] (1≤i≤|C|).

As described below, after the coalition of RAgents and the generation of Route Combinations, the Optimizer Agent has to compute the best combination as follows:

```
function Best_Route_Combinations(I, RC)
In: Requests Itinerary and Routes Combinations
Out: Best Routes Combinations
begin
for each IAgent do
    begin
        Initialise min, and index to 0 for each possible Route Combination RCg,τ of IAgent do
            begin
                Initialise each Cr to 0 for each identified route Rg,τ composing RCg,τ do
                    begin
                        set request (Rg-Agent, cτ)
                        s<ref>-1</ref>
                        s<ref> get response of request (Rg-Agent, cτ) if s≠-1 then min, <ref>Cr</ref>
                        for each Criterion Cr do
                            begin
                                Cr<ref>Σ</ref> (cτ, Cr)
                                index<ref>τ</ref>
                                if p=1 then min, <ref>Cr</ref> else min, <ref>Min(min, Cr)</ref>
                            end
                        end
                    end
                end
            end
        end
end
```

We notice here that if a vehicle is a car, then Cost and total gas emissions charges are divided by the number of passengers.
6. SIMULATION EXAMPLE

In order to illustrate our approach, we propose an example of simulation (Fig. 3). We consider four itinerary requests at t=7h15:

- I₁(A,B(7h15,8h30)): does not like public transport with Criteria weights (0.5,0.3,0.2);
- I₂(C,D(7h40,8h30)): cannot drive a bicycle with Criteria weights (0.2,0.8,0);
- I₃(A,E(7h15,7h55)): does not like carpooling with Criteria weights (0.2,0.2,0.3);
- I₄(A,X₄(7h15,7h40)): nothing to announce with Criteria weights (0.2,0.0,8).

According to these itinerary requests, IdAgent identifies the ZAgents which are ZAgentᵢ₄ for I₁, and I₄ᵢ₃, ZAgentᵢ₅ and ZAgentᵢ₈ for I₂, the cooperation between (ZAgentᵢ₂, ZAgentᵢ₃, ZAgentᵢ₄, ZAgentᵢ₅) for I₃, and then each ZAgentᵢ₉ in its turn the request to the TIAgents existing in that zone. These agents corresponding to a multimodal common transport operator, carsharing or carpooling operator, identify the available vehicles within correspondent time windows with correspondent criteria values respectively Time, Cost and Gas emission volume. Departure time from the departure point is also mentioned if the vehicle is not of type B.

All the generated Routes are transferred to the IdAgent via the ZAgents.

Table 1. Request decomposition

<table>
<thead>
<tr>
<th>C</th>
<th>I₁</th>
<th>I₂</th>
<th>I₃</th>
<th>I₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁(A,X₁(7h15,7h35))</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>R₂(A,X₂(7h40,8h30))</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>R₃(A,X₃(7h30,8h00))</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>R₄(A,X₄(8h00,8h15))</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>R₅(A,B(8h10,8h30))</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>R₆(C,X₆(7h45,7h55))</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>R₇(E,X₇(7h55,7h55))</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

RC₆₃,4₊ means that R₆₃₄ composes a RC₆₃,4₊ ≈ I₃₄

For each route:

- P₀: R₁(A,X₄(7h15,7h35)) V₂(2,4) V₁(3,4) V₁(1,3) V₁(3,4) Bus₁₀ V₁(3,4) V₁(1,3) V₂(2,4)
- P₁: R₂(A,X₂(7h40,8h30)) V₂(2,4) V₁(1,3) V₁(3,4) V₁(1,3) V₂(2,4) V₁(3,4) V₁(1,3) V₂(2,4)
- P₂: R₃(A,X₃(7h30,8h00)) V₂(2,4) V₁(1,3) V₁(3,4) V₁(1,3) V₂(2,4) V₁(3,4) V₁(1,3) V₂(2,4)
- P₃: R₄(A,X₄(8h00,8h15)) V₂(2,4) V₁(1,3) V₁(3,4) V₁(1,3) V₂(2,4) V₁(3,4) V₁(1,3) V₂(2,4)

Thereafter, itinerary requests are decomposed globally into nine Routes as shown in Table 1. All possible itineraries are generated as follows:

- P₁: R₁(A,X₄(7h15,7h35)) : A → X₁ → X₂ → X₃ → B
- P₂: R₂(A,X₂(7h40,8h30)) : RC₆₃,4₊ : C → X₄ → X₅ → D
- P₃: R₃(A,X₃(8h00,8h15)) : RC₆₃,4₊ : A → X₆ → X₇ → E
- P₄: R₄(A,X₄(7h30,7h55)) : RC₆₃,4₊ : A → X₈ → X₉

Fig. 3 Example of transport network (Lille)
Initially, we had this random assignment:

\[
\begin{array}{cccc}
R(X, E, [7h40, 7h55]) & \text{Bus43} & V(2, 4) & \text{Autolib}(2) \\
P_1 & x & x & * \\
\end{array}
\]

This assignment gives the following values:

- \(P_1\): 1, 10, 1, 15
- \(P_2\): 1, 20, 5, 5

We notice here that due to this operation, user 1 finds a better solution: 31.82, 7.93, 13, 11.8.

7. CONCLUSION

This paper presents an evolutionary method based on multi-agent approach which aims to find an effective itinerary proposition to transport users including carsharing and carpooling. The employment of multi-agent system and a rapid assignment process to a combinatory problem thanks to an evolutionary method, make our adopted approach very interesting. Also, the use of the geo-localization software CARTOCOM adds to the system more security, safety and precision. In future work, we intend to develop more the zones identification part and the cooperation of Zones Agents. We also aim to employ a genetic process generating more chromosome generations, in order to improve gradually generated solutions to find better solutions.

REFERENCES