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RESEARCH ARTICLE

An Optimized Product Delivery System for RedX Using Drones: A Case Study

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Abstract: This research aims to create a drone delivery system to meet the e-commerce industry's growing need for quicker and more effective product delivery. Even though using drones for deliveries has drawn a lot of interest, developing an efficient delivery system is complicated due to factors including drone range limitations, frequent charging, and restricted airspace. However, only few studies have considered these factors. In this paper, we propose a comprehensive approach that accounts for several variables, including the position of the drone stations, the warehouse's location, the closest drone station to the delivery destination, and unmanned aerial vehicle (UAV) restricted areas. The study presents a heuristic approach for choosing drone station locations, an algorithm to find the drone station closest to the delivery location, and the K-means clustering technique for determining the optimum warehouse location. Additionally, safety and privacy are crucial considerations, and the study uses the A* search algorithm to avoid restricted areas during the deliveries. Finally, a cost analysis was done to understand the financial feasibility of this study and our delivery system will minimize the delivery cost by 47% approximately. The proposed method provides a time-efficient and profit-maximizing delivery service that can revolutionize the industry and improve customer satisfaction.

Keywords: drone, drone station, warehouse location, drone-restricted area, ArcGIS

1. Introduction

The rapid growth of e-commerce has increased demand for faster and more efficient product delivery. As a result, delivery companies have begun to look at emerging innovations to enhance delivery processes. Drone delivery of products is one such technology that has the potential to cut delivery times and costs significantly. Drones have become quite popular in recent years with their potential to provide quicker and more effective delivery services. However, implementing drone delivery systems has several challenges, including the limited range of drones, the need for frequent recharging, and restricted airspaces.

The use of drones in product delivery has experienced unprecedented growth in recent years, with companies worldwide exploring the potential of this technology to optimize their delivery processes. At the heart of this exploration is the need for safe and efficient product delivery, which requires a comprehensive approach that factors in various variables.

According to recent research, the drone delivery market is expected to reach $11.66 billion by 2028, generating a CAGR of 2028 [1]. The increasing significance of drones in last-mile delivery is attributed to their eco-friendly operations, shorter delivery times, and lower operational costs compared to traditional channels. The demand for drone delivery services has surged globally, driven by the COVID-19 pandemic, which has accelerated the need for alternative, safe, and contactless delivery model [2]. However, there are still challenges to overcome, such as FAA regulations, the need for landing space, and the limitation of payload capacity [3]. Despite challenges, the potential for drone commercial deliveries to reshape the logistics industry is immense. This promises a future where expedited delivery becomes not just a luxury but a necessity [4].

The e-commerce scenario in Bangladesh is increasing rapidly. According to research by Research and Markets, a Dublin-based trade research institution, the size of the e-commerce market was BDT56,870 crores in 2021, which will increase to BDT 1.5 lakh crore by the end of 2026 [5].

In this rapidly growing market of Bangladeshi e-commerce, drone parcel delivery systems can have a massive impact. It will simultaneously reduce the delivery lead time, cost of product delivery, and the human resources needed. It will also positively affect the traffic jam situation in Bangladesh. Small and lightweight parcels can be delivered quickly in this way. But a drone delivery system is a new idea for Bangladeshi customers, so it might become difficult to make customers accustomed to getting their products delivered by a drone.

This study focuses on understanding and creating a sustainable autonomous drone delivery system for Rajshahi [6]. With an area of 96.71 sq km divided into six thanas, Rajshahi City Corporation can be a perfect place to implement a drone parcel delivery system. This study analyses how drone delivery will be done in the city of Rajshahi, where the drone stations will be located, and what will be the best location for the warehouse. This study also finds out the shortest route for drone traveling, tackles the drone-restricted area problem, and finally compares the cost of the drone parcel

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delivery system with an existing design. The product delivery data from RedX was used in this research. RedX is a product/parcel delivery company that acts as a bridge between customers and suppliers. They collect products from different online stores and services and provide home delivery to the customers.

The number of internet users in Bangladesh is increasing rapidly. From 2012 to 2022, the overall number of Internet users increased from 150 thousand to 52.58 million, representing 31.5 percent of the population [7]. With this increase in the number of internet users, the consumer of e-commerce is increasing. Facebook marketplace and other platforms like those are attracting more customers. The merchants may now develop their companies and offer their products to many cities from their warehouses or residences. The product delivery companies need help delivering those products to the customer within the pre-estimated time. It becomes a nightmare during the festival periods like Eid, Puja, and New Year, and also during different campaigns. Product delivery systems need to be more efficient and optimized, and modern technologies must be used in these industries. Otherwise, gaining customer satisfaction will become more challenging every day. With the price hike in fuel, the delivery cost is climbing rapidly as most of the delivery man uses the fuel-powered vehicle. The regular man-powered delivery system also has a high lead time which could be a reason for customer dissatisfaction. With this increased number of online orders and increased delivery, the number of couriers on the roads is also increasing, causing severe traffic jams on the road.

This study examines how drone technology can transform delivery systems, particularly in terms of efficiency, cost reduction, and accessibility for last-mile delivery. This study also offers practical insights, addressing regulatory challenges and emphasizing the integration of advanced technologies. The research contributes to ongoing logistics innovation, providing a glimpse into a future where drone delivery systems play a key role in reshaping supply chain management. The potential outcome of this study will be enhancing delivery speed, cost-effectiveness, and sustainability.

The study's primary purpose is to analyze and understand the possibility of implementing a drone parcel delivery system in Bangladesh, specifically in Rajshahi. If it is possible to use UAV technology in the parcel delivery industry, it will revolutionize Bangladesh's product delivery system.

