Genetic Algorithm Based on Clark & Wright's Savings Algorithm for Reducing the Transportation Cost in a Pooled Logistic System

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Abstract

In this paper, we study a pooled logistic system in which some enterprises share the same depot and fleet of vehicles to deliver products from the shared depots to customers. Genetic algorithm based on Clarke & Wright's algorithm is proposed to solve the problem in order to minimize the total transportation cost which comprises of the total cost of shipping the products from enterprises to the shared depot, and the total cost of all the trips that deliver the products to the customers. The proposed algorithm was applied on a benchmark instance of a vehicle routing problem adapted to the pooled transportation problem. The results confirm the rooms of cost reduction if the pooled logistic will be applied.

Keywords
Pooled logistic system, vehicle routing, genetic algorithm, Clarke and Wright's algorithm,

1. Introduction

In recent years, optimizing a supply chain is getting a great importance since it has a significant effect on product's cost, CO_2 emissions and level of customer service. This optimization was based only on the economic level for long time but now the optimization is happening by integrating both economic, environmental and societal issues which are the objectives of sustainable development (Rosen and Kishawy 2012).

Urban distances represent 28% of the total cost even though these distances is a small part of the total travelled distances (Roca-Riu and Estrada 2012) and 16% to 50% is estimated of air pollution emissions due to transport activities in cities (Battaia et al. 2014). Therefore, improving the efficiency of road transport is a challenge not only in terms of optimizing transport costs but also in terms of reducing the environmental footprint.

Based on the statistics of the European Environment Agency, load of truck transporting cargo are generally at an average of 50 % (Abate 2014). The load factor is an index of the utilization of the available capacity of the used trucks. This is an important room of improvement. Certainly, getting a higher load factor will considerably reduce the freight traffic volume and consequently will reduce the transportation cost and the Greenhouse Gas emissions.

Adopting a pooled logistic system is one of the solutions proposed by researchers to make a new logistic system and overcome these challenges. The pooled logistic system is a cooperation between independent supply chains to build a common supply chain network by sharing the depots and transportation vehicles that yields reduced costs of warehousing and transportation compared to the classical logistics. Indeed, it permits more important delivery frequencies to the customers, improves the utilization of vehicles, and improves ecological impacts.

Collaborative supply chain is a business partnership between two or more companies to achieve common goals. It is differentiated depending on its structure into vertical collaboration, horizontal collaboration and lateral collaboration (Simatupang and Sridharan 2002). European Union (Union 2001) defined horizontal collaboration as "concerted practices among companies operating at the same level(s) in the market".

(Moutaoukil et al. 2012) did a large-scale revision and introduced a conceptual framework for the pooling supply chain implementation as horizontal collaborative logistics strategy. The authors found a similarity between pooling supply chain and horizontal collaboration strategies.

(Pan et al. 2014) proposed three different pooling scenarios and compared with the existing transport organization of the food industry in western France to evaluate cost and emission levels of CO2. The methodology consisted in accessing a current situation through a survey of the flow of goods at one of the main distribution center of the studied supply network, then comparing this situation with three other pooling scenarios.

(Pan et al. 2014) The pooling concept is applied to a collection of small and medium-sized western France food suppliers serving the same retail chain. In order to demonstrate the efficiency of the pooling, the existing transport organization was compared to various pooling scenarios. The authors restrict the pooling only between supplier's sites and retailer's distribution centers. The customers are not included in this study.

(Pérez-Bernabeu et al. 2015) discussed horizontal collaboration and proposed one collaborative scenario and two non-collaborative scenarios in order to calculate the savings in transportation cost between depots and customers by running an experiment based on well-known MDVRP benchmarks. An iterative local search algorithm is proposed to obtain high quality solutions for this collaborative scenario, while non-collaborative scenarios are solved using a well-tested algorithm for the Capacitated Vehicle Routing Problem. Computational results showed that horizontal cooperation strategy can contribute to a noticeable reduction in expected costs, both in terms of distance traveled as well as in terms of greenhouse gas emissions.

(Sanchez Rodrigues et al. 2015) mentioned that before embarking on a horizontal logistic collaboration project, several issues should be taken into account such as: legislation, trust among partners, common suppliers and delivery bases, capable 3PL and an effective commercial model, including a fair sharing of benefits.

(Daoud and Mellouli 2015) presented the location-allocation problem with pooling in the context of merging two networks with two different products to show the effect of pooling and quantify the gains obtained by reducing transportation costs.

