


Article

Optimization of the Distribution Network Using an Emerging Technology

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Abstract: Unmanned Aerial Vehicles (UAVs) are a technology that has recently been incorporated in the distribution of products, which in this study, are packages. It can improve the distribution system in environments where there is significant traffic congestion. Furthermore, UAV can help to deliver small packages between warehouses, by using them as an alternative means of distribution. The incursion is of an emerging technology, in this case the use of drones, for a new delivery system in order to improve a university distribution system, in the view of the fact that in recent years, companies have focused on the use of logistics operations for the improvement of productivity and delivery times. The study presents a mathematical model, based on the Problem of the Traveling Salesman (TSP) for the planning of a route to increase the efficiency in the distribution process at Ciudad Universitaria, an Universidad Autónoma de Nuevo León (UANL) campus that contemplates the use of the emerging technology of UAVs, and the traditional method of using trucks. The model considers restrictions on the use of drones, such as the limitation of travel times and maximum distance.

Keywords: TSP; UAVs delivery; optimization; logistic

1. Introduction

The use of emerging technologies is becoming increasingly frequent in the supply chain because they provide flexibility in processes, achieving a reduction in time, cost and degree of complexity.

A technology that provides logistical advantages involves drones, which are a delivery alternative due to the growth of demand by electronic commerce, where important parcel delivery companies and other commercial sectors have carried out tests to deliver packages with drones, This is because this technology offers less travel time and lower operating costs compared to trucks, and drones have the advantage that they enable fast and direct delivery from the depot to a customer regardless of the traffic conditions [1].

Useful drone functions include delivery of urgent small items and timely delivery, for example, of urgently needed medications such as blood and vaccines. However, locations needing the delivery may have difficult access due to poor transportation infrastructure, or roads blocked by severe weather, disasters or traffic congestion. Since a drone can fly over an inaccessible road, innovative organizations have begun to use drones for healthcare delivery [2].

UAVs bring different benefits to logistic transportation such as avoiding the congestion of traditional road networks by flying over them, higher speeds than trucks, and lower transportation costs per km [3]. The UAVs are less expensive to maintain than traditional delivery vehicles, such as trucks, and can lower labor costs by performing tasks autonomously. Delivering with drones may

be faster than delivering with traditional delivery vehicles, as drones are not limited by established infrastructures such as roads, and generally face less complex obstacle avoidance scenarios [4].

The use of automated UAVs to deliver commercial packages is poised to become a new industry, significantly shifting energy use in the freight sector. If carefully deployed, drone-based delivery could reduce greenhouse gas emissions and energy use in the freight sector [5].

UAV-assisted delivery systems are a reality in the e-commerce business; some recent examples are Google’s “Project Wing” that tested these vehicles as part of a food delivery system at Virginia Tech [6].

UAVs for logistics may be applied for specific delivery tasks that imply urgency, physical inaccessibility or various types of perils humans may be subjected to if delivering goods [7].

Some advantages of implementing drones identified by Cambell and others [8] are the following:

- Truck–drone hybrid delivery has the potential to provide substantial cost savings, especially in suburban areas.
- Incorporating multiple drones per truck offers important but marginally decreasing savings that can be large.
- Measures of savings per delivery and savings intensity per square mile provide complementary perspectives that highlight the conditions and regions likely to generate the greatest savings.
- The benefits from truck–drone delivery depend strongly on the relative operating costs per mile for trucks and drones, the relative stop costs for trucks and drones, and the spatial density of customers.

The use of drones can significantly reduce the traffic-based uncertainty of the shipping process, providing a faster and more reliable service. Both these characteristics increase the probability that customers are home when the shipment is delivered, which, at the same time, helps reducing pollution emissions [9]. UAVs have potential for fast and low cost delivery for short distances, and alternatives for an area of poor transportation infrastructure such as small places [10].

Companies are looking for the best profitable distribution methods for their products in the logistical networks [11]. An alternative of distribution between drones and trucks to improve the delivery companies supply chain has been proposed.

The highest logistics cost is the distribution process with 50.3%, therefore, companies should consider using new modes of transport to improve logistics efficiency [12].