Our proposed system provides a profit-maximizing and time-efficient delivery service that has the potential to revolutionize the industry and increase customer satisfaction. The findings of this study can be implemented in any other region by using data from other companies to create a customized delivery system that meets the unique requirements of various areas. The findings of this study will benefit researchers, practitioners, and policymakers in the field of production research, particularly those interested in developing optimized delivery systems utilizing drones.

2. Literature Review

In the realm of delivery systems, the utilization of drone technology has garnered attention due to its inherent advantages, including heightened service flexibility, diminished delivery time, and a concomitant reduction in both CO2 emissions and energy consumption, as asserted by prior research [8–9]. The significance of optimizing delivery systems through the integration of drones is underscored by the potential for increased flexibility, enhanced accessibility, elevated speed and efficiency, improved safety, and consequential environmental benefits [10]. Notably, drones possess the capacity to significantly augment the efficiency and effectiveness of delivery operations, particularly in the context of humanitarian endeavors [11].

The adoption of drones as a specialized delivery option for logistics service providers depends on addressing critical considerations, including security, ease of use, and key safety factors [12]. Furthermore, optimizing delivery systems by incorporating drones is poised to enhance overall process efficiency, diminish delivery durations, and curtail fuel consumption. The integration of drones with traditional delivery methods, specifically in collaboration with trucks, holds promise for efficient deliveries within restricted traffic zones, thereby minimizing the overall time required to fulfill delivery tasks.

In recent research, [13] extensively discussed policies enhancing future drone-based delivery systems, emphasizing critical factors like drone trajectory, delivery time, energy management, depot placement, distribution of delivery points, payload constraints, and priority-based deliveries. Their work presents a comprehensive overview of design issues, existing drone-based delivery techniques, and outlines future research and development challenges. Bartolini et al. [14] proposed "DRUBER," a trustable decentralized drone-based delivery system, focusing on trustworthiness in decentralized drone delivery. This contribution explores challenges and solutions in decentralized drone-based delivery systems, particularly emphasizing security concerns in large-scale delivery scenarios. Kirschstein [15] conducted a comparative analysis of energy demands between drone-based and ground-based parcel delivery services, highlighting the energy efficiency of drone-based systems. The paper contributes insights into the energy implications of drone delivery, enriching our understanding of environmental impacts. Baldisseri et al. [16] performed an economic and environmental assessment of a truck-based drone delivery system, addressing both economic and environmental aspects and providing insights into potential benefits and challenges. Lastly, [17] evaluated a drone-based delivery system on a mixed Euclidean-Manhattan grid, with a focus on operational aspects in complex urban environments. This study provides insights into challenges and opportunities for deploying drone-based delivery systems in urban settings with mixed grid structures. Collectively, these studies contribute to the evolving landscape of drone-based delivery systems by addressing technological, security, energy, economic, and operational dimensions.

Dey et al. [18] propose a novel approach to developing an unmanned aerial vehicle for emergency healthcare and response systems in Bangladesh. Their research emphasizes the need for specialized drone designs that can accommodate medical equipment and personnel, as well as the importance of effective communication networks to support drone operations during emergencies. Hong et al. [19] range-restricted recharging station coverage model presents an optimization framework for planning drone delivery services with limited travel range and battery life. Lynskey et al. [20] present a facility location problem approach for distributed drones, proposing an optimization framework that considers the placement of multiple drone facilities to maximize delivery coverage and minimize overall costs. Kim and Moon [21], traveling salesman problem with a drone station, propose an optimization model that considers the placement of drone charging stations and the routing of drone deliveries to improve delivery efficiency. Shavarani et al. [22] apply a hierarchical facility location problem to optimize a drone delivery system for Amazon Prime Air in San Francisco. Hong et al. [23] discuss a

Table 1
Previous works on delivery system using drones and their recommendations

SL No	Year	Factors considered				
		ARA	DS	WH	CA	Recommendations
1	(2020)		✓			Consider flight speed, environmental factors for BCR impact.
2	(2019)		✓			Elevates efficiency with the proposed 3SH heuristic algorithm.
3	(2017)				✓	SA implementations aid swift delivery predictions and budget planning.
4	(2021)		✓			Drones collaborating for efficient parcel deliveries.
5	(2017)	✓	✓	✓		Include additional obstacles and restricted zones for flights.
6	(2018)	✓	✓	✓		Emphasize costs and profitability aspects.
7	(2020)		✓			Challenges in managing battery resources.
8	(2019)	✓	✓			Dynamic battery charging and energy optimization enhance realistic routing schedules.
9	(2018)		✓			Increasing demand for drones in emergency services.
10	(2021)				✓	Broaden to humanitarian applications, aiming for equitable relief item allocation.
11	(2018)		✓		✓	Interest lies in hybrid systems combining trucks, SUVs, and drones.
12	(2020)		✓		✓	Explore congested models for minimizing waiting time.
13	(2019)		✓			Enhance computational efficiency in the proposed algorithm.
14	(2019)		✓			Investigating the dynamics of a complex system in an infinite horizon poses an intriguing challenge.
15	(2021)		✓	✓		Assess the development of a decomposition heuristic for larger instances.
16	(2020)		✓		✓	Examine the coordination of trucks and drones in the given scenario.
17	(2019)				✓	The proposed algorithm holds potential for widespread adoption in solving analogous planning and scheduling issues.
18	(2020)		✓			Implementing drone-based parcel delivery using city building rooftops as drone hubs.
19	(2020)		✓			Design a system integrating the proposed model with drone technology.
20	(2021)				✓	Extend MTSP-MD to enable parallel operation of multiple trucks.
21	(2021)		✓		✓	SM models should consider linear or planar touchpoints for primary and supporting vehicles.
22	(2017)		✓		✓	Incorporate planning robust trunk delivery routes and dynamically adjusting them based on real-time customer travel information.

Notation: ARA = Air-restricted Area, DS = Drone Station, WH = Warehouse, CA = Cost Analysis.

single UAV-based transportation strategy for metropolitan areas that would avoid obstacles by locating recharge stations and building communication pathways around them.

