Balancing cost and emission preferences of heterogeneous customers in a VRP

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1. Introduction.

In traditional vehicle routing, solutions are evaluated from the perspective of the carrier regarding costs and on-time performance. From the customer perspective, however, the assessment of a solution is more complex as different preferences may exist among the customers served on the same route. Often, it is argued that minimizing the total cost allows the carrier to offer lower prices which contributes to the overall customer satisfaction. How total cost is really allocated to the customers is decided by the carrier. In recent years, customer preferences became more complex. In particular, cost is only one aspect driving customer satisfaction among others. An increasingly important aspect is the eco-friendliness of the transport service, which is recognized by the customer through the amount of greenhouse gas (GHG) emission allocated to his shipment. In this paper, a VRP is proposed to maximize total customer satisfaction, called the VRP with customer preferences (VRP-CP). In this problem, customer satisfaction is defined by the degree at which individual customer expectations for costs and emissions are met.

2. Allocation of cost and emission for transport services.

According to Göthe-Lundgren, Jörnsten, and Värbrand (1996), the allocation of total cost to the customers in a VRP is called the vehicle routing game. As the name suggests, allocation policies discussed in literature focus on concepts of cooperative game theory like the core, nucleolus, or Shapley value (Engevall, Göthe-Lundgren, and Värbrand 2004). Unfortunately, these concepts are computationally complex and difficult to explain to customers, as noticed by Kellner and Otto (2012). Thus, in practice, transparent and easy to grasp policies based on transport distance, payload, or transport performance are preferable for distributing the total cost of a tour to the customers served on the tour. These measures are also recommended in the European reporting standard EN 16258

Table 1 Example with three customers

	input parameters			allocation weights				allocation amount			
customer	t	km	tkm	t	km	tkm	egal.	t	km	tkm	egal.
A	10	2	20	$1/2$	$1/5$	$10/32$	$1/3$	6	2.4	3.75	4
B	7	5	35	$7/20$	$1/2$	$35/64$	$1/3$	3.5	6	6.56	4
C	3	3	9	$3/20$	$3/10$	$9/64$	$1/3$	1.8	3.6	1.69	4
$\sum$	20	10	64	1	1	1	1	12	12	12	12

(European Committee for Standardization 2013) with respect to the allocation of GHG vehicle emissions to customers served on the tour. In case of less-than-truckload (LTL) transportation, the total emission quantity produced by a vehicle on a tour has to be allocated to the served customers. EN 16258 mentions a set of possible allocation policies like egalitarian, distance-based, load-based, or transport performance based allocation, but it also allows a linear combination of these measures. Thus, selecting a certain allocation measure establishes an additional instrument for the carrier to meet the customers' expectations.

In the following example, we consider payload-based, distance-based, transport performance-based, and egalitarian allocation measures for three shipments A, B, and C of three customers as shown in Table 1. Assume the customers are served from a depot on a tour of 12 km length with a total emission of 12 kg CO_2e produced. For each customer, load weight, pendulum distance, and the respective transportation performance are shown in columns 2–4. If load-based allocation is used for allocating emissions to shipments (column 5), each customer receives a share of the total emission based on the percentage of his payload. For shipment A, this is $\frac{10}{20} \cdot 12 = 6$ kg CO_2e. If the allocation policy changes, the GHG allocation changes accordingly as shown in columns 9–12. The norm EN 16258 allows the carrier to select either of the shown results or a linear combination thereof to allocate the total emission to the customers.

3. Modeling customer satisfaction.

In addition to common VRP data, preference values expressing the customers' expectations regarding costs and emissions are included in the VRP-CP. Let $\text{pref}_i \in [0, 1]$ denote the emission sensitivity of customer $i \in C$ with $\text{pref}_i = 1$ signaling that customer i is perfectly emission sensitive, i.e. his satisfaction depends on the received emission declaration only. Likewise, $\text{pref}_i = 0$ signals perfect cost sensitivity meaning that the emission declaration does not affect the customer at all. In order to evaluate the cost and emission quantity assigned to a shipment, upper and lower bounds for cost and emission declarations of each shipment are calculated. Upper bounds $\overline{c}_i$ and $\overline{e}_i$ are given by the costs and emissions generated for each of the pendulum tours from the depot to the shipments' destinations. Lower bounds are calculated by solving a selective traveling salesman problem (sTSP),

