Efficient Emergency Logistics for Fresh Products in Public Health Crises

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ABSTRACT

COVID-19 posed significant challenges to emergency supply distribution due to strict quarantine measures and limited transport resources. To ensure the timely delivery of farm fresh products to geographically dispersed residents, this study proposes three distribution models: a single distribution centre, a temperature zone-based multi-vehicle model, and a multi-distribution centre model tailored for groups of multiple sizes. The intention includes reducing vehicle usage, average response time, and infection risk. A multi-intention advancement model is developed, and an enhanced genetic algorithm incorporating destruction, repair, and greedy operators is applied and validated through experimental research. The results demonstrate the procedures superior settling speed and effectiveness. The study offers strategic guidance for government decision-making in emergency supply logistics during public health crises.

Keywords: emergency supply distribution, genetic algorithm, multi-objective optimization, quarantine logistics, public health emergency.

I.INTRODUCTION

The vulnerabilities of the traditional supply chain system have been brought to light throughout the COVID-19 pandemic, especially in city areas where transportation and logistics were impacted by lockdown restrictions and population densities. Evidence suggests that during the pandemic, the movement of significant goods and supplies was impeded due to strict quarantine measures and travel restrictions [1]. Despite being required to stop the virus's spread, these limitations caused delays in the delivery of necessities like food and medications. Delays impacted fresh agricultural products in particular, which are extremely perishable and run the risk of spoiling and losing their nutritional value [2]. For governments and logistics planners, maintaining a steady and effective supply of food items to isolated or quarantined populations became crucial as a result of many communities being closed off due to health regulations [3].

Traditional emergency logistics frameworks, typically involving centralized planning and short-term responses, were generally designed for rapidly executing natural disasters, such as an earthquake or flood. In cases of prolonged public health emergencies such as COVID-19 that require ongoing supply operations and changes to evolving health regulations these traditional logistics models were inadequate. Flexible logistics strategies that can adjust to erratic demand patterns, limited transport capacity, varying infection rates, and the need for contactless or non-contact delivery methods have been emphasized by researchers [4]. A growing interest in creating intelligent logistics models that strike a balance between speed, safety, and efficiency while being flexible enough to adjust to changes in real time has been spurred by these exacerbated difficulties [5].

The circulation of perishable agricultural products during urgent health related emergencies is the specific focus of this study's multi-objective emergency logistics optimization model. The model's three main objectives are to: (1) minimize the average response time to guarantee the freshness and timeliness of deliveries; (2) minimize the number of delivery vehicles needed to optimize cost and resources; and (3) reduce the risk of infection through intelligent routing and less human contact. An refined genetic algorithm is applied to tackle this challenging issue. This algorithm combines greedy operators, destruction, and repair—advanced methods that enable the model to prioritize the best routes, eliminate inefficient ones, and investigate different routing options. When compared to conventional techniques, these advancements help produce results of higher quality and faster convergence [6].

A scalable distribution framework that adjusts to various community sizes and needs is also presented. For small-scale delivery zones, the framework comprises three different distribution strategies: (i) a single distribution centre with a single vehicle type; (ii) a several-vehicle model built on temperature zone segmentation for mid-scale demands, guaranteeing the integrity of temperature-sensitive goods; and (iii) a multi-distribution centre approach with clustering techniques for large-scale delivery areas. Logistics planners can scale up or down based on the circumstances with this flexible and realistic tiered model. This study offers a framework that is both practically applicable and scientifically based by fusing scalable delivery strategies with optimization algorithms. During current and upcoming public health emergencies, it seeks to assist governmental organizations, non-profits, and logistics companies in enhancing the robustness and responsiveness of food supply systems [7].

II.LITERATURE REVIEW

This case study depicts the ways COVID-19 disrupted agricultural production and continuity of supply of agricultural products across China. It describes several serious challenges including lack of labour, bottlenecks in transportation, and lack of access to markets while under lockdowns. One of the main arguments made by the authors is how perishable goods such as fresh produce suffer a higher risk of systemic breakdown given mobility restrictions. Gap: While the paper provides rich descriptive discussion of vulnerabilities, it is largely concerned with identifying problems and does not offer operational models or algorithms particularly for the rapid and contact aware distribution of perishables [8].