These optimization frameworks aim to improve routing and charging station placement while reducing overall costs. While some studies have focused on specific regions or applications, there is a growing need for more comprehensive analyses that consider a range of factors such as environmental impact, public acceptance, and regulatory requirements.

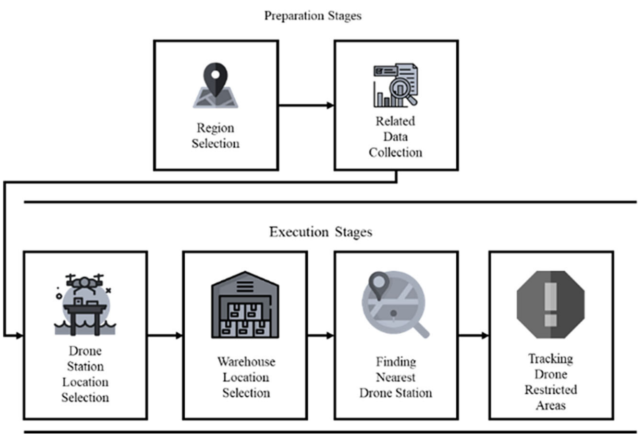
Table 1 shows that drone station or recharging station for drones has been considered in most of the papers, and air-restricted area, location of warehouse, and cost calculation are not much considered. Hong et al. [19] considered air-restricted area, drone station, and warehouse in their research, and they recommended other researchers to focus on cost and profit. We are highly motivated to use all of these factors along with the cost analysis in our study.

3. Our Proposed Model

The implementation of a drone-based product delivery system is a complex undertaking that requires both technical and non-technical strategies. It involves a multitude of challenges, ranging from regulatory requirements to practical considerations. In this study, we propose a model that builds upon previous research efforts, which were exhaustively reviewed in the literature. The proposed model has been designed to address some of the shortcomings identified in earlier works, with the overarching goal of advancing the state of drone technology to the next level. Our case study highlights the significance of these advancements, emphasizing the importance of continued research into the development of effective drone-based delivery systems for the benefit of society as a whole.

Figure 1 describes our proposed model consists of two major stages, preparation stages and execution stages. Preparation stage has the individual sub-stage like case study region selection and collecting delivery data from a product delivery company. The execution has four sub-stages. They are Drone Station location selection Warehouse Location Selection, Finding the nearest drone station, and Tackling drone-restricted areas.

Figure 1
Our proposed model



4. Model Implementation

4.1. Stage 1: Case study region selection

The process of selecting a suitable region for the case study was carried out meticulously, given the critical role played by the selected region in the success of the goal of this research. We choose Rajshahi, Bangladesh, as our case study suitable region.

Rajshahi is a city in Bangladesh. The Rajshahi City Corporation has a total area of 96.72 sq Km, divided into 4 thanas. The city's growing economy and increasing demand for efficient logistics and delivery services provide an opportunity to assess the potential benefits of drone-based deliveries compared to traditional transportation methods.

Furthermore, the regulatory environment in Bangladesh has become increasingly supportive of the drone industry. New regulations introduced in 2020 allow for drone usage in various industries after obtaining proper clearance from aviation authorities, making it easier for businesses to leverage drone technology for delivery purposes.

Conducting a case study in Rajshahi would provide valuable insights into the feasibility, efficiency, and social impact of using drone technology for product delivery in developing countries. With its rapidly growing economy and unique logistical challenges, this case study can inform policymakers and industry leaders on the potential of drones for improving logistics and supply chain processes in similar regions.

Overall, the potential benefits of drone-based delivery systems, coupled with the challenges and supportive regulatory environment present in Rajshahi, make it an excellent choice for a case study on the use of drones in product delivery.

4.2. Stage 2: Collecting delivery data from a product delivery company

To gather demand data for our study on product delivery services in Rajshahi, Bangladesh, we chose RedX as our primary data source. RedX is a highly regarded product delivery company that operates throughout Bangladesh. Through the analysis of their data, we gained insights into the patterns and trends of delivery demand within the Rajshahi City Corporation.

4.3. Stage 3: Drone station location selection

When considering the implementation of an advanced delivery system utilizing drones, it is important to acknowledge certain limitations inherent to the technology. Specifically, the flight range of drones is limited, and they are powered by batteries or fuel cells, necessitating refueling or recharging stations for extended coverage in a wider area.

To account for this limitation, a heuristic method was employed in the selection of drone station location within the Rajshahi City Corporation. This approach involved using practical guidelines and problem-solving techniques to determine optimal locations for the deployment of these stations, with the aim of maximizing the range and efficiency of the drone delivery system.

By utilizing this heuristic method, we were able to effectively address the limitations posed by the range and power requirements of drones. Our research suggests that the identification and strategic placement of drone stations can significantly enhance the effectiveness and practicality of drone-based delivery systems, particularly in areas with unique geographic and logistical challenges.

The drones under consideration for this particular case study possess a flight time of 20 min while carrying a load of 5 kilograms and 40 min without any load. The aforementioned flight times have been calculated for a height of 10 meters above sea level at an average speed of 40–50 km/h. In the event that the battery level drops to 15%, the drones will begin their journey towards the nearest drone station. With a 5 kg payload, the drone can remain airborne for approximately 3 min while it can last up to 6 min without any payload. With a charge of 15%, the minimum distance that the drone can cover is 2 kilometers. Hence, we have set the range of the drone station at 2 kilometers.

The location determined as suitable for the drone station installation, based on the calculations discussed earlier, has been presented in Figure 1. The coordinates for this location are provided below.

