General Share-A-Ride Problem

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Abstract. Inefficiencies in transportation have resulted in economic and environmental problems. High levels of traffic congestion increase waste of resources and pollution. To address such issue, the Share-A-Ride Problem (SARP) has been developed. In SARP, a taxi could serve passenger and parcel requests at the same time. However, SARP has certain limitations, such as assuming that a taxi should not serve more than one passenger at the same time and should observe the maximum number of parcel requests that could be inserted between the pickup and drop-off / delivery points of a passenger. This study introduces a generalized model for SARP, called General Share-A-Ride Problem (G-SARP), which allows the taxi to serve more than one passenger request at the same time and has no restriction in terms of the number of parcel requests that could be served between the pickup and drop-off/delivery points of a passenger. The objective of G-SARP is to maximize total profit obtained from serving people and parcel requests. We present a mathematical model for G-SARP and perform a numerical study using CPLEX to solve small G-SARP instances.

Keywords: General share-a-ride problem, Ride sharing, Dial-a-ride problem

1. INTRODUCTION

Traffic congestion and air pollution are common problems in the urban area. The main cause of these problems is the increasing number of vehicles on the road. Ride-sharing, which aims at minimizing the number of vacant seats in vehicles, thereby reducing the number of required vehicles, has emerged as an essential practice that could reduce traffic and fuel costs as well as support green initiatives that aim at improving urban life and mobility conditions.

The traffic and pollution problem affects transportation of people as well as goods or packages. In a practical situation, online shopping has become popular, and same-day delivery has become a common feature of online shopping (B. Li, Krunshinsky, D., Woensel, T.V., Reijers, H.A., 2016). Road congestion is a serious obstacle for achieving this feature. New city logistic approaches are needed to ensure efficient urban mobility for transporting people and goods. Recently, study integrated people and freight transportation using a model called Share-a-Ride Problem (SARP) (Li, 2014).

The SARP model was implemented on conventional taxi operations, and assumed that the same taxi would be unable to respond to a two-passenger request at the same time. Therefore, the SARP model takes the approach of combining one passenger trip with a goods delivery request, but ensures that the passenger has the highest priority.

Sharing a taxi has recently become popular in several countries. In Europe, a mobile application can assist a passenger in finding a taxi for sharing nearest to his/her location. Taking advantage of this opportunity, this study introduces a new approach for improving mobility condition by combining sharing taxi and goods transportation service. The proposed service is called General Share-a-Ride Problem (G-SARP). From the modeling point of view, this problem is a generalized version of SARP and a variant of Dial-a-Ride Problem (DARP). The aim of this model is to plan a set of maximum profit vehicle routes that could accommodate all passenger and package requests.

The key contribution of this paper is that the generalized model of SARP could maximize profits for taxi companies because this model relaxes constraints that relate to customer priority and sharing rides among passengers.

This paper organized as follows. Section 2 presents an overview of the related literature on share-a-ride and dial-a-ride problem. Section 3 describes the model formulation of General Share-a-Ride Problem. Experimental results and comparison with other approaches are presented in Section 4. Finally, conclusions and future research are identified in Section 5.

2. LITERATURE REVIEW

For several years, the ride-sharing problem has been widely studied. Most issues are derived from the Dial-a-Ride Problem, which is the extended version of the Pickup and Delivery Problem (PDP) (Braekers, 2014; Coredeau, 2003; Markovic, 2015; Parragh, 2010). The purpose of this model is to design routes capable of accommodating all requests while minimizing total cost, under a set of constraints, such as vehicle capacity, route duration, and maximum riding time for each customer. A common DARP application is for door-to-door transportation service for elderly and the disabled (Laporte, 2007). The differences between DARP and other VRP variances is a trade-off between transportation cost and user convenience that are considered when designing a solution given that the models allow more than one passenger to use the same vehicle at the same time. Coredeau (2003) proposed a DARP model with capacitated vehicle and time windows. The maximum total duration for each vehicle was added as a constraint. Small instances were solved using the Tabu Search heuristic. Using other heuristic methods for solving the DARP problem, Parragh (2010) suggested a competitive Variable Neighborhood Search-based heuristic using three classes of the neighborhood. This study provided 16 new best solutions if compared with the benchmark study according to Coredeau (2003).

