AN INTEGRATED DECISION SUPPORT SYSTEM TO SOLVE MULTI-CRITERIA ORIENTEERING PROBLEM

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ABSTRACT
In this work we proposed an integrated support system combining a meta-heuristic algorithm and a multi-criteria decision analysis method to solve an orienteering problem applied to car-pooling system. For this purpose a Genetic Algorithm (GA), an Analytical Hierarchy Process (AHP) are implemented. The research is based on the awareness that decision makers (DMs) often face situations in which different conflicting viewpoints (goals or criteria) are to be considered. Current car-pooling web platforms are focused on the exchange of information among potential users and drivers. The aim of this work is to include in web platform a decision procedure to support driver to organize the tour considering more criteria. The driver has to decide which tour does and which users to take into the trip Preliminary test are given to validate the functionality and usefulness of created integrated decision support system.

Keywords: Orienteering Problem, Car Sharing, Multi-criteria decision support system.

1. INTRODUCTION

In these years a lot of sharing systems in mobility's field are born due to several opportunity linked to advances in technology and to European people's lifestyle. The systems known as car sharing, transportation on-demand, car-pooling and others, are some of the mobility solutions proposed to reduce the number of vehicles circulating and increase their occupancy. The major reasons for which these systems have developed itself during the last years are ascribable to: (i) travel cost, (ii) financial means (iii) traffic and environmental questions. Their development is due also to great progress of information and communication technologies like Geographical Information System (GIS) and Global Positioning System (GPS) that have allowed the realization of new and enhanced Intelligent Transport Systems (ITS). All policies and strategies minimizing traffic and travel demand are based on three major elements: cost-sharing, road-sharing, time-sharing. This is true in special way for car-pooling, where users share a car for a long or short trip using usually a web platform to take information and agreement about the travel. Frequently the driver of a car-pooling system, is not interested to realize a profit but only to share the travel costs, in some other cases he is a owner of several cars and for him, the travel sharing is a profit-making business. In literature there are several works that studied and described the car-sharing systems, less for car-pooling systems. Moreover, the great part of these last works take into consideration the user point of view, focusing the attention on communication protocols, rather than to optimize the whole sharing process. Furthermore, nearly all scientific works and web platforms dealing with car-pooling, take into account only the matching between supply and demand. The authors in this work propose a decision support system (DSS), able to introduce elements of optimizations and multi criteria decision making into one-way car-pooling process. The tool is developed from driver's point of view and the aim is to optimize the car filling and consequently the car's tour with respect to several criteria as travel cost, travel comfort and respecting the timing. The proposed DSS is structured into two decisional levels. Suppose to have n users distributed on m cities that have to share a travel or a part of travel and they are ready to pay a price for this trip. The first decisional level takes into account the matrix of distance from each city and the price offered by the users. Applying a genetic algorithm able to solve a capacitated orienteering problem we obtain as output the best tour that maximizes the Total Revenue and respects the constrains relative to car's capacity and time schedule. The designed algorithm returns as output not only the best solution, but also a set of good solutions characterized by a different sequence of visited nodes and by different revenues, travel costs and time schedule. These solutions constituted the input for the multi criteria analysis realized with methods known in literature as Analytical Hierarchy Process (AHP) (Saaty, 1980). The output of the multi-criteria decision-making analysis is an ordered set of solutions that takes into account the criteria weights given by the driver of car-pooling system. The tool presented in this paper can be integrated in several web platforms that manage car-pooling system as: "www.blablacar.com", "www.autostradecarpooling.it", "www.carpooling.co.uk", "www.redefinder.com", "www.ride4cents.org", www.eurokm.com and others. This market is a business of several millions of dollars, and it is based on information and communication technologies. After all the service offered is a single travel with a traditional car, the innovative aspect is linked to the way to reserve this service and on the composition of total price of the service. For this reason the great investment in this market have to go on the software innovation direction. The proposed tool could be an additional intelligence to insert into the current web-platforms of car-pooling. The rest of paper is so organized: in the first paragraph a review of literature is given, in the second one the mathematical model and its resolution with genetic algorithm is faced in details. Following, a paragraph on the multi-criteria analysis tools like AHP model and its integration with optimization model is discussed. The last two sections are relative to presentation of results obtained in a real application and comments and conclusions about the presented scientific work. Future researches are proposed, in order to incentive the researchers to suggest innovative solution for this market characterized by a fast growth.