Table 2
Drone station locations

	Location name	Coordinates
Drone station 1	Binodpur	24.3657664, 88.6440941
Drone station 2	Alupotti	24.3612125, 88.6052031
Drone station 3	Sufinagar	24.3971752, 88.6083409
Drone station 4	Verypara	24.3739063, 88.5680601

Table 2 shows the coordinates of the drone station location found based on the calculations discussed earlier.

Figure 2 illustrates the identification of four appropriate locations earmarked for the establishment of drone stations.

4.4. Stage 4: Warehouse location selection

The selection of a suitable warehouse location is a crucial decision for any logistics company, as it directly impacts the efficiency and cost-effectiveness of their operations. In this study, we leveraged the delivery data of RedX, a leading logistics company in Bangladesh, to identify an optimal warehouse location for their operations in Rajshahi City.

To begin with, we obtained the number of deliveries for Rajshahi City from RedX's delivery records. Then, using K-means clustering – a popular machine learning method for partitioning data into groups – we segmented the delivery demands into four distinct clusters. The iterative nature of K-means enabled us to obtain reliable and accurate results for cluster formation.

Once we had the four clusters, we identified the centroid – or center – for each cluster, representing the average point in that cluster. We also calculated the respective demand for each centroid based on the total demand within that cluster. Using these four centroids and their corresponding demands, we applied the Center of Gravity Method to determine the optimal warehouse location.

Our analysis was performed using Python programming language, which enabled us to efficiently process and visualize the data. Ultimately, our methodology yielded the longitude and latitude coordinates for the ideal warehouse location. This approach can be replicated in other contexts to identify suitable warehouse locations for logistics companies looking to optimize their operations. Table 2 depicts the coordinates of our selected warehouse.

Figure 2
Locations of the drone stations

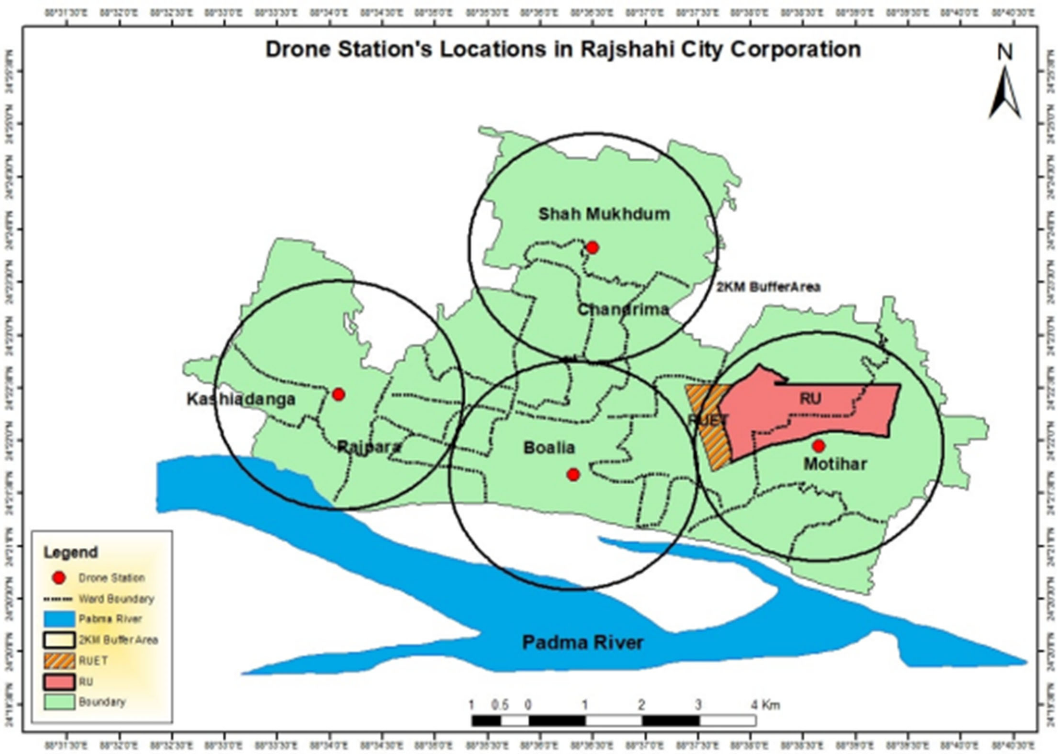


Table 3
Warehouse location

Latitude	Longitude
24.373892	88.607576

Table 3 shows the latitude and the longitude of the warehouse location found using k-means clustering.

4.5. Stage 5: Finding the nearest drone station location

In this study, we developed a code to find the nearest drone station in real time using the Haversine formula.

$$\begin{aligned} a &= sin^2\left(\frac{latDifference}{2}\right) \\ &\quad + \cos(lat1).\cos(lat2).sin^2\left(\frac{lonDifference}{2}\right) \\ c &= 2.atan2\left(\sqrt{a},\ \sqrt{(1-a)}\right) \\ d &= R.c \end{aligned} \tag{1}$$

Where
latDifference = lat1 – lat2
lonDifference = lon1 – lon 2
R is the radius of earth, that is, 6371 Km

Our proposed model has four designated drone stations for recharging of the drones, and our code is designed to identify the closest one based on the current location.

The code takes the present location's longitude and latitude as input and calculates the distance from all four stations using the Haversine formula. It then finds the station with the shortest distance and designates it as the nearest drone station.

Our approach enables logistics companies to efficiently utilize their drone fleet by ensuring that each drone is dispatched from the nearest station, reducing travel time and cost. This methodology can be adapted to other contexts where multiple drone stations are present, allowing for more effective and streamlined logistics operations.

4.6. Stage 6: Tackling drone-restricted areas

One of the significant challenges in drone logistics operations is navigating through restricted areas without compromising safety and regulatory requirements. In this study, we developed a method to minimize the number of nodes required for the drone's path while avoiding restricted areas.

