Solving the Lane Selection Problem in Multi-Period Transportation Auctions

Chefi Triki, Syedmehdi Mirmohammadsadeghi, Sujan Piya

***Abstract*—** In this research, the Multi-period Shipper's Lane Selection Problem (M-SLSP) has been considered. In M-SLSP some lanes may be serviced directly by the company and the remaining by third party through the use of the auction mechanism. The purpose of this study is to consider Shipper's Lane Selection Problem (SLSP) by introducing multi period condition to bring the model closer to reality and solve the model in a reasonable timeframe by administering a Simulated Annealing algorithm (SA). To make the solutions relevant, nine special Solomon benchmark instances are modified in order to increase the validity and efficiency of the aforementioned algorithm and to show the consistency of the results. The algorithm is found to be appropriate and relevant for solving this real-world M-SLSP.

***Keywords*—**Shipper's lane selection problem, simulated annealing, transportation auction.

I. Introduction

The world has witnessed and experienced decades of unprecedented breakthroughs within the realm of transport system development, vehicle technology, and traffic network extension. Many companies now a day have to satisfy more complicated customer demands due to the concept of mass customization. Therefore, a large number of logistic companies are trying to achieve a high level of reliability, flexibility, and agility in their transportation system in order to fulfill these demands. Transportation represents the largest logistics expense for a vast number of firms and companies. Streamlining the transportation network can quickly and drastically reduce the overall expenses of the company.

If companies and business entities aim to be sustainable in today's competitive atmosphere, they are required to cut down their costs in order to offer a better service and increase their profit. It is widely accepted that firms aiming to service the customers scattered in a vast area should possess a good service plan to save time and money.

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One of the best approaches to work out on this problem is to consider auction as an alternative instead of serving all the customers directly by the company or through expensive contracts. In this paper, we consider the service in the context of transportation procurement and the items auctioned off are transportation services. In this domain, the buyer is a manufacturer, a distributor, a retailer or any other company that needs to move goods. On the other hand, potential sellers are all the trucking companies. From now on, we will refer to the buyer as the shipper and to the sellers as the carriers. Items being auctioned off are distinguishable pairs of origin-destination nodes, usually called lanes, to which the shipper associates the number of loads that have to be moved from an origin to the destination during the temporal horizon considered in the proposed agreement [1].

Electronic auctions, conducted over the Internet, have several benefits compared to the traditional ones such as lower transaction and participation costs and allow the access to possibly larger markets [2]. Despite most of the auctions involve the sale of multiple distinct items, research in auction theory has traditionally focused on single item auctions assuming that bidders have no preferences to bundle. E-procurement of transportation services is a typical application domain where agents participating in the procurement auction show complementarity or substitution preferences on service contracts and have to solve a complex decision problem [3].

An important factor contributing to a carrier's transportation costs is indeed the deadheading cost (also called repositioning cost) which can be defined as the cost incurred when moving an empty truck from its current position to the origin of a new lane [4]. Thus, one of the main problems faced by a carrier is to find the right bid (the right bundles of lanes) and the corresponding price to submit as an auction bid [5]. On the other side of the auction, there are shipper's decision problems [6]. A shipper that manages a fleet of vehicles may get substantial benefits from running an auction and outsourcing some of the lanes rather than serving all the lanes by his own fleet to achieve significant overall lower cost. As far as we know, the first research on SLSP is due to [7]. The paper has proposed two different integer programming models for the problem in a single period settings. Since the problem addressed in [7] is NP-hard in its strongest sense, there is a need to design an efficient and effective heuristic to solve industrial size problem within a reasonable computational time.

In transport service procurement, rather than making a plan of serving lanes for a single period, company may benefit from

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planning it for multiple periods as some customers may need to be served more than once. Therefore, in this study, at first, a mathematical model for Multi-period SLSP (M-SLSP) is developed. Thereafter, a simulated annealing algorithm (SA) is applied to overcome the limitation of [7]. Through computational analysis the paper has demonstrated that the SA algorithm is efficient in solving M-SLSP. For the purpose of analysis nine benchmark instances which are originally derived from Solomon [9] are modified for the M-SLSP.

The remainder of the paper is organized as follows. In Section 2, the detailed descriptions and formulations are provided. The simulated annealing heuristic is described in Section 3, followed by computational results in Section 4, and by conclusions in Section 5.