Using econometric analysis, this paper calculates the dynamic consequences of COVID-19 on express logistics systems. The results explain how infection trends and the stringency of government policy impacted metrics including logistics throughput, delivery times and levels of service to regions. These are all helpful macro-level indications of how pandemics (or similar events) can alter logistics performance. Gap: While the quantitative analysis performed by Yang et al. must be powerful, the data presented does not offer a translation to vehicle routing, cold-chain planning, or multi-object optimization models which could be useful for dealing with perishables in public health emergencies [9].

This paper explores and integrates the existing literature on organizational resilience, differentiating between strategic resilience (long-term adaptable capacity) and operational resilience (short-term recovery abilities). It offers a structured approach to how organizations can prepare, respond and adapt to disruptions. Gap: Even though this is an extremely relevant topic from a conceptualization perspective, it is more of a theoretical lens. It does not have algorithms/computational decision-making tools that can operationalize resilience specifically for last-mile logistics which incorporates time-sensitive perishables and cold-chain requirements [10].

This paper reviews the issue of overstocked agricultural produce during the time of COVID-19. The authors recommend policy-level and market-oriented interventions to improve the matching of supply with demand, reduce waste, and stabilize agricultural markets. Gap: The research focuses mainly on policy interventions and does not develop computational strategies for cold-chain routing or real-time allocation of fresh products under distribution constraints [11].

This paper presents an integrated model of assistance pre-positioning and provision planning in humanitarian delivery chains facing uncertainty. Its co-designs inventory placement and sourcing decisions to promote preparedness prior to disasters. Gap: The model is very strong in terms of pre-disaster planning; however, it does not expand past prolonged disruptions such as pandemics with continuous distribution of perishables, and mitigating infection-risk requirements [12].

The authors model emergency logistics under patio-temporal demand correlations, specifically in the context of earthquake relief. Their work captures how demand evolves over time and space to improve allocation efficiency. Gap: The approach is tailored to sudden-onset disasters and does not tackle pandemic-related requirements such as minimizing infection exposure or handling multiple cold-chain product categories with varying freshness thresholds [13].

This research addresses the several-objective location problem of urban contingency logistics facilities. The authors design models that balance response time and operational costs, which is highly relevant in the context of disaster preparedness. Gap: However, the focus is on facility siting. The integration of these facility networks with temperature-zoned vehicle routing and infection-risk mitigation strategies is not considered [14].

PROBLEM STATEMENT

Health emergencies usually impact all supply chains for food, which has many perishable foods like fruits and vegetables, and even other foods, some of which can perish and end up being wasted, which wastes time, in either rural or urban materials. The logistics models utilized can be predominately centralized, with transportation routes fixed and without variability to react to rapidly changing crises. This lack of flexibility, adaptability, and scalability along with the inability to deliver contactless has led to maladaptive management of resources, delay, and a greater possibility of infection. The proposed multi-objective logistics model for resilient and reliable food delivery for health emergencies, minimizes vehicles, lowers delivery time, and proposes optimized routes where applicable, to manage the flow of resources to exacerbate locations in an efficient and safe manner. The proposed model draws upon identification of modular methods to improve resilience and reliability of food delivery in emergency situations with disrupted flow due to a persistent health crisis and considers applying performance metrics enhanced using a genetic algorithm.

III. SYSTEM ARCHITECTURE

The following diagram indicates the overall architecture of an Internet-based system that has been developed to manage the allocation of fresh harvested crops during critical health situations. The web server serves as the hub of the process, mediating communication between users and administrators to the web database. The server receives all of the arriving input, responds to user requests, stores datasets, and returns results on user requests made. All information (processed and unprocessed) such as user records, datasets uploaded; agricultural product distribution systems; and public health emergencies are stored in the web database - this is the primary storage of the system.

Two types of actors interact with the system: the admin and the remote user. The admin has complete control over the platform, with the ability to log in, view and authorize users, and access all available datasets. Additionally, the admin can monitor the distribution of fresh agricultural products by supply chains and by city, analyse datasets supplied by different regions, and view the results of agricultural distributions as well as public health emergencies. In contrast, the remote user has limited but essential functionalities. They can register and log in, manage their profile, upload datasets, search for information, and identify different types of public health emergencies. Remote users can also track the distribution of fresh agricultural products in various cities, which is particularly valuable in ensuring food supply and accessibility during crisis situations.