In Figure 1, we show how these technologies participate in the supply chain; UAVs can perform in various processes. UAVs help to count products in the warehouse, to monitor work and are also used for the collection of products that must be returned to the production center. UAVs have a greater influence in the distribution due to their unique characteristics, which are delivering quickly, safely, and autonomously. Furthermore, these vehicles pollute less than trucks and represent a cost saving, therefore, service companies are considering them for their distribution to improve their service.

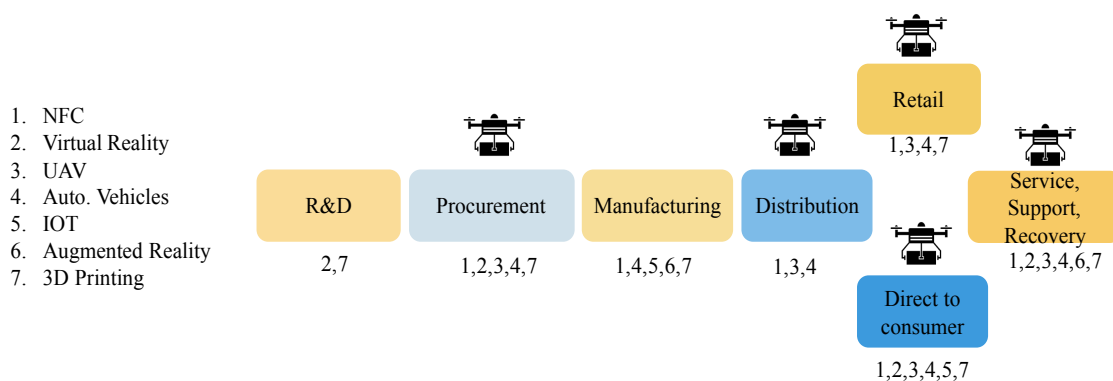


Figure 1. Emerging technologies. throughout the supply chain. Source: based on [13].

UAVs provide preferable means to deliver packages in e-commerce businesses. These allow to quickly reach predefined and specific destinations without the need for great human support to improve the customer experience [14,15].

UAV delivery is an innovative issue in the logistics environment because it is considered an alternative for package delivery companies, such as DHL, Amazon, SF Express, UPS, and Jingdong, which have used them to improve their services.

Zipline, a company based in the United States, focuses on the creation of medical devices and has incorporated the use of UAVs, making it one of the most important companies in the world for the transport of medicines and blood products. In 2016, the company began transporting blood and platelets to the Kabgayi hospital in Rwanda; to date, they have delivered more than 2600 units of blood to 12 points in Rwanda health centers that perform more than 1400 flight appointments rosemary.

Another well-known case is Amazon, an American company dedicated to electronic commerce, which believes that using drones will allow savings in delivering services through its prototype Prime Air. The company's drones can fly up to 15 miles with a maximum speed of 50 miles per hour and carry packages weighing less than 2.27 kg. Amazon claims that 86% percent of their items can be delivered by drones [16].

Zookal is a company that rents out textbooks to students and links with the company Flirtey, to deliver packages directly to customers, where customers receive a phone to track the product through GPS and then receive the package in one place outdoors. As a result, there was the decrease in waiting times from two to three days to just two or three minutes [17].

Furthermore, another case is Dominos New Zealand that has made deliveries of pizza using an unmanned aircraft, which flies from 30 km per hour to 1.5 km per hour, increasing delivery speed and taking orders up to 2.5 kg [18].

In 2016, Czech online Mall operating in Poland, Slovakia, Hungary, Slovenia, and Croatia, reported the success of a pilot program using drones. The pilot program consisted of transporting the package at a distance of 2 km and was the first such operation in Central and Eastern Europe. [19]. The authors commented that the operation worked with the staff of the Center for Artificial Intelligence at the Faculty of Electrical Engineering of the Czech Technical University in Prague; the important thing to emphasize is that the drone can transport packages of units of up to 2 kg for a distance maximum of 60 km.

The examples explained have something in common, because all the tests were carried out in countries where there are no regulations that prohibit the use of drones; in the case of Mexico, the agency responsible for the use of drones is the "Dirección General de Aeronáutica Civil" (DGAC).

Currently, the use of UAVs is included in the business models for e-commerce companies by including new modes of transport according to industry 4.0, considering that emerging innovations are focused on the last mile [20].

Cohn and others [21] consider that drones will be implemented within five to ten years in the distribution process, therefore, a mathematical model is proposed that plans an optimal distribution route between drones and trucks to create a better service delivery.