2. LITERATURE REVIEW

Transport is the sector with the fastest growth of greenhouse gases emissions, both in developed countries that developing. Developing countries, rely heavily on energy consumption for its daily mobility. The aim of the different plans to reduce the greenhouse gas emissions and, hence, the adverse climate change impacts, can usually be achieved with different transport policies. In this context, as stated by Yan et al. (2014), carpooling is one method that can be easily instituted and can help resolve a variety of problems that continue to plague urban areas, ranging from energy demands and traffic congestion to environmental pollution.

There aren't many scientific works that face the optimization of car-pooling or car-sharing process from the driver's point of view. Uesugi et al (2007) propose an optimization model to solve the problem to distribute cars among stations in a car-sharing system.

This problem is faced as an Assignment Problem and the system's manager point of view is assumed. Some experimental results of a simulation are given but it is not clear which type of simulation technique is applied.

Maniezzo et al. (2003) take into consideration a problem of partitioning to solve the Long-Term Car Pooling Problem (LCPP), different from Daily Car pooling Problem (DCPP) because the trip is long more than one day. The authors in their paper propose a mathematical formulation and a meta-heuristic resolution approach to solve this problem: to partition the set of users into subset such that each member of the pool in turns will pick up the remaining members in order to drive together to and from the workplace. The LCPP is studied supposing the users as component of an enterprise's staff and solved with an ANTS (Approximated Non-deterministic Tree Search alghoritm). The objective function minimizes the cost of employees' transfer from enterprise's point of view.

In Baldacci *et al.* (2004) the same problem is re-proposed using a different approach to solving the mathematical problem, the Lagrangian Column Generation.

In Calvo *et al*. (2003) DCPP is approached as a Vehicle Routing Problem with pickup and deliveries time windows (VRPPDTW). In this case it is supposed a central decision-maker that collect all information about the needs and solve the model to optimize the assignment of users and routes to the cars. The proposed model is NP-hard so a heuristic based on local search algorithm is implemented in C++ languages to find a solution for this problem.

Most carpooling organizations currently use a trial-and-error process, in accordance with the projected vehicle travel times, for the carpooling, which is neither effective nor efficient. In other words, stochastic disturbances arising from variations in vehicle travel times in current operations are neglected. In order to choose the optimal policy action to reduce the adverse climate change impacts due to the transport sector, Berrittella et al., 2007 applied the analytic hierarchy process. The AHP has become a significant methodology due to its capability for facilitating multi-criteria decisions (Ramanathan, 2001). Nosal and Solecka (2014) proposed AHP model to evaluate an integrated system of urban public transport.

3. THE MATEMATICAL MODEL AND ITS RESOLUTION APPROACH

In this research the problem to fill a car for car-pooling system is faced as a Capacitated Orienteering Problem. In a Capacitated Orienteering Problem there is a set of nodes each one with an assigned score. In the case of car-pooling the authors suppose that the nodes are the cities of users and the score is the price that users is ready to pay for travel from a city to another one. The distance among the nodes is known in terms of miles and in terms of time. The price of users is function of distance between the city of departure to city of arrive. A solution of this kind of problem is represented by single tour or path that satisfy the following request:

- The tour has to start and to end in predefined cities.
- The tour has to respect the maximum time to arrive to the destination.
- The tour has to visit more cities and to collect more users in order to maximize the travel's revenue.
- The car has a limited capacity of 4 persons (1 is the driver)
- The time of departure is known.

