Optimizing the multiple trip vehicle routing plan for a licensee green tea dealer in Sri Lanka

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Abstract

Purpose – This research is designed to optimize the business process of a green tea dealer, who is a key supply chain partner of the Sri Lankan tea industry. The most appropriate trips for each vehicle in multiple trip routing systems are identified to minimize the total cost by considering the traveling distance.

Design/methodology/approach – The study has followed the concepts in vehicle routing problems and mixed-integer programming mathematical techniques. The model was coded with the Python programming language and was solved with the CPLEX Optimization solver version 12.10. In total, 20 data instances were used from the subjected green tea dealer for the validation of the model.

Findings – The result of the numerical experiment showed the ability to access supply over the full capacity of the available fleet. The model achieved optimal traveling distance for all the instances, with the capability of saving 17% of daily transpiration cost as an average.

Research limitations/implications – This study contributes to the three index mixed-integer programing model formulation through in-depth analysis and combination of several extensions of vehicle routing problem.

Practical implications – This study contributes to the three index mixed-integer programming model formulation through in-depth analysis and combination of several extensions of the vehicle routing problem.

Social implications – The proposed model provides a cost-effective optimal routing plan to the green tea dealer, which satisfies all the practical situations by following the multiple trip vehicle routing problems. Licensee green tea dealer is able to have an optimal fleet size, which is always less than the original fleet size. Elimination of a vehicle from the fleet has the capability of reducing the workforce. Hence, this provides managerial implication for the optimal fleet sizing and route designing.

Originality/value – Developing an optimization model for a tea dealer in Sri Lankan context is important, as this a complex real world case which has a significant importance in export economy of the country and which has not been analyzed or optimized through any previous research effort.

Keywords Optimization, Supply chain, Tea industry, Vehicle routing problem

Paper type Case study

1. Introduction

1.1 Background investigation

Sri Lanka is a developing country, where several economic crops contribute to its economy. Tea is one such economic crop which has earned the international reputation with the brand name, "Ceylon tea" (Herath and Weerasinghe, 2007). Sri Lanka is considered as the largest value-added tea producer and the 4th biggest tea producer in the world. Tea is not only the major export, but it also provides 15% of direct employment opportunities to its citizens

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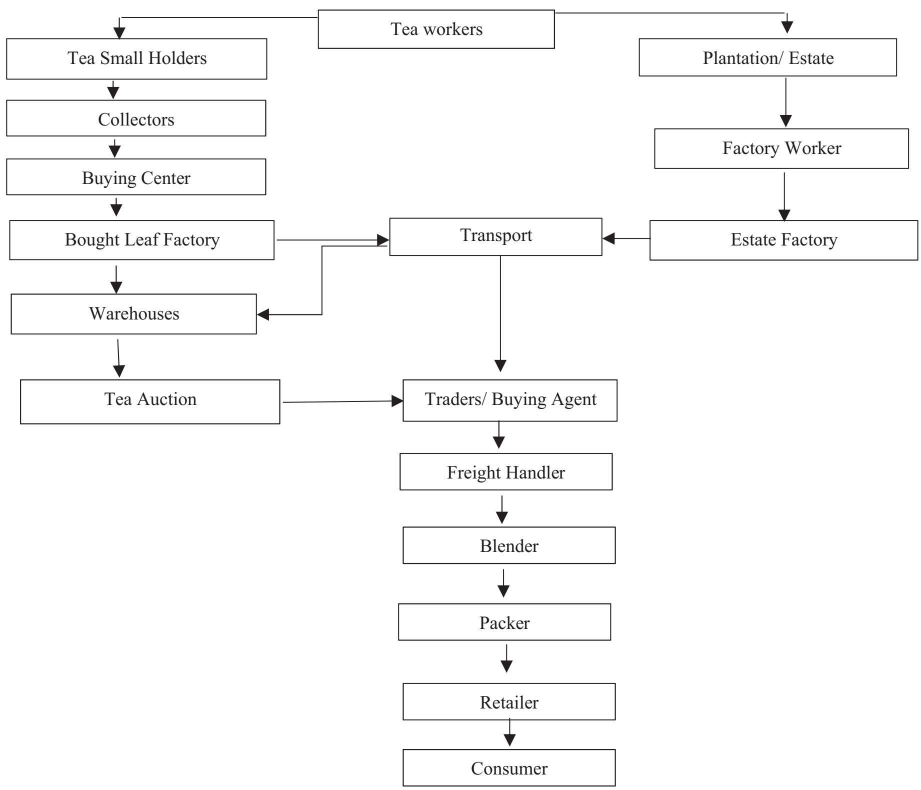
(Jayarathne, 2011). It is vital to comprehend the jobs of tea smallholders as a significant partner in the Ceylon tea industry regarding the expansion of their significance (Sandika, 2018).

