Node Formulation and a Heuristic Algorithm for Location Routing Problem of Electric-Powered Vehicles

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Abstract. Electric vehicle (EV) in the robotic context and also in the future of logistics networks, as a sustainable and emission-free tool of transportation, will play an important role. One of the main EV restrictions is the limited stored energy. Energy-efficient location routing problem (LRP) which has not been investigated vastly in literature can provide solutions to limited energy issues. This paper provides a novel formulation of LRP as well as a heuristic method which finds the best location-allocation, and routing plan of EVs with the objective function of minimizing the total energy cost. The experimental result shows the energy consumption of vehicles using the exact and heuristic method presented in this paper is better than the traditional formulation and heuristic method developed for LRP.

1. Introduction

The problem addressed in this paper is the Energy Efficient Location-Routing problem (EELRP). The problem is a combination of location-allocation problem (LAP) and vehicle routing problem (VRP). LRP is defined as the problem of locating a set of potential facilities, allocating customers to them, and finding a set of routes originating from depots to serve the customers. Each customer must be visited only once and all the vehicles should return to the depot from which they departed. Demand of customers should not exceed the vehicle capacity. The objective of LRP is usually minimization of transportation cost based on the travelled distance and has been vastly investigated by researchers [1-4]. Although, energy consumption of a vehicle is dependent on the distance travelled, other factors may also influence energy consumption. For instance, fuel economy of a vehicle decreases as the vehicle weight increases and as a result the transportation cost increases. There is limited research that addresses energy consumption in location-routing problem.

In traditional LRP formulation, the obtained result is link-based, i.e. each route is formed by a set of links. The position (order) of customers on each route cannot be determined unless the links are connected in the right order. The interpretation of the sequence of visits in each route is thus obtained after the solution is obtained and hence cannot be used as an input when there are parameters associated with different sequence of customers in a route. On the other hand, the proposed model output is the sequence of visits of the customers in each route and hence it is called "node-based" formulation. The proposed node-based model can also be used wherever there is any constraint, cost, or risk associated with the sequence of customers in a route.

The new LRP formulation presented in this paper reflect the impacts of vehicle weight on transportation cost which can be significant in most real case scenarios. The objective function presented in this paper is to minimize energy and depot establishment cost, while maximizing the profit and the following questions are expected to be answered by solving the model:

- What is the best strategy regarding the location of distribution centers (DCs)?
- How to allocate customer to DCs?
- What is the routing plan of DCs to serve the customers?

2. Experiment, Results, Discussion, and Significance

A mathematical formulation for the problem is developed [5], and used to solve some small case studies. However, as the problem is a NP-hard network configuration problem with many binary variables, the computational effort for solving a large size problem will be huge. Hence, a heuristic method, inspired from Clark-Wright (CW) algorithm, for tackling large size problems is developed. The results obtained by solving benchmark problems are presented in Table 1. As shown in the table, the presented method not only provides a better result in terms of energy consumption, but also it has a better in terms of distance travelled in more than 50% of the case studies.

Table 1 Results obtained from solving benchmark problems, Tare weight=5000lb, VC=5000(lb)

	Traditional Algorithm		New Algorithm		Distance	Energy
Problem ID	Distance	Energy	Distance	Energy	Increased (%)	Saved (%)
A-n32-k5	844	6473445	801	6292318	-5.02	2.8
A-n33-k6	776	6243964	775	5726121	-0.2	8.29
A-n34-k5	807	6193736	799	6027908	-1.05	2.68
A-n36-k5	831	6460393	838	6229602	0.81	3.57
A-n37-k5	705	5609465	720	5373546	2.16	4.21
A-n37-k6	980	7463236	979	7461704	-0.02	0.02
A-n38-k5	795	6296086	770	5778124	-3.17	8.23
A-n39-k5	902	6950672	880	6584526	-2.42	5.27
A-n39-k6	883	6694567	873	6501903	-1.05	2.88
A-n44-k7	1021	7769893	986	7214163	-3.42	7.15
A-n45-k6	1013	7962101	1015	7335817	0.16	7.87
A-n46-k7	940	7171920	941	6831624	0.1	4.74
A-n48-k7	1115	8745357	1114	8399277	-0.08	3.96
A-n53-k7	1093	8391221	1098	8305064	0.48	1.03
A-n54-k7	1202	9193927	1215	9114286	1.15	0.87
A-n55-k9	1111	8597747	1117	8438239	0.62	1.86
A-n60-k9	1377	10655183	1414	10606486	2.64	0.46
A-n61-k9	1103	8616088	1065	8098089	-3.45	6.01
A-n63-k9	1691	12764461	1691	12614399	0.02	1.18
A-n64-k9	1482	11258034	1472	10891675	-0.66	3.25
A-n80-k10	1837	13830715	1822	13625643	-0.83	1.48
B-n57-k9	1656	12784510	1617	12281527	-2.38	3.93
B-n63-k10	1598	12488059	1563	11742275	-2.22	5.97
B-n64-k9	922	7203047	924	7097811	0.17	1.46
E-n76-k7	752	5785811	737	5753896	-1.99	0.55
E-n76-k10	909	6955017	915	6855668	0.67	1.43
F-n45-k4	730	5822656	762	5425172	4.36	6.83
F-n135-k7	1232	9321421	1215	9186198	-1.44	1.45

3. Conclusions

In this research a novel formulation and a new heuristic method for VRP are presented which approach the problem from an energy efficiency perspective. There are many factors contributing to the amount of energy used by a vehicle, among those vehicle weight and distance travelled are the major contributing factor considered in this research. Moreover, a new heuristic method is developed which finds the best routing plan of DCs with respect to the energy consumption. The performance of the proposed method is tested by several case studies. By evaluating the case studies it is perceived that the proposed method as well as improvement in energy consumption of the vehicle can also provide better result in terms of distance travelled. There are many heuristics and meta-heuristics developed for VRP with the objective of distance minimization. Energy minimization is a new window through which these heuristics/Meta heuristics can be viewed through.

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