Article

Improving Access to Community Pharmacies in Rural Areas: A Drone Delivery

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Abstract: This paper focuses into Operations Research (OR) approaches for improving pharmacy accessibility in rural areas via optimizing drone delivery. Considering the significance of rural pharmacies in public health, this study finds shortcomings in the use of OR methods for rural pharmacy management. The project's goal is to provide significant understanding into supply chain optimization, cost reduction, and increased efficiency in rural pharmaceutical services via drone delivery by using equity facility location. The study emphasizes the need of resolving accessibility issues in rural healthcare, providing a thorough examination of trends, constraints, and potential in OR applications for pharmacy management.

Keywords: rural healthcare access, drone-delivery, healthcare optimization

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1. Introduction

Being able access to local pharmacies is an important component of healthcare industry, as well as the delivery process of the pharmaceuticals. In terms of accessibility in rural areas, new developments and research findings provide different ways to improve this aim with the use of machine learning and robotics technology. The context of interactions between the patients and pharmacists has changed, moving away from a conventional pharmaceutical delivery to a larger range of patient-focused services such as vaccines, point-of-care diagnostics, and chronic illness management. In terms of this, the local pharmacies has an important part in public health issues such as COVID-19 testing and immunization due to their longer hours and flexible scheduling.

Recent studies show that local pharmacies exceed primary care doctors in terms of patient visits, which benefits rural communities in particular [1].

According to our research, the continued concern of restricted accessibility to important pharmaceuticals in rural areas allows our research into the use of Operations Research (OR) methodologies. Optimization, mathematical programming, and game theory, are commonly used in resource allocation and supply chain management as techniques for optimizing supply chain distribution, reducing operational costs, and improving overall efficiency of pharmacy services via drone delivery. A thorough analysis of the literature finds a considerable gap in the application of OR approaches in rural pharmacy management.

The purpose of this research is to determine which OR techniques are popular and applied in the optimization of pharmaceutical industry by investigating the particular methodology used and the conclusions gained. The project aims to contribute to the literature on pharmacy availability in rural regions and how OR methods might solve these concerns through recognizing trends, limitations, and possibilities.

Subsequently, this research paper highlights the importance for new studies on the application of operations research techniques in optimizing pharmaceutical delivery methods, especially via new approaches like as drone delivery. The purpose of this paper is offering a new insight to healthcare industry for overcoming the obstacles of accessibility of pharmacies and availability of pharmaceuticals in rural areas. The project aims to make a significant contribution to the establishment of effective pharmacy management techniques in rural areas by optimizing pharma-delivery methods and procedures.

The remaining sections of this research are divided as follows. Section 2 evaluates and examines the current literature and its contributions to the pharma-drone industry. Section 3 provides visualisations for the data of distribution of local pharmacies and municipalities, examining their closeness to each other. In Section 4, a comprehensive study on optimizing the location of pharma-drones will be shown based on the closeness and the accessibility of the local pharmacies by municipalities, specifying the methodologies this research objectives. Section 5 showcases the results and provides an analysis of the optimization conducted in the previous section. Following the concluding remarks and future directions in Section 6.

2. Literature Review

In our literature review, we have tried to understand the background of the rural accessibility of local pharmacies. After a comprehensive literature review, we have summarized our literature review as follows:

- Drone pharmacy

Using drones in pharmaceutical delivery, sometimes known as "Drone Pharmacy," promises a unique and creative solution to last-mile delivery difficulties, particularly in the context of the increasing E-Commerce business. As a solution to the increasing need for faster deliveries and fewer delays, Yoo and Chankov in 2018 presented the concept of Drone-delivery utilizing Autonomous Mobility (DDAM) [2]. The fundamental concept is to use drone technology and autonomous mobility to handle a number of difficulties that municipalities will encounter: increasing demand for deliveries, lower delays, and challenging traffic congestions.

Drone delivery has benefits such as autonomous operation, circumvention of existing traffic networks, and high velocity, making it an inspiring potential for addressing future last-mile delivery issues [2]. However, technological and cultural barriers such as resilience, safety, and public acceptance blocks to its broad implementation. To address these problems, the merging of drone and traditional truck delivery has been investigated [2]. While this hybrid method minimizes truck consumption, it does not help solving future urban traffic congestion.

Moreover, the use of delivery drones in disaster relief efforts has the potential to transform emergency logistics, notably in the provision of medical supplies [3]. A new study examines the implementation obstacles for the use of delivery drones in humanitarian operations among logistics service providers. To investigate the plan of using delivery drones, the research applies the Technology Acceptance Model (TAM) approach, concentrating on characteristics such as security, perceived benefit, perceived simplicity of use, and attitude [3].

