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Implementation of Drones in Logistics System

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Abstract: This article assesses the prospects for the development and change of logistics systems in accordance with the introduction of unmanned drones. Their use is an innovative solution that can significantly improve the efficiency of goods transfer. Key technological parameters, such as the global positioning system (GPS), are considered. Calculations are made to estimate the number of drones required delivering 100,000 orders per day, and various drone models are analyzed. The relevance of using drones in solving warehouse problems and delivering goods on the "last mile" is described. Domestic experience in using quadcopters in logistics is touched upon. Particular attention is paid to the scalability of unmanned aerial vehicles for delivery to hard-to-reach areas, such as the Arctic zone of the Russian Federation. The use of drones in urban areas is also taken into account.

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1 INTRODUCTION

Modern logistics systems are undergoing significant transformations due to the introduction of new technologies, including unmanned aerial vehicles (UAVs). Their use is becoming an important stage in the development of both internal and external logistics. In particular, drones have found wide application in warehouse inventory, where they replace traditional methods where operations require the participation of employees, significantly increasing productivity and reducing the risk of industrial injuries to people (Kostin, 2021).

A promising direction is the use of drones for the delivery of goods "last mile", which can radically change approaches to the distribution and delivery of goods in cities and remote regions. Transportation of goods at the last stages of the journey is faced with traffic jams, limited availability of transport routes. Drones can effectively solve these problems, overcoming barriers that limit the operation of traditional transport, reducing delivery time and significantly reducing costs (Kostin, 2021). Russian Post, which has already announced the launch of a drone delivery network in hard-to-reach regions, justifies this prospect in practice (Matyukha, 2021). An important part of the innovation is the integration of precise GPS technologies that provide route management (Patrik, 2019; Suleimanov, 2020). Despite the difficulty of using such navigation when positioning drones at close range, quadcopters may well become the main means of delivering small-sized cargo in the next 10-15 years (Patrik, 2019).

2 MATERIALS AND METHODS

The methodological basis of the work is a comprehensive analysis of publications over the past 6 years with an emphasis on the use of unmanned aerial vehicles (UAVs) in logistics, inventory and last-mile delivery. Technological parameters such as GPS and GNSS systems are considered. The scalability of UAVs is assessed.

3 REVIEW

The use of drones in logistics can be divided into two areas: internal and external. External - any delivery outside the warehouse, internal, respectively, the opposite.

1.1 Internal logistics

Currently, the use of drones in a warehouse is one of the main trends in the development of the logistics industry. A simple example is inventory, especially checking the accuracy of high-altitude storage and counting pallets. The standard process includes removing a pallet, scanning and moving it, which takes about 3 minutes per piece. With time rationalization, for example, with lifting an employee, this process can be accelerated to 30 seconds, but this increases the risks and requires the involvement of additional resources - a storekeeper, a driver of loading and unloading equipment. At the same time, the productivity will be 120 pallets per hour. Experiments with a drone have shown that it can be used with the same result - 120 pallets per hour, without additional resources. Also important is the ability to set routes and schedules for checking pallets and cells, thereby making the process completely autonomous (Kostin, 2021). The efficiency of warehouse logistics using drones is also due to cost reduction. Savings per warehouse can amount to more than $1 million per year (Grankin, 2019).

Most foreign and Russian companies already offer drones for warehouse work. Among them, drones from the following companies can be distinguished: StockTaking.pro, Fast Sense, Eyesee, MIT Media Lab, Intelligent Flying Machines, FlytWare, Leica Geosystem (Barkova, 2022).

Manual control is still necessary in many cases to implement the warehouse inventory process. However, visual methods for barcode recognition are increasingly being used in internal logistics systems, and autonomous methods for using quadcopters are being actively developed (Kostin, 2021).

1.2 External logistics

External drone applications or last-mile delivery is a promising area in logistics. Last-mile delivery is the stage of delivery of goods from the warehouse to the end consumer. The implementation of this technology has a number of advantages. The main one is speed and efficiency: drones are able to deliver goods to hard-to-reach places and overcome traffic jams, significantly reducing delivery times.