The mathematical model can be so formulated. $S_i \geq 0$ is the score associated to node *i*, c_{ij} is the distance associated to path between node *i* and node *j*. The first expression is called Objective Function and represents the Total revenue obtained summarizing all prices paid by users. The first constraint (2) ensures that the city of departure and the city of arrival are included into the tour. The constraint (3) guarantees that each city is visited at most one. The constraint (4) ensures the limited time budget (T_{max}). The constraint (5) guarantees the respect of limited capacity budget (C_{max}). Constraints (6) and (7) are necessary to prevent sub-tours. The binary variable x_{ij} is equal to 1 if the node *i* and the node j are visited then the users of city *i* and *j* take part to travel of car pooling.

$$\text{Max} \sum_{i=2}^{n-1} \sum_{j=2}^{n} S_i x_{ij} \qquad (1)$$

Subject to

$$\sum_{j=2}^{n} x_{1j} = \sum_{i=1}^{n-1} x_{in} = 1 \qquad (2)$$

$$\sum_{i=1}^{n-1} x_{ik} = \sum_{j=2}^{n} x_{kj} \leq 1 \quad \forall\ k=2,\ldots,n-1 \qquad (3)$$

$$\sum_{i=1}^{n-1} \sum_{j=2}^{n} c_{ij} x_{ij} \leq T_{max} \qquad (4)$$

$$\sum_{i=1}^{n-1} \sum_{j=2}^{n} x_{ij} \leq C_{max} \qquad (5)$$

$$2 \leq u_i \leq n \quad \forall\ i=2,\ldots,n \qquad (6)$$

$$u_i - u_j + 1 \leq (n-1)(1-x_{ij}) \quad \forall\ i, j=1,\ldots,n \qquad (7)$$

$$x_{ij} \in \{0,1\} \quad \forall\ i, j=1,\ldots,n \qquad (8)$$

The Orienteering problems are classified as NP-hard problems, then, in literature several heuristic and meta-heuristic algorithms are developed to solve these kinds of problems (De Falco et al, 2015). For this reason don't exist exact algorithm to find optimal solution of this problem but only heuristic or meta-heuristic approach able to find rather good solutions. The genetic algorithm is one of these. This meta-heuristic was developed by Holland (1975) and then studied by Goldberg (1989) and it is based on evolution's concept as method to explore the solutions' set. As described in Askin et all (2013) the algorithm starts with a creation of a population of individuals corresponding to a set of solution. Each individual is a solution represented by a chromosome of integer number – combination of nodes to visit – a value of objective function – representative of solution's goodness – a fitness function – indicator of probability to create offspring. In this work each chromosome is encoded as a vector of integer number representing the nodes or the cities of the problem. In this case, the problem's solution is not represented by whole chromosome, but only of a part of this. The chromosome's part or as we call it, the tour, is composed by a sub-set of nodes that can be visited by tourist respecting the limitation time and the limitation capacity imposed. Usually the chromosome's code has a linear structure, the authors proposes a closed loop structure, thanks to it, it's possible to explore a greater number of solutions in a shorter computational time. The set of chromosomes is always structured as population, which size is a algorithm's parameter. The passage from old to new population is the core of the algorithm, following it is explained way. The fitness function value associated to each individual is greater when the individual represent a good solution for the problem. Thanks to this value the new generation will be generated with a more high probability by a set of good parents. Thanks to the use of this value the second generation of individuals will be in average better then the first since generated by the set of best parents of the first population. This mechanism guarantees the convergence of the algorithm but to explore the solutions' area in a better way some elements of variability have to be inserted. These elements are known as genetic operators and the most applied in operation research field are: crossover and mutation operators. The first one generated the offspring as combination of two parts of two chromosome's parents. In our work we implement the single crossover (one cut) and the PMX Crossover (two cuts). The mutation is an operator that changes some genes of chromosome inserting variability into new generation with respect to precedent one. The authors implemented several types of mutation operators as 2-opt and swap procedures that can be applied to population with different probability. Also the elitism mechanism it is implemented in order to create a container of best solutions founded during the several iterations. The algorithm stops when the parameter of iteration's number is reached.