UAVs do not need a road network to deliver packages and their use is cheaper than conventional methods (trucks); this technology makes a straight route, allowing faster delivery. To improve the routes we rely on the literature to give a proposal that can reduce the cost of delivery using emerging technology.

Reducing the cost or the time of delivery systems is always a logistical challenge; therefore, an effective delivery path is essential. Although several works have already attempted to solve the drone-based routing problem, in this study, we propose a mathematical model that considers an optimal route using two types of transport, UAV and traditional, to efficiently improve the delivery services.

Inspired by this delivery approach, Yoon [22] presented a TSP model with multiple drones, in which he found improvements in operating costs considering this model for the planning of routes.

In the present article, it was focused on a TSP that considers multiple drones, giving the functionality to choose the vehicle, UAVs or trucks, to send the product to faculty.

Emerging technology is studied in the distribution process because they can offer better routing than traditional modes, being even more efficient from the logistic point of view and considering as a package delivery alternative in the distribution, where they are more functional.

In the following section, the routing problems of vehicles with Unmanned Aerial Systems (UAS) are detailed, highlighting the use of drones in logistics problems where they have been based on mathematical models to optimize delivery routes.

The contributions of the article are the following:

- Mixed routing independently between UAVs and trucks to improve transport optimization in the delivery of packages in an internal logistics.
- Proposal of a mathematical model that contemplates the use of emerging technology for package delivery.

2. Literature Review

The literature review focused on mathematical models that considered unmanned aerial systems, in this case, combined with the traditional delivery approach. It can be seen that the most common are the Vehicle Routing Problem (VRP) and Travelling Salesman Problem (TSP) for Unmanned Aerial Systems.

The authors emphasize that the classic VRP configurations according to the characteristics of the UAVs are functional with this mode of transport; it should be noted that this mathematical model focuses only on the use of UAVs, therefore, it is very different from the mixed model that is proposed in this investigation.

Wang et al. [23] presented a VRP, objective to minimize the maximum 130 duration of routes. The variant of the VRP that they used was the delivery and collection (VRPD); they consider that the use of drones and trucks would be a common practice, therefore, companies from the United States and Europe consider this alternative. The study presents various theorems where each one contemplates the savings that organizations can obtain by implementing this technology.

Poinoken et al. [24] presented a VRP model based on the VRPD variant. The objective of this study was to expand and strengthen the previous results in its article emphasizing the importance of drones in industries such as Amazon, Google, DHL, and Walmart. They demonstrate the maximum benefit of the model presented in ideal circumstances, taking into account a series of UAVs with a speed greater than that of a truck, presenting important practical advantages. The authors claim that the UAV returns to the top to recharge the battery quickly; its main objective is to minimize delivery times in the last mile.

Pugliese and Guerreiro [25] used the Vehicle Routing Problem (VRP) with windows of time contemplating the delivery of packages between drones and trucks, concluding that this new modality gives competitive advantages to companies, and the benefit of the use of UAV is relevant. These time window restrictions are useful for the mathematical formulation that is proposed in this study; the important thing is the consideration of time windows for customer service and other jobs do not add them and propose an exact model.

Dayarian et al. [26] have a new way to further exploit this technology in delivery systems. They propose that drones can supply delivery trucks in the last mile using a VRP and algorithms found the advantages of saving costs and travel faster than vehicles since they are not limited the road network and traffic congestion.

The work by Murray and Chu [27] is the first study that introduces TSP-D, the Flying Sidekick Traveling Salesman Problem (FSTSP) which provides one solution by allowing delivery trucks to deploy UAVs. It is based on a route first-cluster; they improved delivery times using drones in the truck route using a heuristic for their solution. Delivery times improved as trucks were included and drones were integrated to improve deliveries, but they did not contemplate the time windows.

Ponza [28] used simulated solutions for the model, where the results were favorable for the FSTSP since he considered that it may be more practical in the real world because the use of drones allows a considerable amount of time to travel through a set of nodes. This is viable to improve and optimize the delivery of packages.