In 2019, DHL Express, a world leader in international logistics and express delivery, introduced an innovative program aimed at implementing a fully automated solution for the delivery of goods using drones. The initiative was

aimed at solving the problems of last-mile delivery in densely populated cities in China. A DHL customer received their parcel using the latest drone in Guangzhou. For this operation, a special route of about 8 kilometers was designed from the DHL logistics center to the final destination. A new generation Falcon drone, created by EHang, was used to perform the flight. According to the experiment, the drone covered the route in 8 minutes, while on the road this journey took 40 minutes. The use of drones made it possible to reduce delivery costs by 80% (Kostin, 2021).

Unmanned deliveries can solve many problems in remote parts of Russia with a limited transport network (Pustokhina, 2021):

1. There are settlements cut off by waterways from large cities and transport routes (for example, Yakutsk is located across the river from the railway, there is no railway connecting Norilsk and Kyzyl to the main route).

2. In Russia, there are no or insufficient services for delivering groceries from stores or ready-made meals from catering establishments to small settlements located far from large cities.

3. In the Arctic and Far Eastern regions, there are a large number of islands and oil platforms. It is much faster and cheaper to deliver food, parts, components, tools and other goods for workers in the oil and gas industry using drones than by water transport.

1.3 Calculating the number of drones to service a city with N orders

Let's calculate the number of drones needed by a food delivery company to serve a city with 100,000 food orders per day. We'll also compare drones from manufacturers such as Amazon, DJI, and Flytrex.

Let's calculate the number of Amazon drones, model Prime Air - MK27-2. The maximum speed of such a drone reaches 80 km/h. Let's assume that due to external factors (wind, rain, technical limitations); the drone will fly at an average speed of 60 km/h. The operating time is 60 minutes, after which it needs to be charged. The charging time is 20 minutes. Let's also take into account the time for loading and unloading the drone. Let it be 6 minutes in total (3 minutes for loading by the manufacturer and 3 minutes for unloading by the consumer). Let's assume that the probability of one drone breaking down per day is 1%. Let the delivery distance be 3 km one way (6 km for the entire journey).

1) The time the drone spends on one flight.

If the one-way distance is 3 km then the time the drone spends flying there and back:

$$T_{flight} = \frac{6\ km}{60\ km/h} = 0{,}1\ h = 6\ min \quad (1)$$

Now let's add time for loading and unloading:

$$T_{full} = 6\ min + 6\ min = 12\ min \quad (2)$$

The drone takes 12 minutes to complete one flight.

2) Charging time and work cycle.

The drone can operate for 60 minutes, and then it needs 20 minutes to charge. Thus, the full work cycle is:

$$T_{cycle} = 60\ min\ + 20\ min = 80\ min \quad (3)$$

Then, in one cycle, the drone can perform:

$$N_{flights\ per\ cycle} = \frac{60\ min\ work}{12\ min\ on\ flight} = 5\ flights\ per\ cycle \quad (4)$$

3) The number of flights a single drone can perform per day.

Assuming a drone operates 16 hours per day (960 minutes) (this is an optimal working day, taking into account recharging and maintenance). The number of cycles a drone can perform:

$$N_{cycles} = \frac{960\ min}{80\ min/cycle} = 12\ cycles \quad (5)$$

In 12 cycles the drone can complete:

$$N_{flights\ per\ day} = 12\ cycle \cdot 5\ flights\ per\ cycle = 60\ flights\ per\ day \quad (6)$$

4) Number of drones needed to fulfill all orders.

To deliver 100,000 orders per day, given that each drone can perform 60 flights per day:

$$N_{drones} = \frac{100000\ orders}{60\ flights/drone} = 1667\ drones \quad (7)$$

5) Let's take into account the probability of drone failure. If the probability of one drone failure per day is 1%, then to ensure uninterrupted operation we need to have spare drones. The number of spare

drones will be equal to 1% of the total number of required drones:

$$N_{spare\ drones} = 1667 \cdot 0{,}01 \approx 17\ drones \quad (8)$$

6) Total number of drones can be calculated.