Different value addition processes in the tea supply chain increased the total number of competitors in the industry. It is the biggest employment provider in the local sector where tea smallholders are the majority (ILO Research Team, 2018). The individual exclusive tea domains are considered as tea smallholdings.

Licensee green tea dealers (LGDTs) are indicated as collectors in Figure 1. They are an intermediary party in-between the tea growers (smallholders) and tea factories. They are authorized to collect tea leaves from framers and supply those fresh tea leaves to tea factories. LGTDs play a major role as a critical supply chain partner. They transport tea leaves with the expected quality level using standard loading, packing and transportation facilities. Therefore, time and distance of the transportation affect the value addition activities of dealers (Thushara, 2015). This research focused on a LGTD, whose business process is fully based on transportation. Their task was to collect tea leaves on daily basis, from the tea farmers by visiting different locations in the region and to supply the total collection to the depot within a limited time. Thus, few variants of vehicle routing problem (VRP) were combined in this study to meet all the requirements of real-world application.



Source(s): ILO research team, 2018

Figure 1.
Tea supply chain of Sri Lanka

1.2 Description of the problem problem description

An LGTD connects with a set of farmers, who are geographically located in the same area. Thus, they have to visit short distances, several times per day. The cost of transportation increases day by day due to the increase in the price of crude oil in the world market. An LGTD has a limited time to visit all the collection points during the day. The farmers start to pluck tea leaves early in the morning and finish it around 3.30 p.m. in the evening. Then the dealers visit the collection points. Vehicles from the factories arrive to depot around 6.30 p.m. in the evening. Thus, the dealers need to perform their tasks under a time constraint. Furthermore, there is a 15 kg bin policy, which controls the volume and the maximum weight of a vehicle. Consequently, it is difficult for dealers to use a single vehicle in this process. Increasing the fleet size correspondingly increases other expenses due to the labor requirement such as drivers and helpers. It is challenging to implement an optimal routing plan without a systematic procedure. Currently, they do not follow any special model, software or structure to arrange a routing plan. Therefore, this study is focused on the development of a cost-minimizing optimal network model for an LGTD in Sri Lanka.

1.3 Research objectives

This research focuses on the process of an LGTD in the Kandy district, Sri Lanka with the generic objective of determining an optimal routing plan for its fleet of vehicles. Specific objectives of the study are as follows.

(1) To collect the total tea leaves supply of the farmers.

(2) To visit all the collection points and to finish trips within the given time window.

To the best of our knowledge, none of the past research efforts are focused on the tea leaves collection network. The role of the LGTD is common in the Sri Lankan tea industry. According to the strength and financial status of individuals, the number of vehicles and number of farmers in this network can be varied. Accordingly, this study has contributed to the application of multiple trip VRPs and supply chain management of the Ceylon tea industry.

1.3.1 Literature review. The supply chain is a vast area with the number of sophisticated processes and key partners. Moving of products or materials between different facilities and locations has been considered as a core problem in the supply chain management (Anily and Bramel, 1999). Transportation cost keeps increasing in the modern business context; therefore, organizations struggle with developing optimal transportation networks. VRP is a well-known methodology which has the capability of identifying an appropriate routing plan while minimizing the associated transportation cost. In 1959, the general VRP was introduced (Cattaruzza *et al.*, 2016). VRP begins with the aim of identifying cost-effective routes to cover a geographically scattered set of customers. Later more variants were added to this due to the sophisticated nature of different industries (Laport, 2009). Since the number of constraints needs to be considered in practical scenarios, the complexity of the VRP has been rapidly increased over time (François and Basterrech, 2016). All types of VRPs including the classical VRP can be considered as NP (nondeterministic polynomial time) hard problems. These problems are unable to solve within polynomial time due to the complexity of problems (Lenstra and Rinnooy Kan, 1981). Classical VRP was generalized as traveling salesman problem (TSP). In TSP, there is a salesman and a set of cities. The salesman should satisfy the demand at each city by starting and ending the sales journey from the same city (Király and Abonyi, 2011). If there is n set of cities, the set of feasible solutions of the TSP is $(n-1)!/2$. Multiple TSP is an extension of TSP, where m number of salesmen considered in the problem and all salesmen initially located in a central deport. All types of VRPs have similar background to TSP. Every problem formulates and solves to obtain a set of routes with minimum distance to reduce the transportation cost (Matai *et al.*, 2010). Mathematical formulation focusses on the set of undirected and directed graphs based on the symmetric and asymmetric condition of the problem. Similarly, there is a set of vertexes corresponding to the cities which generally denotes by set V and a set of edges used to represent the possible arcs or routes among the cities. Further, there is a cost matrix that was indicated with $C_{ij,}$ where i, j are the two cities included in V.

