



The possibilities of using drones in the courier services

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ABSTRACT

The article analyzes the market for postal services on the example of Poland. Then there were presented the advantages of using drones in postal courier services. Next the assumption of conception of using unmanned aerial vehicles in courier services and a procedure of delivery of consignments were presented. Then for the real example of a drone there were conducted the calculation of real flight parameters and the forces effecting on a drone. At the end the economic aspect of using the drones in the courier services was calculated. Based on the results were discussed the usefulness of the use of of drones in courier services. In summary it was concluded that courier deliveries using the drones can be competitive in the future for the traditional methods of delivery. The cost of 1 parcel delivery can be even about 9% lower than so far. Consideration should be given that the prices used to estimate the cost of production machines are retail prices. The mass production of drones can bring savings in production costs in the range of 15-20%. The only element that does not allow to run the project of delivering items using the drones is the battery. The calculations show that at the proposed subassemblies the battery capacity allows only for a 7-minute flight. However, the works on the new sources of supply are conducted - lithium batteries, the anodes of pure lithium, the fuel cells.

Keywords: drones, courier services, delivery on consignments, flight parameters, economic aspect

Nomenclature:

a = speed of the during the flight

a_p = climbing time

C = string of single motor

C_p = battery capacity

c_x = air resistance coefficient

F_g = gravity force

F_o = air resistance force

F_n = lift force

F_w = resultant force

I = charging current

I_p = current efficiency of accumulator

I_s = average current consumed by the system

K_d = daily cost of maintaining of the drone in motion

M = mass of drone,

m = mass of load

n = number of engines,

P = power of charging current

s = butting face, which causes aerodynamic resistance force

t = charging time

t_d = runtime of the drone

U = charging voltage

W = power needed to charge the battery

v = founded speed of the drone

x = overload factor

ρ = air density

1. INTRODUCTION

Drones are unmanned flying ships, used in various fields of life. The biggest and the first their application is concerned with military purposes. In recent times drones are used increasingly for civilian purposes. The drones are applicable in the civil service (police, fire brigade, border guards), in many branches of industry, but for research purposes, because of the huge functionality. Drones are used successfully in the agriculture, mining and even during emergency medical action. They also facilitate to perform geodetic and meteorological measurements. Drones are also used for monitoring the objects, to study the oceans and depths, and even to perform aerial photographs. Recently, the functionality of drones was interested the creator of Facebook and Google with a view to their use as a mobile hotspot sites.

About the method of using the drone determined mainly its size, time of flight and the value of maximum load. The most popular are devices with average size from two to three meters and mikrodrones, famous under the popular name quadrocopters. As average size drones are used most often to take photos, agricultural crop monitoring, patrolling the borders, and even observe the animals moving into areas inaccessible to humans. On the other hand

mikrodrones, which are controlled using a mobile phone are not only the devices useful in many areas, but also modern gadgets using for private purposes by the ever enlarging group of people.

Drones are finding increasing use in delivering shipments. The first company that used the functionality of drones in delivering shipments is known around the world Amazon.

2. ANALYSIS OF THE POSTAL SERVICES MARKET IN POLAND

On the Polish CEP market (Courier-Express-Pack) are the following types entities providing postal services:

- Polish Post Sp. with o.o - The operator designated to provide universal service,
- alternative operators.

The simplest postal service is based on receiving a package from the client and its delivery to the correct address, which is done in many stages. It covers reception of the pack, sorting, transport and delivery. Accompanying services can be: handing the package to the addressee in a specific time (9.00, 12.00), a Saturday delivery, COD, telephone or SMS message monitory note of package delivery.

The postal market is regulated by the Act of 23 November 2012 the "Postal Law". It defines the types of consignments, their sizes and the formalities which had to be fulfilled by the company that to be admitted by the Electronic Communications Office for activities on the the postal market.

The deregulation of the postal market in Poland has been since 1 January 2013. Since that day, the public sector companies may use the services of other companies than the Polish Post. Were also the The services reserved exclusively for the universal service provider are abolished, namely the post items weighing up to 50g. Previously (until the end of 2012) the companies that want to transport small enveloped-shipments, had to be burden additionally with the metal sheets.