Table 2 Example with ten customers

input parameters			bounds				CVRP optimal			VRP-CP optimal		
cust.	demand	pref	$\underline{c}_i$	$\overline{c}_i$	$\underline{e}_i$	$\overline{e}_i$	c_i	e_i	s_i	c_i	e_i	s_i
1	5	1	14.9	30.5	11.1	21.1	30.5	21.1	0 %	28.1	11.5	96 %
2	3	1	13.2	36.0	11.0	24.2	31.6	11.0	100 %	31.6	11.0	100 %
3	6	0	22.5	44.7	18.1	31.3	23.8	18.1	94 %	23.8	18.1	94 %
4	9	1	26.2	50.0	21.9	36.4	31.6	36.4	0 %	31.6	36.4	0 %
5	13	1	20.9	41.2	17.6	31.6	20.9	31.0	4 %	41.2	23.1	61 %
6	1	1	1.7	22.4	1.3	14.6	20.9	1.3	100 %	22.4	3.9	81 %
7	2	0	8.7	42.4	6.6	28.1	26.0	7.2	49 %	21.2	23.7	63 %
8	4	0	19.9	52.5	14.9	35.8	26.0	17.8	81 %	34.9	35.6	54 %
9	8	0	30.2	64.0	24.1	46.0	45.5	34.6	55 %	45.5	34.6	55 %
10	8	0	20.7	51.0	16.64	36.7	26.0	34.5	82 %	28.1	30.8	75 %
Σ	59	5	–	–	–	–	283.0	213.0	565 %	308.6	228.7	679 %

which selects a tour from the set of shipments such that the allocated cost or emission quantity of customer $i \in C$ is minimal (Kirschstein and Bierwirth 2017). As a result, intervals $c_i \in [\underline{c}_i, \overline{c}_i]$ and $e_i \in [\underline{e}_i, \overline{e}_i]$ are obtained for each customer denoting the ranges for cost and emission declarations. Based on the preference of customer i, his satisfaction on declaration (c_i, e_i) is computed by

$$s_i = \text{pref}_i \left(1 - \frac{e_i - \underline{e}_i}{\overline{e}_i - \underline{e}_i}\right) + (1 - \text{pref}_i) \left(1 - \frac{c_i - \underline{c}_i}{\overline{c}_i - \underline{c}_i}\right).$$

Note that customer i's satisfaction is 100 % (0 %), if i receives his individual lower (upper) bounds in both declarations. Depending on how $\text{pref}_i \in [0, 1]$ is chosen, this holds for cost or emission allocation, or both. Using this approach, the objective to be maximized in the VRP-CP is the total customer satisfaction, i.e. $\max \rightarrow \sum_{i \in C} s_i$.

4. Example illustrating the VRP-CP.

We illustrate the VRP-CP by solving the Solomon instance R101. Table 2 shows the customer demands and preferences as well as upper and lower bounds for the cost and emission declarations. In the example, customers are either perfectly cost sensitive or emission sensitive. Costs are assumed to be equal to travel distances. The optimal vehicle tour obtained for the standard CVRP with subsequently maximizing customer satisfaction is shown in Table 3 (column 2). The corresponding declarations (c_i, e_i) for the customers are reported in Table 2 (columns 8 and 9). The optimal solution of the VRP-CP is shown in Table 3 (column 5) and Table 2 (columns 11 and 12) as well. Both solutions use five vehicles, whereby the tours differ slightly. Therefore, the cost and emission declarations (c_i, e_i) assigned to the customers differ, too. Note that the total customer satisfaction increases from 565 % to 679 % when the VRP-CP is solved compared to first solving the CVRP and maximizing customer satisfaction in a second step. This means that solving the VRP-CP allows the carrier to consolidate shipments more effectively creating tours where cost-sensitive customers are charged with higher emission declarations and emission-sensitive customers receive higher cost declarations.

Table 3 Optimal tours of CVRP and VRP-CP

vehicle	optimal solution of CVRP			optimal solution of VRP-CP		
	tour	cost allocation	emis allocation	tour	cost allocation	emis allocation
1	0-1-0	load-based	performance	0-1-10-0	egalitarian	performance
2	0-6-5-0	egalitarian	performance	0-6-8-0	egal & load	performance
3	0-3-9-0	performance	performance	0-3-9-0	performance	performance
4	0-10-7-8-0	egalitarian	performance	0-5-7-0	egal & load	dist.-based
5	0-4-2-0	egalitarian	egal & perf	0-4-2-0	egalitarian	egal & perf

5. Outlook.

In this paper we propose the VRP-CP which aims at maximizing total customer satisfaction considering heterogeneous customer preferences. The approach can be used integratively or in a two-stage procedure, where first an ordinary CVRP is solved and customer satisfaction is maximized subsequently. The example sketches the impact of the approaches when costs and emissions are subject to heterogeneous customer preferences. The talk will present a computational study on a wider set of artificial and real-world instances (Behnke and Kirschstein 2017). Here, cost-optimal tours often differ from emission-optimal tours, which extends the room for finding preference-optimal tours.

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