II. Mathematical Formulation

In this paper we consider a shipper who has to serve lanes either by themselves or through auction. Using its own fleet will result into repositioning cost and cost of serving lanes. On the other hand, auctioning lane(s) incur the cost for setting auction and the price to be paid to the successful bidder. Under such situation, the shipper may be able to reduce its total service cost by serving some of the lanes by their own fleet and then delegating the remaining to the successful bidders. However, the problem for the shipper is to identify lanes to auction off and the lanes to be served by them. We considered this problem in a multi-period situation with the assumption that the auction set up cost is fixed irrespective of number of lanes auctioned off.

An extended planning horizon (T=1,…,H) composed of a certain number of days has been considered in the model. A set of lanes (L) has to be served one or more times during the planning horizon [8]. Each lane is identified by an origin and a destination. Given a complete bi-directed graph G=(V,A) with node set V (including the depot), arc set A and lane set L⊆A, the problem looks for a directed cycle starting and ending at the depot, covering a subset of lanes while minimizing the traveling costs plus the sum of costs incurred by the shipper to auction off the lanes not served by his own vehicle. Therefore, the problem M-SLSP is similar to the problems belonging to the class of arc routing problems [10] except that in M-SLSP apart from travel cost associated with each arc, the costs associated with auctioning the lanes needed to be taken into consideration. The auction costs are the sum of the costs paid to the bidders for the requests auctioned off plus a fixed cost incurred for running the auction. Assuming C_ij as the travel cost from node i to node j,(i,j)∈A, Ć_ij as the estimated cheapest price asked by a potential carrier for serving lane (i,j)∈L and F as the fixed cost for running an auction, the objective is to identify lanes, out of many, the shipper will serve by their own fleet and the lanes shipper will delegate to the third party such that the total costs of serving the entire lanes is minimized.

It is to be noted that, for simplicity, the model described below refers to a shipper having one vehicle only, but its extension to the general multi-vehicle case is straightforward.

The problem's decision variables are of three types. X_{ij}^{t} takes value 1 if lane (i,j) is served by the shipper in day t and 0 otherwise, and Y_{ij}^{t} that assumes value 1 if lane (i,j) is auctioned off. Finally, variable Z is 1 only if the shipper will organize the auction and, thus, a fixed running cost F will occur. If no lane will be auctioned off than Z will take value 0. The formulation of the M-SLSP is as follows:

(1) $\text{Minimize} \quad \sum_t^T [\sum_{i\in V} \sum_{j\in V} C_{ij} X_{ij}^t + \sum_{(i,j)\in L} \acute{C}_{ij} Y_{ij}^t] + FZ$

Subject to:

(2) $\sum_{i\in v} \sum_{j\in v} X_{ij}^t + \sum_{(i,j)\in L} Y_{ij}^t = 1 \qquad t = 1, 2, \dots, T$

(3) $\sum_t^T \ \sum_{(i,j)\in L} Y_{ij}^t \le M_1 Z$

(4) $\sum_{j\in v}(X_{0j}^t) = 1 \qquad \forall t = 1,2,\dots,T$

(5) $\sum_{i\in v}(X_{i0}^t) = 1 \qquad \forall t = 1,2,\dots,T$

(6) $\sum_{i\in v}\sum_{j\in v} X_{ij}^t - \sum_{i\in v}\sum_{j\in v} X_{ji}^t = 0 \qquad \forall t = 1,2,\dots,T$

(7) $\sum_{i\in S}\sum_{j\in S} X_{ij}^t \ge u^S \quad S \subseteq V\setminus\{0\}, S \ne 0 \quad \forall t = 1,2,\dots,T$

(8) $\sum_{i\in S}\sum_{j\in S} X_{ij}^t \le |S| - 1 + M_2 u^S \ S \subseteq V\setminus\{0\}, S \ne 0 \ \forall t = 1,2,\dots,T$

(9) $\sum_{i\in S}\sum_{j\notin S} X_{ij}^t \ge 1 - w^S \quad S \subseteq V\setminus\{0\}, S \ne 0 \quad \forall t = 1,2,\dots,T$

(10) $u^S + w^S \le 1 \qquad S \subseteq V\setminus\{0\}, S \ne 0 \qquad \forall t = 1,2,\dots,T$

(11) $X_{ij}^t \in \{0,1\},\ Y_{ij}^t \in \{0,1\}, (i,j) \in L, \qquad \forall i,j \in v,$