At present classical VRP is not a realistic application for large scale industries, as it considers only an identical set of vehicles, n number of nodes, t time limit (each vehicle has a time limit for a single trip) and single depot (Şen and Bulbul, 2008). Capacitated vehicle routing problems (CVRP) and vehicle routing problems with time windows (VRPTW) were widely discussed variants of VRP. VRPTW tries to minimize the total transportation cost within the given time limit (Belver *et al.*, 2017). Weight or the capacity of vehicles has become a constraint in CVRP (Li, 2015). Fleet sizing and mixed VRP is another common perspective of VRP. The introduction of third-party logistics services and organizations with numerous resources such as a heterogenous fleet and a homogenous fleet of vehicles made this concept more realistic. Fleet sizing receives importance in VRP, as it facilitates cost reduction through the reduction of the number of vehicles in the fleet. In the fleet sizing problems, there are different variants like deliveries and pickups, homogenous and heterogenous. Heterogenous fleets are complex, as there are fixed operating costs and variable costs associated with each vehicle (Liu and Shen, 1999).

Multiple trip vehicle routing problem (MTVRP) is another significant variant of VRP, which was raised in the last two decades. Comparatively a smaller number of research efforts and past literature are available for this concept (Cattaruzza *et al.*, 2012). In 1990, multiple trips were aligned to the working paper by Fleischmann. In this study, they used the same assumptions as in classical VRP and facilitated with special relaxation that each vehicle can perform more than one trip within a given time limit. Further there is another option that a vehicle can take a longer time than the given time limit with a penalty cost (Cattaruzza *et al.*, 2016). Companies that owned vehicles with a comparatively less capacity can serve only a few customers on a trip. In such situations, it is necessary to perform multiple trips, to satisfy customers and to achieve the cost reduction (Battara *et al.*, 2009). As per the study of Wassan (2016), this variant of VRP is an essential extension as it helps for cost reduction in practical situations by reducing the number of vehicles purchased or hired. Real-time application of MTVRP was done by Brando and Mercer (1997) with more assumptions. In the problem formulation, they used multiple trips, capacitated heterogenous fleet of vehicles, maximum operating time per vehicle and unloading time of vehicles. Furthermore, it considered the hiring of vehicles if the available fleet is not enough. According to Brando and Mercer (1997) there is a possibility to make this problem more complex by facilitating to hire vehicles if an insufficient number of vehicles are available with the company, restriction to visit some customers on specific days, and restriction to visit some customers by specific vehicles, maximum driving time per day and adding unloading time when calculating total time. The objective function of this study has combined with several cost factors like fuel cost, wages, fixed cost and maintenance cost of the vehicles.

Further, there is a significant importance of MTVRP applications for the process of tactical and strategic planning as it helps critically in overall cost reduction of logistic activities (Petch and Salhi, 2004). Real-life application of MTVRP has been used by Gribkovkaia *et al.* (2006). There was no solution interpretation, but a mathematical model development was available. Most of the recent studies combined MRVRP with time windows and different types of heuristic algorithms were applied to build proper and faster solving mechanisms. MTVRP with time window and the heterogenous fleet has been studied by Despaux and Basterrech (2014), where novelty was added to objective function by including total distance traveled, cost of the time taken and the cost of waiting time. A new variant of

MTVRP was introduced by combining backhauls. Here, the problem was described in-depth with integer linear programming (Wassan, 2016). Another MTRVP was presented by Azi *et al.* (2010), where an exact algorithm was proposed to solve the MTVRP with a time window.

MTVRP with time window and the heterogenous fleet was studied by François and Basterrech (2016). The combination of many aspects related to the VRP made this problem more complex. Here, the delivery process and the customers were assigned with time windows. Also, the objective function of this study has a novelty, as it included total distance, cost of travel time and cost of waiting time when they fail to achieve the time window. Still, MTVRP is an underserved area among VRP extensions (Carroll and Keenan, 2019). Thus, this study was designed to contribute to the significant and comparatively less focused extension of VRP, which is known as MTVRP. The model was tested and validated with real-world data to contribute the real-life applications.

2. Methodology

The study has contributed to both mathematical model development and the solving process. Thus, the main stages of the research are identified as in Figure 2.

2.1 Stage 1 – systematic study

A literature survey was conducted in the initial phase, to have a better idea of logistic and distribution networks, applicable approaches and existing gaps in the literature. Key characteristics of the distribution networks were closely investigated to identify the related business context, assumptions and techniques to be utilized in the modeling. A background investigation of the tea supply chain was performed through secondary data sources like reports, publications and articles. Discussions and interviews were carried out with the supply chain partners in the tea industry, especially with the LGTD to have solid and specific information of the tea leaves collection process.

