Expert Systems With Applications 62 (2016) 161–176

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Multi-Hop Ridematching optimization problem: Intelligent chromosome agent-driven approach

Sondes Ben Cheikh*, Slim Hammadi

CRISTAL, Ecole Centrale de Lille, Cité Scientifique, Villeneuve d'Ascq, France

ARTICLE INFO

Article history:
Received 15 February 2016
Revised 31 May 2016
Accepted 1 June 2016
Available online 14 June 2016

Keywords:
Intelligent ridesharing system
Ridematching optimization
Evolutionary algorithm
Chromosomes agents
Negotiation protocol

ABSTRACT

In order to solve the now ubiquitous transport problems we face, may they be financial or environmental, we are primarily interested in the development of a dynamic optimized ridesharing service. Shared cars was developed in order to meet transport needs (spatio–temporal flexibility) and to promote the co-modal practice. The focus is thus for different modes of transport, whether public or private, to complement each other by integrating the car pooling system as an efficient alternative. Keeping this in mind, we concentrate on setting up an automatic and optimal ridesharing system. Said system is part of an intelligent co-modal platform which provides the required efficiency in such a context. In order to solve the problem, we must create a Ridematching solution with an arbitrary number of transfers that respects the personal preferences of the users as well as their time constraints. However, as considered to be NP-Complete, a more efficient metaheuristics is required in the application in order to solve the dynamic Multi-Hop Ridematching problem (*MHRP*). Evolutionary Algorithms (*EAs*) are known as a powerful and robust optimization technique. Nevertheless, *EAs* are not only expensive but also difficult to configure. This study puts forward an original Evolutionary Approach in which the chromosomes are defined as Autonomous and Intelligent Agents (*E2AIA*). Through an accurate protocol negotiation, the chromosomes agents can control the genetic operators and provide guidance when searching for optimal solutions within a reasonable time. This is crucial in real-world systems, where time for deliberation is a very important factor. Test results indicate that the classical evolutionary algorithm, developed to solve the dynamic *MHRP*, results in poor performance when compared with our *E2AIA* in terms of optimality and computational time. It is worth noting that the proposed agent-driven method is general and could be adapted to expert design and intelligent systems for other complex search issues.

1. Introduction

Due to a combination of different factors: socio-economic (higher prices for fossil fuels, congestion in large cities, lack of alternatives to car transportation for poor households, ect.), societal (rise of environmental concerns and associative actors able to participate in the collective organization of mobility) and technology (Internet, mobile communications, embedded systems, geo–location, open data, ect.), we are witnessing a veritable transformation in the mobility of goods and people. These changes translate into the emergence of a new-generation of innovative mobility assistance systems. These developing systems are flexible, responsive, they fall under the logic of *Shared Vehicle* and they involve the new information and communications technologies. Such systems, include car sharing, car pooling and demand-responsive transport (*DRT*), have several forms of intelligence (geo–localizable, communicating, semi-autonomous) and manage wide databases relating to the supply and demand of transport. These emerging systems form part of co-modal transport (Giannopoulos, 2008), and operate in interaction with existing modes of transport (Bus, tram, trains, ect.) and possibly with other alternative operators (bicycle sharing system, ect.). The notion of co–modality[1] was introduced in 2006 and it consists of developing infrastructures and taking measures that will ensure the optimum combination of individual and public transport modes.

So far, these emerging systems occupy a relatively marginal and unstable space in mobility landscape. Increasing and stabilizing this space becomes an issue when referring to the aim of better mobility and therefore respecting environmental and energy

* Corresponding author.
E-mail addresses: sondes.ben-cheikh@ec-lille.fr (S.B. Cheikh), slim.hammadi@ec-lille.fr (S. Hammadi).

[1] http://ec.europa.eu/transport/themes/strategies/doc/2001/white/paper/lb/com/2001/0370en.pdf.

http://dx.doi.org/10.1016/j.eswa.2016.06.001
0957-4174/

constraints. The key to competitiveness for these emerging systems lies within their organization and in the ability of their operators to manage such factors so as to reduce costs and increase reliability and the ability to respond effectively to the users' expectations. Setting out from this premise, this study addresses the dynamic ridematching optimization system, with the goal of facilitating its integration as an alternative mode in an co-modal platform.

There is a wide set of literature surrounding the ridematching issue, notably in the dynamic context. The issue consists in matching, automatically and optimally, a set of riders' requests with a set of drivers' offers by synchronizing their points of departure, destination and time frame (Agatz, Erera, Savelsbergh, & Wang, 2011). In the dynamic context, drivers and riders are matched on a very short notice to create the possibility of ridesharing (Agatz et al., 2011). Santos et al. deal with a dynamic shared transport system served by private cars and taxis (Santos & Xavier, 2015). To solve this dynamic problem, days are divided into time periods. For each time period, an instance of a static problem is created and solved by a greedy randomized adaptive search procedure. Experiments with instances based on real data were provided to evaluate the heuristics and the proposed method. Numerical results show that the generated solutions could decrease the cost of trips by 30% when compared to a non–shared service.