The services offered by the Polish Post are as follows:

- universal postal items in domestic and foreign markets (postal items registered and unregistered, postal parcels weighing up to 10kg - domestic turnover and up to 20kg - foreign turnover)
- services within the scope of universal services in domestic and foreign turnover (post items for national broadcasters, hybrid shipments, business and COD),
- courier service,
- other postal services (unaddressed deliveries, telegrams, parcel weighing more than 10kg).

Whereas alternative operators provide the following services:

- services within the scope of universal services in domestic and foreign turnover (post items and packages)
- courier services (post items and packages of a certain size),

- other parcel services (packages and letters of dimensions not meeting the standards for courier services, advertising parcels).

The number of companies permitted by the UKE for providing the postal services has increased from 157 in 2006 to 274 in 2013, therein there were 90 in 2006 and 160 in 2013 the active operators. Most of companies offer courier services, where until 129 companies focus on a single type of services, and only 5 perform complex services. Narrowing the business profile and adapting to only one type of service can affect the growth of the quality of service, more optimal use of resources and lower overall costs of doing business.

43% of the total volume supplied by the Polish Post constitute the universal services, which brought 66% of total revenue. An important element in terms of quantity and income are services within the scope of the universal services and "other" services. The first one brought the Polish Post 20% of revenue, and the second 12%. The smallest income equal 2% brought courier shipments, due to the high popularity of these services among alternative postal companies. However, despite of the small amount (4.6% of the volume) they accounted for 86% of revenues, in contrast of other consignments (eg. advertising) in which at 86% of the volume obtaining the revenue equal just under 6%.

Among the 98 companies offering courier services found 5, whose total revenue was 52% of the entire sector courier deliveries. These were: UPS Poland, Polish DPD, DHL Express, TNT Express, Seven, InPost Ltd., which transported 97% of all shipments, which accounted for 90% of total revenue. Among the largest companies InPost Sp. with o.o. offered services from all three categories: postal parcels, advertising mails and unaddressed mails.

The most common type of universal services offered by the Polish Post are post items, that constituted 98% of all shipments. Są to przesyłki z korespondencją lub druki, z wyłączeniem przesyłek reklamowych o maksymalnej wadze 2 kg i obwodzie 900 mm [15]. In 2013 alternative operators performed 59% of the services and Polish Post 41% of services. Despite this, the Polish Post has obtained 67% of the revenue of the entire market. It can be caused by sending through alternative postal companies a large number of other items such advertising, which generate a negligible percentage of revenue.

Both the Polish Post, as well as alternative operators focus their activities in the urban areas, while in the case of Polish Post the difference between the numbers of urban and rural objects is lower. It is associated with the requirements of the Act "Postal Law", which was specified the minimum number of institutions per defined area and population. It is estimated that the real number of outlets of alternative operators is smaller by about 7500.

On the postal market can see the following trends:

- among shipments of Polish Post postal, the consignments dominate in terms of both volume and revenue,
- among the shipments of alternative operators significant in terms of volume are other shipments (unaddressed mailings, advertising), but the revenues associated with them are small,
- despite the small volume the most revenue for alternative operators accounted the courier shipments.

Courier services market is constantly evolving. In 2013 compared to 2012. the market value increased by 27%. Revenue of alternative operators was about 66% higher than in the

previous year, and the Polish Post Office by about 14%. An important role is played by an increase in Internet trading by 116% for the period 2009-2013. The result of the development of distance shopping is less revenue growth than the volume of shipments. Thanks to the activities of brokers courier the customers can choose a cheaper delivery option and the size of packages is also reduced. Companies are increasingly deciding on a reduction of magazine stocks to an absolute minimum, thanks to deliveries just in time, namely almost when the merchandise is needed. This requires from the courier companies to prepare the services, which are tailored precisely for one client, which are an essential element of IT systems. They allow keeping timeliness and check the shipment location (track & trace). This contributes to the fact that the entire supply chain is transparent. Any delay or irregularity can be noticed almost immediately, allowing you to take countermeasures and remedies.