The other version of DARP is Shared-Taxi Problem. This model has several advantages that could minimize vacant seats in a taxi and reduce taxi operational costs. Consequently, taxi fares will be lower for passengers and traffic congestion reduced. The shared-taxi problem seeks to determine the optimal assignment of passengers to taxis as well as the optimal route for each taxi. Each taxi passenger request has to define a pickup and a drop off location, and the earliest acceptable pickup time and latest acceptable drop off time (Hosni, 2014). The application of ride sharing is used by travelers. A mobile application was developed to facilitate travelers with similar itineraries and time schedules on short notice. This problem is identified as dynamic-ride-sharing. The system may provide significant societal and environmental benefits by reducing the number of cars used for personal travel and improving the utilization of available seat capacity (Agatz, 2012). The impact of driver and rider flexibility on the dynamic ride-sharing problem could increase the performance of a ride-sharing system (Stiglic, 2016).

Recently, an extended model of DARP, called SARP, was proposed by Li et al. SARP combines passenger and package request at the same taxi. Given that the system uses a taxi as a transportation mode, this model cannot allow more than one passenger to ride the same taxi at the same time. Moreover, the passenger has higher priority over package requests. Passenger and package requirements have several differences. For instance, the pickup and delivery times for passengers are more critical than for packages. Hence, not taking parcel requests and obtaining different costs and benefits from package and passenger services are obvious. The objective of this study is to maximize total profit obtained from serving passenger and package requests. The small instances used in this study were solved by GUROBI (Li, 2014). The other research solves this problem by using Adaptive Large Neighborhood Search heuristic. This study compared the solutions with DARP proposed by Laporte et al., and showed that their method could deliver better solutions in terms of time and quality (B. Li, Krunshinsky, D., Woensel, T.V., Reijers, H.A., 2016). Recently, Li et al. developed a new variant of share-a-ride problem that considered stochastic travel time and stochastic delivery locations. The objective of this research is to maximize expected profit of serving passengers and parcels using heterogeneous vehicles. The result of this research suggested that stochastic information is valuable in real life and could dramatically improve the performance of taxi sharing system, compared to deterministic solutions (B. Li, Krunshinsky, D., Woensel, T.V., Reijers, H.A., 2016)

3. MODEL FORMULATION

The General Share-a-Ride Problem (G-SARP) is a generalized model from SARP proposed by Li. This model allows more than one passenger riding a taxi at the same time, like Taxi Sharing Problem or Dial-a-Ride Problem. Moreover, no restriction is imposed on the maximum number of requests that could be inserted into the passenger service as long as these trips do not exceed capacity constraints. The aim of this problem is to maximize total profits that the taxi company will obtain after serving all requests while considering penalty costs incurred from exceeding the direct travel time for passenger request.

In this problem, a set of N passenger requests and M package requests are given, which correspond to demand type C = {1, 2, .., |C|}. For this particular study, c = 1 denotes passenger and c = 2 denotes package. The formulation of G-SARP is defined on a complete undirected graph G = (V, A), where V is a set of vertex partitioned into $\{V^p, V^f, \{0, 2\sigma+1\}\}$. Subsets V^p and V^f correspond to passenger and parcel requests, respectively, while 0 and $2\sigma+1$ represent origin and destination depots for the vehicles, respectively. Subset $V^{p,0}$ and $V^{f,0}$ represent the origin nodes for each passenger and parcel request, respectively, and the origin nodes always precede destination nodes.

Each vertex is associated with service time duration $s_i \geq 0$ with $s_0 = s_{i+\sigma} = 0$. Each arc $(i,j) \in$ A is associated with travel distance d_{ij} and travel time t_{ij}. The detailed formulation of G-SARP is shown as follows:

Parameters:

m	Number of package requests
n	Number of passenger requests
k	Number of vehicles
σ	Total number of all request (σ =m+n)
q_i^c	A load quantity of stop *i* for demand type c
t_{ij}	Travel time between stop *i* and *j*
d_{ij}	Travel distance between stop *i* and *j*
s_i	Service duration of a request at stop *i*
$[e_i, l_i]$	Time windows at stop *i*
Q_k^c	Maximum capacity of vehicle *k* for demand type *c*, for $k \in K$ and $c \in C$
T_k	Maximal duration of route vehicle *k*
α	Initial fare charged for delivering one passenger
β	Initial fare charged for delivering one parcel
γ_1	Fare charged for delivering one passenger per km
γ_2	Fare charged for delivering one parcel per km
γ_3	Average cost per kilometer for delivering request
γ_4	Discount factor for exceeding the direct delivery time of passengers

