A Sustainable Travelling Purchaser Problem Model

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Abstract

This paper proposes a multi-objective mixed-integer linear programming (MOMILP) model to solve the travelling purchaser problem (TPP) with a sustainable supplier selection, order allocation, with multiple vehicles and a single product. The manufacturer's target is to choose the best green suppliers from whom the materials can be purchased, which means that suppliers who will be able to provide low-cost products and generates minimum CO_2 emissions from transportation, while maximizing the social and environmental criteria of the material will be selected. As a result, the model consists of three objective functions, the first objective function aims at minimizing the total fixed and variable purchasing and transportations costs; the second objective function aims at minimizing the total transportation-related CO_2 emissions; the third objective function aims at maximizing the total green and social value of the materials purchased from the selected suppliers.

Keywords
Travelling purchaser problem, Supplier selection, and Environmental routing.

1. Introduction

Pollution nowadays is increasing compared to last decades, since the number of vehicles increased, which led to producing several issues such as global warming, greenhouse gases and many more problems, which affect the environment directly and indirectly. Carbon emissions have increased by 2% since 2018, as reported by BP Group Chief Economist, Spencer Dale, which is equal to carbon emission related to the increased number of vehicles by one third (BP Group, 2018).

As a result of these issues, governments recently raised their concerns about the environment, many international conferences such as (United Nations Climate Change Conference) have been conducted across the globe to discuss and propose solutions for these issues. This paper aims to study and propose a model for the travelling purchaser problem (TPP). TPP aims at finding the optimal route to collect products by one or multiple vehicles by visiting several suppliers (Manerba, Mansini, & Riera-Ledesma, 2017).

Several researchers have studied TPP, (Naka, Asai, Sakakibara, Seo, & Nishikawa (2018) propose a branch and price approach to solve a multi-vehicle travelling purchaser problem, on the same regard researchers in Laporte, Riera-Ledesma, & Salazar-González (2003) used a branch and cut algorithm to solve the problem, authors in Riera-Ledesma & Salazar-González (2012) studied a multi-vehicle travelling purchaser problem model for school bus tour using branch and cut approach which aims at minimizing the travelling cost. Almeida, Gonçalves, Goldbarg, Goldbarg, & Delgado (2012) introduced a transgenetic algorithm to solve a bi-objective TPP formulation. Gendreau, Manerba, & Mansini (2016) used a branch–and–price method to solve a multi-vehicle TPP with a limited capacity. Ausiello, Demange, Laura, & Paschos (2004) studied a quota traveling salesman problem that aims at delivering a quota of sales for each supplier while minimizing the consumed time.
Naka et al. (2018) developed an optimization method for a multi-vehicle routing problem in which a logistic system used to deliver electric devices to a certain destination by a heuristic technique, then the executed routes are selected by a set of covering model. Archetti et al. (2013) proposed a split delivery vehicle routing problem using a branch and cut algorithm. Messaoud, El Bouzekri El Idrissi, & Alaoui (2018) proposed a model to solve the dynamic green vehicle routing problem. The proposed solution technique uses hybridization based on ant colony optimization algorithm to minimize the greenhouse gases.
Halim & Ismail (2019) studied six meta-heuristic algorithms, which are (nearest neighbor, genetic algorithm, simulated annealing, tabu search, ant colony optimization, and tree physiology optimization) on several travel salesman problems. Praveen, Keerthika, Sarankumar, & Sivapriya (2019) surveyed different algorithms to optimize the travelled distance and concluded that bat algorithm gives the best output compared to the rest of algorithms.
To the best of the authors' knowledge, most of the works mentioned above aimed at proposing a solution of TPP focusing on minimizing the cost and the travelled distance. Some papers also like (Almeida et al., 2012) and (Riera-Ledesma & Salazar-González, 2005) proposed TPP models but without CO_2 emissions considerations. Recently, works started to consider environmental aspects in routing (Bektaş, Demir, & Laporte, 2016; Braekers, Ramaekers, & Van Nieuwenhuyse, 2016), supplier selection (Banaeian, Mobli, Fahimnia, Nielsen, & Omid, 2016; Freeman & Chen, 2015; Genovese, Koh, Bruno, & Bruno, 2010; Hamdan & Cheaitou, 2017) and the integrated routing and supplier selection problem (known as TPP) (Hamdan, Cheaitou, Larbi, & Alsyouf, 2018; Hamdan, Larbi, Cheaitou, & Alsyouf, 2017). Hamdan, Larbi, Cheaitou, & Alsyouf (2017) proposed a single-product single-vehicle bi-objective green TPP that is solved using branch and cut algorithm. The proposed model focuses on minimizing CO_2 emissions and the total cost of purchasing and transportation. Androutsopoulos & Zografos (2017) proposed an integrated model for a bi-criterion vehicle routing problem to the environmental criteria. A three objective model was presented by (Dehghanian & Mansour, 2009) to maximize the social value and minimize the total cost.
This work proposes a multi-objective formulation for sustainable TPP. The proposed model considers a single product and multiple vehicles and aims to minimize the total purchasing cost, the CO_2 emissions from transportation and maximize the total social and environmental value of the products from the selected suppliers.
The organization of the paper is as follows: Section 2 presents the mathematical model and the solution approach. Section 3 presents a numerical example. Section 4 concludes the paper and gives some future work.