3. THE CONCEPT OF USING UNMANNED AERIAL VEHICLES IN COURIER SERVICES

The using of drones for delivering courier and postal shipments to the recipient is supported by the following reasons:

- reducing the cost of activity,
- increasing the flexibility of delivery time (possibility of delivery after standard working time of couriers),
- speeding up delivery time,
- reducing a negative impact on the environment.

3. 1. A concept assumptions

It was assumed the number of 15 branches, which will be equipped with drones delivering the shipment. In the initial phase, only one sorting plant can be equipped with a drones, because more number of machines will allow, through economies of scale to reduce unit costs of purchasing, maintenance and servicing.

To supply program 15 largest Polish cities were selected based on the number of inhabitants and the items on the list of most congested cities in Poland. It was there the most shipments are delivered and the couriers lose a lot of time standing in traffic jams.

The following operating parameters of the drone are assumed:

- flight speed - 60 km / h,
- range of 40 km,
- load capacity – 10 kg,
- maximum dimensions of packages: 640 x 640 x 640 mm,
- cruising altitude - max. 200 m.

It was established the following work schedule drone:

- time delivery: 6.00-22.00 (16 hours),
- the maximum time of a one delivery - 54 min., including:

- time to take the package - 2 minutes,
 - the maximum flight time to the recipient - 20 min.,
 - the time of issuing the consignment - 3 min.,
 - flight duration to the sender - 9 min.,
 - the time of adoption of the package - 3 min.
 - flight duration to the branch - 12 min.
 - time adoption - 2 min
 - time battery replacement / maintenance - 3 min.
- The minimum number of courses done by 1 drone is 17/day. The number of packages that it might take at once depends on the version of the drone and the distances at which the recipients and the sender will be deployed. The optimal number of packages delivered and broadcast shall be 8, assuming that the next customers will be remote from one another by a maximum of 2 minutes of flight. Drones can be adapted for carrying parcels of specified sizes, so their cargo space can be divided into 2, 4, 6, 8 or more parts for letter posts.
 - the calculations show that the maximum number of packages served by an 1 drone ranges between 17 and 144 arts (sum of parcels delivered and received by broadcasters). The way to increase this number is the extension of drone working time on one battery.

3. 2. The procedure for delivery

The following stages of the delivery items by Unmanned Aerial Systems were suggested:

- 1) Taking the shipment by the drone.
- 2) Start.
- 3) Sending to the recipient an SMS with information about the exact time of delivery.
- 4) Flight.
- 5) Sending another SMS "for 1 minute. Exit the house. Your PIN is... "
- 6) Landing before entering the house.
- 7) Entering the PIN code by the addressee.
- 8) Opening the cargo hatch of the drone.
- 9) Downloading the package by the addressee.
- 10) Start.
- 11) Send SMS to the sender of the package No.2 "for x minutes get out in front of the house in order to impart the shipment. Your given PIN code is... "
- 12) Flight.
- 13) Sending SMS "For 1 minute exit the house. Your PIN is... "
- 14) Landing.
- 15) Entering the the PIN code by the sender.
- 16) Placing the pack by the sender in the baggage hold.
- 17) Starting the drone and a passage for sorting plant.
- 18) Landing in the zone of sorting plant broadcasts.
- 19) Getting the parcels from the drone.
- 20) Battery replacement and eventual service of the drone.

A delivery process begins with the taking over the consignment / consignments by drones. A worker places the consignments in the appropriate compartments. After completing these steps follows the start of the drone, which then moves at a certain height to your destination. A very important element is the construction of the entire control system of drones, whose task would be to accurate mapping the route of each drone. Along with sensors located in the drones it would allow to avoid a collision between the drones and between buildings, trees or power lines.

The SMS with information about the estimated time of delivery should be sent at the start of the drone to the phone number. Another SMS should be sent for 2 minutes before delivery, which will allow for a smooth transfer of the package. Upon arrival the drone to place follows his landing, which should take place as close as possible of the front door of the building, to the address of which has been ordered courier service to ensure maximum comfort for the recipient. For this reason, the very accurate maps and sensors will be needed to ensure a safe landing. To receive by the addressee the consignment and the verification of the person receiving it will be necessary to enter the consigned PIN in a second SMS. After the entering the correct code the door of proper compartment will open and it will be possible to pull out the package. Then the drone takes off towards the next place of destination or broadcasting and the sequence of actions is similar, as in the case of the first delivery. A drone returns to the branch, when all the planned shipments will be delivered and received. It lands in the area of broadcasts where user charges are all given shipment. Here a battery replacement and possible service operations are taken place. After completing all steps the following goods can be taken.