Decision Variables:

x_{ij}^k	Binary decision variables equal to 1 if stop *i* and *j* served respectively by vehicle *k*
u_i^k	Arrival time for vehicle *k* at stop *j*
w_i^{kc}	The load of vehicle *k* for demand type *c* upon leaving stop *i*
r_i^k	Time spent by request *i* in vehicle *k*
p_i	Ratio between actual passengers riding time with its direct travel time

Objective Function:

$$\max\Big(\sum_{i \in V^{p,0}} \sum_{j \in V} \sum_{k \in K} (\alpha + \gamma_1 d_{i,i+\sigma}) x_{ij}^k + \sum_{i \in V^{f,0}} \sum_{j \in V} \sum_{k \in K} (\beta + \gamma_2 d_{i,i+\sigma}) x_{ij}^k - \gamma_3 \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} d_{ij} x_{ij}^k - \gamma_4 \sum_{i \in V^{p,0}} (p_i - 1) \qquad (1)$$

Constraints:

$$\sum_{j \in V} \sum_{k \in K} x_{ij}^k = 1, \forall i \in V^{p,0} \cup V^{f,0} \qquad (2)$$

$$\sum_{i \in V} x_{0i}^k \leq 1, \forall k \in K \qquad (3)$$

$$\sum_{i \in V} x_{i,2\sigma+1}^k \leq 1, \forall k \in K \qquad (4)$$

$$\sum_{i \in V} x_{i0}^k = \sum_{i \in V} x_{2\sigma+1,i}^k = 0, \forall k \in K \qquad (5)$$

$$\sum_{i \in V} x_{ij}^k = \sum_{i \in V} x_{i,j+\sigma}^k, \forall j \in V^{p,0} \cup V^{f,0}, \forall k \in K \qquad (6)$$

$$\sum_{j \in V} x_{ij}^k = \sum_{j \in V} x_{ji}^k, \forall i \in V^p \cup V^f, \forall k \in K \qquad (7)$$

$$u_j^k - u_i^k \geq s_i + t_{ij} - M(1 - x_{ij}^k), \quad \forall k \in K, i \in V, j \in \{V^p \cup V^f\} \qquad (8)$$

$$w_j^{kc} - w_i^{kc} \geq q_j^c - M(1 - x_{ij}^k), \quad \forall k \in K, i \in V, j \in \{V^p \cup V^f\}, c \in C \qquad (9)$$

$$r_i^k = u_{i+\sigma}^k - u_i^k, \forall k \in K, i \in V^{p,0} \cup V^{f,0} \qquad (10)$$

$$u_{2\sigma+1}^k - u_0^k \leq T_k, \forall k \in K \qquad (11)$$

$$e_i \leq u_i^k \leq l_i, \forall k \in K, i \in V \qquad (12)$$

$$\max\left\{0, q_i^c\right\} \le w_i^{kc} \le \min\left\{Q^{kc}, Q^{kc} + q_i^c\right\}, \quad \forall k \in K, i \in V, c \in C \tag{13}$$

$$u_{i+\sigma}^k \ge u_i^k + (s_i + t_{i,i+\sigma})x_{ij}^k, \quad \forall k \in K, i \in V^{p,0} \cup V^{f,0}, j \in V \tag{14}$$

$$p_i \ge 1, \forall i \in V^{p,0} \tag{15}$$

$$p_i \ge \sum_{k \in K} \frac{r_i^k}{(t_{i,i+\sigma} + s_i)}, \forall i \in V^{p,0} \tag{16}$$

$$x_{ij}^k \in \left\{0,1\right\}, \forall i, j \in V, k \in K \tag{17}$$

Objective function (1) maximizes the total profit obtained for passenger and parcel delivery, and comprises passenger fare, parcel fare, cost of distance traveled, and penalty cost for passenger extra riding time compared to direct delivery. Constraint (2) ensures that all requests are served exactly once by the same vehicle. Constraints (3), (4) and (5) guarantee that each vehicle starts and ends its route at the depot. Constraints (6) and (14) ensure that origin and destination nodes for the same request visited by the same vehicle and origin node will be visited before destination node. Every stop, except for the depot, must have one preceding and one succeeding stop, which is defined in constraint (7). Constraints (8), (9), and (10) define the starts of service times, vehicle loads, and riding times of passenger request, respectively. Total service time for each vehicle must not exceed maximum vehicle operational time, which is defined by constraint (11). The time window constraints for the request are defined in (12). Constraint (13) defines the load of vehicle k after visit, and vertex i must not exceed the maximum vehicle capacity. Constraints (15) and (16) ensure that the ratio between a passengers riding time and the corresponding direct travel time is greater than or equal to 1 so that the last term in the objective function has a positive value. Constraint (17) shows the decision binary variable.

