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LAST MILE DELIVERY MODEL FOR SUSTAINABLE DEVELOPMENT

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Abstract.

Last mile delivery is defined as the movement of goods to/from a transportation hub from/to final delivery destinations, this part of the logistics chain being in general for many fields of logistics the more problematic and costly. Latest technologies are providing new means for collecting and exchanging information as well as for delivering logistics services. For example, advanced drone technology can produce today logistics solutions considering that UAVs can now provide acceptable payloads, autonomy and collision avoidance capabilities. This technology appears to be an opportunity to reduce the last mile logistics costs as well as to contribute to sustainability objectives.

This paper focuses on the development of a methodology to design last mile logistics based on a hybrid solution composed of ground vehicles addressing the planned demand and of UAVs processing the unplanned demand. The ultimate objective of this study being to estimate the generated UAVs traffic in the urban space, a global continuous approach is adopted. The ground LMD routing and scheduling activities are considered globally using an empirical formula relating the minimum cost route operation in a dense urban area with the mean distance necessary to serve a customer. The UAV LMD activity, which here almost exclusively supports the unplanned demand, is analyzed globally using a stochastic model. In both cases, the generated traffic is estimated and performance indexes, related to the quality of service and the environmental impact, are produced.

1. Introduction

Global trend towards increased urbanization and the rise of e-commerce have changed the patterns of the last mile delivery (LMD) in urban areas: according to the United Nations [1], 60% of people are expected to live in cities by 2030, while the volume of parcels delivered worldwide should reach 200 billion by 2025 [2]. Around 86% of the parcels delivered by one of the main actors in urban logistics, Amazon, are lighter than 2.27 kg. Also, the major industrialized countries have engaged in a long-term decarbonization policy while the urban logistics are an important contributor to air pollution. Thus, a new organization of the urban logistics operations based on more environmental friendly vehicles seems desirable. UAVs appear to be strong candidates to provide, in cooperation with other vehicles types, an answer to this need.

In this communication, after analyzing the current trends in last mile delivery (LMD), a general strategy is developed for the management of UAV traffic dedicated to LMD in urban space. After that, it is shown that it is possible to avoid the curse of dimensionality by adopting a continuous modelling approach to get rough estimates of the generated traffic, the costs and benefits associated with LMD hybrid solutions (ground vehicles and UAVs).

2. The current perspective for UAVs in urban logistics

Important perspectives for the development of urban logistics based on the operation of UAVs are currently consolidating according to recent publications [3], [4], [5], [6], and [7]. They will be able to benefit from the empty urban airspace and to alleviate the ground traffic by diminishing the needs for the ground-based logistic transportation, which is one of the main contributors to the ground urban traffic congestion and pollution. Previously, many studies have been dedicated to the design of efficient UAVs based urban logistics systems; see for example [6], [7] and [8], where in general, traffic volumes and capacities are not taken as an issue. However, other studies [9] expect within a few decades the occurrence of high traffic densities of drones operating in the common urban airspace, making imperative and urgent its effective design and organization.

In the near future, the main application of UAVs in the urban space appears to be last-mile delivery, which refers to all those logistics activities related to the distribution of shipments to private customers in urban areas. Last-mile delivery begins when a shipment has left a warehouse located inside or near a urban area and finishes once the shipment has been delivered by a vehicle to the final customer at his location inside the city. Afterwards, the vehicle may continue to perform deliveries according to the available cargo and the planned route or may return to the warehouse.

Compared to UAVs, ground logistics vehicles have two important advantages: they can transport larger or heavier loads and the scale effect makes it possible to reduce the unit cost of transport. But they contribute in an important way to the urban traffic congestion and pollution, they lack flexibility and the urgent transport of individual requests by their means is extremely expensive. Then it appears that ground last mile delivery will remain of interest when it is possible to group together several requests known in advance so as to promote the effect of scale to optimize delivery routes so as to make better use of the fleet and ensure good quality of service. With the fast development of the e-commerce, the on-line delivery demand for small packages scattered all around the urban space has been increasing and the use of UAVs for their deliveries appears already as a promising solution. It seems that the urban logistics and in particular, the last mile delivery, will continue to be performed partly by using ground vehicles, but the share of UAVs in this activity is likely to increase highly, thus representing an important part of the drone traffic in the urban space.

3. The proposed strategy

For the urban traffic manager, ground and air, it is of importance to predict what can be the demand for using the available space, so that it is of interest to foresee the way the main users of the 3D urban space will generate traffic demand. This will allow the local authorities to design a traffic plan to structure the 3D urban space which will allow to balance the potential traffic demand with the social acceptance and the quality of life for the urban citizens.

