Comparison of Efficient Planning and Optimization Methods of Last Mile Delivery Resources

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Abstract. A review of recent Last Mile Delivery optimization proposals is presented. The proposals are classified according to the criteria of collaboration, ranging from optimization of a single route to the integration of multiple carriers. An alternative proposal is presented, based also on collaboration, but which does not involve either integration into a single organization or sharing of its resources. Each carrier is represented as a Virtual Organization of Agents (VO). A global optimizer, also a VO, oversees the search for deliveries that can be better delivered by another carrier and new routes are calculated based on a win-win approach. This approach has the advantages of being easily configurable by integrating or removing the VO of each carrier, highly distributable using a cloud infrastructure, easily scalable both for physical areas and computational resources using the cloud infrastructure in case more computational power is needed. It also allows the sharing of the least amount of information possible among carriers, so that they only know about the deliveries that they are losing or gaining.

Keywords: Multi-Agent Systems · Last mile delivery · Planning optimization · Cloud computing

1 Introduction

Last Mile Delivery (LMD) is increasing in importance due to several reasons, such as the growing population in cities and the progressive increase in deliveries associated with e-commerce [1, 2]. Urban freight distribution, while necessary to maintain the supply of goods in cities, support economic development and increase customer satisfaction, has some drawbacks. The more common side effects mentioned in literature include: congestion, air pollution, greenhouse gas (GHG) emissions, traffic accidents, noise, etc. [2–4]. As freight delivery in urban areas can be up to 15–20% of the vehicle traffic [2], an optimization in this field can contribute to increase the sustainability of the service as well as to a significant reduction of its side effects.

Several attempts have been proposed to try to reduce the economic cost of the LMD, usually by reducing the length of the route in a few ways. These approaches range from crowdsourcing, to integrating several carriers to share resources, among others. For

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example, the crowdsourcing approach seeks to reduce the number of stops on a route or even eliminate the route altogether by replacing carriers with ordinary people. The opposite approach attempts to reduce cost by sharing the resources of several carriers and behaving as if they were one.

The rest of this paper is organized as follows: the following section contains a review of the different alternatives that can be found in recent publications. This is followed by our own approach, a solution based on agents and collaboration. Discussion and final remarks end the paper.

2 Optimization in Last Mile Delivery

The optimization of last mile delivery has been approached from several points of view. The proposed solutions range from the simple use of optimization methods to group the recipients and the delivery route(s) to the integration of several carriers in a city and the search for a common and global solution for the whole set of deliveries. Intermediate solutions include various kinds of cost reduction by sharing resources, using alternative forms of delivery, using alternative vehicles, incorporating additional infrastructure, or sharing resources among several carriers. [5] includes a good description of the LMD problem, which can be summarized as: several carriers compete with each other in the city and this results in a fragmented market and a lack of coordination and therefore to low vehicle load factor, excessive vehicle movement, a high cost for the overall delivery system and environmental side effects. Authors enumerate a set of problems associated with the LMD problem, namely: (*i*) pick-up and delivery points often located in areas of restricted access, far from large distribution centers, with scattered demand groups and with some access restrictions such as time windows for delivery; (*ii*) congestion, (*iii*) limitations on the use of the vehicle fleet; and (*iv*) with a dynamic interaction among many interests and services, polices and interventions. [5] also proposes four areas to achieve collaboration between the different actors in urban freight delivery: (*a*) eco-friendly collaborative delivery, (*b*) synchronization & multi-objective planning, (*c*) multi-party coordination and (*d*) data harmonization & analytics. Most of the proposed solutions can be classified in one or more of these areas. However, focusing especially on collaboration among carriers, the literature reviewed can be classified according to the degree of collaboration they seek to achieve in three main groups, namely: (*I*) single-route optimization, (*II*) increasing the vehicle load factor, and (*III*) joint optimization of multiple carriers. A graphic description of the possible options could be represented as in Fig. 1.

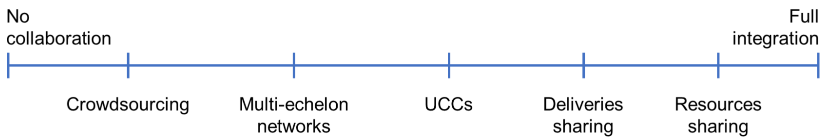

Fig. 1. Different kinds of collaboration among carriers arranged progressively.

2.1 Single-Route Cost Reduction

Some approaches are based on optimizing a single route or maybe several routes for the same carrier. The approaches chosen include several options as the final objective, the cost reduction, can be achieved in several ways. For instance, by asking others to make the delivery or by using existing public transportation.