In the relevant literature, two fundamental forms of ridesharing can be distinguished. The problem is termed multi–hop ridematching and it refers to the possibility of matching requests with different offers at different times so that the rider reaches his destination by hopping from one ride to another. It is otherwise called single–hop ridematching. The dynamic Multi-Hop Ridesharing Problem (*MHRP*) is more flexible than other forms of ridesharing and provides more choices for the rider. The *MHRP*, which is considered to be NP–complete (Herbawi & Weber, 2011), has received great attention from the optimization community. It is the subject of multi-objective Optimization: maximizing the number of serviced passengers, minimizing the operating cost or minimizing passenger inconvenience. This justifies the application of metaheuristics such as evolutionary algorithms in order to solve it (Herbawi & Weber, 2011; Ming-Kai, Shih-Chia, & Chih-Hsiang, 2013; Shih-Chia, Ming-Kai, & Chih-Hsiang, 2015). There is no known solution for such a problem, but near optimal solutions will suffice. Moreover, such algorithms are considered as *anytime algorithm* that can return a set of valid solutions to a problem even if it has stopped at any time before its termination. Indeed, setting up a ridematching system operating in the real world, where the environment is highly scalable and unstable, involves dealing with several unpredictable events (Likhachevt, Ferguson, Gordon, Stentz, & Thrun, 2005). System managers have to make decisions and act upon these decisions rapidly, notably in the case of a disturbance. With this observation in mind, metaheuristics, which are based on anytime algorithms, are particularly well suited to solve such kinds of issues.

Nevertheless, the existing methods are not efficient enough for large scale instances (Furuhata et al., 2013). Indeed, the complexity of the problem increases rapidly as the number of carpool users and, thus, the number of possible solutions grow (Ming-Kai et al., 2013). Additionally, solving the ridematching problem, especially in the dynamic context, is always a complicated process due to the importance of computation time, the variability of the data and their size during the optimization process (Agatz, Erera, Savelsbergh, & Wang, 2012). Then, a more efficient metaheuristics is required in the application in order to solve real–world cases.

Given the complexity accentuated by the domain expert's requirements, traditional optimization approaches based on classical expert techniques became inadequate in guaranteeing the efficiency expected of such systems. By anticipating these changes, the research landscape is evolving, and knowledge and technological capabilities continue to grow, the aim of which is to develop new intelligent optimization methods that can cope with these arising challenges.

It is within this framework that our article is written, its main objective being to develop an intelligent evolutionary algorithm which is able to effectively solve the ridematching optimization problem. The algorithm is characterized by a very large solution space in a reduced calculation time which subsequently allows the seamless integration of car pooling as an optimized alternative mode in an intelligent co–modal system.

Despite its effectiveness, the classical evolutionary approach has some limitations. Firstly, they handle several solutions at once meaning that evolutionary algorithms are computationally expensive operations (Ong, Nair, & Keane, 2003; Tenne, 2012). In addition, the Evolutionary Algorithm (*EA*) is often difficult to set (Eiben, Michalewicz, Schoenauer, & Smith, 2007). Indeed, the implementation of the *EA* requires adjusting certain parameters such as population size and mutation rate, that might not always be apparent. Consequently, many trials are essential to proving the effectiveness of the algorithm and measuring its performance.

It is evident that the efficiency of an evolutionary algorithm depends, crucially, on how individual crossing operates. In addition, controlling the random aspect of genetic operators may offer an interesting component for improving evolutionary algorithms. From this perspective, an alliance between *EAs* and other artificial intelligence techniques such as Multi–Agent Systems (*MAS*) could lead to good results in a reasonable time.

Concentrating our efforts on the development of an optimizing ridematching process while avoiding its combinatorial complexity, we suggest setting up a hybrid approach based on a combination of Evolutionary Algorithm and Autonomous Agent Chromosomes. *MAS* is a set of intelligent entities that coordinate their knowledge, goals, experiences and plans to act or solve problems (Bond & Gasser, 1988). The distribution aspect is an asset for *MAS* as it reduces the problem's complexity by dividing the processing into several tasks which are distributed on autonomous and intelligent entities (Sghaier, Hammadi, Zgaya, & Tahon, 2011). From this assessment, the key insight of this paper is to make the chromosome entity intelligent by implementing it in the behavior of an agent. As required by multi-agent systems, the agent properties such as autonomy, communication, proactiveness, learning and reactivity, can potentially be used to enhance the performance of *EAs* and to accelerate convergence. It is this which constitutes the originality of our approach.

In order to satisfy these properties and achieve these goals, our chromosome agents design their own powerful negotiation protocols which provide at the same time the main genetic operators: Selection, Crossover and mutation. According to a literature study, this original idea has never been tested in the development of genetic operators in the evolutionary algorithms.

The main body of this paper is composed of three parts:

- The first part describes our car pooling system architecture which includes different resolution algorithms. Placed within the context of the co–modality, this system will interact with other transport modes to generate optimized co-modal itineraries.
- The second part focuses on the algorithmic aspect of the designed system. It discusses the related works, with particular emphasis on the limitations of the classic *EAs*. Then, it introduces the new evolutionary approach and the chromosomes agents' negotiation protocol.
- The last part presents the dynamic ridematching optimization problem as an application for the proposed approach. To assess the effectiveness of the alliance between *EA* and *MAS*, a comparative study will be conducted between the classic