(Montoya-Torres et al. 2016) performed a case study for three companies in which each company has its own stores. Then compared two scenarios mainly in terms of travel distance and then evaluated the travelled time and carbon emission from the travel distance. The first scenario is a non-collaborative scenario in which each company distribute goods to its own stores. The second scenario is a collaborative scenario in which the stores of the three companies are allocated to one of the three companies' headquarters, and then routing is performed for each new allocation. This study considered only distance as an input and neglected both the demand of each stores and the capacity of each vehicle.

(Ouhader and Elkyal 2018) studied the impact of network structures in a collaborative distribution system and concluded that strategic decisions of facility location has to be considered simultaneously with decisions of vehicle routing in designing the network since it affects the collaborative supply chain.

(Debroy and Sarmah 2019) studied the benefits of carrier collaboration by sharing unused capacity of vehicles and deciding how much to share. Results on a case study showed that sharing of capacity increased the profit by 8.6% compared with the profit gained by a standalone carrier.

(Achamrah et al. 2020) proposed two simulation models to evaluate the advantages and disadvantages of sharing pallets in a collaborative supply chain. The first model is a non-collaborative supply chain in which each producer manages his own pallets while the second model is a collaborative supply chain in which producers share their empty pallets. Results showed that collaboration between producers can reduce the transportation and inventory costs.

(Amer and Eltawil 2015) performed a literature review on quantitative models for horizontal collaboration. (Chen et al. 2017) conducted a systematic literature review and a quantitative bibliometric analysis on supply chain collaboration for sustainability. (Basso et al. 2019) did a survey on practical issues in implementing horizontal collaboration. (Ferrell et al. 2019) performed a review in existing horizontal collaboration researches. (Pan et al. 2019) performed a review in horizontal collaborative transport and classified the previous studies according to two directions: horizontal collaborative transport solutions and implementation issues. Results regarding horizontal collaborative transport showed that pooling is gaining an increased attention.

The rest of this paper is organized as follows: section 2 presents a description of the problem. A description of the genetic algorithm and the Clarke & Wright's Saving algorithm is presented in section 3. Section 4 shows the computational results. Finally, concluding remarks are discussed in section 5.

2. Problem Description

The pooled logistic problem is a two-echelon location routing problem 2E-LRP, which has two levels. In the first level, products shipped from enterprises to depot, which must be located. Then the products are distributed to customers from these selected depots. The version studied in this paper states that once a depot is selected, it should be shared by at least two enterprises and no enterprises will have it is own depot to satisfy pooling. It is an NP-hard problem since it combines facility location problem (FLP) and vehicle routing problem (VRP) which are both NP-hard problems. Decisions taken are based on a strategic level and an operational level. Assignment of depots to enterprises and the location of depot are strategic decisions while routing strategy to distribute products from depots to customers is an operational decision. Once a depot is select and assigned to enterprises, the cumulative demand of customers will be delivered from these enterprises through the assigned depots. The costs involved in this problem that will be optimized are: total cost of transporting products from firms to assigned depots which is referred to as "first level cost" and total cost of routing from those depots to customers and referred to as "second level cost". The difference between the proposed version of a pooled logistic system and the classical logistic system is illustrated in Figure 1. In this figure, there are two enterprises, two depots and three customers. For the classical logistic system as shown in Figure 1. (a), each enterprise has its own depot (i.e. enterprise 1 has depot 1 and enterprise 2 has depot 2). Then, each depot has its own fleet of vehicles to deliver orders to customers. On the other hand, in the pooled logistic as shown in Figure 1. (b), both enterprises share the same depot (i.e. depot 2) and the same fleet of vehicles to deliver orders from the shared depot to customers.