(12) $u^S \in \{0,1\}, \quad w^S \in \{0,1\},\ Z \in \{0,1\}$

As shown in Equation (1), the objective is to minimize the total cost of serving all the lanes. It is to be noted that the objective function can also be extended in order to maximize the profit determined as the revenue minus the cost. Equations (2) ensure that all the lanes will be serviced either directly by the shipper or through action. Constraint (3) forces the binary variable Z to take value of 1 if at least one lane is auctioned off. Constraints (4) and (5) ensure that the route must be started from the depot and terminated at the depot. Constraints (6) establish that, at optimum, the total number of arcs entering into any node must be equal to the total number of arcs leaving it. Constraints (7)-(10) eliminate any isolated sub-tour. Finally, constraints (11) and (12) define all the variables to be binary.

The above model results to be a linear integer program with all binary variables for which it is known that efficient solutions approaches are difficult to be developed when the size of the problem increases to represent realistic scenarios. For this reason we propose in the sequel a heuristic method based on the simulated annealing technique.

III. Simulated Annealing Method

As the problem we are addressing is strongly NP-hard a heuristic method is proposed using simulated annealing (SA) technique to solve industrial size problem. SA is the most famous algorithm in local search methods. In SA, it is important to define an appropriate method for finding the effective neighbors to improve an existing solution. A random neighborhood structure including swap, reversion and insertion is used for generating an appropriate neighborhood from a current solution. At each iteration, the algorithm generates a new solution Y from the current solution X by using swap, reversion and insertion. The description of the SA procedure can be found in many references such as [11].

IV. Computational Experiments

The SA algorithm was coded by MATLAB R2014a using a computer with a 2.4 GHz dual processor and 4 GB RAM. Since there is no any known benchmark available in the literature for the M-SLSP problem, special 9-benchmark-instance problems from Solomon [9] have been modified in order to test the effectiveness of the proposed algorithm. The coordinates of the vertices as well as the number of nodes are assumed to be same as in Solomon's instances but some additional data have been randomly generated in order to suit our problem's characteristics.

The parameters used in the model may affect the quality of the computational results. In order to obtain better solutions, different values were tested in the initial experiments as shown in Table1. In the Table, T indicates the thermodynamic temperature which is used to simulate the system at different temperatures. The value of T gradually cools down from an initial high temperature (T_0) to a final low temperature (T_f). This means that the procedure will be stopped when the temperature becomes lower than T_f. I_iter represents the number of iterations during the procedure. K is the Boltzmann constant which is used in the probability function. N_non denotes the maximum number of allowable iterations in a given temperature. The algorithm will be terminated if the number of iteration exceeds N_non without improving the best cost. α is the coefficient for controlling the cooling scheme. In addition, n_pop is the number of initial solutions that should be considered for producing new solutions and n_move is the number of move from the current solution to generate new solutions. Each current solution can produce n_move new solutions and the best one will be chosen as a new solution. I_iterpertemp is the number of iterations in each temperature value T [11].

TABLE I
PARAMETER VALUES FOR THE INITIAL EXPERIMENTS

α	0.99, 0.975, 0.95
I_{iter}	20000, 40000, 60000, 80000, 100000
$I_{iterpertemp}$	2, 4, 6, 8, 10
K	1, 0.9, 0.8, 0.7, 0.6, 0.5
n_{pop}	1, 3, 5, 7, 9
n_{move}	1, 3, 5, 7, 9
T_o	1000, 10
T_f	0.1, 0.001
N_{non}	100, 200

Our computational experiments have been carried out while considering different values of the SA parameters as shown in Table 1. As a consequence the following values have been empirically selected for our computational study: α=0.95, I_iter=500, K=0.7, T_0=10, T_F=0.001, n_pop=5, n_move=9, I_iterpertemp=6 and N_non=200. These parameter values seem to produce the best results for the problem under consideration. It is worth noting, however, that similar trends of the results have been observed even when using the other parameter values reported in Table 1, a fact that proves that robustness of our approach with respect to the SA parameters.

The results obtained for the different test instances while using the selected parameter values are presented in Table 2. Each set has been run 10 times and for each test instance the best solution (Best-sol) and the average solution (Avg-sol) are shown in the same Table. Moreover, the percentage of lanes auctioned with respect to the total and the computational (CPU) time needed to get the best solution for each instance are presented in the last columns of the Table.