Crowdsourced and Mixed Delivery. Several authors have proposed using any kind of 'crowdsourced' delivery. Crowdsourced delivery–also known as crowd-shipping– is described in [6] as the crowdsourcing of the delivery task to a set of individuals who deliver parcels along their routes while using the empty space in their cars or luggage. In this case, a win-win relationship can be obtained: better customer experience is achieved, and the crowd individuals get some additional income. At the same time, some side effects can be reduced, such as reducing the urban traffic, or a lower environmental footprint.

In [7] it is proposed to use this approach for food delivery using motorbikes. [8] also describes how to use a crowdsourcing model in a two-echelon distribution network: first, a truck transports the parcels from a depot to the city center, then, at an arranged location(s), parcels are transferred for crowdsourced delivery to their final recipients. [9] goes one step further and extends the problem to a network of crowdsourced drivers that can transfer parcels to each other at agreed locations to avoid long detours for the drivers. This allows for a more flexible assignment of drivers and parcels. [6] includes not only crowdsourced drivers but also pedestrians and cyclist. [10] proposes to mix some professional drivers with crowdsourced ones who deliver parcels from a shop on their way to their own destination. Moreover, time can be introduced as a new variable of the solution: in [9] is proposed to wait to allow the possibility for a store to group deliveries received online, which will be delivered by the customers who are present in the store. Obviously, time windows for delivery and some deadlines must be considered.

In [11] the usage of an online platform –without carrier– to receive pick-up orders, accept the task and compute the route is considered. If a crowdsourced driver is not available, an external carrier is contacted to do the job.

Use of Alternative Means of Transport. Several authors have proposed the use of public transport, such as buses, trams, or taxis, as a means of obtaining savings and reducing side effects. For instance, in [4] it is proposed to mix the usual methods of public transport available such as bus, trams or subway together with e-bikes as they are eco-friendly and can be transported on public transport. A similar idea is presented in [12] where it is proposed to use bus stations as small distribution hubs and bus lines as the transport network. The use of taxis has also been proposed to reduce the cost of parcel transportation by sharing the cost of the ride with passengers [13].

2.2 Increased Vehicle Load Factor Through Consolidation

Some proposals include the use of additional infrastructure other than the carrier(s) main repository or intermediate or auxiliary infrastructure. The usual objective is to reduce the distance that parcels travel by using an intermediate hub for subsequent distribution or to avoid additional trips because the parcel cannot be delivered to the recipient.

Multi-Echelon Networks. A distribution network using only one level can be inefficient, as the origin of the trip, the depot, can imply long trips to the recipients and this led to long trips. The existence of time windows for delivery can also lead to reduced vehicle load factor [14]. This can be mitigated using a network of satellite hubs which can be used to consolidate and deconsolidate the deliveries, allow using smaller and less pollutant vehicles, better fitted for dense traffic. [14] includes an updated review of the relevant literature about this topic. This kind of distribution networks is designed to include ancillary depots or satellites, maybe interconnected among them, located in the city in areas where there is a dense concentration of recipients. The use of this kind of networks is proposed in [8, 14, 15] and [17].

Urban Consolidation Centers (UCC). As a way of balancing interests among carriers, receivers, citizens and public administrators, the use of UCCs has been proposed in some cities. A UCC is a hub, usually located within city limits and easily accessible. The UCC is a consolidation center and the objective are to increase the load factor of the delivery fleet and reduce the distance traveled [3]. The use of a UCC appears to have an economic impact on last mile delivery, however. Cost analyses of the UCCs can be found in [3, 17]. Because of this economic impact, it is stated in [18] that the main decision for a courier is whether to let the UCC deliver a parcel or make a direct delivery to the recipients.

Success of the UCC may depend on some constraints which are out of the control of the carriers. [2] mention some incentives to use a UCC: (*i*) mandatory usage of eco-friendly vehicles for last leg delivery; (*ii*) restrictions on access the city center such as time windows for delivery or depending on the kind of vehicle; (*iii*) pollution charges. For example, [3] describes the UCC in the city of Antwerp, Belgium. The city suffers from traffic congestion, so it has been stated time windows for freight delivery and a Low Emissions Zone (LEZ) in the city. The UCC is used by 4 carrier companies, can benefit from several kinds of freight arrivals, such as trucks or ships, and delivers to the city area, the port, and the outskirts. As the UCC is run by the public postal company, it has enough budget and no other subsidies are needed. Nevertheless, the authors estimate that it needs to increase daily deliveries from 75 to 336 to reach financial equilibrium.