2.2 Stage 2 – LGTDs' process analysis

In this stage, attention was given to investigate the current practices of the business process, requirements of the related parties, consensus on information and data. Accordingly, discussions and interviews with the green tea dealer were used to gather critical data of the business process such as vehicle information, oil consumption and information of employees etc. Moreover, secondary data sources such as logbooks and record keeping of the organization were used to collect and arrange the real data set which was required for the model testing. Necessary assumptions and limitations of the network to be designed were clarified.

2.3 Stage 3 – process optimization

An optimization model was developed with different constraints to satisfy all organizational requirements. Optimization models can improve the existing product or process through

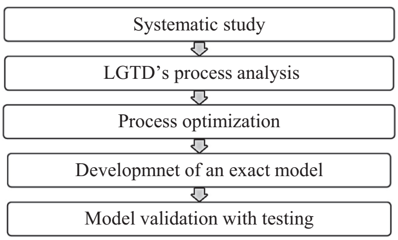


Figure 2.
Research structure

enhancing the quality and prestige features (Chandrasekaran and Gabriel, 2010). Literature also provides instances where optimization models were used in supply chain management to reduce total cost while improving profitability and efficiency (Azi *et al.*, 2010). In the last decade, researchers were highly focused on the development of advanced methods by combining simulation, mixed-integer programming (MIP) and generic algorithm (Truong and Azadivar, 2003). MIP is used when there is a set of variables, where only some decision variables deal with the integer values (Hiller and Lieberman, 2001). VRP and most of the other similar problems in the real-world requires mathematical formula with the number of connected yes or no decisions. A mathematical model with MIP was developed in this study with the specific objective of transportation cost minimization.

2.4 Stage 4 – development of an exact method

The exact method was used as the problem-solving approach. This was implemented within the IBM ILOG CPLEX solver. Exact methods guaranteed the generation of optimal solutions (Rothlauf, 2001). The petroleum distribution network of Sri Lanka has been optimized through an exact model by Sachini *et al.* (2019), with a visual basic application. Solving approach of TSP is also an exact method. TSP and VRPs have similar features, thus there is a potential to use the exact method even for a medium-sized problem. There was a study with 32 nodes, and it showed the capability of solving the problem in a reasonable computational time, with an exact method. Further, this study shows the ability to solve different VRP variants with MIP modeling, vehicle flow modeling, and with different techniques like branch and cut (Carroll and Keenan, 2019). CPLEX Optimization is using a branch and cut algorithm together with the robust dynamic search. Dynamic search also has a similar solving procedure to the branch and cut method. Solving approach of this study associates with those significant features that have been offered by the CPLEX Optimization studio (Garcia-López *et al.*, 2017). The urban waste collection problem studied by Tirkolaee *et al.* (2018) has a model which was developed using the multiple trip capacitated arc routing and obtained research output through CPLEX solver.

2.5 Stage 5 – model testing and validation

The proposed model was tested with a real-world data set, which was obtained from an LGTD in the Bokkawala area of the Kandy district, Sri Lanka, for the model validation.

3. Problem formulation

At present, the subjected LGTD is dealing with a set of small tea growers in the region. All these farmers are located the in same geographical area within 30 km. The model was developed by combining several specifications to compile with the real-world context. Accordingly, the developed model was integrated with the following features.

(1) Pickup problem–Collecting goods from familiar suppliers.

(2) CVRP–Vehicle in the fleet has a maximum loading capacity.

(3) Heterogenous fleet of vehicle–Fleet has vehicles with different capacities.

(4) MTVRPs–Assigning more than one trip for each vehicle.

(5) Time constraint per vehicle–Maximum driving time has been allocated per day.

MIP technique was used for this three-index formulation. According to Cattaruzza *et al.* (2016), three-index vehicle flow formulation is common. By avoiding the complexity of the four-index formulation, three-index formulation was utilized without a trip index (Aghezzaf *et al.*, 2006;