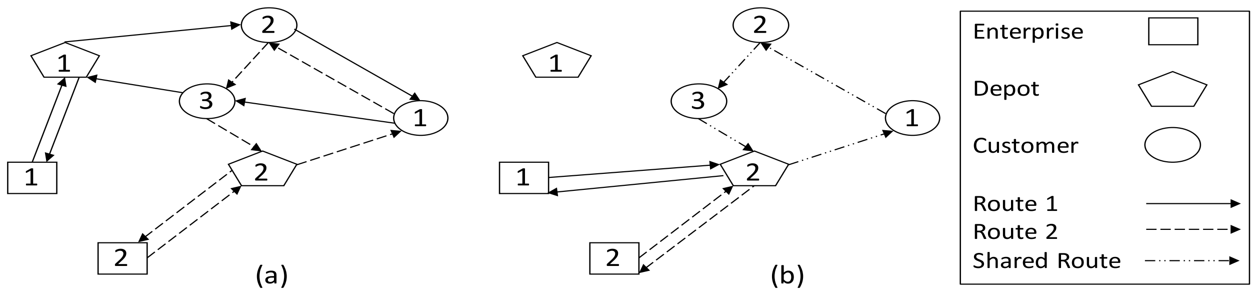

Figure 1. (a) Classical logistic system. (b) Pooled logistic System

2.1 Model Assumptions:

1. Each enterprise should be assigned to only one depot.
2. Direct shipments from enterprises to customers are not allowed.
3. The capacity of the large vehicle is four times the capacity of the small vehicle.
4. Each customer's demand is satisfied.
5. Vehicles are homogeneous with predefined capacity.
6. The number of vehicles is not specified prior.
7. Demand of customers is related to enterprises.
8. The cost per unit distance of a vehicle is equivalent to the distance travelled.
9. The cost per unit distance of a truck is equivalent to four times the distance travelled.

3. Solution Methods

In this paper, genetic algorithm based on Clarke & Wright's Saving algorithm is proposed to find the total transportation cost in a pooled logistic system. Genetic algorithm is used to find the assignment of enterprises to depots. Then, Clarke & Wright's Saving algorithm is used to establish routes from each selected depot to customers.

3.1 Genetic Algorithm (GA)

Genetic algorithm (GA) is one of the most popular evolutionary algorithms used to randomly search for good solutions for complex optimization problems (De Jong 1985; Goldberg and Holland 1988). GA works by randomly generating a set of candidate solutions called a population. Then new generations of the previous populations are created at each iteration while using some operators: First, a selection operator is used to select chromosomes to be parents. Second, the selected parents undergo some alterations, using the crossover and the mutation operators. Repairing the resulting chromosomes is required if they don't represent feasible solutions of the problem. Each individual is evaluated using a fitness function of the considered problem. The process of generating a new population is repeated until a stopping criterion is satisfied. The solution is the best chromosome found among these generations. A flowchart of the genetic algorithm is shown in Figure 2.

Standard selection, crossover and mutation operators are used to generate new population from a previous one. Each chromosome includes as much genes as the number of the enterprises. The possible value for each gene is the depot selected for that enterprise. In order to assess each chromosome, the supplies of the enterprises assigned to the same depot are unified, then a vehicle routing problem is solved for all the depots that are assigned to at least two enterprises. If a depot appears once in the chromosome then this means that the enterprise assigned to that depot will not collaborate with other enterprises, thus the chromosome will be repaired to ensure that each depot already assigned to one enterprise should be assigned to at least another or it should disappear from that chromosome. Since the vehicle routing problem is solved as much as the number of the depots for all the chromosomes over all the iterations of the genetic algorithm, then the number of the vehicle routing problems to be solved will be huge. Thus a fast heuristic of the vehicle routing problem is required to ensure a reasonable execution time to the proposed genetic algorithm. Clarke & Wright's Saving algorithm is selected to be used since it's one among the fastest heuristics of the vehicle routing problem in the literature. In addition to its short computational time, Clarke & Wright's saving algorithm is quite efficient.

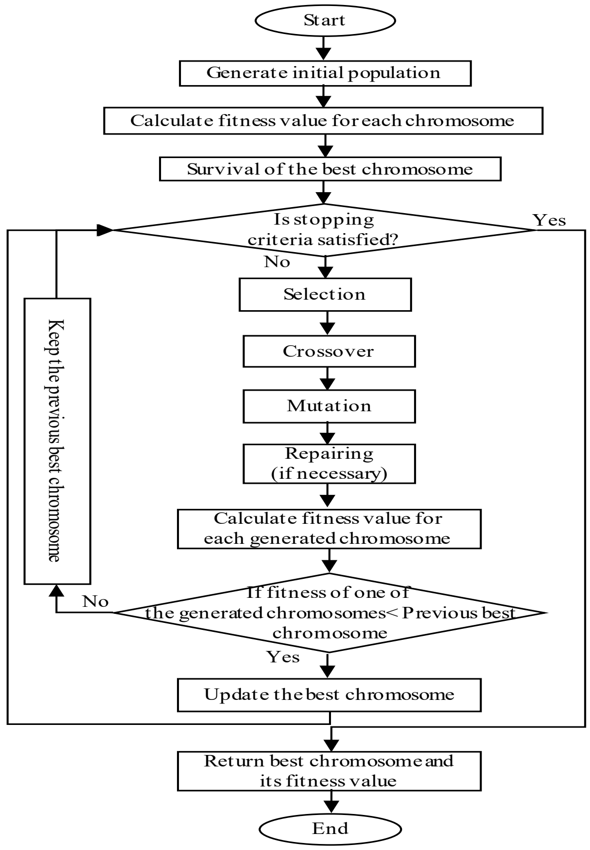

Figure 2. Flowchart of genetic algorithm

3.2 Clarke & Wright's Saving algorithm (CWS)

Clarke & Wright's Saving algorithm (CWS) is an iterative procedure firstly proposed by (Clarke and Wright 1964) to build routes by combing nodes that give saving in cost compared with a single route for each node. It is commonly used to solve travelling salesman problem and vehicle routing problem.