The G-SARP model ignores customer priority constraints in the SARP model. Those constraints define that customer riding time should not exceed a specific amount of time, and restrict the same customer ride in the same taxi at the same time. Therefore, in this model, passenger riding time is limited only to the origin and destination point time windows, and allows the taxi to serve more than one passenger at the same time.

Table 1: Parameters used for GSARP and SARP model

Parameters	Values	Parameters	Values
$\lvert K\rvert$	{1, 2}	α	3.5
$m + n$(m = n)	{4, 6}	β	2.33
e_i	U(0:00 h, 12:00 h)	γ_1	2.70
l_i	U(8:00 h, 14:00h)	γ_2	0.90
q_i	1	γ_3	0.80
Q_k	5	γ_4	3.5

4. COMPUTATIONAL STUDY

The computational experiment is performed on Intel® Xeon® 3.70 GHz CPU 40 GB computer, under Windows 7 operating system. AMPL was used for solving small instances. The tested instances are explained in the next section. This section compares the solutions obtained from G-SARP and SARP by solving the same instances.

4.1 Instance Design for the G-SARP model

Table 1 shows the G-SARP instances generated by using parameters from Li et al. The passenger and package request randomly generated the following uniform distributions U([0,17]×[0,10]) km. Each request has pickup and delivery nodes. Time windows for all of the request are drew uniformly at random from intervals between 0:00-12:00 h for the earliest time window and 8:00-14:00 h for the latest time window. The distance between the nodes was calculated using Manhattan distance.

4.2 Comparison Result of G-SARP and SARP Model

To compare the benefits of the G-SARP with the SARP, eight small instances were run using AMPL. The two models ran under the same conditions. For each instance, a different number of customer requests, number of vehicles, and different length of time window were used. Table 2 reveals the results for G-SARP and SARP.

The G-SARP result exhibited larger values for all solutions than the SARP model. Because the objective of this model is maximizing profit, the G-SARP model gives a better solution than the SARP model.

Although the G-SARP model ignores customer priority constraints of the SARP model, customers still do not spend too much time in the taxi. Higher profit was obtained by the taxi based on the formulation for calculating the profits and by including penalty cost for exceeding the direct travel time.

Four of the eight instances have narrow time window (instance 14n, instance 24n, instance 16n, and instance 26n). The result of those instances have smaller solution values and larger gap percentage than the instance with wider time windows. Narrow time windows makes the high quality solutions for the customers but makes more difficult to get the optimal solutions. However, for both conditions the G-SARP model gives better solution than the SARP model.

Table 2: Comparison results for all instances

No.	**Instances**	**G-SARP**		**SARP**		**Gap (%)**
		Solution	**Time (s)**	**Solution**	**Time (s)**	
1	instance14	70.406592	5.632	59.239641	8.565	15.861%
2	instance14n	55.008824	0.718	45.128686	0.515	13.730%
3	instance24	24.389367	11.997	20.771831	8.689	6.248 %
4	instance24n	16.673837	4.009	13.726851	9.672	28.407 %
5	instance16	94.601476	22.137	85.084201	70.278	10.060 %
6	instance16n	88.422139	1.014	73.448513	3.963	15.270 %
7	instance26	86.050674	128.545	78.392481	297.229	8.139 %
8	instance26n	66.427720	6.771	51.148263	17.597	20.458 %

5. CONCLUSIONS AND FUTURE DIRECTION

This study proposed the G-SARP model to address the problems on passenger and parcel delivery services. The objective of this model is to maximize total profit for transportation companies. Results indicated that G-SARP yielded better solutions than SARP. Hence, the public transportation system could be managed more efficiently, while increasing profits and reducing traffic congestion and air pollution. Future research could apply the model and the proposed metaheuristic algorithm for solving bigger instances.

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