Lei *et al.*, 2006). Background for this model formulation has been provided by the graph theory. A direct graph $g = (V, E)$, where V is a set of vertexes that represent each customer and E is a set of edges or arcs. $V = (0, 1, 2 \ldots n)$ in general form 0 denotes the central deport while other integers from 1 to n denote the customers in a particular network. Always E is supposed to be a non-negative parameter where $(i, j) \in E$. Then the transportation cost between nodes has been calculated proportionally to the length of the arc (i, j) (Archetti *et al.*, 2006). Researchers Tirkolaee *et al.* (2018); Komijan and Delavari (2017) have utilized a single index to denote both heterogenous and homogenous fleet of vehicles. Indices of the subjected problem was defined with set of nodes $N = (0, 1, 2, 3 \ldots .. 15)$ and arcs $A = \{(i, j) \mid (i, j) \in N\}$. N represented a set of 15 suppliers that have to be visited where 0 is the depot. Four vehicles in the fleet were represented by V ($V = 1, 2, 3, 4$), and indices of the vehicles have been denoted by v. A survey on multiple trip vehicle routing by Cattaruzza *et al.* (2016), summarized their findings with a general definition. Accordingly, traveling time along an arc (i, j) was defined as the T_{ij}. q_j was used to denote the quantity need to be served at the customer i. The time duration was set as a customer is available from time 0 to TH. The sum of the time taken by all the trips assigned to the same vehicle should not exceed the TH. A problem based on capacitated vehicle routing by Tirkolaee *et al.* (2018) defined the limited capacity of the vehicles in its fleet, W_k, where vehicles in its fleet have been represented by k. This study has used $T_{\max}$ to represent the maximum time allocation. The mathematical formulation of the study includes parameters and decision variables, which were adopted from Cattaruzza *et al.* (2016), Tirkolaee *et al.* (2018), Azi *et al.* (2010), Cattaruzza *et al.* (2012) as follows.

Parameters,

L_{ij} - Distance from node i to j.

w_j - Quantity of tea leaves supply by node j.

C_v - Capacity of the vehicle v.

t_{ij} - Time taken to travel from node i to j.

$T_{\max}$ - Maximum available time for a vehicle.

Decision variables,

$$X_{ij}^{v} = \begin{cases} 1 \text{ If vehicle } v \text{ visit node } j \text{ afternode } i \\ 0 \text{ Otherwise} \end{cases}$$

$$y_j^{v} = \begin{cases} 1 \text{ If vehicle } v \text{ visit node } j \\ 0 \text{ Otherwise} \end{cases}$$

t_v = Number of trips assigned to vehicle v in a particular day.

w_j^v = The cumulative weight of vehicle v, after serving to node j.

T_{ij}^v = Total time taken by vehicle v in a particular trip to visit node j through node i.

t_i = Cumulative time taken to visit node i from the depot.

Objective function:

$$\text{Min} Z = \sum_{v=1}^{4} \sum_{i=0}^{15} \sum_{j=0}^{15} X_{ij}^{v} L_{ij} \tag{1}$$

Subject to

$$\sum_{i=0}^{15} X_{ij}^{v} = y_j^{v} \quad \forall j \in N/\{0\},\ v \in V \tag{2}$$

$$\sum_{i=0}^{15} X_{ji}^{v} = y_j^{v} \quad \forall j \in N/\{0\},\ v \in V \tag{3}$$

$$\sum_{v=1}^{4}\sum_{i=0}^{15} X_{ij}^{v} = 1 \quad \forall j \in N/\{0\} \tag{4}$$

$$\sum_{j=1}^{15} X_{0j}^{v} = \sum_{i=1}^{15} X_{i0}^{v} \quad \forall v \in V \tag{5}$$

$$(t_{oj}) = X_{0j}^{v}(t_j) \quad \forall j \in N/\{0\}, \ v \in V \tag{6}$$

$$w_j^v = X_{0j}^{v}(w_j) \quad \forall j \in N/\{0\}, v \in V \tag{7}$$

$$t_j = X_{ij}^{v}(t_i + t_{ij}) \quad \forall i \in N/\{0\}, \forall i \in N/\{0\}, v \in V \tag{8}$$

$$X_{ij}^{v}\left(w_i^v + w_j\right) = w_j^v \quad \forall i \in N/\{0\}, \forall j \in N/\{0\}, v \in V \tag{9}$$

$$T_{i0}^{v} = X_{i0}^{v}(t_i + t_{i0}) \quad \forall i \in N/\{0\}, v \in V \tag{10}$$

$$\sum_{i=1}^{15} T_{i0}^{v} \leq T\max \quad \forall v \in V \tag{11}$$

$$\sum_{i=1}^{15} X_{i0}^{v} = Z_v \quad \forall v \in V \tag{12}$$

$$C_v \geq X_{ij}^{v}\left(w_j^v\right) \quad \forall j \in N, i \in N, v \in N \tag{13}$$