Now, to account for both primary and backup drones, the total number of drones needed to ensure uninterrupted operation will be:

$$N_{general} = 1667 + 17 = 1684\ drones \quad (9)$$

To serve 100,000 food orders per day, you will need approximately 1,684 Amazon Prime Air – MK27-2 drones.

In the same way, we will calculate the number of DJI drones of the Matrice 300 RTK model. The maximum speed of such a drone reaches 80 km / h. Let's assume that due to external factors, the drone will fly at an average speed of 60 km / h. The operating time is 55 minutes, after which it requires charging. The charging time is 18 minutes. We will leave the rest of the conditions unchanged.

1) The time that the drone spends on one flight.

If the one-way distance is 3 km then the time that the drone spends on a round-trip flight:

$$T_{flight} = \frac{6\ km}{60\ km/h} = 0{,}1\ h = 6\ min \quad (1)$$

Now let's add the time for loading and unloading:

$$T_{full} = 6\ min + 6\ min = 12\ min \quad (2)$$

It takes the drone 12 minutes to complete one flight.

2) Charging time and work cycle.

The drone can work for 55 minutes, and then it needs 18 minutes to charge. So the full work cycle is:

$$T_{cycle} = 55\ min + 18\ min = 73\ min \quad (3)$$

Then, in one cycle, the drone can perform:

$$N_{flights\ per\ cycle} = \frac{55\ min\ work}{12\ min\ on\ flight} = 4{,}58 \approx 4\ flights\ per\ cycle \quad (4)$$

3) The number of flights a single drone can perform per day.

Assuming a drone operates 16 hours per day (960 minutes) (this is an optimal working day, taking into account recharging and maintenance). The number of cycles a drone can perform:

$$N_{cycles} = \frac{960\ min}{73\ min/cycle} = 13{,}15 \approx 13\ cycles \quad (5)$$

In 13 cycles the drone can perform:

$$N_{flights\ per\ day} = 13\ cycles \cdot 4\ flights\ per\ cycles = 52\ flights\ per\ day \quad (6)$$

4) Number of drones needed to fulfill all orders.

To deliver 100,000 orders per day, given that each drone can perform 52 flights per day:

$$N_{drones} = \frac{100000\ orders}{52\ flights/drone} = 1923\ drones \quad (7)$$

5) Let's take into account the probability of drone failure. If the probability of one drone breaking down per day is 1%, then to ensure uninterrupted operation we need to have spare drones. The number of spare drones will be equal to 1% of the total number of required drones:

$$N_{spare\ drones} = 1923 \cdot 0{,}01 \approx 20\ drones \quad (8)$$

6) Total number of drones can be calculated.

Now, to account for both primary and backup drones, the total number of drones needed to ensure uninterrupted operation will be:

$$N_{general} = 1923 + 20 = 1943\ drones \quad (9)$$

To serve 100,000 food orders per day, you will need approximately 1,943 DJI Matrice 300 RTK drones.

Now let's calculate the number of drones from the Israeli company Flytrex model M600. The maximum speed of such a drone reaches 60 km / h. Let's assume that due to external factors, the drone will fly at an average speed of 40 km / h. The duration of operation is 15 minutes, after which it requires charging. The charging time is 6 minutes. We will leave the rest of the conditions unchanged.

1) The time that the drone spends on one flight.

If the one-way distance is 3 km then the time that the drone spends on a round-trip flight:

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$$T_{flight} = \frac{6\ km}{40\ km/h} = 0{,}15\ h = 9\ min \quad (1)$$

Now let's add time for loading and unloading:

$$T_{\text{полное}} = 9\ min + 6\ min = 15\ min \quad (2)$$

The drone takes 15 minutes to complete one flight.

2) Charging time and work cycle.

The drone can operate for 15 minutes, and then it needs 6 minutes to charge. Thus, the full work cycle is:

$$T_{cycle} = 15\ min\ + 6\ min = 21\ min \quad (3)$$

Thus, per cycle, the drone can perform 1 flight.

3) The number of flights that one drone can perform per day.