3. 3. Calculation of real flight parameters and the forces for the drone proposed

The drone model consisting of the following components was proposed:

- Frame: Tarot T18,
- Engines (8 pieces) T-motor U7 V2.0,
- T-motor propellers (Tiger Motor RC)
- lithium-polymer accumulator type 7S.

3. 3. 1. Current efficiency

$$I_p = c_p \cdot x \quad (1)$$

where:

I_p – current efficiency of accumulator,

c_p - battery capacity,

x – overload factor.

Hence I_p will amount 880A.

3. 3. 2. Runtime of the drone

$$t_d = c_p / I_s \quad (2)$$

where:

c_p - battery capacity,

I_s - average current consumed by the system.

Calculated the drone working time amounts to 7 minutes.

The use of very powerful and modern engines was necessary to raise more than twenty-kilogram machine. High engine power translates into a high power consumption, which results that suggested most capacious battery (22 Ah) on the market allows for a 7-minute flight. In order to enable a predetermined length of the flight (60 min.) and a 10-minute reserve it is needed to give hiding 9 extra batteries or increase the capacity of a single accumulator tenfold. As seen from the calculations it will be necessary to invent and introduce into general use a new type of accumulators. Currently, the intensive researches for the development of the power cells of all kinds of mobile appliances are lasted, which allow the use of drones on the mass scale.

Further calculations were based on the assumption that the battery has a required capacity of 220 Ah with unchanged weight. Each one weighs 3 kg, which represents 29% of the whole drone weight.

3. 3. 3. Battery charging time

$$t = 1,4 \cdot c_p / I \quad (3)$$

where:

P – the power of charging current [W],

t – charging time [h],

U – charging voltage [V],

I – charging current [A].

The calculated power amounted 55,6 kWh.

3. 3. 4. The power needed to charge the battery

$$W = P \cdot t = U \cdot I \cdot t \quad (4)$$

where:

P – the power of charging current [W],

t – charging time [h],

U – charging voltage [V],

I – charging current [A].

The calculated power amounted 55,6 kWh.

3. 3. 5. The force of gravity

$$F_g = (M + m) \cdot g \quad (5)$$

where:

M – mass of drone,

m – mass of load.

On the basis of calculations force of gravity amounted 199.62 N

3. 3. 6. The overall pulling force of all the engines are:

$$F_c = n \cdot C \quad (6)$$

where:

n – the number of engines,

C – a string of single motor .

The calculated value amounted 261,02 N.

3. 3. 7. Climbing speed

During the start the whole string is directed vertically upwards, hence the climbing speed can be calculated with the following formula:

$$a_p = (F_w - F_g) / M + m \quad (7)$$

where:

F_w – resultant force.

The calculated value amounted 3,02 m/s².

During the flight, the force F_n and F_g are in balance, and the movement is caused by the force F_w , which is dependent on the angle of attack relative to the direction of movement.

- The optimum angle of attack for maximum loaded octocopter is calculated from the relationship:

$$\cos\alpha = F_n / F_c \quad (8)$$

The calculated angle amounted the 40°.

- A resultant force of alignment forces, assuming equilibrium between the forces of gravity and capacity, can be calculated as the difference in the horizontal component of pulling power and a resistance force:

$$F_w = F_c \cdot \sin\alpha - F_o \quad (9)$$

$$F_w = F_c \cdot \sin\alpha - c_x \cdot \rho \cdot s \cdot v^2 / 2 \quad (10)$$

where:

- c_x – air resistance coefficient – 0,7,
- ρ – air density 1,17 kg/m³,
- s – the butting face, which causes aerodynamic resistance force [N],
- v – founded speed of the drone – 16,67 m/s.

The calculated resultant force amounted 79,6 N.