$$w_j^v \geq X_{ij}^{v}(w_j) \quad \forall j \in N, i \in N, v \in V \tag{14}$$

$$X_{ij}^{v} \in \{0, 1\} \quad \forall v \in V, (i, j) \in A \tag{15}$$

$$y_j^v \in \{0, 1\} \quad \forall v \in V, j \in N \tag{16}$$

$$0 \leq w_j^v, Z_v, t_i, T_{ij}^{v} \quad v \in V, \ j \in N \tag{17}$$

The objective function (1) was developed to minimize the total traveling distance. Constraint (2) and (3) show the flow conservation. Constraint (4) denotes that every collection point should be visited exactly once per day. Constraint (5) implies that every vehicle should start and end every trip from the depot. Cumulative time taken to visit the first node from the depot should be equal to the time taken visit from 0th node to that particular node considered as in Eqn (6). Constraint (7) denotes that the total weight of the vehicle in the first collection point that was visited by each trip should be equal to the quantity of tea leaves supplied by that collection point. Constraint (8) shows that the total time taken to visit a particular collection point in each trip should be equal to the cumulative time along its path. Similarly, constraint (9) shows that the total weight of a vehicle at a particular collection point in each trip should be equal to cumulative weight of tea leaves collection along its path from the deport. The total traveling time of each trip, which are starting from the depot and end at the deport was calculated using Eqn (10). Constraint (11) shows the maximum traveling time of a vehicle per day should be less than or equal to the allocated time limit. Constraint (12) was used to calculate the number of trips performed by each vehicle by considering the number of times that entered to the depot by each vehicle. Constraint (13) shows that the total weight of collected tea leaves in each node should not exceed the maximum capacity of the vehicle. Constraint (14) means that the cumulative weight of tea leaves collection in a node should be greater than or equal to the quantity of tea leaves supplied by that node. Constraints (15) and (16) indicate the binary variables and (17) indicates the set of is integer variables that are used in this model formulation.

4. Results and discussion

The model was tested and validated with real data instances. CPLEX Optimization solver version 12.10 was utilized with the python programming language. CPLEX is an improved technological instrument that is embedded with amazing and dependable solvers and algorithms that depend on superior scientific programming. There are specific languages for some solvers while most of the solvers available to use as a separate module through other programming languages. Among those languages, Python has been highly utilized by most of the model developers and researchers, due to the lucrative features of this language. Python was utilized through Jupiter notebook integrated development environment to execute this algorithm.

Tea leaves supplied at each collection point is given as a quantity in kilogram (kg). Currently, their own fleet of heterogenous vehicles is used. They have four lorries with different capacities. The capacity of the fleet was further limited by the transportation bin policy which was imposed by the Sri Lankan Tea Board. Vehicle information was summarized and developed in Table 1 by the author. Distance and time matrices were developed using the Google map by following the Komijan and Delavari (2017).

The distance matrix consists of the distances between two nodes, thus the distance between all 15 nodes are indicated in Table 2. Distances are given in kilometers (km). In the mathematical modeling and code development stages, the depot was assigned with "0" and all the other collection points were given numbers from 1 to 15. Corresponding to the distance matrix, a time matrix was developed as shown in Table 3, where time was given in minutes. These data were inserted into the solver as an excel file. From the LGDT, 20 data instances were obtained to test the model. In most of these instances, collection points were with supply

Vehicle name	Vehicle type	Actual capacity (kg)	Number of bins per vehicle	Maximum capacity (Kg)
Lorry A	Dimo Batta	840	50	750
Lorry B	Bolero Truck	1,400	80	1,200
Lorry C	Tata ACE	1,030	65	975
Lorry D	Mahindra Maxitruck	1,200	75	1,125

Table 1.
Vehicle information

L_{ij}	0	1	2	...	14	15
0	0	6.1	1.5	...	5.7	7
1	6.1	0	9.5	...	6.5	4.4
2	1.5	9.5	0	...	3.2	5.3
...	...	...	...	...	...	...
14	5.7	6.5	3.2	...	0	3.3
15	7	4.4	5.3	...	3.3	0

Table 2.
Distance matrix

t_{ij}	0	1	2	...	14	15
0	0	14	8	...	12	19
1	14	0	22	...	16	10
2	8	22	0	...	10	12
...	...	...	...	...	...	...
14	12	16	10	...	0	9
15	19	10	12	...	9	0

Table 3.
Time matrix

in between 200 kg and 350 kg. Hence, the total tea leaves supply of the day exceeded 4000 kg. Thus, it is necessary to use a multiple trip model as it is impossible to collect total supply through a single trip model. Pseudo code of the model is given below,