TABLE II
THE M-SLSP RESULTS

Number	Original Solomon Problem	Number of customers	Number of lanes	Best-sol	Avg-sol	Lanes Auctioned (%)	CPU Time (minutes)
1	R101	100	50	6731	7054	30	1
2	C101	100	50	7588	7963	40	1
3	RC101	100	50	8688	9023	34	1
4	R201	200	100	9267	9470	52	2
5	C1-210	200	100	33745	34193	61	2
6	C1-410	400	200	111384	118938	67	3
7	C1-6-1	600	300	207295	210389	59	7
8	C1-8-1	800	400	375032	378930	63	12
9	C2-10-1	1000	500	573760	577893	70	18

To indicate the convergence of the proposed approach, the trends for problems RC101 and R201 are shown in Figure 1 (the other problems exhibit similar behavior). The figure shows the variation of the obtained objective function value with respect to the number of iterations. As can be noted, the improvement rate of the solution decreases as the number of iterations increases and after a certain number of iterations, the solution value converges. Consequently, the quality of the solution cannot be enhanced further by allowing a greater number of iterations.

Furthermore, it is evident from Table 1 that the difference between the obtained best solution and the average solution is very low. This fact, together with the attractive characteristic of the algorithm convergence, represents a clear signal of the efficiency of our SA algorithm.

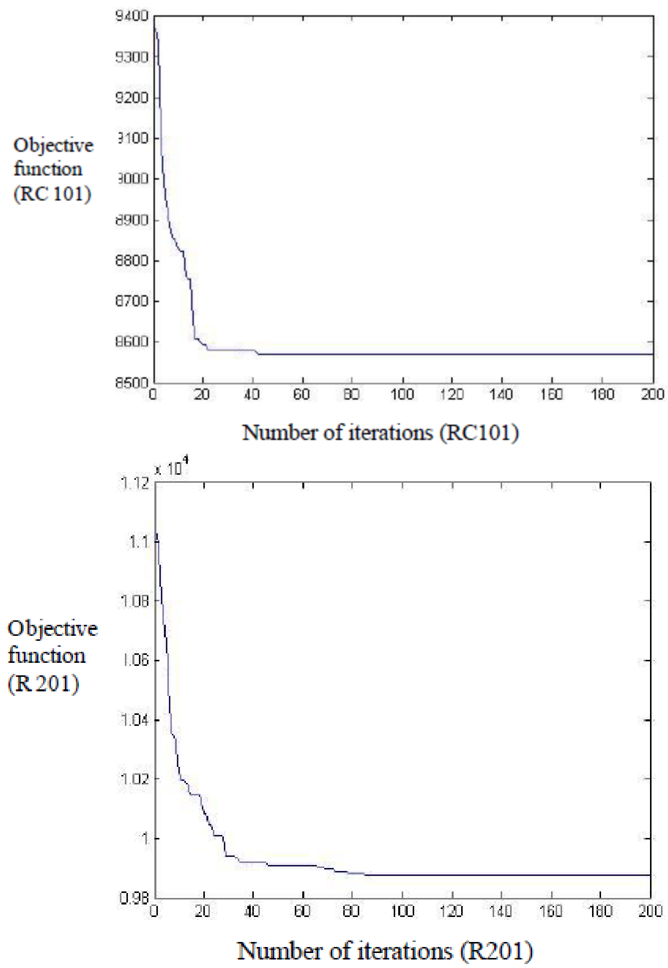

Fig 1: Convergence trend for the SA solution on RC101 & R201

V. Conclusion

In the SLSP each lane can be served either by the shipper or by a third party carrier by using the auction mechanism. This paper extends the SLSP in order to consider the extended time horizon case. It introduces, thus, the new variant M-SLSP of the problem, and develops an optimization model and a SA method for its solution. Nine M-SLSP benchmark test problems, based on the Solomon library, have been generated in order to show the validity and efficiency of the algorithm. The collected results confirm how our method exhibits attractive features related to the quality of the solution, to the convergence of the algorithm and to the reasonable computational time.

This work can be extended towards several research directions. First, some practical or real-world conditions may be introduced within the M-SLSP formulation by incorporating, for example, the periodic aspect of the problem. Second, from the methodological point of view, the lanes to be auctioned may be identified by using the clustering technique by using the concept of synergy (as employed, for example, in [5]). Finally, the interest in this topic may be extended to solve specific variants related to real-life applications.

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