Other authors provide simulations on the viability of the introduction of a UCC in some cities. For example, [1] considers introducing a UCC in the city of Frankfurt am Main (Germany), and [2] in the city of Austin, Texas (USA). The latter considers using electric vehicles (vans) and e-bikes for delivery and also, the renewal of the existing fleet of polluting vans for newer and less polluting ones. Both present several scenarios and estimate the impact of the proposed changes.

Both approaches, the multi-echelon network and the UCC, can be combined when designing the distribution network, as proposed in [14] and [15]. The latter also includes a collaboration approach and proposes sharing both UCC and satellites among several carrier enterprises to reduce the infrastructure costs.

2.3 Joint Optimization of Multiple Carriers

[19] classifies the possible collaboration between urban freight delivery enterprises into 3 interaction levels:

1. Transactional: coordination and standardization of administrative practices and exchange techniques.
2. Informational: exchange of business information, for instance, sales forecasts, stock levels or scheduled delivery dates.
3. Decisional, which can be divided into 3 kinds of collaboration at different planning horizons of logistics and transportation activities: (*i*) Operational planning (everyday operations that can be coordinated or shared such as freight transportation or cross-docking); (*ii*) Tactical planning (middle-term planning stage, which includes operations such as forecasting, shipping, inventory, production management, quality control); (*iii*) Strategic planning (long-term planning decision such as network design, facility location, finance, and production planning).

Local/Global Route Optimization by Collaboration. A curious form of collaboration is proposed in [20]. Assuming that stores send new orders based on stock management, the delivery process will produce some inefficiencies such as vehicles not being fully loaded. To reduce this problem, it is proposed that carriers ask stores on the route already set to anticipate their orders, so that the load factor of the vehicles increase, and the overall process becomes more efficient. Therefore, stores collaborate to increase efficiency in the delivery process, which allows them to reduce the total cost of delivery and travel less distance to serve the same load. Stores anticipating their orders receive a discount on the cost of the delivered freight.

Other possible form of collaboration is proposed in [21]. The routes are built by a set of collaborating agents, in a Multi-Agent System. Each agent represents a carrier and contains its own goals. However, the agents collaborate to optimize all the routes, including having one carrier deliver parcels from another carrier if this is the best computed solution. If so, the carrier should visit, in this order, both the other carrier's depot and the recipient, to make the delivery.

Resources Sharing. [19] describes a possible solution through collaboration in which three different carriers coordinate and collaborates to increase vehicle load factor and reduce delivery costs. In this proposal, the solution is achieved by transferring part of the freight to be delivered from two of the carriers to the other one because the better location of its depot and the possible routes from it allow them to optimize costs. A reduction in the number of trips and travelled distance is obtained and therefore, the corresponding savings in delivery cost. This approach consists mainly of coordinating the three carriers as if they were one, sharing parcels, vehicles and therefore drivers, as necessary.

[15] describes the case of the city of Quongqing (China), where two carriers joined in an alliance. The proposed solution includes the design of a multi-echelon network and a set of Collection Points (CP). A cost reduction in the number of vehicles from 37 to 20 at best, compared to maintaining two independent carriers, is reported.

Table 1 shows a classification of the proposals considered in the review. Proposals are classified according the kind of collaboration they propose, the kind of problem being solved (B2C or B2B), and the kind of solution they propose: agent-based, machine learning, heuristics, exact solution using mainly linear programming.

Table 1. Classification of the proposals considered in the review.

	Single Route		Load factor		Carrier integration	
	Crowd-based	Public transport	Multi-echelon	UCCs	Collaboration	Integration
Proposal	[6–11]	[4, 12, 13]	[8, 14–16]	[1–3, 14, 15, 17, 18]	[20, 21]	[15, 19]
B2C	[6–11]	[4, 12, 13]	[8, 14, 16]	[14]		[15, 19]
B2B			[15, 16]	[1, 15, 18]	[20]	
Agents	[6]	[4]	[16]	[1, 18]	[20, 21]	
M.L.	[7]	[13]		[18]		
Heuristics	[8–10]	[13]	[8, 14, 15]	[15, 18]	[21]	[15, 19]
Exact	[8, 11]	[12]	[8, 14]		[21]	[19]

2.4 Criticisms of the Proposed Approaches

Single Route Cost Reduction. Although this type of optimization can achieve a reduction in costs by reducing stops on a route, it cannot allow for an overall optimization of routes, since the reduction is not based on increasing the vehicle load factor but on reducing the number of parcels delivered by the carrier. It is assumed that some reduction of the route for the carrier can be achieved by making some of the deliveries by occasional drivers, or other form of collective courier. Furthermore, as pointed out in [11], on the one hand, the crowd-based approach to delivery is scalable, but on the other hand, the quality obtained by a fleet of professional drivers can be higher.