Pseudo code of the proposed MIP model

Input Problem data
Declaration of indices
Declaration of parameters
Declaration of the model
Declaration of decision variables of the model
Define Objective Function, equation (1)
for v = 1:4 do
  for j =1:15 do
    Calculate the sum of the entrance to node j by vehicle v using X_{ij}^{v} and make it equal to the value of y_j^v according to equation (2)
    Calculate the sum of leaving from node j by vehicle v using X_{ji}^{v} and make it equal to value of y_j^v according to equation (3)
  end for
end for
for j =1:15
  Calculate the sum of the entrance to node j from every node by every vehicle and make it equal to 1 as in equation (4)
end for
for v = 1:4
  Compute the number of trips that starts from the deport by vehicle v and make it equal to the number of trips ends from the deports by vehicle v according to the equation (5)
end for
for i =0:15
  for j =0:15
    for v=1:4
      if i=0 and j ≠0 and X_{ij}^{v} =1
        Calculate the total time taken to visit node j from the deport as in equation (6)
        Set the cumulative weight of vehicle v at the first collection point equal to tea leaves quantity supply by node j according to equation (7)
      else if i ≠0 and j ≠0 X_{ij}^{v} =1
        Calculate the total time taken to visit node j, starting from the deport and considering the distances through previous nodes as in equation (8)
        Calculate the total weight of tea leaves collected by vehicle v at the collection point j according to equation (9)
      else if i ≠ 0 and j = 0 X_{ij}^{v} =1
        Calculates total time taken to complete each trip in the routing plan according to equation (10)
      end if
    end for
  end for
end for

```
34: for v =1:4
35:     Set the maximum available time limit for each vehicle to perform its daily routing
        plan by using equation (11)
36:     Calculate the number of trips performed by each vehicle Z(v), using equation (12)
37: end for
38: for i=0:15
39:     for j=0:15
40:         for v=1:4
41:             Ensure that in every village total weight of the vehicle not exceeding
                the maximum capacity of the vehicle according to equation (13)
42:             Ensure that cumulative weight of tea leaves collection at each
                village greater than or equal to the weight of tea leaves supply by
                that village according to (14)
43:         end for
44:     end for
45: end for
46: Set Branch and cut strategy to solve the model
47: Output the optimal solution to model (daily routing plan)
```

Given MIP gap was 0.1 and the time limit was 120 s for all the instances to achieve the consistency of the solving process. According to the result obtained in Table 4, it is clear that this model satisfies the multiple trip condition by relaxing the single trip condition. Thus, the supply over the full capacity of the available fleet is able to access.

Optimal traveling distance was obtained successfully for all the instances. Additionally, authors (Komijan and Delavari, 2017) obtained promising performance by solving the developed MIP model with an exact technique. Authors (Altekin *et al.*, 2017; Yousefikhoshbakhta *et al.*, 2015) have used commercial solvers including CPLEX, with exact techniques to compare the

Table 4.
Obtained results by CPLEX solver

Pro No	Total supply (Kg)	Original fleet size	Used fleet size	Z^*
1	4,084	4	3(B,C,D)	91.5
2	4,090	4	3(B,C,D)	91.95
3	4,119	4	2(B,D)	91.5
4	4,053	4	2(B,D)	91.5
5	3869	4	2(B,D)	91.85
6	4,097	4	2(B,D)	90.95
7	4,069	4	2(B,D)	91.95
8	4,036	4	2(B,D)	91.85
9	4,113	4	3(B,C,D)	92.35
10	4,097	4	3(B,C,D)	91.15
11	4,114	4	2(B,D)	92.15
12	4,110	4	2(B,D)	91.75
13	4,048	4	2(B,D)	92
14	4,153	4	2(B,D)	91.95
15	4,155	4	2(B,C)	91.95
16	4,204	4	2(B,D)	91.75
17	4,185	4	2(B,D)	91.65
18	4,166	4	2(B,D)	92.25
19	4,180	4	3(B,C,D)	90.5
20	4,018	4	2(B,C)	91.95

Note(s): Z^*: Optimal distance in Km efficiency of their proposed solving algorithms. In each instance, the exact technique provided optimal solutions for the tested data sets. The critical practical scenario has been discussed by Bredstrom *et al.* (2015). Here, the mathematical model was tested with the commercial solver and achieved a feasible solution with less computational time.

In this problem, the original fleet size is 4 for all the instances and no single instance has utilized the full fleet. The size of the used fleet and the name of the used vehicles (e.g. 2(BD)) were included in Table 4. According to the illustration of output, all the instances can be operated with only three vehicles in their fleet. Only five instances out of the considered 20 instances have been operated with three vehicles.

Fleet size corresponding to the problem numbers 1, 2,9,10 and 19 have used three vehicles. Further remaining 15 instances out of 20 have used two vehicles only. The two vehicles B and D are with the highest capacities (vehicle B- 1200 kg and vehicle D-1125 kg), and those were contributed to 13 instances of two vehicle routing plans. Vehicle A has been avoided by all the instances, as it was with the least capacity (750 kg). Thus, it is clear that there is a significant reduction in the used fleet size. Generally, LGDTs pay daily wages for the drivers and for the other laborers. Currently, two workers for each vehicle, one driver and a helper are assigned. Accordingly, the total cost of a vehicle based on human resource allocation is as follows.

Daily payment for a driver - 1000 LRK.

Daily payment for a helper - 800 LRK.