The Clarke & Wright's Saving algorithm (CWS) works using the cost c_{ij} between all couple of nodes *(i,j)* including the depot node as follows:

- First, calculating the saving S_{ij} in cost resulted when two nodes *i* and *j* are pooled in only one route starting from a depot and returning to it, instead of two routes (one route for node *i* and other for node *j*): $S_{ij} = c_{0i} + c_{j0} - c_{ij}$.
- Second, sorting the saving values in descending order.
- Finally, starting from the highest saving in the saving list, add the pair (*i, j*) in one route if all constraints are satisfied (mainly capacity constraint of the vehicle) and repeat this process for next pair until all nodes are assigned to routes. If still exists a node that could not be added to any route, establish a single route for that node.

4. Results and Discussion

The proposed GA is implemented using the C++ programming language and tested on one instance with characteristics described in Table 1 and available upon request from the corresponding author. The considered instance is originally used in (Christofides N 1979) for the vehicle routing problem and modified to meet with the requirements of the pooled transportation problem. The first seven nodes represent the enterprises. After that, the next nine nodes represent the depots. Finally, the remaining nodes represents the customers. Since a customer will have a demand from each enterprise, the demand of each customer from each enterprise is randomly generated between [5, 25] units. The computational tests were run on a Laptop with an Intel® core i7-5500U CPU with 2.4 GHz and 8.00 GB memory.

Table 1. Characteristics of the used instance

# of nodes	# of enterprises	# of depots	# of customers	Capacity of a vehicle	Capacity of a Truck	Capacity of a depot
51	7	9	35	160	640	1902

In the implementation of GA, the maximum number of generations is set to 200 and the population size is set to 130 chromosomes. Each chromosome is encoded by a number of positions equal to the number of enterprises. The possible values for each position (i.e. enterprise) is the selected depot for that enterprise. For the selection method, the tournament selection is used by randomly drawing three chromosomes and then selecting the best among them. The two-point crossover with probability 0.9 is used to combine some characteristics of the two parents to generate new children and an insertion mutation with probability 0.01 is used to alter some characteristics of a single chromosome. The resulted chromosome could violate the objective of the proposed scenarios. Therefore, the chromosome is repaired so that it satisfies the objective of the proposed scenario. Another chromosome repairing method is dealing with exceeding depot capacity which could occur when there is more than one enterprise share the same depot and the transported demand from these enterprises to the shared depot exceeds the depot capacity. In this case, a big number is assigned to the fitness of this chromosome so that this chromosome will have a low probability to be selected in the next generation.

The solutions of the proposed version of a pooled logistic system and the classical logistic system are illustrated in Table 2 and Table 3, respectively.

Table 2. Results for the proposed pooled logistic version

1st level				2nd level		Cumulative Demand
From enterprise	To depot	Distance	Cost	No. of Routes	Distance and Cost	
3	2	52.08	208.32	7	620.62	1066
5	2	20.5331	82.1324			
1	4	21.2662	85.0648	8	607.02	1102
2	4	18.0712	72.2848			
0	5	13.2221	52.8884	12	798.35	1637
4	5	23.0551	92.2204			
6	5	29.9261	119.7044			
Total	3	178.1538	712.6152	27	2025.99	3805

Table 3. Results for the classical logistic system

1st Level				2nd Level		Cumulative Demand
From enterprise	To depot	Distance	Cost	No. of Routes	Distance and Cost	
3	1	35.4396	141.7584	4	177.93	159
2	2	27.674	110.696	4	178.27	155
5	3	23.593	94.372	4	167.94	157
1	4	21.2662	85.0648	4	167.85	151
0	5	13.2221	52.8884	4	147.03	153
6	7	17.0907	68.3628	4	178.75	160
4	8	34.7171	138.8684	4	189.86	157
Total	7	173.0027	692.0108	28	3455.21	3805

Table 2 and Table 3 contain two levels: the first level is the assignment of enterprises to the selected depots, the distance and the cost of trucks routes from each enterprise to its assigned depot. The second level contains the number of vehicle routes from each selected depot, and both the distance and cost of these vehicle routes. In addition to these two levels, a cumulative demand of customers in all routes from each selected depot is presented.