To achieve this, we utilized two lines parallel to the x-axis and y-axis, respectively, and compared the goal point with the cross-section of these lines. By analyzing the position of the goal point relative to these lines, we determined whether the drone needed to navigate through any nodes or not.

Our approach effectively reduces the number of nodes required for the drone's path, improving its efficiency, and reducing the risk of deviation from the designated path. Moreover, it ensures that the drone adheres to safety regulations and avoids restricted areas. This methodology can be applied to other contexts requiring efficient and safe drone logistics operations.

Figure 3
Identification of drone-restricted area using ArcGIS

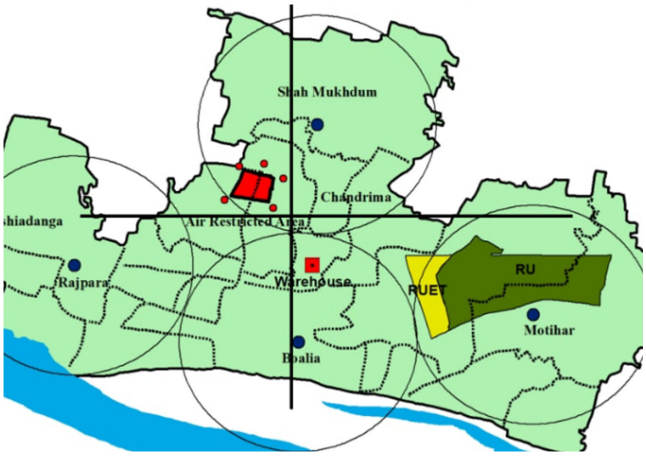


Figure 2 provides an expanded view showcasing the demarcation of restricted drone areas through the application of ArcGIS in this research study.

In this study, we implemented a method to determine the nodes that a drone would follow to reach its delivery destination while avoiding restricted areas. To achieve this, we used two parallel lines (one parallel to the x-axis and the other parallel to the y-axis) and compared the delivery destination's coordinates with the cross-section point of these lines.

If the delivery destination's x-coordinate is less than the cross-section points and the y-coordinate is greater than the cross-section point, then the drone would use nodes to navigate to the delivery destination.

To identify the nodes that the drone would follow, we employed the A* search algorithm.

Our methodology enables efficient and safe navigation for drones, ensuring that they adhere to regulatory requirements while minimizing the number of nodes required. This approach can be adapted and expanded to other contexts, supporting the development of scalable solutions for drone logistics operations.

4.6.1. Example

The delivery network illustrated in Figure 1 features a warehouse at point A and a delivery point at point G. However, an obstacle in the form of a restricted area exists between these two points, impeding direct travel from A to G. To navigate around this obstacle, nodes (B, C, D, E, and F) were strategically plotted around the restricted area. The objective was to find the optimal path from the warehouse (A) to the delivery point (G) by traversing these nodes.

Figure 4
A visual representation of the nodes and the delivery destination G

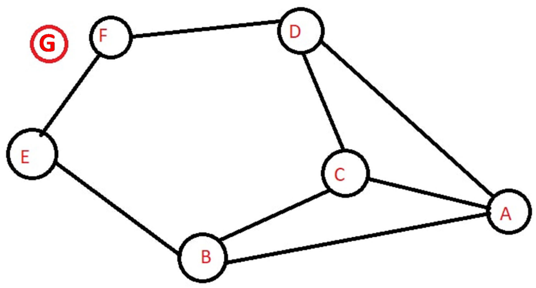


Figure 4 presents a visual representation detailing the nodes and the respective delivery destinations denoted by the label "G."

In the process of optimizing drone navigation from the warehouse located at point A to the delivery point (G), several tests were conducted. The A* search algorithm was used to determine the best possible route, leading to the discovery that the most effective path was through intermediate point D, resulting in the sequence A → D → G. Further analysis revealed that point F was never utilized during any of the tests. Consequently, point F was removed from consideration in subsequent iterations of the drone navigation system. These findings demonstrate the importance of continuous testing and optimization to improve the efficiency and effectiveness of complex systems.

Figure 5
Second iteration of the algorithm to make it more optimized

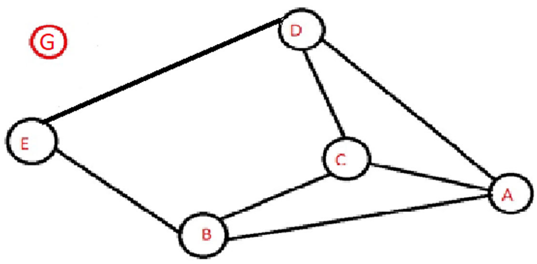


Figure 5 illustrates a visual representation depicting the nodes and the designated delivery destination marked as "G," building upon the insights presented in Figure 4.

The A* search algorithm was employed to navigate a drone from point A, a warehouse, to the final destination at point G located within a restricted zone. The resulting path generated by the algorithm was A → D → G, indicating that the drone must pass through intermediate point D before arriving at the final destination. This finding highlights the effectiveness of the A* search approach for navigating complex environments with obstacles and limited access.

Figure 6
Restricted area and node distribution

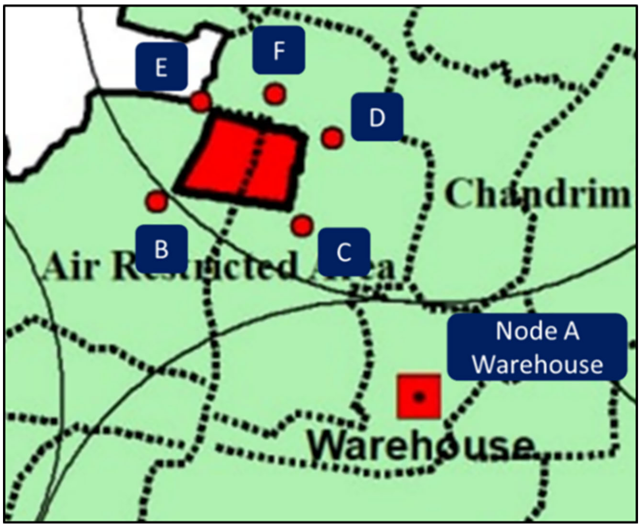


Figure 6 displays the map after plotting the nodes for restricted zone.