Daily human resource allocation cost of a vehicle - 1800 LRK.

These workers do not spend the full day for this task. Only half a day workload is performed as they start the daily process in the afternoon. As per the model based routing plan, there is a possibility to reduce the number of workers as well as the daily fleet size. Hence, this provides cost reduction opportunities to the organization.

Results in Table 4 are aligned with the cost analysis in Table 5. Cost analysis was included with a comparison of actual cost and model based optimal cost. For this comparison, the fuel expenses of 20 days have been collected from the subjected LGTD and optimal distance was generated for each day. Gathered data and derived cost values were represented in Table 5. By observing the current status of Sri Lanka's fuel price, 38 LRK per km has been taken as the average fuel cost per km. At present, LGTD does not follow any routing method which has been developed by a scientific technique. Randomly identified routes are incurred with more cost than the optimal routes which are obtained through the proposed multiple trip routing model. Subjected tea dealer was able to save 743.9 LRK in the 6th instance as the maximum saving per day. Total fuel cost saving through multiple trip model is 13,113.30 LRK per 20 days. Accordingly, data can be summarized as follows.

Average fuel cost saving per day - 655.665 ≅ 656 LRK.

Average fuel cost saving per month - 19669.95 ≅ 19670LRK.

Percentage of fuel cost saving per day - 17.6%

Percentage of daily cost saving has achieved a significantly higher value, which shows considerable cost benefits for the organization. These figures depict the advantages of using a multiple trip model for the subjected LGTD.

5. Research implications

5.1 Theoretical implication

This study has contributed to an evolving area in the field of VRP. Most of the proposed models were based on assumptions, hence there is a research gap for real-world application of VRP.

Pro No	Fuel expenses (LRK) Actual	Optimal	Cost saving (LRK)
1	4,020	3459.9	560.1
2	4,020	3440.9	579.1
3	4,020	3440.9	579.1
4	4,035	3478.9	556.1
5	4,040	3478.9	561.1
6	4,200	3456.1	743.9
7	4,210	3494.1	715.9
8	4,110	3490.3	619.7
9	4,180	3509.3	670.7
10	4,190	3463.7	726.3
11	4,080	3446.6	633.4
12	4,210	3486.5	723.5
13	4,250	3496	754
14	4,210	3494.1	715.9
15	4,200	3494.1	705.9
16	4,210	3486.5	723.5
17	4,190	3482.7	707.3
18	4,290	3505.5	784.5
19	4,000	3389.6	610.4
20	3880	3437.1	442.9
Total saving			13113.3

Table 5.
Cost analysis

Pick up problem was encountered comparatively in fewer research efforts. All these important points were successfully addressed through this MIP model. The accuracy of the model could be increased by considering service time. A combination of the least encountered concept like split delivery will be an interesting future research area. Future research avenues can also consider to combine the traveling time with the service time as well.

5.2 Practical implication

Higher accuracy of the model was achieved by avoiding human errors in the manual routing plan. LGDT needs less initial investment as this model operates with a standalone computer without any other facility like networks and Internet. Merely this model can be implemented without adding extra resources or processes to the existing business environment. Instead, it can minimize the current resource utilization. These significant features make this an appropriate model for frequent short distance traveling processes. This has a higher degree of applicability for developing countries like Sri Lanka as this associate with a less initial investment.

6. Conclusion

This paper used a scientific decision-making process to optimize the routing plan of LGTD in the Ceylon tea industry. LGTD is a critical supply chain partner, whose process is malfunctioning and has not been analyzed by any other previous research effort. A MIP model has been developed with a three-index formulation by avoiding the complexity of four-index formulation. An exact algorithm was used to obtain a solution of the mathematical model. Results have proven that the proposed model reduced the transportation cost than the current practices of the company. Reduction in the total distance saved the average daily fuel consumption by 17.6%. Rather optimal resource allocation has been achieved. The optimal fleet size which was obtained through the model is always less than the original fleet size of them. Elimination of one vehicle from the fleet enables to reduce workforce by two (driver and helper).

Thus, the proposed model for MTVRP is more appropriate for the LGDT as it reduces the cost considering two main aspects including fuel cost and cost of labor. Since the applicability of the model has been proven with the cost analysis including the comparison of actual cost and model based optimal cost, it can be concluded that the proposed MTVRP model is an appropriate routing plan for the LGDT.

List of abbreviations

CVRP	Capacitated vehicle routing problem
LGTD	Licensee green tea dealer
LRK	Sri Lankan rupees
MIP	Mixed-integer programming
MTVRP	Multiple trip vehicle routing problem
NP	Nondeterministic polynomial
TSP	Traveling salesman problem
VRP	Vehicle routing problem
VRPTW	Vehicle routing problem with time window

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