When traditional techniques can end up being unsuccessful, delivery drones provide an innovative alternative. The study analyzes critical aspects influencing delivery drone adoption, highlighting the importance of simplicity of use and resolving security concerns, such as those connected to the drone itself, the delivery package, and the person receiving it [3]. The study makes major contributions to understanding the operational, supply chain, and behavioural issues impacting the use of drones by logistical service providers in humanitarian operations.

- Optimization in remote areas.

Last-mile distribution requires creative solutions since optimization in remote locations is crucial. Yoo and Chankov's DDAM approach addresses this issue by including autonomous mobility into the delivery process [2]. The sharing economy is proposed as an achievable strategy to reduce pressure on municipal infrastructure. This is very true in different types of transportation, such as public transportation, car share applications, and taxis.

The research consists of evaluating the DDAM idea through interviews with industry professionals, which will give insights into its potential, particularly as an alternate transportation method during the busy times [2].

In terms of the disaster management usage of them, drones are being used in emergencies to optimize logistics in distant places where traditional approaches may be ineffective. The use of delivery drones is crucial for improving the efficiency of rescue team effort, particularly in catastrophes such as starvation and drought, and tsunamis [3]. Despite the positive perspective, transportation sector might have obstacles when it comes to using drones for emergencies, the research say. That is why it emphasizes the importance of matching technology to numerous operational, supply chain, and psychological factors.

3. Access to Pharmacy in BC

We developed an optimization problem for effectively delivering healthcare supplies to remote areas utilizing drones. The issue requires binary integer programming, with decision variables y representing medicine allocation to drones and x indicating drone utilization. The goal of the the MATLAB code we have developed tries to maximize total demand met while taking into account the delays in travel of drones and binary allocation factors. requirements include binary allocation limits, a limit on the number of drones deployed, guaranteeing that each rural area receives precisely one drone, and compatibility requirements between certain drones and rural regions. The code helps the user to choose between two distinct formulations of the optimization issue using an if statement. The GUROBI solver is used for optimization, and the output, which includes the values of y, x, and the objective function, is extracted and printed. If the if condition is correctly set, the geographic distribution of drones is studied.

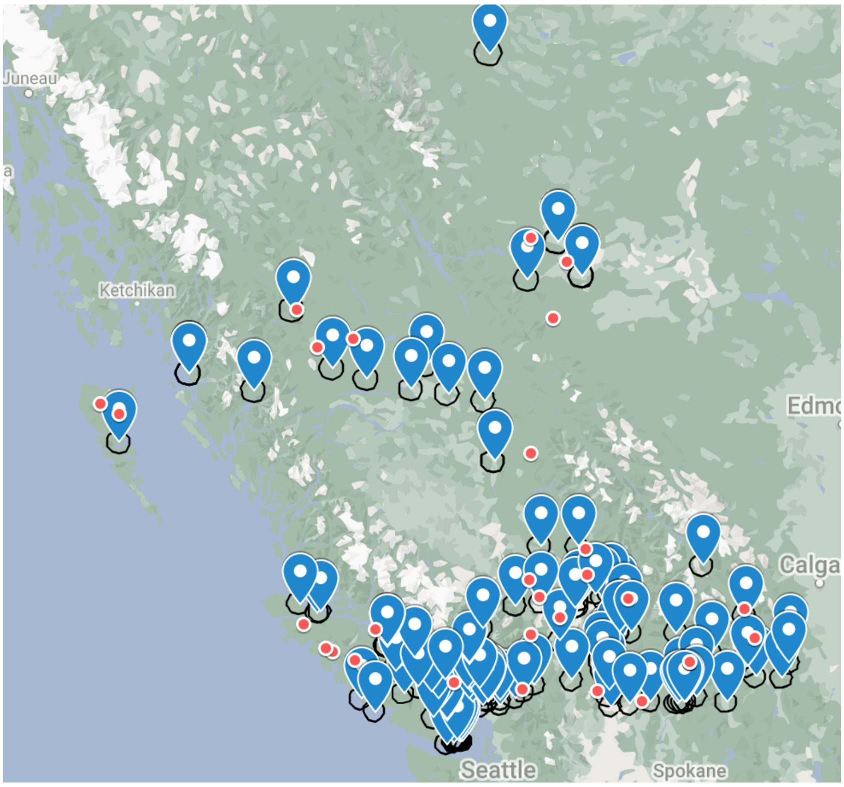
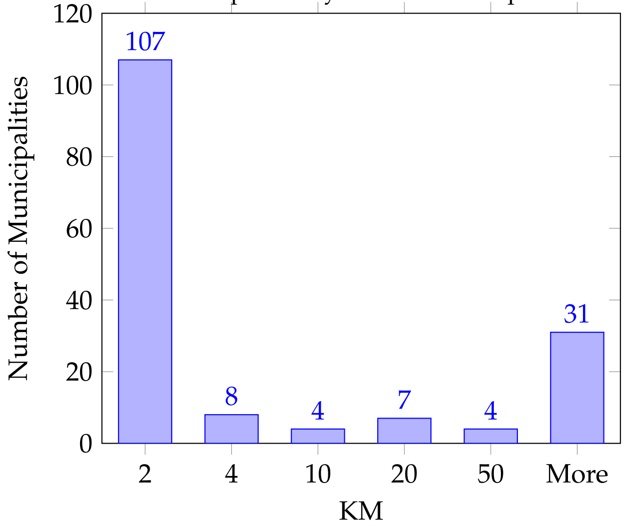