2. Mathematical Model

2.1 Model Independent Parameters

- c_i: Unit variable purchasing cost of the product from supplier i, $\forall i \in \mathcal{S}^O$ [USD/kilogram].
- C_i: Fixed purchasing cost of the product from supplier i (if selected), $\forall i \in \mathcal{S}^O$ [USD].
- d_{ij}: Distance of arc (i,j) from i to j, $\forall i,j \in \mathcal{S},\ i \neq j$ [meter].
- D: Total deterministic demand to be satisfied [kilogram].
- K_i: Available capacity for the product from supplier i, $\forall i \in \mathcal{S}^O$ [kilogram], such that $\sum_{i\in \mathcal{S}^O} K_i \geq D$.
- CO_2: Emission factor per meter.
- U: One vehicle's carrying capacity [kilogram].
- GW_i: The priority weight of supplier i.

Note that GW_i can be calculated using any multi-criteria decision-making tool such as the analytic hierarchy process and technique for order of preference by similarity to ideal solution (Kokangul & Susuz, 2009; Sevkli, Zaim, Turkyılmaz, & Satır, 2010).

2.2 Decision Variables

- q_i^l: Quantity of product p to be purchased from supplier i and collected by vehicle l, $\forall i \in \mathcal{S}^O \forall l \in \mathcal{L}$ [kilogram].
- y_i^l: A binary variable with $y_i^l = 1$ if supplier i is visited by vehicle l and $y_i^l = 0$ otherwise, $\forall i \in \mathcal{S}^O, \forall l \in \mathcal{L}$.
- f_{ij}^l: A continuous variable representing the total amount of flow on arc (i,j) if vehicle l is used on arc (i,j) with $i,j \in \mathcal{S},\ i \neq j, \forall l \in \mathcal{L}$ [kilogram].
- z_{ij}^l: A binary variable indicates if arc (i,j) is visited by vehicle l ($z_{ij}^l = 1$), or $z_{ij}^l = 0$ otherwise, $\forall i,j \in \mathcal{S}, i \neq j, \forall l \in \mathcal{L}$.
- u_i^l: An integer variable representing the order of visit of supplier i by vehicle l, $\forall i \in \mathcal{S}, \forall l \in \mathcal{L}$.

2.2 The model

$$Min\ C = \sum_{l \in \mathcal{L}} \sum_{i \in \mathcal{S}^O} C_i y_i^l + \sum_{l \in \mathcal{L}} \sum_{i \in \mathcal{S}^O} c_i q_i^l \tag{1}$$

$$Min\ \mathrm{E} = \sum_{l \in \mathcal{L}} \sum_{j \in \mathcal{S}} \sum_{i \in \mathcal{S}} \mathrm{CO_2}\ d_{ij}\, z_{ij}^l \tag{2}$$

$$Max\ \mathrm{G} = \sum_{l \in \mathcal{L}} \sum_{i \in \mathcal{S}^O} GW_i q_i^l \tag{3}$$