Let's assume that the drone works 16 hours a day (960 minutes) (this is an optimal working day, taking into account recharging and maintenance). The number of cycles that the drone can perform:

$$N_{cycles} = \frac{960\ min}{21\ min/cycle} = 45{,}71 \approx 45\ cycles \quad (5)$$

In 45 cycles the drone can complete:

$$N_{flights\ per\ day} = 45\ cycles \cdot 1\ flights\ per\ cycles = 45\ flights\ per\ day \quad (6)$$

4) Number of drones required to fulfill all orders.

To deliver 100,000 orders per day, given that each drone can perform 45 flights per day:

$$N_{drones} = \frac{100000\ orders}{45\ flights/drone} = 2223\ drones \quad (7)$$

5) Consider the probability of drone failure. If the probability of one drone failure per day is 1%, then to ensure uninterrupted operation we need to have spare drones. The number of spare drones will be equal to 1% of the total number of required drones.:

$$N_{spare\ drones} = 2223 \cdot 0{,}01 \approx 23\ drones \quad (8)$$

6) Total number of drones can be calculated.

Now, to account for both primary and backup drones, the total number of drones needed to ensure uninterrupted operation will be:

$$N_{general} = 2223\ + 23 = 2246\ drones \quad (9)$$

To serve 100,000 food orders per day, you would need approximately 2,246 Flytrex M600 drones, fig.1.

Let's compare drones from Amazon, DJI, and Flytrex.

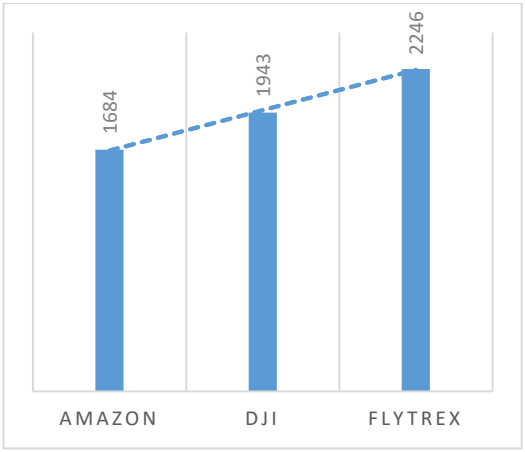

Figure 1: The number of drones from different manufacturers needed by a food delivery company to serve a city with 100,000 food orders per day.

According to the calculations, it can be concluded that Amazon's UAVs are the most efficient to use. DJI is in second place, and Flytrex is in third place.

4 POSITIONING SYSTEMS

The GPS system is critical for the accuracy of delivery and navigation of quadcopters. For uninterrupted navigation of an autonomous drone, accurate location data is required. This is achieved by using GNSS (Global Navigation Satellite System) (Patrik, 2019). This system provides access to a larger number of satellites, which allows the drone to fly long distances with high accuracy and minimal deviations from the planned route.

The disadvantage is the difficulty of reaching the target at short distances. A decrease in positioning accuracy is due to errors that occur when using the GNSS module, especially in densely populated areas, where signals from satellites can be reflected

from the walls of buildings, causing multipath effects and errors in determining the location. Also, due to a GPS error of about 10 m, it is extremely difficult to deliver the cargo to a specific recipient's door (Suleimanov, 2020). To solve these problems, additional local navigation systems are being developed using QR codes, radio beacons, and ultrasonic sensors. These technologies allow the drone to navigate precisely indoors or in conditions of limited satellite visibility (Patrik, 2019).

5 SCALABILITY

Delivery to hard-to-reach regions, such as the Arctic Zone of the Russian Federation (AZRF), poses a significant challenge to traditional transport solutions. The AZRF includes 9 subjects of Russia, partially or completely covering: Murmansk Oblast, districts of the Republic of Karelia, most of the Arkhangelsk Oblast, the Nenets Autonomous Okrug, districts of the Komi Republic, the Yamalo-Nenets Autonomous Okrug, a significant part of Krasnoyarsk Krai, the northern part of the Sakha Republic (Yakutia) and the Chukotka Autonomous Okrug. In the AZRF, with an area of 3.1 million km² and a population of over 2.5 million people, the transport infrastructure is extremely limited. There is almost no rail service, and water and road transport operate seasonally. The only year-round mode of transport is aviation (Matyukha, 2021). One of the steps towards the introduction of UAVs for delivery to hard-to-reach areas was the initiative of Russian Post, which announced the launch of an experimental network for unmanned aerial delivery, including 48 routes in four regions - the Chukotka Autonomous Okrug, Kamchatka Krai, Yamalo-Nenets and Khanty-Mansi Autonomous Okrugs (Matyukha, 2021).