Mourelo and others [29] used the TSP model; in comparison to other articles mentioned, they proposed an optimization algorithm to determine the optimum number of launch sites and locations that have delivery requirements with drones and trucks. They reduced delivery times and determined that this technology outperforms trucks in energy efficiencies when they are delivered to one hundred customers in a delivery distance of 100 km. Their method presents a TSP with several drones, which explains that there is an average of 30% savings in realistic scenarios if a UAV is used, but in the worst case, a 4% improvement and in the best case a 55% improvement; this study showed that there are time restrictions to create a synchronization between the UAV and the truck [22].

In the literature review, it is mentioned that in the future, this technology can have a great impact because of large companies that test drone delivery; these articles comment that the use of drone trucks will greatly favor the delivery of packages between branches and customers.

Although the TSP or VRP are used for routes, the UAV specifications should be considered in the restrictions and parameters. It was important to analyze the distance, speed, battery life and weight that drones can send. The papers mention optimization models and different solution methods.

The difference between all the analyzed articles is that the mathematical model that we proposed considers the independent use of UAVs and the trucks to deliver packages, this is because we wanted to observe the advantages of delivering with this technology and experiment with the data collected to analyze the results. This approach is considered for internal deliveries.

When reviewing each article, the use of drone-adapted TSP variants was considered, because it was found that according to the literature it is the best option, and this provides great help for the contribution of this research; therefore, this is a functional method to achieve the purpose of the project.

The proposed mathematical model to solve the problem is described below.

3. Mathematical Model

This section presents a mathematical model called the Travelling Salesman Problem with Multiple Drones (TSP-MD) based on delivery with heterogeneous transport (truck and drones).

The model minimizes the cost per travel based on time, achieving a route that takes into account multiple UAVs.

The assumptions that were used for the operation of the mathematical model are presented in Section 3.1.

3.1. Assumptions

- UAVs are limited to flight time and distance.
- The demand for the products is randomly for experimentation.
- The costs of each transport mode are very different and are categorized differently.
- The products have different weights.
- Drones are capable of operating to all customers; the load capacity and maximum distance are very different in each of the drones.
- There are very heavy products that cannot be sent by UAV.
- Drones are autonomous (no operating costs are required) and a required distance from an operator is not necessary.
- The times and distance traveled by UAVs are different from those of the truck.

The sets of the mathematical model are presented in Section 3.2, and are the elements considered for the problem.

3.2. Sets

- I : set of package type $I \in I$
- L : set of vehicle type, $l \in L$
- K : set of customer types, $k \in K$

The parameters presented in Section 3.3, are all used to incorporate into the mathematical model.

3.3. Parameters

- p_i : weight of product types i .
- d_{ik} : demand for the type of product i to customers k .
- a_{jkl} : distance from the distribution center j to the customer k in the vehicle l .
- $dist_l$: maximum allowed distance of UAVs $l \{l_2 \dots l_5\}$.
- b_l : vehicle capacity l .
- tt_{jkl} : travel time of distribution center j to each arc of customers k in the transportation l .
- t_l : maximum flight time for UAVs $l \{l_2 \dots l_5\}$.
- tc_{jkl} : travel time for each arc of the distribution center j to the customer k in the truck $l \{l_1\}$.
- td_{jkl} : travel time for each arc of the distribution center j to the customer k in the UAVs $l \{l_2 \dots l_5\}$.
- s_j : service time for each customer j .
- uu_j : customer service start time j .
- v_j customer service closing time j .
- c_l : cost for drone electricity $\{l_2 \dots l_5\}$.
- cc_l : cost for truck labor $l \{l_1\}$.
- f_l : fixed transportation cost l .
- M : It is big number.

The variables in Section 3.4 represent the value sought in the model.

3.4. Variables

- w_{ijkl} : number of packages i that will move from j to k in the vehicle l .
- u_{kl} : order of customer visit k in the vehicle l .
- r_{jl} : start of customer service hours j in the vehicle l .

$$x_{jkl} = \begin{cases} 1, & \text{if you move a package } i \text{ from } j \text{ to } k \text{ in the vehicle } l. \\ 0, & \text{otherwise.} \end{cases}$$

$$y_l = \begin{cases} 1, & \text{if the vehicle is assigned } l. \\ 0, & \text{otherwise.} \end{cases}$$

The MILP formulation is as follow:

$$\min \sum_{j \in J} \sum_{k \in K} \sum_{l=1} c_l tc_{jkl} x_{ijl} + \sum_{j \in J} \sum_{k \in K} \sum_{l \in L - \{l_1\}} c_l td_{jkl} x_{ijl} + \sum_{l \in L} f_l y_l \tag{1}$$