Increasing the Load Factor Through Consolidation. Some authors have mentioned the drawbacks of the UCCs. For instance, [1] mention that the cost associated with the UCC makes it unattractive to carriers, and [2] summarizes four reasons for the failure of the UCCs, namely: (*i*) lack of planning, (*ii*) too ambitious forecasts, (*iii*) dependence on local authorities for subsidies and too high operating costs, and (*iv*) some wrong decisions such as the location of the UCC or the kind of vehicles in the fleet. In addition, regarding the cost associated with the establishment of the UCC, it has been proposed to be established by a large company, to avoid dependence on public subsidies [3].

Progressive Integration of Carriers. Some proposals, being theoretically interesting, are difficult to be practical. For instance, proposals such as [19] or [16] basically involve uniting carriers to work as one. However, some practical problems need to be addressed, for instance, in [19] part of the freight is transferred from two of the carriers to a third one, because its depot allows for better routes, if the depot can store the extra freight, if it can manage the extra freight or if there are enough bays for the extra delivery vehicles or not is not taken into account.

3 Alternative Proposal

The idea of consolidating deliveries to increase the load factor of delivery vehicles as a way to improve the delivery process that underlie the UCC is attractive, although the drawbacks, mainly the operational cost of introducing new delivery infrastructure can make the idea unsuitable for all cities. However, a cost reduction can be achieved by collaboration without the drawbacks of establishing a new UCC and avoiding the integration of several carriers into one. The idea of a virtual UCC was already proposed in [5] based on an auction mechanism in which carriers offer some deliveries and other carriers bid for them.

As an alternative, focused more on a collaboration approach, it is proposed to perform a general optimization of the routes. The proposed process consists mainly of sending the routes already built to a common shared optimizer. This central element will try to improve the group of routes, in a win-win basis. The optimizer will seek out stops on the route that can be delivered by another carrier at a lower cost, based on a distance/cost travelled criterion. Some basic assumptions must be made: first, the routes are at least partially overlapped, and second, the individual routes are already optimized for delivery.

To obtain a robust, flexible, configurable and extendable solution, the use of an agent-based approach is proposed, and more precisely a Virtual Organization (VO) of Agents [22–24] which is a paradigm for managing collaboration between Multi-Agent Systems (MAS). A MAS is formed by a group of agents, which have some characteristics such as: sociability, autonomy, and proactivity [25]. The agents will pursue their own goals or the global goal, and behaviors such as goal delegation or collaboration among several agents to achieve a goal can be present [26]. One of the key features of a MAS is its ability to reorganize and adapt to changes in the environment. VOs go one step further, agents and MAS arranged in organizations needs to coordinate resources and services across the organizational boundaries to achieve their goal [23]. Thus, VOs allow to organize groups of agents and MAS, not necessarily homogeneous, and so that they can achieve their goals through collaboration.

An agent-based solution has some advantages to deal with complex problems, such as the capacity of distribution in computers and organizations, the ability to deal with complex communication, independence in the behavior of the agents, etc. Some proposals already mentioned include agent technology in the solution, such as [4, 6] or [16]. The agent technology will provide the solution with a great versatility and the ability to be distributed and even easily scalable. Examples of the use of the MAS approach and challenges related to it can be found in [25].

3.1 Organizational Design

Each carrier and the common shared optimizer will be organized as VOs of agents. To optimize the routes, there are agents for performing each of the task needed, such as: recovering the stops for each route from local systems, planning an optimized route, with the help of some other agents for obtaining the street map, the information about cut-off or worksite streets from local authorities, weather forecast, urban traffic information (if available), etc. Some other agents can be available *e.g.* an agent for learning the real route the drivers do, because of the weather, an accident, knowledge about parking, etc. for further route optimization. Also, there will be agents to manage the communication with the common shared optimizer. These agents will oversee sending the locally optimized routes, provide any other information necessary and receive the globally optimized routes.

The common optimizer will also consist of several agents capable of developing complex tasks such as: identify possible stops on a route that can be changed to other carrier-route based on optimization criteria, performs their own route optimization process, and hence, those auxiliary agents for obtaining the street map, the state of the city streets, the forecast and traffic information, will also be present. The agent being able to manage the communication should also be included.