4. MULTI CRITERIA ANALYSIS TOOL

4.1. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) breaks down a decision-making problem into several levels in such a way that they form a hierarchy with unidirectional hierarchical relationships between levels (De Felice and Petrillo, 2014). The AHP for decision making uses objective mathematics to process the inescapably subjective and personal preferences of an individual or a group in making a decision. With the AHP, one constructs hierarchies or feedback networks, then makes judgments or performs measurements on pairs of elements with respect to a controlling element to derive ratio scales that are then synthesized throughout the structure to select the best alternative (De Felice, 2012). The top level of the hierarchy is the main goal of the decision problem. The lower levels are the tangible and/or intangible criteria and sub-criteria that contribute to the goal. The bottom level is formed by the alternatives to evaluate in terms of the criteria. The modeling process can be divided into different phases for the ease of understanding which are described as follows:

- PHASE 1: Pairwise comparison and relative weight estimation. Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criterion. Saaty suggested a scale of 1-9 when comparing two components. For example, number 9 represents extreme importance over another element. And number 8 represents it is between *''very strong important''* and *''extreme importance''* over another element. The result of the comparison is the so-called dominance coefficient aij that represents the relative importance of the component on row (i) over the component on column (j), i.e., $a_{ij}=w_i/w_j$. The pairwise comparisons can be represented in the form of a matrix. The score of 1 represents equal importance of two components and 9 represents extreme importance of the component i over the component j.

- PHASE 2: Priority vector. After all pairwise comparison is completed, the priority weight vector (w) is computed as the unique solution of $Aw = \lambda_{max}w$, where λ_{max} is the largest eigenvalue of matrix A.
- PHASE 3: Consistency index estimation. Saaty (1990) proposed utilizing consistency index (CI) to verify the consistency of the comparison matrix. The consistency index (CI) of the derived weights could then be calculated by: $CI = (\lambda_{max}-n)/ n-1$. In general, if CI is less than 0.10, satisfaction of judgments may be derived.

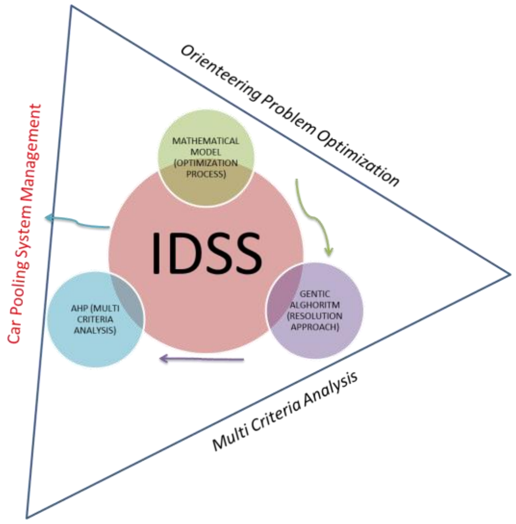

Figure 1: Integrated Decision Support System (IDSS)

For this application the AHP takes as input the results of optimization process and evaluates these under several criteria better explained in the next paragraph. The Figure 1 represents the most significant phase of the proposed integrated DSS. As first activity the mathematical model is supposed to model the capacitated orienteering problem, as second phase we solve the formulation implemented a meta-heuristic known as Genetic Algorithm (GA). Then, we applied a multi-criteria analysis (AHP model) to algorithm's results with the aim to order the founded solutions respect to the following objectives: timing, revenue and comfort of travel.

5. EXPERIMENTAL RESULTS

Experimental results are so achieved. From a web platform of car sharing we select a day and do a query of all users' requests for the same destination. Then, we build a matrix of distance among the several cities with a request and the start and destination point. This experiment is been done on Italian highway network.

Supposing to be Naples (node 0) the origin and Milan the destination (node 14) of car-pooling's travel. We collect 13 requests from the following cities' toll booths: *Caserta, Latina, Rome, Civitavecchia, Viterbo, Grosseto, Orvieto, Florence, Bologna, Genova, Reggio Emilia, Turin, Parma.*

Solving a Capacitated Orienteering Problem with the Genetic Algorithm described in paragraph 3, we obtained a set on n better solutions, so structured:

- List of cities to visit or rather the tour of trip;
- Total revenue coming from users taking part of tour.
- Travel time from origin to destination;
- Travel distance from origin to destination;
- Number of passengers that taking part of the tour.