The objective function (1) minimizes the cost per route of each vehicle.

$$\sum_{j \in J} \sum_{l \in L} w_{ijkl} \geq d_{ik} \quad \forall i, \forall k \tag{2}$$

The restriction (2) guarantees customer demand.

$$\sum_{i \in I} \sum_{j \in J} \sum_{k \in K} w_{ijkl} p_i \leq b_l \quad \forall l \quad (3)$$

The restriction (3) ensures that the capacity of the vehicles is not exceeded.

$$\sum_{i \in I} \sum_{j \in J} \sum_{k \in K} w_{ijkl} \leq M_l y_l \quad \forall l \quad (4)$$

Indicates (4) that if a product is not shipped, the assigned vehicle is not used.

$$\sum_{i \in I} w_{ijkl} \leq M_2 x_{jkl} \quad \forall j, \forall k, \forall l \quad (5)$$

Indicates (5) whether the vehicle is used for the route when sending a product, for the use of drones.

$$\sum_{j \in J} \sum_{k \in K} x_{jkl} t_{jkl} \leq t_l \quad \forall l \in L - \{1\} \quad (6)$$

The Equation (6) was used to ensure that the maximum flight time of UAVs is not exceeded, in the same way.

$$\sum_{j \in J} \sum_{k \in K} x_{jkl} a_{jkl} \leq dist_l \quad \forall l \in L - \{1\} \quad (7)$$

The Equation (7) ensures that the maximum flight distance is not exceeded.

$$\sum_{j \in J} \sum_{k \in K} x_{jkl} \leq y_l \quad \forall l \quad (8)$$

If a product is shipped, then the assigned vehicle is used 8.

$$u_{jl} - u_{kl} + \|K\| x_{jkl} \leq \|K\| - 1 \quad \forall j, \forall k, \forall l \quad (9)$$

The Equation (9) eliminate sub-tours

$$\sum_{j \in J} x_{jkl} \leq 1 \quad \forall k, \forall l \quad (10)$$

$$\sum_{k \in K} x_{jkl} \leq 1 \quad \forall j, \forall l \quad (11)$$

The Equations (10) and (11) ensure that each of the transports can enter and exit once at each node

$$\sum_{k \in K} x_{kjl} = \sum_{k \in K} x_{jkl} \quad \forall j, \forall l \quad (12)$$

The Equation (12) indicates the flow conservation.

$$r_{jl} + s_j + t_{jkl} - r_{kl} \leq (1 - x_{jkl}) M_l \quad \forall j, \forall k, \forall l \quad (13)$$

$$r_{jl} \geq u u_j \sum_{k \in K} x_{jkl} \quad \forall j, \forall l \quad (14)$$

$$r_{jl} \leq v_j - s_j \sum_{k \in K} x_{jkl} \quad \forall j, \forall l \quad (15)$$

The Equations (13)–(15) guarantees the viability of the sequence for time conditions.

$$w_{ijkl}, u_{jl}, r_{kl} \geq 0 \quad \forall i, \forall j, \forall k, \forall l \quad (16)$$

$$y_l, x_{jkl} \in \{0, 1\} \quad \forall j, \forall k, \forall l \quad (17)$$

The definitions of decision variables are provided (16) and (17).

M_1 and M_2 are big numbers, therefore:

$$M_1 = \min\{b_l, d_{ik}\}$$

$$M_2 = \max\{w_{ijkl}\}$$

The following section explains the case study and the generation of the scenarios and instances for the experiments.

4. Experiment and Results

In this section, we describe a case study where the mathematical model was used and the results obtained in the different scenarios.

The university has 11 faculties; each faculty has a warehouse; if a department needs a product, generally it goes to the central warehouse of the university. Currently, the distribution is manual; for the experiments, 29 departments are also considered, considering a total of 40 delivery points on campus and clients were classified into five instances, the low number of clients was considered as 4, 8 and 12 clients; the average number of clients was 20 and the high number of clients between 30 and 40.

The results were obtained from the mathematical model; therefore, no real deliveries were made. Table 1 shows the UAVs and truck for experimentation. These data were used in the model, the four types of UAVs have different characteristics but all are autonomous UAVs.