Subject to

$$y_0^l = 1 \qquad \forall l \in \mathcal{L} \tag{4}$$

$$\sum_{\substack{j \in \mathcal{S} \\ j \neq i}} z_{ij}^l = y_i^l \qquad \forall i \in \mathcal{S}, \forall l \in \mathcal{L} \tag{5}$$

$$\sum_{\substack{i \in \mathcal{S} \\ i \neq j}} z_{ij}^l = y_j^l \qquad \forall j \in \mathcal{S}, \forall l \in \mathcal{L} \tag{6}$$

$$\sum_{l \in \mathcal{L}} y_i^l \leq 1, \qquad \forall i \in \mathcal{S}_0 \tag{7}$$

$$q_i^l \leq K_i y_i^l \qquad \forall i \in \mathcal{S}^O, \forall l \in \mathcal{L} \tag{8}$$

$$\sum_{l \in \mathcal{L}} \sum_{i \in \mathcal{S}^O} q_i^l = D \tag{9}$$

$$f_{ij}^l = 0, \qquad \forall j \in \mathcal{S}, \quad i = 0, \quad \forall l \in \mathcal{L} \tag{10}$$

$$\sum_{j \in \mathcal{S}^O} f_{j0}^l = \sum_{j \in \mathcal{S}^O} q_j^l, \qquad \forall l \in \mathcal{L} \tag{11}$$

$$\sum_{j \in \mathcal{S}^O} f_{ji}^l + q_i^l = \sum_{j \in \mathcal{S}^O} f_{ij}^l \qquad \forall i \in \mathcal{S}^O, \forall l \in \mathcal{L}, \tag{12}$$

$$f_{ij}^l \leq U z_{ij}^l, \qquad \forall (i,j) \in \mathcal{A}, \forall l \in \mathcal{L} \tag{13}$$

$$1 \leq \sum_{l \in \mathcal{L}} \sum_{j \in \mathcal{S}^O} z_{ij}^l \leq L \qquad i = 0 \tag{14}$$

$$u_i^l - u_j^l + (S-1) z_{ij}^l \leq S - 2 \qquad \forall i, \forall j, \forall l \in \mathcal{S}, i \neq j \tag{15}$$

$$q_i^l \in \mathbb{R}^+ \qquad \forall i \in \mathcal{S}^O \tag{16}$$

$$f_{ij}^l \in \mathbb{R}^+ \qquad \forall (i,j) \in \mathcal{A} \tag{17}$$

$$z_{ij}^l \in \{0,1\} \qquad \forall (i,j) \in \mathcal{A} \tag{18}$$

$$y_i^l \in \{0,1\} \qquad \forall i \in \mathcal{S}^O \tag{19}$$

$$u_i^l \in \mathbb{N} \tag{20}$$

$$u_i^l = 1 \qquad \forall l \in \mathcal{L}, i = 0 \tag{21}$$

The multi-objective equation model is defined in equations from (1) to (3). The first objective function (1) minimizes the total cost [USD], which consists of the total fixed and variable purchasing costs. The second objective function (2) minimizes the CO_2 emissions of the vehicles. The third objective function (3) maximizes the total environmental and social sustainability value of the purchased products.

Constraint (4) ensures that the depot is visited by each vehicle. On the other hand, Constraints (5) and (6) ensure that a supplier, selected to be visited by a specific vehicle, is visited once. Constraint (7) ensures that a supplier is visited by one vehicle. Constraint (8) guarantees that the purchased quantity from supplier i visited with vehicle l is at most supplier i's capacity. Constraint (9) ensures that the demand is satisfied by the purchases. Constraint (10) to ensure that any supplier leaving the depot has a starting flow value equal to zero. Constraint (11) to ensure that the flow that enters the depot is equal to the total quantity purchased. Constraints (12) and (13) ensure flow conservation. Constraint (14) guarantees that each vehicle l leaves the depot at most once and that one vehicle at least leaves. Constraint (15) represented the MTZ sub-tour elimination constraint and was adopted from (Bianchessi, Mansini, & Speranza, 2014). Equations (16)-(21) are the non-negativity and integrality constraints of the decision variables. The multi-objective model is solved using the weighted comprehensive criterion method (Hamdan & Cheaitou, 2017). This technique normalizes each objective function and combines all the objective in one objective that aims to minimizes the total variation as follows:

$$\min V = \alpha_1\left(\frac{C - C_{min}}{C_{min}}\right) + \alpha_2\left(\frac{E - E_{min}}{E_{min}}\right) + \alpha_3\left(\frac{G_{max} - G}{G_{max}}\right), \tag{22}$$

where C_{min}, E_{min} and G_{max} are the optimal values obtained from solving the model for each objective function separately and α_1, α_2 and α_3 are the importance weights of the objective functions such that $\alpha_1 + \alpha_2 + \alpha_3 = 1$.