The Figure 2 represents the algorithm's solution supposing to have a maximum time for the travel equal to 550 minutes, and 4 seats for passengers at most. The algorithm is set to obtain 6 six different solutions.

T max	Distance	Cost	Revenue	Tour					Passengers
550	535	149	212	0	1	7	8	14	3
550	539	150	191	0	1	7	11	14	3
550	550	153	200	0	1	7	9	14	3
550	550	152	201	0	1	3	13	14	3
550	538	150	187	0	3	7	8	14	3
550	549	153	205	0	1	3	11	14	3

Figure 2: GA's solutions with T_{max} = 550 minutes and capacity equal to 4

The same experiment has been repeat for three different Tmax equal to 550, 600 and 650 minutes. Like it is possible to observe from next Figure with more time available the car can keep 4 passengers and fulfilling the car. Moreover, in the last instances with 650 minutes to end the travel, the driver can increase the total revenue linked to transfer.

T max	Distance	Cost	Revenue	Tour						Passengers
600	582	155	270	0	1	3	7	11	14	4
600	593	921	279	0	1	3	7	9	14	4
600	588	158	262	0	1	5	7	11	14	4
600	584	156	283	0	1	5	7	8	14	4
600	598	153	318	0	1	3	4	6	14	4
600	582	154	266	0	1	3	7	13	14	4

Figure 3: GA's solutions with T_{max} = 600 minutes and capacity equal to 4

T max	Distance	Cost	Revenue	Tour						Passengers
650	944	172	319	0	1	3	7	5	14	4
650	905	165	314	0	1	3	5	6	14	4
650	880	160	319	0	1	3	5	7	14	4
650	875	169	310	0	1	5	4	6	14	4
650	874	159	329	0	1	3	4	5	14	4
650	828	161	327	0	1	2	4	6	14	4

Figure 4: GA's solutions with T_{max} = 650 minutes and capacity equal to 4

The outputs of optimization process as before described, are given as inputs of AHP model built as in Figure 5. In the present paper AHP Absolute model is applied (De Felice and Petrillo, 2013). AHP Absolute model is based on paired comparisons among the elements of a set with respect to a common attribute. This process is essential for comparing intangible attributes for which there are no agreed upon measures. Absolute method is typically used in a decision situation that involves selecting one (or more) decision alternatives from several 'candidate' decision alternatives on the basis of multiple decision criteria of a competing or conflicting nature.

Experts team developed pairwise comparison matrices to determine the weights of criteria. Figure 6 shows an example of pairwise comparison. Consistency index has been estimated (CI 0.051). As it is possible to note the most important criteria is "Profit" with a score of 49%, followed by "Time" with a score of 31% and finally is the criteria "Comfort" with a score of 19%.

In AHP Absolute model criteria are further subdivided into a level for intensities. Experts team defined each alternative by assigning the intensity rating that applies to them under each criterion. The scores of these intensities are each weighted by the priority of its criterion and summed to derive a total ratio scale score for the alternative. Each criterion has ratings listed under it. Figure 7 shows the final ranking of the AHP Model.