Table 1. Transport modes. Source: based on [30].

| | Transportation | Maximum Load | MáXimum Distance |
|-------|----------------|--------------|------------------|
| UAVs | Matternet M2 | 2 kg | 20 km |
| | Amazon dron | 2.3 kg | 16 km |
| | Geodrone | 3 kg | 20 km |
| | Jingdong dron | 15 kg | 25 km |
| Truck | Renault Kangoo | 750 kg | - |

The Universidad Autónoma de Nuevo León (UANL) uses 120 types of products for satisfying each faculty and department; 95% of these products are small products, 3.3% are medium products and the rest are big products; in this case, we used a random demand.

In Section 1, it was mentioned that Amazon considers that 86% of its products can be sent by drones; according to the packages that are in the UANL, this percentage is similar to the Amazon company emphasizing that most of the packages are fit for this technology.

The model was executed in different approaches, to determine its feasibility in the distribution process with the incursion of the UAV with the traditional method. The experiments were performed in a CPLEX GAMS computer package with version 25.1.3 on a Mac Air with an Intel Core i5 1.4 GHz processor and a 4 GB memory.

In Figure 2, the three approaches that were handled in the experiments are shown according to the allocation of the vehicles to satisfy each client; in this case, they are faculties and departments of the UANL.

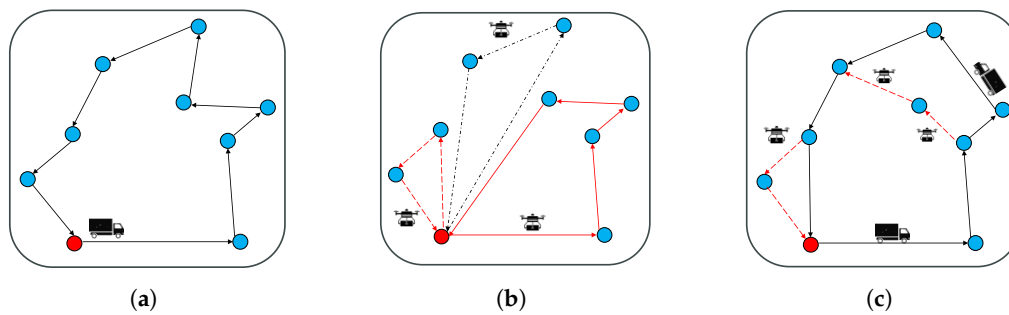


Figure 2. Modes of distribution in parcel delivery. (a) The traditional approach. (b) The modern approach. (c) The mixed modern approach.

The first approach (Figure 2a) is the traditional approach in which a delivery truck visits all customers, but a second scenario (Figure 2b) can be observed taking into account an emerging technology. This is known as a modern approach, where delivery UAVs visit all customers and, finally, you can have a combination called a mixed modern approach Figure 2c, where UAVs and delivery trucks visit all customers.

We analyzed the route cost of the traditional approach (only truck) with the modern approach and the mixed approach. We also compares the routes of these approaches and how they impact the use of UAVs when used with the truck.

For the case study, seven scenarios were considered according to the sizes of the packages described in Table 2; each client instance was executed 12 times using the three approaches to determine the savings.

Table 2. Package Category.

| Scenarios | Size Packages | | |
|------------|---------------|--------|-----|
| | Small | Medium | Big |
| Scenario 1 | | | |
| Scenario 2 | | | |
| Scenario 3 | | | |
| Scenario 4 | | | |
| Scenario 5 | | | |
| Scenario 6 | | | |
| Scenario 7 | | | |

Figure 3 shows the result of a rout emphasizing the difference between the traditional approach and the modern approach. In the figure, we can see that the first route needs to use the road and

in the second, the drones make a star type route to deliver the packages, while the last approach is much better.