Figure 7 shows the final map made by Arc GIS after plotting the nodes for drone-restricted zone.

5. Implementation Cost of Our Proposed Model

In this section, we have calculated the cost of implementing our model in the existing world. This cost is measured using various online sources, and we have considered cost factors such as construction cost, labor costs both for warehouse and drone stations, cost of drone purchase, drone-rescue cost, drone charging cost, and drone management cost.

5.1. Construction cost

Table 4 shows the construction cost for one drone station. We have four drone stations, so the total construction cost for drone stations will be BDT 5974200. And the construction cost of the warehouse is also similarly calculated and the cost is BDT2000000.

So, the total construction cost of the first year will be BDT 7974200.

5.2. Labor cost

Table 5 shows the total cost of labor which is 4980000 BDT for the first year of operation.

There will be 4 laborers in each drone station. The monthly salary of the labor is BDT 15000 each. So, per drone station the total labor cost will be BDT 60000 per month and BDT 2880000 per year. In the warehouse, there will be a total of 10 laborers. A manager, a drone manager, and a product manager. And their salaries are BDT 30000, BDT 25000, and BDT 25000, respectively. And in a year, the total salary for the managers will be BDT 960000. There will be five laborers who will associate

Figure 7
Final map after plotting the nodes for restricted zone

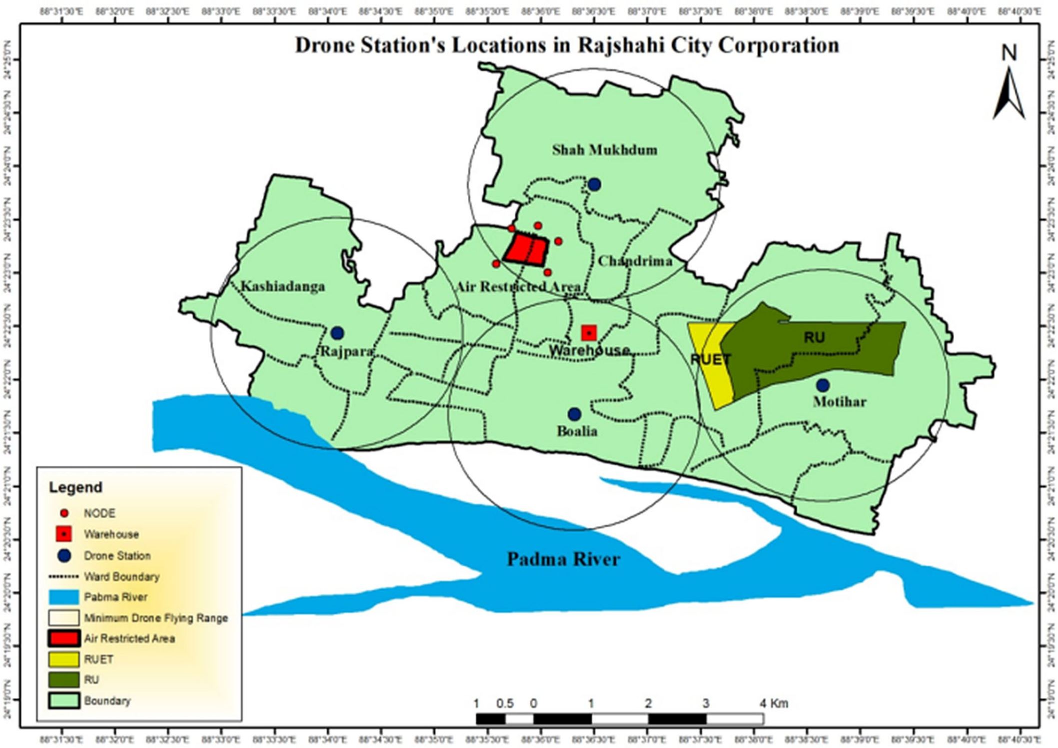


Table 4
Cost of construction for single drone station

No.	Product description	Unit	Unit price (BDT)	Quantity	Total (BDT)
1	Cement	Bag	520	580	301600
2	Local sand	Cft	24	1500	36000
3	Brick	Nos.	13	17500	227500
4	Brick for aggregate	Nos.	10	16000	160000
5	Rod 8 mm	Kg	75	500	37500
6	Rod 10 mm	Kg	75	2200	165000
7	Rod 12 mm	Kg	75	750	56250
8	Rod 16 mm	Kg	75	2700	202500
9	Sylhet sand	Cft.	52	600	31200
10	Labor cost	Sft.	230	1200	276000
				Total	1493550

Table 5
Labor cost for first year

Labor cost for the first year		
	Number of personnel	Total cost (BDT)
Drone station labor cost	16	2880000
Warehouse labor cost		
Management	3	960000
Drone management	5	900000
Cleaning and others	2	240000
Total	26	4980000

with the product delivery by the done. And their monthly salary is BDT 15000. And that will be BDT 900000 yearly. And for clearing and other things, the cost for labor will be BDT 240000 per year. If we add on all the costs, then it will be BDT 4980000 in the first year. We will increase 5% salaries for all the labor and workers yearly. So, the total labor cost for the second, third, fourth, and fifth year will be BDT 5229000.00, BDT 5490450.00, BDT 5764972.50, and BDT 6053221.13, respectively.

5.3. Annual cost analysis

Table 6 shows all costs of first year. This year's consist of drone station construction cost, warehouse construction cost. Inclusion of these cost this becomes the most cost-heavy year.