A feature of Russian hard-to-reach territories, such as the Arctic zone, is their huge area and low air traffic density. This creates ideal conditions for the development of unmanned technologies, where the absence of intense traffic and long distances provide significant advantages for drones. It is also worth noting that drones can be effectively used in areas where there is no stable Internet, and communication with the network is often absent.

The use of drones in such conditions became possible due to the use of a radio signal for their control. Drone models from the Chinese company DJI, such as the DJI Matrice 300 RTK, Matrice 30 and Mavic 3 Enterprise, can operate without the Internet, transmitting information via radio signal. These devices can create maps of the area and then upload them to the remote control using the DJI Pilot 2 app.

For navigation in the absence of the Internet, a D-RTK2 ground station is used, which allows the drone to operate in RTK mode, determining the exact location with minimal error. The station transmits data via the OcuSync protocol, and also supports all major satellite systems (GPS, GLONASS, BeiDou and Galileo) and provides high accuracy over long distances (see “Can drones…”, 2023).

Unmanned drones can also be used to deliver goods within the city. In the first quarter of 2025, the Samokat Company begins testing the delivery of products using drones in several areas of Tolyatti. The range of products available for delivery by drones is limited, and the maximum weight must be 5 kg (Savitsky, 2017). Quadcopters will be used to transport orders to parcel terminals. Delivery time will be about 30 minutes, and the shelf life in the parcel terminal is up to 3 hours (see "Aerological logistics in retail ...").

Uber demonstrated testing of a food delivery service by drones in 2019 in San Diego. VOXL systems were used for navigation, which include 4G communication, GPS, cameras and an ADS-B transceiver (Efremova, 2019, Andrievsky, 2023). Uber Eats drones delivered food using specially equipped landing pads and cars. It was assumed that this would allow the company to use its taxi service as landing pads (Gonta, 2023). Uber notes that drones make delivery of orders faster, reducing its time from 21 minutes when using ground transport to 7 minutes by air. According to Tech Crunch, the first quarter of 2019 brought the company a 105 percent increase in revenue compared to 2018, amounting to $3.07 billion.

Thus, delivery of goods using UAVs allows solving problems with accessibility and speed in both remote areas and cities.

6 RESULTS AND DISCUSSION

1. Warehouse logistics: drones improve inventory efficiency, reducing costs by up to $1 million per year in one warehouse.

2. "Last mile" delivery: delivery time is reduced by 5 times (for example, with DHL); costs are reduced by up to 80%.

3. Remote regions: drones are effective in areas without transport - the huge area and low air traffic

density there create ideal conditions for the development of unmanned technologies.

4. When theoretically calculating the number of drones to deliver 100,000 orders per day, we can conclude that Amazon drones are the most effective.

5. Navigation: GPS is convenient, but not accurate enough in urban conditions - additional systems are required, such as QR codes.

6. Scalability: UAVs are the optimal solution both in the Arctic, where there are significant communication problems and there is no stable Internet, and in cities for transporting small cargo and food.

7 CONCLUSIONS

The introduction of unmanned aerial vehicles in logistics opens up new opportunities for increasing efficiency and optimizing processes, both in warehouses and in the process of delivering goods to end consumers (Kostin, 2021). The use of drones can significantly reduce delivery costs, improve delivery speed and solve logistics problems in hard-to-reach regions of Russia (Matyukha, 2021). The development of more accurate navigation systems and the use of drones as an effective means of transportation create significant prospects for the growth and development of the logistics industry.

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