In a pooled logistic version as shown in Table 2, depot 2 is allocated to enterprises (3 and 5), depot 4 is allocated to enterprises (1 and 2) and depot 5 is allocated to enterprises (0, 4, and 6). From each selected depot, a routing plan is established using Clarke and Wright's Saving algorithm to deliver customers' demand with seven routes from depot 2, eight routes from depot 4, and twelve routes from depot 5. The total first level distance =178.1538-unit distance and the total second level distance = 2025.99-unit distance. Therefore, the total transportation distance = 2204.1438-unit distance, and the corresponding total transportation cost is 2738.6052-unit cost/unit distance.

Similarly, the results for the classical logistic system as presented in Table 3 showed that for each enterprise, a unique depot is allocated to it and a routing plan from these depots with four routes is established using Clarke and Wright's Saving algorithm to deliver customers' demand. The total transportation distance and the total transportation cost for the classical logistic system is equal to 3628.213-unit distance and 4147.221-unit cost/unit distance, respectively. The comparison of the first level and second level costs for both the classical logistic system and the pooled logistic system is visually represented in Figure 3.

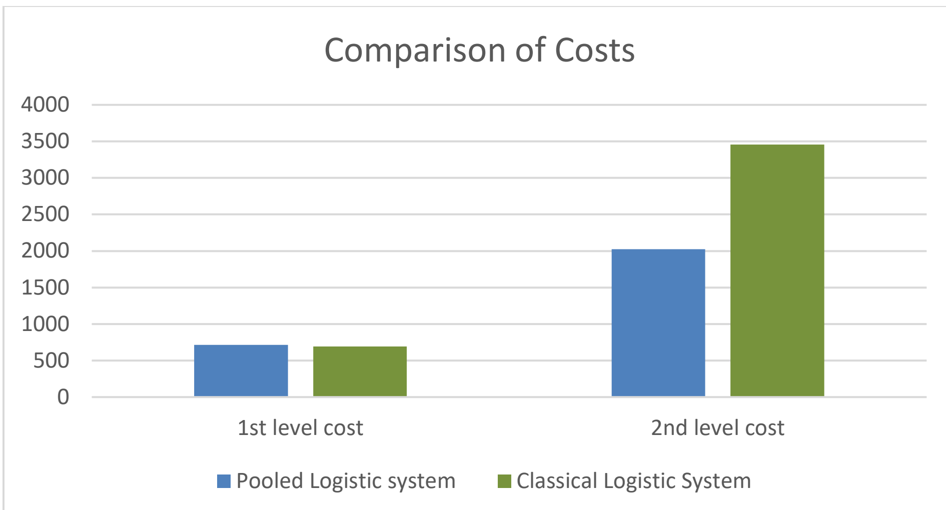

Figure 3. Comparison of cost of the proposed logistic systems

The results show that the collaboration between each group of enterprises to share the same depot and fleet of vehicles reduces the total transportation distance and the total transportation cost to deliver products from enterprises to customers through selected depots. The savings in the total transportation distance and the total transportation cost by adopting a pooled logistic system in the studied instance are 1424.0689-unit distance and 1408.616-unit distance/unit cost, respectively. Furthermore, the number of customers visited by each vehicle is reduced due to the cumulative demand of the collaborating enterprises. On the other hand, vehicles in the classical logistic system have to visit more customers in order to improve the utilization of their vehicles. However, this action results in long distances travelled by vehicles.

In the proposed GA, there is a repetitive calling of CWS algorithm in each chromosome of each population and for each generation. However, implementing CWS algorithm to evaluate fitness of a chromosome helped us to obtain good results in a suitable amount of time.

5. Conclusion

In this paper, genetic algorithm and Clarke & Wright's saving algorithm are proposed for the assignment of enterprises to depots and the routing of vehicles from depots to customers. The objective is to study the impact of a pooled logistic system in reducing the total transportation cost as compared with noncollaboration between enterprises. Computational results obtained from an instance adapted from the literature showed that the pooling logistic version outperforms the classical logistics in reducing the total transportation cost. Moreover, the utilization of vehicles is enhanced and the number of both vehicles and visited customers for these vehicle is reduced compared with the classical logistic system.

Future work is to propose other versions of a pooled logistic system, consider other heuristic solutions and study the problem with heterogeneous fleet of vehicles.

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