3. Numerical Example

In this example, five suppliers are considered with $\mathcal{S}^O = \{S1, S2, S3, S4, S5\}$. Google Maps is used to locate the five potential suppliers and the depot on six real locations. The locations (shown in Table 1) are chosen to give a realistic aspect of the application. Suppliers' available capacity, fixed and variable costs are given in Table 2. Noting that the total demand is equal to 85.8% of the total suppliers' capacity D= 4000[kilogram]. Two vehicles are available, each with a carrying capacity of $U = 2000$ [kilogram]. The emission factor per unit distance is assumed to be $CO_2 = 0.120\ g/m$ The importance weights of the objective functions (α_1, α_2 and α_3) are assumed to be $\alpha_1 = 0.3$, $\alpha_2 = 0.3$, $\alpha_3 = 0.4$, respectively.

Table 1. The location of the depot and the five suppliers

	X	**Y**
Depot	40.65722	17.72942
S1	41.04545	16.88115
S2	40.76076	17.69496
S3	40.92566	17.00234
S4	41.80674	15.85219
S5	41.77643	15.43667

Table 2. Suppliers' capacity, fixed and variable costs

Supplier i	Capacity, K_i [kilogram]	Variable cost, c_i [USD/kg]	Fixed cost, C_i [USD]
Depot	-	-	-
S1	817.752	22	7510.713
S2	582.763	21	7560.83
S3	1340.339	25	6916.282
S4	863.202	20	7785.999
S5	1057.138	25	7495.186

The model was solved using a mathematic program software called CPLEX, the optimal solution was calculated within a reasonable time (less than 3 minutes), the solution of the model for the first objective function defined in (1) (i.e., cost minimization) and the optimal total cost (C_{min}) was equal to 90,899.682 USD. Then, the second objective function (CO_2 minimization) defined in (2) was solved, and the optimal total CO_2 (E_{min}) was equal to 17,747.52. The third objective function (Social maximization) defined in (3) was solved, and the optimal total social value (G_{max}) was equal to 1,752.348. Finally, the three objective functions are combined, and the model is solved using Equation (22) to obtain the final solution. The variation from the third objective function (V) was found to be 1.5%. As an example, Table 3 ((Solution of Cost Equation) shows that the first and the second vehicles have a final load of each vehicle is less than its carrying capacity (which is equal to 2000). It can be observed that both vehicles start from the depot and return to the depot. Tables 3-6 show the detailed optimal solution for each single-objective problem and the multi-objective problem.

Table 3. Solution details of cost minimization only

Optimal route (quantity)	Vehicle 1	Depot → S2 (582.763) → S5 (554.035) → S4 (863.202) → Depot
	Vehicle 2	Depot → S1 (817.752) → S3 (1182.248) → Depot
Total purchasing cost		90900
Total emitted CO_2		18536
Total social value		1563.1

Table 4. Solution details of CO_2 minimization only

Optimal route (quantity)	Vehicle 1	Depot → S1 (554.035) → S4 (863.202) → S2 (582.763) → Depot
	Vehicle 2	Depot → S5 (659.661) → S3 (1340.339) → Depot
Total purchasing cost		91691
Total emitted CO_2		17748
Total social value		1673.8

Table 5. Solution details of social value maximization only

Optimal route (quantity)	Vehicle 1	Depot → S5 (1057.138) → S2 (582.763) → S1 (360.099) → Depot
	Vehicle 2	Depot → S4 (659.661) → S3 (1340.339) → Depot
Total purchasing cost		93290
Total emitted CO_2		18074
Total social value		1752.3

Table 6. Solution details of the multi-objective problem

Optimal route (quantity)	Vehicle 1	Depot → S5 (1057.138) → S1 (360.099) → S2 (582.763) → Depot
	Vehicle 2	Depot → S4 (659.661) → S3 (1340.339) → Depot
Total purchasing cost		93290
Total emitted CO_2		18023
Total social value		1752.3
Total variation		1.5%

From the Results in tables (3 - 6) we can conclude that after applying the weighted comprehensive criterion method the total optimal solution was found for the optimal solutions of three functions.

4. Conclusion

In this paper, a multi-objective mixed-integer linear programming model is presented for the TPP with multiple vehicles and a single product. CPLEX software and the weighted comprehensive criterion method were used to solve the model and the multi-objective formulation. The results proved the feasibility of the algorithm to reduce the cost and CO_2 emissions, for improving the environment and social criteria.
In order to solve large-size instances of this problem, a heuristic approach needs to be developed. Moreover, the formulation can be extended to account for multiple products and to have a limitation on the maximum travelled distance for each vehicle.

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