For instance, the last mile delivery traffic demand by a logistics company will result from its solution to different inter-related problems:

- location and sizing of the logistics centers;
- size and composition of the delivery fleet;
- policy for handling delivery requests;
- fleet management, scheduling and routing;

while the underlying process will result in the final delivery demand characterized by its spatial and temporal distributions and the nature and the physical parameters of the delivered packages.

Depending on the decision problem considered, different representations of the logistics urban space are more suitable to contribute to its solution. The logistics urban space can be considered to consist of the space in which is performed transport, the urban transport space, and the space where demand is located, the urban demand space. Of course, both spaces have the same geographical references and are closely connected. Discrete or continuous representations can be adopted to represent the urban transport space and the urban demand space. For example, a 2D graph representation can be based on the grids of streets and lanes in the city through its ground circulation plan to display the transit opportunities for ground delivery vehicles, while a 3D graph representation can be adopted for a structured airspace [8]. The period of operations can be taken either as a continuum or as a succession of discrete time periods associated with different demand and traffic patterns.

Based on discrete representations of space and time, problems such as scheduling and routing of deliveries either by ground or air, where the operations costs have to be minimized while satisfying a known demand, can be tackled using an already existing vast literature in the field of Operations Research about the variants of the vehicle routing problem [9], [10] and [11]. However, whenUAVs have to be considered in the delivery fleet, numerical complexity issues will arise unless the logistics urban space is divided someway in subareas. Observe that in general, these approaches complexified by time windows deliveries and capacity constraints do not really consider the environmental issues.

Here it is assumed that the logistics center location is already in an acceptable location and that additional areas for UAVs operations are available close to the warehouse of the logistics center. The location of the logistics centers is in general chosen to be at the same time close to the delivery area and easily accessible for the wholesale supply chains. All this makes that the logistics centers associated with the last mile delivery are very often located on the outskirts of urban areas.

Two types of last mile delivery vehicles are considered: ground vehicles and UAVs. They are characterized by their respective payload volume and weight capacity, by their nominal speed and by their operating costs (travel cost per unit of distance and remit cost) and their loading and unloading times.

When considering the demand for products which are stored in the logistics center, it is assumed that this demand is spread stochastically over the considered urban space and during different periods of the day. Part of this demand is known beforehand due to its periodicity or its prior request, it is called here *planned demand*. Another part of the demand appears online and has a stochastic nature, it is called here *unplanned demand*. The planned and unplanned demands have common parameters: the location for delivery, the volume and weight of the package to be delivered, but the performance indexes are different. In the case of planned demand, it is supposed that delivery must be realized within a given large time window by minimizing delivery costs, while in the case of unplanned demand, delivery must be performed as soon as possible after the delivery request.

It is supposed that parcels with a volume greater than V_{max} or with a weight greater than M_{max} will be delivered on the next day by ground transportation as a planned demand, while smaller or lighter parcels can be delivered either by ground transportation or by UAVs. Observe also that smaller or lighter parcels which are part of the planned demand but are difficult to be reached by ground vehicles or whose introduction into a planned delivery route turns out to be too costly, may be added online to the unplanned request log at a time when UAVs should be available. Then, to improve the effectiveness of the LMD system, it appears of interest to have an intelligent dispatcher system that can classify online any new request in terms of planned or unplanned, light or heavy, big or small.

4. Ground last mile delivery for planned demand.

With respect to planned demand, an empirical formula [12] based on the BHH theorem [13], can be used to approximate the mean distance to be travelled to serve N points uniformly distributed in a square area A (in square meters) from and outside depot positioned at a distance l of the center of the area (see Figure 1). This formula supposes that the delivery tours minimize travel distances.

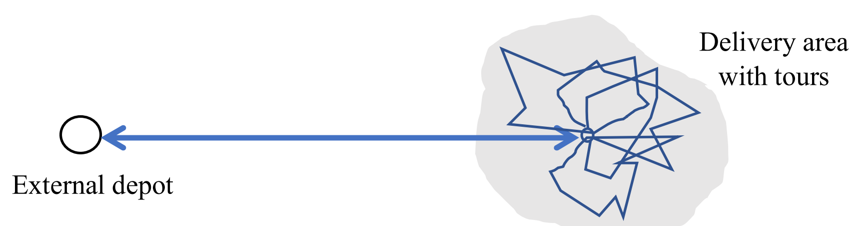

Figure 1. Organization of ground delivery for planned demand

$$L_N = 2\, l \cdot N/C + \rho \cdot N \cdot \sqrt{A}\left(\left(\frac{1}{C}\right) + \left(\frac{1}{\sqrt{N}}\right)\right) \quad (1)$$

where ρ is a shape parameter of the distribution area and C is the capacity of the ground vehicles (equal to the maximum number of standard parcels the vehicle is able to deliver in a single tour). It is supposed that $N \gg C$. This formula has been used to optimize the shape of delivery sub-areas in the urban space [14].