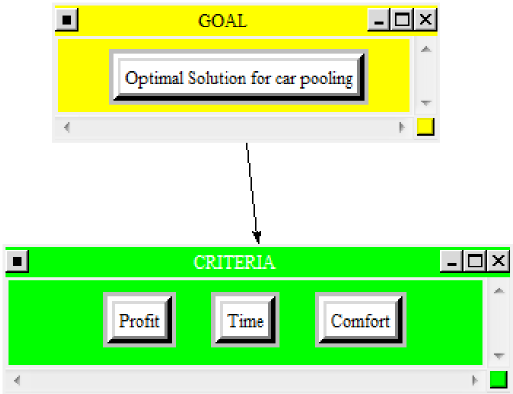

Figure 5: AHP Absolute Model

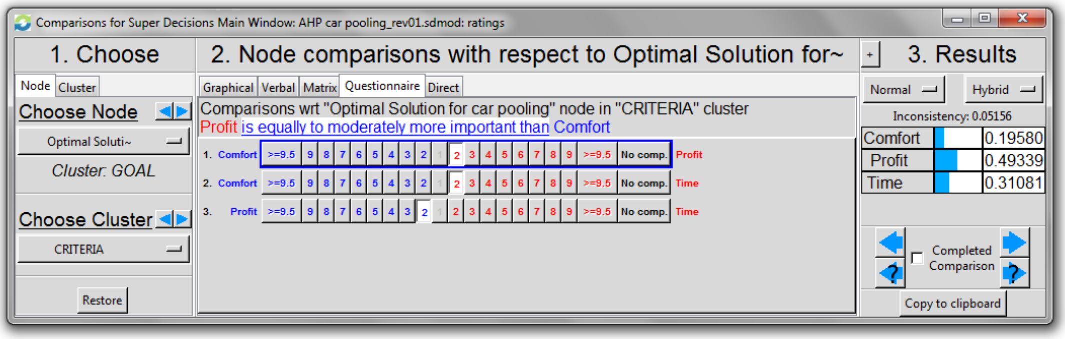

Figure 6: Pairwise comparison for criteria cluster

	Priorities	Comfort 0.195800	Profit 0.493386	Time 0.310814
1-7-8	0.062982	2-3 passengers	63	550 minutes
1-7-11	0.087823	2-3 passengers	41	550 minutes
1-7-9	0.089523	2-3 passengers	47	550 minutes
1-3-13	0.076631	2-3 passengers	49	550 minutes
3-7-8	0.084930	2-3 passengers	37	550 minutes
1-3-11	0.071373	2-3 passengers	52	550 minutes
1-3-7-11	0.029034	3-4 passengers	115	600 minutes
1-3-7-9	0.028972	3-4 passengers	111	600 minutes
1-5-7-11	0.028997	3-4 passengers	104	600 minutes
1-5-7-8	0.030263	3-4 passengers	127	600 minutes
1-3-4-6	0.036766	3-4 passengers	165	600 minutes
1-3-7-13	0.029015	3-4 passengers	112	600 minutes
1-3-7-5	0.051728	3-4 passengers	147	650 minutes
1-3-5-6	0.054441	3-4 passengers	149	650 minutes
1-3-5-7	0.056425	3-4 passengers	159	650 minutes
1-5-4-6	0.054832	3-4 passengers	141	650 minutes
1-3-4-5	0.063277	3-4 passengers	170	650 minutes
1-2-4-6	0.062989	3-4 passengers	166	650 minutes

Figure 7: Pairwise comparison for criteria cluster

As it is possible to note from Figure 3 the preferable solution is 1-7-9 with a priority of 89%, followed by 1-7-11 with a score of 87%.

6. CONCLUSION AND FUTURE WORKS

In this work the authors present an Integrated Decision Support System (IDSS) that integrate a meta-heuristic and multi-criteria analysis in order to create an intelligent tool for car-pooling system. Actually in fact, all web platform that manage car-pooling system are finalized only to create a communication protocols to match supply and demand. With the proposed tool will be possible to insert inside the traditional system an additional “intelligence” able to found the best combination of travel for the driver point of view. If the users are ready to pay different prices then the driver has to choose the solution that maximize the revenue, minimize the cost of travel, guarantee the comfort and respect the timing. These entire requests can’t be satisfied with a simple optimization or with a simple communication protocols, an integrated intelligent system is necessary and its what the authors have implemented in this work. Future research can focus their attention to rich the proposed tool of other methods, others meta-heuristic (i.e. Ants Algorithm) and others method for multi criteria analysis (i.e. ELECTRE). The aim of these future researches will be offer a complete system flexible and fast for each situation. Will be also interesting introduce directly into the IDSS some elements of communication and negotiation, since in this work we take into consideration only one driver point of view. Another interesting act could be to use the weight of multi criteria analysis in order to realize a multi-objective function of the orienteering problem. These could be the starting points for future researches.

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