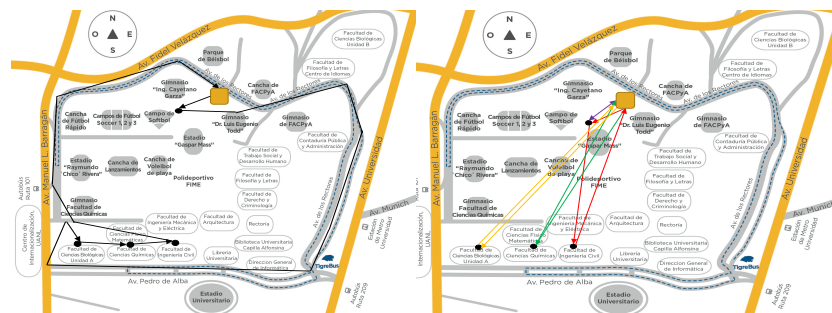


Figure 3. Traditional approach vs modern approach.

In scenario 1, the difference of a drone route and a truck route were observed, which are very different; the trajectory cost was much lower than the traditional cost.

The routes generated by each case give us a perspective that a drone can arrive faster than a truck and that it is more flexible when delivering packages since these vehicles do not need roads, such as trucks; drones can go in a straight line and there is no obstacle along the way.

The results of the study are presented in the following Table 3. Scenario 1 presents the greatest savings in comparison to the other scenarios because this scenario considers small packages; it should be noted that all these packages can be sent by drone. It is also observed that there is a maximum saving and a minimum saving, this changes depending on the number of customers, due to the demands generated by each of the clients.

Table 3. Scenario comparison (drone routing).

| Scenarios | 4 Customers | | | 8 Customers | | | 12 Customers | | | 20 Customers | | | 30 Customers | | | 40 Customers | | | Total Saving |
|------------|-------------|-----|-----|-------------|-----|-----|--------------|-----|-----|--------------|-----|-----|--------------|------|------|--------------|------|-----|--------------|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | |
| Scenario 1 | 36% | 61% | 93% | 21% | 43% | 98% | 10% | 32% | 97% | 2% | 16% | 34% | 9% | 12% | 21% | 2% | 13% | 26% | 30% |
| Scenario 2 | 38% | 47% | 63% | 11% | 22% | 34% | 0.7% | 6% | 13% | 0.5% | 5% | 11% | 0.09% | 1% | 2% | 0.6% | 1% | 2% | 13% |
| Scenario 3 | 17% | 20% | 22% | 0% | 9% | 12% | 0.4% | 2% | 10% | 0.01% | 1% | 4% | 0% | 0.2% | 0.5% | 0% | 0% | 0% | 5% |
| Scenario 4 | 18% | 28% | 56% | 11% | 23% | 36% | 0.3% | 10% | 22% | 0.01% | 6% | 24% | 2% | 6% | 11% | 5% | 11% | 17% | 14% |
| Scenario 5 | 18% | 24% | 39% | 9% | 16% | 22% | 0.7% | 8% | 13% | 0.3% | 2% | 4% | 0.2% | 0.9% | 2% | 0.2% | 0.7% | 1% | 9% |
| Scenario 6 | 18% | 32% | 57% | 13% | 22% | 25% | 12% | 20% | 32% | 0.03% | 9% | 14% | 2% | 7% | 17% | 1% | 9% | 25% | 16% |
| Scenario 7 | 18% | 20% | 22% | 10% | 21% | 32% | 11% | 14% | 25% | 1% | 9% | 11% | 0.3% | 4% | 10% | 1% | 8% | 12% | 12% |

Therefore, in this study, an average saving percentage of 30% was found; it was convenient to perform tests with different customer sizes, and it can be indicated that it is a considerable percentage when taking into account the participation of these packages in the University.

Scenario 2 presents a saving of 13% which is the fourth best scenario of those evaluated; this percentage is because they are medium products which can be sent by drones although only one drone is qualified to fulfill the deliveries with these packages.

In scenario 3, we observed how the percentage of savings is determined; with an average fuel savings of 5% only one product can be sent with this technology; this is as an example that the smaller the packages are the more the percentage of saving.

In scenario 4, all package sizes were contemplated where small packages were sent regularly with drones to delivery points; the savings represent almost half that obtained from the first scenario with 14% being the third best scenario.

Scenario 5 includes only medium and big products, which resulted in a saving of 9%, and is one of the scenarios where there were little savings due to the size of the packages.

Scenario 6 obtained an average saving of 16% which the second best of savings due to the large products that were sent by truck and allowing small products that were sent by drones; in this scenario, it was verified that mixed delivery is a good option. In scenario 7, a saving of 12% was obtained; this was because there were more medium packages than large products. It was verified that considering this scenario, good savings can be obtained by using drones for deliveries.