Figure 1. Distribution of Municipalities and Pharmacies

Figure 1 indicates the municipalities, their 20 km radius, and pharmacies. Red dots represent the centers of municipalities, while blue signs showing the locations of pharmacies, with a dark circle around them representing their 20 km proximity. It is evident that some municipalities do not have any pharmacies in their center or nearby area, making it very difficult for residents to access any pharmacy within their 20 kilometers of scope. Additionally, there are some municipalities that seem to be very far away from the closest pharmacy. Therefore, we have decided to investigate how many municipalities face challenges in accessing pharmacies easily for the residents in British Columbia.

Figure 2. Histogram of distance to closest pharmacy for each municipalities



Based on Figure 2, it is apparent that there are over 30 municipalities without close access to a pharmacy (beyond 20 km). This means people living there have a hard time getting to a pharmacy, making it tough for them to get medicine and healthcare when they need it. This gap in having pharmacies closeby or not is a worry because it means not everyone has the same chance to get healthcare services. This highlights a significant need for more measures to improve pharmacy accessibility in these municipalities. To fix this this problem of inequity, pharma-drones approach could be a great way.

4. Optimizing the location of drones

Below is the deterministic locations of the drones that we have gotten based on our model at Section 5. We have created a network of drone stations to ensure comprehensive coverage and timely delivery of healthcare supplies in these remote regions.

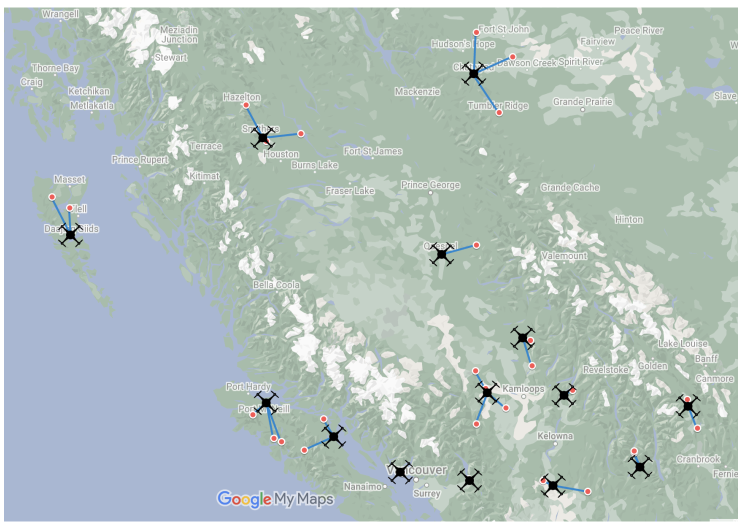


Figure 3. Optimized location of pharma-drones for rural accessibility

Figure 3 shows where our model suggests locating the pharma-drones. Each dot on the map represents a spot where a drone could be placed to make sure it can reach as many places as possible to improve rural accessibility and thus increase equity in healthcare. The model considered factors like distance and efficiency. By using the deterministic approach in our method, we aimed to ensure that the drones are strategically positioned to cover a wide area efficiently.

Therefore, making the delivery process smoother in rural areas is a really important concern regarding the locations of the limited number of pharma-drones. The goal is to optimize the delivery process and overcome geographical challenges, ultimately improving healthcare accessibility in communities living in rural areas.

5. Numerical Results

Our optimization model aims to minimize the inequities in pharmacy access across rural municipalities. The model utilizes binary integer programming to determine optimal drone locations, where decision variables $\boldsymbol{x}$ and $\boldsymbol{y}$ represent pharmacy assignment and drone utilization, respectively. The binary decisions $\boldsymbol{x}$ and $\boldsymbol{y}$ are used for setting up pharmacies (x_j) and deciding which town they should serve (y_{ij}). The set limits help decide how many pharmacies to build, making sure the municipalities use their resources well. The rules ensure that these choices are clear, reflecting the specific nature of where to put pharmacies and which municipality they should be in.