To ease the MAS design and the scalability of the solution, each VO representing a carrier will communicate with the optimizer VO through the communication agent. A graphical representation is depicted in Fig. 2. The internal structure of agents in each VO fits well with the federation organization described in [22, 25] and [26]. The common optimizer will prevent carriers from exchanging unnecessary information and undesirable behaviors in the agents in the VO of any carrier. The common optimizer would be a single point of failure as its main drawback.

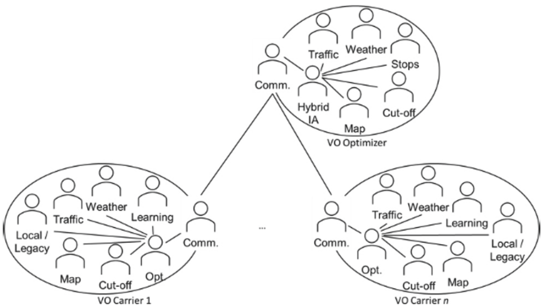

Fig. 2. Virtual Organizations of agents for the route optimization solution.

The usage of VOs proposed will allow the system to add or remove carriers (VOs) easily and thus, to adapt to changes in the environment. This also will allow to change the scope of the solution easily. For cities small enough, a single optimizer would be sufficient, bigger cities may need to replicate the solution for neighborhoods for instance, but the adaptability of this kind of systems help to manage these situations.

Cloud deployment provides the solution with flexibility, general availability and the ability to change the scope and computing requirements. A carrier (its VO) can easily be added or removed since only the global optimizer needs to be contacted via its communication agent and the necessary information exchanged, while the VO can be kept in the company's own cloud. Computing resources can be adapted as necessary to meet requirements due to the number of carriers using the service.

3.2 A Hybrid AI-Based Solution

The proposed solution is based on Artificial Intelligence (AI) to globally optimize routes. To control the computational cost of the process, an exact global solution is discarded. Our solution is divided into two parts. First, a heuristic is proposed to select the stops that can be changed to another route. Those stops on a route closer to a stop on another route are candidates to be changed. In case of an exchange of stops, a transfer point, the place where both drivers must meet, and where the freight is exchanged, must also be added to both routes. Although, this is not necessarily a synchronous event. Locations for a possible asynchronous transfer include the carrier's depot, parcel lockers, stores, etc. Once the transfer point has been selected for the exchange of parcels, parcels that could be interchangeable and that are at stops on the route prior to the exchange point should be reconsidered if their exchange is still feasible or has become unfeasible due to the cost of the detour. Second, as both routes must be modified, a hybrid approach is proposed [27], so that an expert system and route optimization algorithms will calculate the new routes. The chosen optimization algorithm will be based on the characteristics of the route, for instance the number of stops or the existence of restrictions on the route. Thus, it is possible to choose the best possible option, even an exact solution, depending on the optimization algorithm that is best suited for each route. Many of the current proposed solutions to LMD rely on some AI algorithm, for instance, a heuristic solution such as in [8, 9] or [14], or based on Machine Learning such as in [7, 13] as a way to avoid the computational cost of obtaining an exact solution.

Given that the new solution should improve the existing one, two constraints should be included: (*i*) a transferred stop from a route allows the carrier who lose the stop not to worsen its cost function, and (*ii*) the set of routes reduces the overall cost. Thus, both local and global optimization is considered. This also allows some preferences to be included in the corresponding agents, such as: is it necessary to make a profit to accept the changes in a route? Is it enough if the new route is not worse than the original one? Is it enough to make an overall profit to accept the proposed changes?

4 Discussion and Final Remarks

A review of recent proposals for LMD is presented. The different proposals have been classified based on how the collaboration is approached. Those proposals closer to crowd-sourcing try to reduce stops on the route or even the route itself. This option, however, does not allow for any further optimization as no other stakeholders are included. The load factor increase approach may need to include expensive extra facilities that may hinder the economic viability of this solution. Other approaches based on collaboration between carriers have also some drawbacks. Full integration of carriers can be cost-effective for companies, but competition among carriers disappeared. A proposal for route optimization based on collaboration has been included. The proposal seeks to reduce inefficiencies in the delivery process due to the distance to some stops, which perhaps may be better served by other carrier. This approach seeks local optimization for each carrier and, at the same time, global optimization for the overall LMD system. To achieve this, the solution is divided into two stages: first, stops on the route are identified that can be served more efficiently on another route. Then, as any route can lose some stops and gain others, a new optimization process is developed using a hybrid solution based on an expert system and several optimization algorithms.

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