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# Transportation cost allocation on a fixed route ☆

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ABSTRACT

A fundamental problem for determining the service cost in logistics is to allocate the transportation cost on a given route. Our real application usually has 5–20 customers per route, and the routing to all customers or any subsets of customers may not be optimal with respect to total distance travelled. To identify the objective and evaluate different cost allocation methods, five fairness criteria are introduced. We investigate a number of popular allocation mechanisms to identify their properties on fairness and feasibility for implementation. A contribution constrained packing model is proposed to consider these multiple fairness criteria for cost allocation. To determine the proper parameters in our model for different routes, a modified Nelder–Mead algorithm with a simplex enlargement operation is introduced. Two approximation methods for computing excess rate, an important measure of a fair allocation, are analyzed and the original routing sequence approximation is recommended for application. Through a computational study, we demonstrate that our method satisfies an important set of fairness axioms and improves cost allocation from the existing allocation schemes within acceptable time requirements.


## 1. Introduction

As an indispensable activity in a supply chain, transportation service accounts for upwards of 50% of total logistics costs (Swenseth & Godfrey, 2002). To reduce overall cost and obtain a guaranteed quality of logistics, collaborative transportation strategies are commonly adopted by companies among horizontal partners or even competitors (Esper & Williams, 2003). Products from different companies could be shipped by a third-party logistics provider on the same route to increase truck utilization and lower operation cost. A leading supplier may coordinate the cooperative transportation activities of its customers and delivers orders on an efficient route.

Even though collaborative transportation provides substantial discounts for the group as a whole, each entity is concerned with its own benefit. This raises a question as to how to allocate the joint transportation cost among partners on the same route. Our research is motivated by our collaboration with a large manufacturing firm, which delivers packaged products from its plant to several customers on a route. A *fairly* determined cost to serve each customer provides a base to calculate the pricing benchmark for contract renewal. Allocating too little cost to a customer will reduce the profit margin. But, if the allocated cost is greater than its fair value, there is a risk in losing existing customers to competitors.

When collaborators are explicit at the planning stage, all the necessary routing factors are available and can be considered endogenously in an allocation model. For example, several shippers negotiate the operating policy and cost/benefit allocation mechanism simultaneously (Frisk, Gothe-Lundgren, Jornsten, & Ronnqvist, 2010; Yilmaz & Savasaneril, 2012); under a vendor managed inventory policy, a supplier calculates the cost to serve customers while optimizing the delivery patterns (Özener, Ergun, & Savelsbergh, 2013).

However, for some industries, the delivery charges are offered to customers as part of a long term (e.g. one year) contract before daily delivery planning (Sun, Karwan, Gemici-Ozkan, & Pinto, 2015). The company conducts cost analysis on historical routes to evaluate and update its existing pricing policy. In such a setting, past actual routing factors may not always be available. First, the necessity of fair cost allocation is recognized only recently by many industries, and data shortage commonly exists for traditional manufacturers. Fig. 1(a) illustrates a given delivery route, where five customers received their orders from plant 0. The route itself might be impacted by complex constraints, such as delivery time

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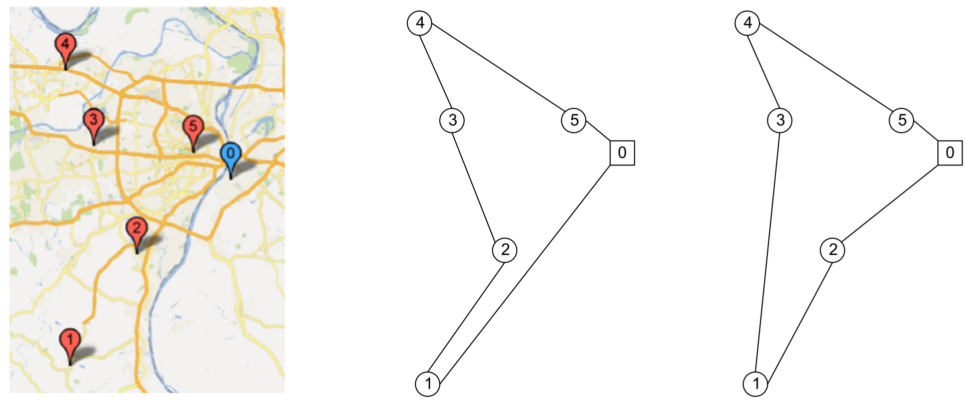


(a) A real-world delivery route (b) Route in Euclidean plane (c) Route with minimum length

**Fig. 1.** Illustration of a fixed route.

windows and traffic conditions, but these factors have not been recorded. Second, various factors were associated with different routes, and it is impossible to try to reconstruct why a particular route was employed for thousands of routes in practice.