Table 6
Total cost of first year

First-year cost (BDT)	
Drone station construction cost	5,974,200.00
Warehouse construction cost	2,000,000.00
Drone purchase cost	2,800,000.00
Labor cost	4,980,000.00
Drone charging cost	129,600.00
Drone rescue cost	150,000.00
Drone maintenance	250,000.00
Total	16,283,800.00

Table 7
Total cost of second year

Second-year cost (BDT)	
Drone station construction cost	0.00
Warehouse construction cost	0.00
Drone purchase cost	0.00
Labor cost	5,229,000.00
Drone charging cost	129,600.00
Drone rescue cost	150,000.00
Drone maintenance	250,000.00
Total	5,758,600.00

Table 8
Total cost of third year

Third-year cost	
Drone station construction cost	0.00
Warehouse construction cost	0.00
Drone purchase cost	400,000.00
Labor cost	5,490,450.00
Drone charging cost	151,200.00
Drone rescue cost	150,000.00
Drone maintenance	250,000.00
Total	6,441,650.00

Table 7 shows in the second year only labor cost increased by 5% but other costs will remain same. And drone station construction cost, warehouse construction cost, drone purchase cost will be 0. As we will not build any drone station or warehouse, we will not buy any drone this year.

Table 8 shows in the third year, because of increasing delivery of products, we will buy 5 new drones and that will cost BDT 400,000.00. And it will affect the charging cost. So, the charging cost will be increased by BDT 21,600.00. And the rest cost will be the same as the second year.

Table 9 shows in the fourth year, the labor cost will also be increased by 5% but other costs will remain same. And drone station construction cost, warehouse construction cost, drone purchase cost will be 0. As we will not build any drone station or warehouse, we will not buy any drone this year.

Table 10 shows that in the fifth year, because of increasing delivery of products, we will again buy 5 new drones and that will cost BDT 450,000. And it will affect the charging cost. So, the charging cost will be increased by BDT 21,600.00. And the rest cost will be the same as fourth year.

Table 9
Total cost of fourth year

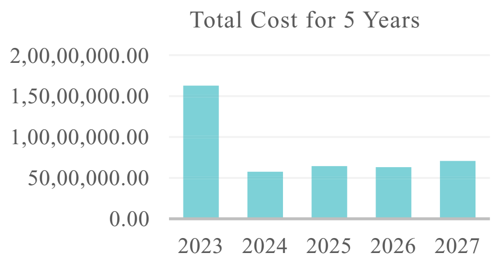
Fourth-year cost	
Drone station construction cost	0.00
Warehouse construction cost	0.00
Drone purchase cost	0.00
Labor cost	5,764,972.50
Drone charging cost	151,200.00
Drone rescue cost	150,000.00
Drone maintenance	250,000.00
Total	6,316,172.50

Table 10
Total cost of fifth year

Fifth-ear cost	
Drone station construction cost	0.00
Warehouse construction cost	0.00
Drone purchase cost	450,000.00
Labor cost	6,053,221.13
Drone charging cost	172,800.00
Drone rescue cost	150,000.00
Drone maintenance	250,000.00
Total	7,076,021.13

Figure 8 portrays the total cost over the upcoming five years.

Figure 8
Total cost for 5 years (2023 to 2027)



5.4. Revenue analysis

Table 11 shows that in year 2023, the revenue was 6,552,000.00 Taka by delivering 187200-unit products. In 2024, the revenue will be increased by 5% and the revenue will be BDT 6,904,800.00, and the number of products delivered will be 197280. In 2025, the growth of revenue will be 1%, revenue being BDT 6,993,000. In 2026, because of the increase in 5 drones, the revenue will also increase 8% to revenue BDT 7,585,200.00. In 2027, the total amount of 221400-unit products will be delivered which will increase the revenue 2% to BDT 7,749,000.00. The calculation of this revenue used the delivery fee of BDT 45.

Figure 9 displays the revenue analysis for next 5 years.

Table 11
Revenue analysis

Year	2023	2024	2025	2026	2027
Unit delivered	187200	197280	199800	216720	221400
Revenue	8,424,000.00	8,877,600.00	8,991,000.00	9,752,400.00	9,963,000.00

Figure 9
Revenue analysis for 5 years

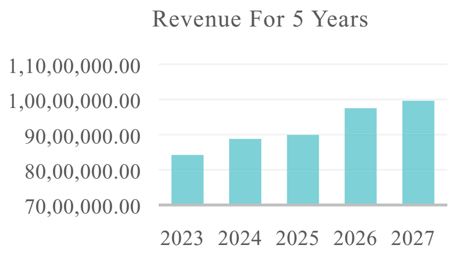


Figure 10
Revenue analysis for 5 years

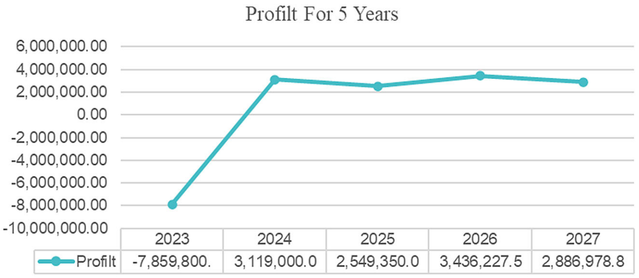


Figure 10 shows a 5-year profit graph. In 2024, there was a significant increase in profit and the profit margin reaches positive from then the profit stays stable indicating a stable market of the business.

From Table 12, we can see the profit margin from 2023. As our initial cost is high, our profit margin is in the negative, and we will be at a loss in the first year. After that our profit margin will increase.