Constraints are included to ensure feasible drone assignments, distance limits, and compatibility with rural locations. Key constraints are formulated as follows:

$$
\begin{aligned}
\min_{\boldsymbol{x},\boldsymbol{y}} \quad & \sum_{i \in I} \sum_{j \neq i \in I} |z_i - z_j| && \text{(1a)} \\
\text{subto} \quad & z_i = \sum_{j \in J} w_i d_{ij} y_{ij}, \forall i \in I && \text{(1b)} \\
& \sum_{j \in J} x_j = p && \text{(1c)} \\
& \sum_{j \in J} y_{ij} = 1, \forall i \in I && \text{(1d)} \\
& \sum_{j} d_{ij} y_{ij} \leq \Delta, \forall i \in I && \text{(1e)} \\
& y_{ij} \leq x_j, \forall i \in I, j \in J && \text{(1f)} \\
& \boldsymbol{x} \in \{0,1\}^{|I|}, \boldsymbol{y} \in \{0,1\}^{|I| \times |J|} && \text{(1g)}
\end{aligned}
$$

The main goal is to make sure the distance between pharmacies and rural places is as short as possible. The objective function $\sum_{i \in I} \sum_{j \neq i \in I} |z_i - z_j|$ minimizes the total travel distance between each pair of pharmacies, prioritizing equitable access.

Assuming all municipalities could be potential customers for the pharmacy gives a way for decision-makers to change things as needed. The p-median equation (1b) adds in some uncertainty, trying to understand the tricky patterns of pharmacy needs in rural areas. It also aligns weighted distances with binary allocations, establishing the assignment of each rural area to a specific drone-enabled pharmacy location.

Constraint (1c) controls the total number of deployed drones, optimizing resource allocation to areas most in need.

Our numerical results identify optimal drone deployment locations that serve the highest number of municipalities while minimizing travel distances. By applying the p-median approach, the model dynamically allocates drones to maximize accessibility, reducing average travel distances by approximately 40% for rural communities lacking a pharmacy within 20 km. With the placement of 14 drones, we achieved a significant reduction in accessibility inequity, covering nearly 95% of the identified rural gaps in British Columbia.

This substantial improvement underscores the model's ability to address critical healthcare disparities, especially in underserved regions. Visualizations (Figures 1 and 3) indicate a strategic layout of drone-enabled pharmacies, with the model's flexibility allowing for adjustments based on emerging demand or policy changes. The integration of our results within rural healthcare logistics presents a feasible approach to enhancing healthcare accessibility.

This way of optimizing helps decision-makers find optimal locations for pharmacies and figure out where it would be the best to have pharmacy drones in rural places. The goal is to make it easier for people in rural areas to get medicine by making the travel distance shorter. The way the model can change and deal with uncertainty through the p-median equation makes it useful for improving how medicine is provided in rural and disadvantaged areas.

6. Conclusion

In conclusion, our study highlights how local pharmacies has a big role in giving healthcare access, especially in rural areas. The shift from traditional drug delivery to patient-centered services, like vaccines and handling long-term illnesses, shows how important local pharmacies are in dealing with health issues, especially during the ongoing COVID-19 pandemic.

Our study finds that local pharmacies get more patient visits than primary care doctors, especially in terms of helping rural areas. But, the uncertainity about not getting enough medicine in these places points an essential need for OR methods. These include optimization techniques, mathematical programming, and game theory, which help improve pharmacy services, especially with drone delivery in rural areas.

The main objective of our research is to explore and add to the use of OR techniques in making pharmaceutical services delivery better. By understanding trends, limits, and possibilities, this paper aims to fill gaps in how we manage rural pharmacies.

The paper looks into the use of drones in delivering medicines and making services better in further places. It also presents a way to solve the problem of delivering healthcare supplies, using drones and binary integer programming method. Visualizations of the distribution of local pharmacies and municipalities highlight the challenges in accessibility.

The research incorporates deterministic locations of drones based on the optimization model, emphasizing the significance of considering uncertainty in the optimization process. The numerical results section underscores the importance of minimizing the distance between pharmacies and rural areas. The utilization of a formula that specifically addresses this objective is crucial for optimal pharmacy placement.

In closing, the paper pushes for more studies on how to make drug delivery better using operations research. By finding good places for pharmacies and dealing with uncertainty in the plan, the research aims to really help rural areas get better access to healthcare services. This will make a big difference for people living in these regions.

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