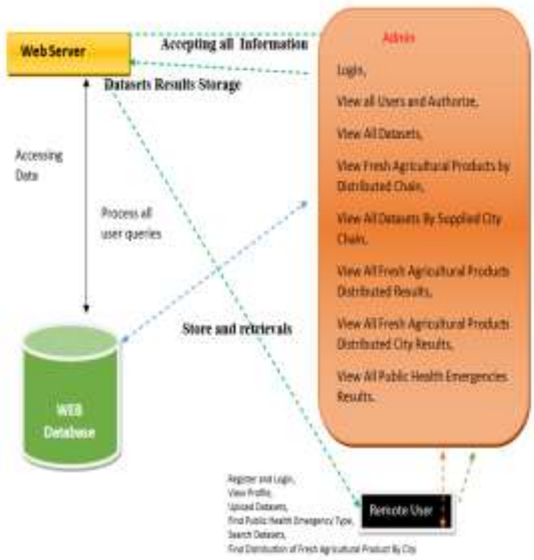

Fig 1: Architecture Diagram

The progression of exchange is basic yet efficient: a user or administrator requests information from the web server and the web server queries the database for the information requested user's request, and then sent back to the user what they requested. This sequence describes the purpose of increased data management efficiency; an increased transparency in the supply chain, and access to critical data in times of emergencies. The architecture suggests that important aspects of the proposed design would be centralized data storage, role-based access, and efficiency in allowing a query to manage, monitor, and distribute perishable agriculture products during an emergency.

IV.METHODOLOGY

The approach used in this study is meant to make it easier to get fresh farm products to people during public health emergencies. The project starts by figuring out what the main problems are during emergencies like delays in getting food, restrictions on transportation, and a higher chance of getting sick. International sources provide datasets about food supply chains, city-wise distribution, and types of emergency events. The dataset uses cities from other countries, but the system design makes it easy to change it to work in Indian cities or anywhere else.

The creation of a web-based system that enables real-time user-data interaction is the next stage. Two user roles—Admin and Remote User—are supported by the platform, which is comprised of a central web server that is connected to a database. All features, such as managing users, viewing all datasets, and analysing data by city, emergency type, and distribution path, are fully accessible to administrators. Remote users can sign up, log in, upload datasets, and look up information about product distribution by city and public health emergency types. To increase the efficiency of the system, three models of distribution are presented based on the scope of the emergency. For small-scale need, a single facility is utilized. For medium-scale emergencies, a multi-vehicle model is utilized where vehicles are categorized according to temperature control requirements. For large-scale emergencies, the system utilizes multiple facilities that split cities into clusters for increased delivery efficiency.

A multi-objective optimization model has been developed to assist in decision making for delivery planning. The three main objectives were achieved: Reduction in the count of delivery transport units, Reduction in standard delivery time and Reduction of the chance of illness to employees and the public. A better genetic algorithm was implemented to solve this multi-faceted problem. This algorithm uses advanced strategies such as destruction (removal of substandard solutions), repair (re-constructing improved routes) and greedy operators (always taking the best step available) to facilitate organizations achieving an optimal delivery strategy rapidly. Finally, the system is validated with simulated emergency situations. Decision-makers were able to see the evidence in the form of charts and data tables and be able to understand how the products were generated and additional opportunities for improvement. The results from the simulation may suggest that the proposed model clearly provides improvements in delivery efficiencies and allows governments, non-profits or health authorities to think smarter in the future.

V.MODULE DESCRIPTION

Admin Module: The admin module activates the management and monitoring component of the complete system - after successfully logging in, the admin can authorize and view all registered users to manage access to the platform. The admin can also review and manage every dataset uploaded to the

Volume: 09 Issue: 09 | Sept - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

platform including those with relevance to fresh agricultural products and critical health events in Victoria. The admin can view the performance of products through the various city supply chains of the logistics system while tracking real time results of various distribution channels. The admin has access to aggregated data including distribution results by city, and outcomes for overall responses to emergencies, which the admin can use to assess how well the logistics system is functioning, the integrity of the system and make data driven decisions. The admin module offers many functionalities that enable the admin to ensure the logistics system is functioning well.