The savings results of each scenario are shown in Figure 4. In scenario 1, analyzing the instances with few clients (4, 8 and 12 clients) presents average savings from 32% to 61%; when adding more delivery points, the percentage tends to decrease in the majority of times; when considering 20 clients, the average savings percentage decreases to 16%. It was observed that when taking into account high customer quantities (30 and 40 customers) the trend is between a saving of 12 % and 13% with small packages.

In the first instances of customers, scenario 1 obtained average savings of more than 30%, and the other instances were reduced by half of these savings; the advantage of this scenario is that drones are able to ship any product, and we verified that the use of drones is cheaper than the traditional approach and one can have logistic advantages in package delivery.

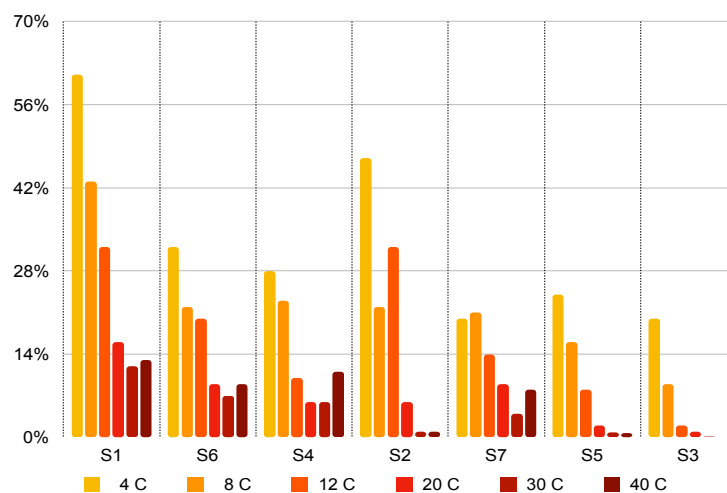


Figure 4. Total savings graph by scenario.

The second-best scenario is the 6, where savings were identified by contemplating few clients of more than 20%. As we increased the number of customers, the savings were decreased by half but without much difference between the last instances; in the instance of four customers, the mixed modern approach achieved good results.

The best third scenario is 4; we can see in the graph that the last instances have almost the same level of savings, achieving a better result than scenario 2; this is because this scenario, when experiencing with 20, 30 and 40 clients, has less participation to use drones and therefore, the level of savings is low.

According to the experimentation, it is concluded that greater savings are obtained from small packages; it should be noted that most of the packages that the university needs are of that size, and when taking into account mixed packages, the savings are reduced by almost 50%; it was shown that the use of drones can have savings in any scenario.

The use of drones offers logistical advantages in the distribution process, according to the scenarios, savings are obtained in several examples; it is important to understand that the traditional approach needs improvement.

In the experiments, CO₂ was also analyzed in the routes, INECC [31] describe the truck used in the experiments generates 255 g/km of carbon dioxide, a comparison of the mileage saved when using drones was made, the comparison is presented in Figure 5.



Figure 5. CO₂ route.

Starting from instances of big customers, a route of 1143.1311 km was obtained, while using drones decreased to 871.982 km, where the difference lies in 271.1491 km; the use of UAVs allowed the km traveled by the truck to be reduced; analyzing this factor, the CO₂ that was saved was of 69.143 g per km.

We conclude that there are considerable savings when using Unmanned Aerial Vehicles, there are different percentages of savings according to the size of the packages.

5. Conclusions

Parcel delivery with drones offers an alternative solution to the distribution process, generating savings and reducing time on delivery routes, and even giving flexibility to the supply chain. A mathematical model that contemplated several vehicles was used to meet the demand. Current studies have shown that the use of UAV with the traditional method (trucks) is very useful for logistics.

The mathematical model we propose will represent a contribution to logistics, mainly in the distribution process, because in the future, the number of packages will probably increase through electronic commerce; another problem arises in urban cities where there is a large congestion that causes delays in deliveries, where sometimes there are packages that are urgently needed.

It should be noted that the impact of technologies on logistics has provided the opportunity to break the gaps in new ways of working every time companies are innovating their processes, such as Amazon and UPS that deliver to customers through UAV. The study contributes to the efficient use of this technology in distribution and in the improvement of the value chain in package delivery companies.

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