For our application, we consider a cost allocation problem where routes are exogenously defined. Since geometric features of a route are always the primary basis for cost allocation, and the route itself is an outcome from all necessary routing factors, we must fairly allocate cost of a fixed route to customers based on geometric information. Comparing Fig. 1(b) and (c) in the plane, the given route may not be optimal in distance. Different from the optimal route allocation problem, an exogenously-defined route emphasizes on-route information that provides crucial arguments for a reasonable allocation.

This study considers many practical factors such as multiple fairness criteria, the non-optimality of routes, and the feasibility of implementation. Different from the prevalent cooperative game based methods in the literature, our allocation scheme contributes by satisfying multiple fairness criteria, with a game based axiom as one of them. The game based only approaches within the framework of optimal routing can produce significant bias or simply be inappropriate when applied to non-optimal routes, which however are often taken by a computer aided human scheduler in the real world. Thus, the stable performance for both optimal and non-optimal routes is another advantage of our method for use in practice. Moreover, our method can be implemented in a modest amount of time avoiding a much greater computational burden of some game-based approaches.

The remainder of this paper is organized as follows. In Section 2, we review the related literature. Section 3 describes the problem and presents five fairness criteria. In Section 4, we discuss three existing allocation models and propose a new model with tuning parameters. Section 5 details a cost allocation scheme based on a direct search algorithm to find appropriate parameters for the new model. We compare the performance of our method with other allocation methods and analyze the time requirement and approximation accuracy via computational experiments in Section 6. We end with some concluding remarks in Section 7.

## 2. Literature review

The transportation cost allocation problem, that is only based on distances on route, is a fundamental problem in logistics cost analytics. However, it raises a few concerns in terms of fairness criteria and allocation methods. Fishburn and Pollak (1983) proposed a fixed route cost allocation problem along with some fairness criteria. A proportional willingness to pay scheme was shown to allocate costs with satisfactory performance with respect to those fairness axioms. This method provided fast computation and a simple rule for application. But it only took into account the role of single stop delivery costs while ignoring other factors such as the relative locations among customers. We later introduce additional axioms which will be considered in our cost allocation method.

One of the multiple fairness concerns was modeled based on cooperative game theory. Tamir (1989) defined a cost allocation game based on traveling salesman problem (TSP). A set of cooperating players (non-home nodes on a route) is called a *coalition*, and the coalition with all players is called the *grand coalition*. The core was derived from the idea that no subset of players would have incentive to split from the grand coalition; that is, $\sum_{i \in S} x_i \leqslant c(S)$ for all $S \subseteq N$ and $\sum_{i \in N} x_i = c(N)$, where $x_i$ is the cost allocated to player $i$, $c(S)$ is the stand alone coalition cost of subset $S$ and $N$ is the set of all players on a route. Since the core of a traveling salesman game (TSG) may be empty, Faigle, Fekete, Hochstattler, and Kern (1998) defined an approximate core and developed a geometric cost allocation method with the concept of a moat. It was proved that an upper bound on the error of their approximately fair allocation was 1/3 of the underlying optimal TSP cost of the whole network. Blaser and Shankar Ram (2008) provided a polynomial time algorithm for an asymmetric TSG, but only obtained a $\log_2(|N| - 1)$-approximately fair cost allocation. The moat allocation method is the first to consider intra-route synergies among the players. While important, such core allocations are not considerate of and can conflict with other fairness axioms.

The Shapley value (Shapley (1971)) considers the marginal contribution of each participant in a collaborative system and provides a unique allocation solution. However, the Shapley value is usually not an ideal method for allocation problems in networks due to its computational complexity. It also involves fewer comprehensive considerations, e.g. the sanctification of the core requirements. Yengin (2012) discussed a cost allocation problem on a route that is formed based on appointments, where the special cost function requires less computational cost for the Shapley value method. They also analyzed the Shapley value in a class of routing games, but the core characterizations for an appointment game do not extend to others.

Only a few applications of route cost allocation exist in the literature. Engevall, Gothe-Lundgren, and Varbrand (1998) presented a case study on a distribution system in the oil and gas industry, where they introduced the demand nucleolus to consider allocating a large portion of the total costs to customers in coalitions with