Let V_O and V_I be respectively the medium speed adopted to reach the delivery area from the warehouse and the medium speed used during delivery. Then, the mean duration to serve N delivery points is given by:

$$d_N = 2l \cdot \frac{N}{C \cdot V_O} + \rho \cdot N \cdot \sqrt{A}\left(\left(\frac{1}{C}\right) + \left(\frac{1}{\sqrt{N}}\right)\right)/V_I \quad (2)$$

which is an increasing function of N.

Let T be the daily operations time, then the mean number of delivery points which can be treated by a vehicle of capacity C is such that:

$$N(T) = \alpha(A, l, C, V_O, V_I) + \beta(A, l, C, V_O, V_I) \cdot T - \alpha(A, l, C, V_O, V_I)\sqrt{(1 + \gamma \cdot T)} \quad (3)$$

with

$$\alpha(A, l, C, V_O, V_I) = C^2 \frac{\rho^2 A}{2 \cdot \left(\rho\sqrt{A} + 2l/(\frac{V_O}{V_I})\right)^2} \quad (4.1)$$

$$\beta(A, l, C, V_O, V_I) = \frac{C \cdot V_I}{\left(\rho\sqrt{A} + 2l/(\frac{V_O}{V_I})\right)} \quad (4.2)$$

$$\gamma(A, l, C, V_O, V_I) = \frac{V_I}{C \cdot \rho^2 \cdot A}\left(\rho\sqrt{A} + 2l/(\frac{V_O}{V_I})\right) \quad (4.3)$$

Then the size of the fleet necessary to perform the ground delivery is given by:

$$F_G(T) = N_T / N(T) \quad (5)$$

where N_T is the total demand considered during the T period. Then the number of delivery operations is approximated by:

$$N_T/C \quad (6)$$

The estimated total distance traveled at speed V_O is given by:

$$F_G(T) \cdot 2\, l \cdot (N/C) \quad (7)$$

while the estimated total distance traveled at speed V_I is given by:

$$F_G(T) \cdot \rho \cdot N \cdot \sqrt{A}\left(\left(\frac{1}{C}\right) + (\frac{1}{\sqrt{N}})\right) \quad (8)$$

Assuming that the ground vehicles leave the depot at full load C, the total distance travelled in this condition is $F_G(T) \cdot l \cdot (N/C)$, the same distance will be travelled empty. Also, it can be considered that along a delivery tour, the vehicle is unloaded progressively.

All these elements allow not only to estimate global delivery costs for the logistics company but also to estimate the environmental impact resulting from the energy used for delivery and from the emissions in the case of non-electrical vehicles.

5. UAVs last mile delivery for unplanned demand

With respect to unplanned demand, it is supposed that each request is attended using UAVs in a round trip basis from a depot. Available statistics about unplanned demand should be used to size the warehouse or the local production unit of the depot, which can be supplied periodically by large capacity ground vehicles. Then, to diminish the distance covered by the UAVs, this depot can be placed inside the urban area to be covered by the delivery service (see Figure 2).

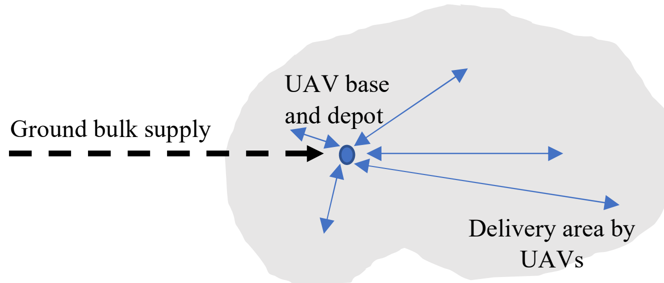

Figure 2. Organization of delivery for unplanned demand

Here a simplistic stochastic model is adopted to represent demand and delivery service so that analytical results can be obtained with respect to the performance of the UAV based delivery system.

It is supposed that requests for delivery are generated by a stochastic process and that once a request appears, an UAV is sent as soon as possible to the request location. It is also supposed that demand is distributed in the urban area according to another stochastic process. Here is considered the case in which requests for delivery follow a Poisson process of rate λ while the time to reach the request location follows an exponential distribution of parameter μ. The Poisson assumption for requests timing is a classical one and can be adopted for different periods of time where the flow of requests remains almost constant. Other stochastic models could have been adopted, however, for the sake of simplicity, the above hypothesis have been adopted, leading to analytical developments even if complex formulas have to be considered. The assumption of an exponential distribution with respect to demand can correspond to the case in which the depot is located centrally in the considered urban area. Considering a fleet of f UAVs used to treat on-line the requests, the adopted assumptions configure a queuing system of the class *M*/*M*/*f* with some peculiarities.