Table 12
Profit margin for next 5 years

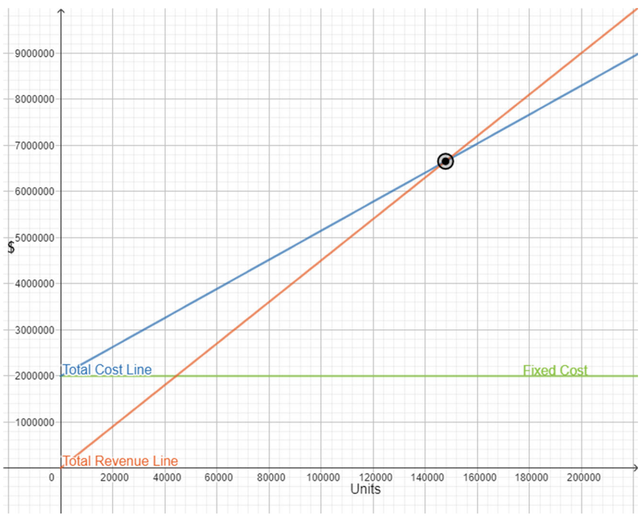
Year	2023	2024	2025	2026	2027
Profit margin	−136%	54%	40%	54%	41%

5.5. Break-even analysis

Table 13 shows the break-even analysis fixed cost is BDT 664966.85. The fixed cost includes maintenance cost, utility bills, and other costs that must be paid over time. Variable costs are changing costs, variable cost includes drone purchase as it is planned to purchase more drones over time, labor cost, and drone charging cost. These are the main variable costs.

In Figure 11, the fixed cost, variable cost, and revenue were plotted in a graph; then, we got our break-even point. We can see we will reach the break-even point after delivering 147766 products to the customers. The delivery charge for every product will be BDT 45, which is 47% less than the present delivery charge of RedX.

Figure 11
Break-even chart



6. Results

This study presents an optimization approach for designing a drone delivery system in Rajshahi City Corporation. The heuristic method was used to minimize the number of required drone

Table 13
Break-even analysis cost and revenue table

	2023	2024	2025	2026	2027
Fixed cost	1,994,840.00	1,994,840.00	1,994,840.00	1,994,840.00	1,994,840.00
Variable cost	7,909,600.00	5,358,600.00	6,041,650.00	5,916,172.50	6,676,021.13
Revenue	6,552,000.00	6,904,800.00	6,993,000.00	7,585,200.00	7,749,000.00

stations, with a minimum flying range of 2 Km. It was found that four drone stations were needed to cover the entire area.

To facilitate efficient delivery operations, a warehouse location was needed to store products and serve as a central distribution point. To determine the optimal warehouse location, K-means clustering was used, resulting in an ideal location at (24.373892, 88.607576), which is located near the center of the city corporation.

However, drone deliveries are subject to airspace restrictions, so the A* Search Algorithm was employed to develop a route planning algorithm that would avoid restricted areas. This algorithm ensures that drones can navigate safely and efficiently to their destinations without violating airspace regulations.

We have calculated the costs for creating the drone stations and warehouse. We have also calculated the costs of purchasing drones and their maintenance cost along with their charging cost. The labor costs were also included. From the break-even analysis, we can see that the drone product delivery system will be able to reach the break-even at the end of 2023 by completing the delivery of 197280 products while keeping the delivery charge at BDT 45 per product; where the current delivery charge of RedX is BDT 85, it will save the customer and RedX 47% [24] in per-product delivery cost.

Overall, this study demonstrates the importance of optimization techniques in designing effective drone delivery systems that account for various factors such as infrastructure, logistics, and regulatory considerations. The proposed approach can be adapted to other regions and contexts, providing insights into how drone delivery systems can be developed to improve last-mile delivery services.

7. Discussion and Conclusion

Unmanned aerial vehicles or drones have the potential to provide a faster delivery service of small packages in various situations, as they can fly directly from one location to another. But air-restricted areas create problems for drones to fly directly from one place to another. As there is a limitation in the flying range of drones, drone stations are needed for recharging the drones. Though drone delivery service is a low-cost service, its maintenance is very tough. A lot of complications have to be faced in creating drone delivery services. This research has worked on the intricacies of delivering products using drones and developed an optimized delivery system.

Drone stations have been created using a heuristic method for recharging drones. A warehouse was created using the K-means clustering method to keep the products and deliver them to the customers. As the drone flies directly from one point to another, air-restricted or drone-restricted areas create problems. This problem has been overcome with the A* Search algorithm. Routes have been created for drones so that they will never fly over restricted areas. This research used data from RedX. If any company is willing to give their data, a profit-maximizing delivery system can be developed in any location using this study. The unmanned aerial vehicle or drone delivery system is both a profit-maximizing and time-consuming service. As customer satisfaction plays a vital role in this competitive world, this delivery service will be a great innovation.

Though the case study was conducted in Rajshahi City Corporation, this can be implemented throughout Bangladesh. If any industry is willing to give their data regarding their products, it is possible to create an optimized product delivery system using drones for that company. This delivery system currently includes only the products delivered manually by RedX. But using this research, any company will also be able to deliver food, medical kits, medicines, etc. As the world is being digitalized day by day, the time is very close when manual delivery will not exist. Drone delivery system is the best way to cope with the digitalized world.

This study, while promising, has limitations, focusing on RedX and potentially limiting its generalizability to diverse industries. The geographical applicability is uncertain, having been tested in a specific location, and relying on data from a single source may not fully capture industry complexities. Regulatory challenges in widespread drone usage are overlooked, emphasizing the need for further research. Despite these limitations, the research demonstrates potential reproducibility, provided companies share relevant data. Future research directions could explore broader industry applications beyond RedX, adapting the optimized drone delivery system for various products and sectors. Addressing regulatory challenges, legal frameworks, environmental impact, safety measures, and public acceptance is crucial for a comprehensive understanding of the drone delivery system's viability on a larger scale.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support the findings of this study are openly available in [repository name, for example, "figshare"] at http://doi.org/[doi]

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