- Thus, the speed of the during the flight can be calculated with the following formula:

$$a = F_w/m + M \quad (11)$$

The calculated value will be 3,78 m/s². This means that the assumed speed of the equal to 16,67 m/s the drone reaches in less than 4,5 seconds. Therefore the maximum speed exceeds a predetermined value.

4. THE ECONOMIC ASPECT THE USE OF DRONES IN THE COURIER SERVICES

The most common model of courier companies work is to outsource the supply of "last mile" companies having the car fleets. Often the courier company puts conditions concerning the age (below 5 years) and condition (clean, covered with the colors of the company - principal) cars.

In exchange for each supplied pack of provider receives a set amount (3,5 zł/kg). Considering the maximum weight of the package delivered by a drone equal to 10kg and the maximum number of packages delivered during the course equal to 8, providing a single consignment with the existing method will cost the courier service 3,53 zł.

For the calculations the following conditions were assumed:

- drone lifespan equal to 5 years
- battery life equal to 0.5 years,
- the number of cycles of supplies per day – 17,
- the number of delivered packages – 144,
- the number of drones operated by 1 employee – 10,
- the number of changes – 2.

On this basis, the daily cost of maintaining of the drone in motion was calculated according to the formula:

$$K_d = D + 2 \cdot B + \text{Ł} + 2 \cdot 0,1 \cdot P + S \quad (12)$$

The costs of components for use drones in supplies and the way its calculations are presented in Table 1.

Service costs mainly include the exchange of consumable parts, such as propellers, engines and costs of technical check and other repairs.

The cost of maintaining drone in motion amounted to 461,79 zł. Hence the calculated cost of delivery of a single package amounted to 3,21 zł, which is less than the deliveries by cars.

Table 1. The component costs of using the drones.

Cost	Value [zł]	Method of calculation
The daily cost of a drone (gross)	15817	$D = \text{value of a drone} / 5(\text{ages}) \cdot 12(\text{months}) \cdot 24(\text{days})$
The daily cost of a battery (gross)	2160	$B = \text{value of battery} / 6(\text{month.}) \cdot 24(\text{days})$
The unit cost of loading	31	$L = \text{unit cost} \cdot \text{number of cycles}$
The cost of 1 worker (gross)	2700	$P = \text{monthly cost} / \text{number of working days}$
Servicing (gross annual cost)	7000	$S = \text{annual cost} / (12 \text{ months}) \cdot 24(\text{days})$

5. CONSLUSIONS

Courier deliveries using the drones can be competitive in the future for the traditional methods of delivery. The cost of 1 parcel delivery can be even about 9% lower than so far. Consideration should be given that the prices used to estimate the cost of production machines are retail prices. While the mass production of drones can bring savings in production costs in the range of 15-20%. Calculated pulling force meets the assumptions, and the maximum flight speed significantly exceeds it, which will increase the supply radius by a drone. The only element that does not allow to run the project of delivering items using the drones is the battery. The calculations show that at the proposed subassemblies the battery capacity allows only for a 7-minute flight. However, the works on the new sources of supply are conducted - lithium batteries, the anodes of pure lithium, the fuel cells.

The proposed in the article solution regarding the supply procedure is complicated, due to the anticipated combined deliveries to multiple recipients in a single cycle. There are the easier use of drones as means of transport, such as pizza deliveries, buy groceries from the supermarket or from online stores, where the one place of unloading simplifies the whole process. But due to the massive character of deliveries by courier companies, the costs of such activity will be higher. The introduction of of drones as means of transport in supply courier services can bring numerous benefits. The rapid development of technology will make that they become cheaper and more reliable, and the profit from their use will be greater than presented in this article. Surely this will translate into the emergence of such a delivery option and its fast popularization.

In the nearest future should be taken the steps relating to the control computer system controlling the supply of drones and motion parameters of each. The technical parameters of hardware and software necessary for supporting the multiple machines simultaneously, collision avoidance systems and their elements must be confirmed. In addition, drones must be absolutely not prone on the appropriating. It must also be follow the latest results of studies on batteries. It is essential to create a prototype of a drone and performance on this the endurance and quality tests, on the basis of which it can possible to confirm the calculated results in practice.

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