In this case, once a request has been treated, i.e. a parcel has been delivered by a UAV to a customer, this UAV will have to return to the depot to be available for the treatment of a new request. Considering that the customer starts to be served when the UAVs leaves the depot to deliver his parcel, μ can be defined as:

$$\frac{1}{\mu} = 2 \cdot \delta / V_I \qquad (9)$$

where V_I is the mean speed adopted by the UAVs during their operation and where δ is the mean distance to the depot. Here the loading and unloading times of the drone are assumed to be very small compared to the duration of the journey and are not taken into account.
If $f > \lambda/\mu$ it can be considered that the delivery process reaches a probabilistic stationary state. The mean waiting time to be served (in the queue) is given by [15]:

$$W_q = \pi_0 \frac{\rho\,(f \cdot \rho)^f}{\lambda \cdot (1-\rho)^2 \cdot f!} \qquad (10)$$

where ρ is the utilization level and π_0 is the probability that no client is waiting for the assignment of a UAV to his request. They are given by:

$$\rho = \frac{\lambda}{f \cdot \mu} \quad \text{and} \quad \pi_0 = 1/\left(\sum_{k=0}^{f-1} \frac{(\frac{\lambda}{\mu})^k}{k!} + \frac{(\frac{\lambda}{\mu})^f}{f!} \frac{1}{1-(\lambda/f\mu)}\right) \qquad (11)$$

The average response time for a customer to receive his parcel is given by:

$$T_U = \frac{1}{2\mu} + \pi_0 \frac{\rho\,(f \cdot \rho)^f}{\lambda \cdot (1-\rho)^2 \cdot f!} \qquad (12)$$

The probability for a client to wait more than t to get a parcel is given by:

$$P(W > t) = e^{-\mu t}\left(1 + \frac{\pi_0 \cdot (\frac{\lambda}{\mu})^f}{f!(1-\rho)} \cdot \frac{1-e^{-\mu\ (f-1-\lambda/\mu}}{f-1-\lambda/\mu}\right) \quad (13)$$

These two last indexes can be used to choose the size of the fleet according to a level of service given by a value of T_U or by a value p such that:

$$P(W > t_{max}) < p\ , \qquad p \in]0,1[\quad (14)$$

where t_{max} is a guaranteed delivery time.

It can be also shown that T_U and $P(W > t_{max})$ are decreasing functions of f and V_I so that ways to reduce the average response time or the probability of a timeout, is either to increase the size of the UAV fleet or to increase the flying speed of the UAVs.

The mean total distance d_U travelled at speed V_I by the UAVs during a period Δt is given by the formula:

$$d_U = 2\delta\,\mu \cdot \left(\sum_{n=0}^{f-1} n \cdot P_n + f\sum_{n=f}^{+\infty} P_n\right) \cdot \Delta t \quad (15)$$

where P_n, the probability of having n requests is given by the classical formula of *M/M/f*:

$$P_n = \begin{cases} \pi_0 \cdot \left(\frac{\lambda}{\mu}\right)^n /n! & for\ 0 \le n < f \\ \pi_0 \cdot \left(\frac{\lambda}{\mu}\right)^n /(f! \cdot f^{n-f} & for\ n \ge f \end{cases} \quad (16)$$

Observe that when f is very large, d_U tends to $2\delta\cdot\lambda\cdot\Delta t$ which corresponds to the situation in which no request is left over on the considered period of time.

6. Conclusion

This paper has focused on the development of a methodology to design last mile logistics based on a hybrid solution composed of ground vehicles addressing the planned demand and on UAVs dedicated to the unplanned demand.

The ground LMD routing and scheduling activities have been considered globally using an empirical formula relating the operation of a minimum cost route in a dense urban area to the average distance needed to serve a customer, while the UAV LMD activity has been analyzed globally using a stochastic model.

In both cases, the generated traffic has been estimated and performance indexes related to the quality of service and the environmental impact have been produced. In the case of planned demand, the delivery must be realized within a wide given time window by minimizing delivery costs, while in the case of unplanned demand, the delivery must be performed as soon as possible after the delivery request.

At this stage, it appears of interest in order to guarantee the effectiveness of the proposed hybrid solution, to design an intelligent dispatcher system that can classify online any new request in terms of planned or unplanned demand , light or heavy, small or big...

Finally, it is expected that, as the performances of UAVs in terms of safety, range and payload will improve and they will occupy a growing LMD market share.

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