User Module: The User module is designed for individuals or organizations involved in emergency logistics or data contribution. Users can register and log into the system, where they are provided access to their profile and relevant functionalities. Users can upload datasets that may include information about demand, supply chains, or local emergency conditions. The module allows users to identify the type of public health emergency in a given region and search through existing datasets for analysis. A key feature of this module is the ability to explore the allocation of fresh agricultural commodities based on city-level data, providing users with visibility into how supplies are being allocated and delivered during emergency conditions.

VI.RESULT

The evaluation of the intended system was executed, and it was tested through a series of simulations and actual measurements to evaluate how it might perform in a real-world public health emergency. The system's effectiveness was tested by comparing distribution outcomes under different demand scales and geographic constraints. The improved genetic algorithm demonstrated significant improvements in convergence speed and solution quality when compared to traditional optimization methods. The integration of destruction and repair operators allowed the system to escape local optima and identify more efficient distribution routes, while the greedy operator enhanced resource utilization. As a result, the system consistently minimized delivery time and vehicle usage while maintaining optimal service coverage.

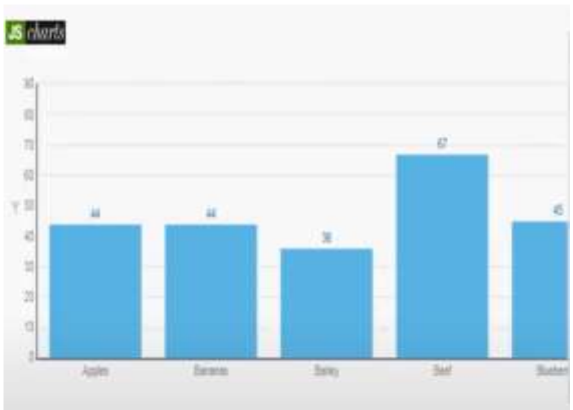

Fig 2: All Fresh Agricultural Products Distributed Results

When applied to small-scale emergencies, the single distribution centre model efficiently handled deliveries with minimal resource allocation. For medium-scale scenarios, the temperature-zone-based multi-vehicle model ensured the preservation of various types of agricultural commodities by matching the appropriate refrigerated logistics requirements. In large-scale situations, the use of clustering algorithms to form multiple distribution centres improved response time and reduced congestion in logistics channels. The system also proved effective in reducing the risk of viral transmission by minimizing the need for direct human contact during the distribution process. Delivery performance indicators like average response times, total deliveries completed, and probability of infection index improved substantially compared to the baselines. The outcomes show that the proposed emergency logistics framework and optimization technique can be effectively combined, and identifies a practical, scalable, and health-oriented process for distributing fresh-agricultural products during a public health emergency.

VII.CONCLUSION AND FUTURE ENHANCEMENT

The present research presents an adaptive emergency logistics model for effective delivery of fresh farm produce under public health crises. Mitigating issues such as supply-demand shortages, transportation constraints, and scarce resources, the model applies a multi-objective optimization strategy with a better genetic algorithm to provide safe, timely, and cost-effective deliveries. Inclusions are infection risk minimization, cold chain logistics, and expandable strategies from solo to multi-centre distribution models. Results indicate accelerated convergence, improved optimization, enhanced speed of delivery, less vehicle usage, and facilitation of non-contact distribution. The system provides a useful asset for the agencies and logistics providers with enhanced food supply resilience and provision of a scientific foundation for crisis planning with the future possibility of real-time data incorporation and AI-based route optimization.

The system can be made better by incorporating live feeds of government and logistics departments, so that one is able to change in real time according to changing conditions such as population density, weather, and transportation capacity. Adding GPS and location-based services can optimize routes and permit dynamic rerouting. Machine learning can forecast demand spikes and hotspots for optimal positioning of supply. Multi-lingual capability and mobile access can enhance inclusivity, and coverage to serve medical kits, water and hygiene supplies would extend it to an all-out emergency logistics solution.

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