A Mixed Integer Linear Programming Approach to Optimize the Capacitated Warehouse Location: a case study of blood donation and distribution in Saudi Arabia

Abdulhadi A. Altherwi*

Department of Industrial Engineering, College of Engineering and Computer Science, Jazan University, Jazan, Saudi Arabia, aaaltherwi@jazanu.edu.sa

Abstract

This paper discusses the optimization of the Capacitated Warehouse Location Problem (CWLP) under uncertain demand and supply. We propose an optimization framework that addresses the CWLP by considering blood distribution to identify optimal blood center locations. The objective is to meet all blood orders at the lowest possible cost, subject to warehouse capacity constraints. This study applies the framework to cities in the Kingdom of Saudi Arabia with high demand for blood delivery. We utilized census data from selected cities, with a representative sample of each city designated as a customer base. A novel mixed-integer linear programming (MILP) model was developed and solved using Python to determine the minimum total transportation and fixed costs for blood center construction. The proposed warehouse locations are presented on a map, showing each city connected to its optimal blood center warehouse.

Keywords: Mixed Integer Linear Programming; Capacitated Warehouse Location Problem; Optimization.

Highlights:

- This paper discusses optimization of the Capacitated Warehouse Location Problem (CWLP) under uncertainty in demand and supply.
- This research proposes an optimization framework that addresses the capacitated warehouse location problem by considering delivery companies to identify optimal warehouse locations so that orders are met at the lowest cost depending on warehouse capacity.
- A novel mixed integer linear programming was proposed and solved by Python to obtain the minimum total transportation and fixed costs for warehouse construction.
- The proposed warehouse sites were presented on a map, and each city was connected to its optimal

Submitted: 7-Mar-2025

Accepted: 7-Aug-2025

Published: 24-12-2025

DOI:10.5455/jeas.2025011210

1. Introduction

This research discusses the capacitated facility location problem involves determining the optimal locations and capacities of warehouses to meet demand efficiently. The capacitated facility location problem involves determining the optimal locations and capacities of facilities to minimize costs while meeting demand. Various approaches have been proposed to address this challenge. Fonkoua Fofou et al. (2022) propose a decision-making model using the Capacitated Facility Location Problem (CFLP) approach to establish remanufacturing facilities in underdeveloped countries, such as SEVALO in Cameroon, to reduce environmental impact. Kao (2023) discusses the Multicommodity Flow Network (MFN) relaxation as a polynomial-time solvable method with a bounded integrality gap for the classic CFL problem, narrowing the integrality gap range. Han (2023) focuses on the location and capacity optimization of precast concrete component factories, enhancing operational efficiency in the prefabricated construction supply chain through a Tabu search algorithm. Jiang (2023) introduces an improved adaptive differential evolution algorithm (IADEA) for solving the un-capacitated facility location problem efficiently, outperforming other heuristic algorithms. Miao and Yuan (2022) present an approximation algorithm for the capacitated facility location problem without the uniformity assumption on facility costs, extending previous results and providing a solution for varying cost scenarios.

The capacitated warehouse location problem is a crucial aspect of supply chain management, aiming to optimize warehouse assignments to minimize overall transportation and service costs while considering capacity constraints. Various approaches have been proposed to address this problem, such as the use of mathematical models (Souto et al. 2021), hybrid algorithms combining Clustering Search, Adaptive Large Neighborhood Search, and Local Branching, and multi-objective mixed-integer non-linear programming models with modified heuristics and metaheuristic algorithms (Golabi et al. 2022). Additionally, approximation algorithms have been developed to handle capacitated facility location problems with penalties and outliers, achieving constant factor approximations while dealing with capacity constraints (Mhana et al. 2021). These diverse methodologies highlight the significance of efficient warehouse location strategies in enhancing supply chain operations and reducing associated costs. Capacitated warehouse location plays a crucial role in supply chain management, aiming to optimize the placement of warehouses to minimize total costs related to transportation and service costs while meeting capacity constraints and customer demand. Various approaches have been proposed to address this challenge. One study introduced a mathematical model using a hybrid biased random-key genetic algorithm to find optimal locations for factories and warehouses, demonstrating reliability and efficiency in solving the Two-Stage Capacitated Facility Location problem (Souto et al. 2021). Additionally, a novel approach was presented to repurpose storage locations within a network, emphasizing the importance of strategic storage placement for operational efficiency and cost-effectiveness (Mhana et al. 2021). These studies collectively highlight the significance of efficient warehouse location strategies in enhancing supply chain performance and reducing operational expenses.

Optimizing warehouse location in a supply chain is crucial for enhancing customer satisfaction, reducing costs, and improving overall efficiency. Various algorithms and methods have been proposed to address this issue. Research has highlighted the importance of Warehouse Optimization Systems (WOS) in optimizing space, logistical procedures, and inventory management (Babar et al. 2022), while studies have introduced optimization algorithms based on big data mining to improve user satisfaction, reduce costs, and determine the best warehouse locations in cross-border medical supply chains (Ma 2023). Additionally, the use of metaheuristic methods like the artificial bee colony algorithm and genetic algorithms has been explored to find optimal warehouse locations, aiming to minimize costs and distances between warehouses and customers (Belayachi et al. 2023) and (Mankour and Yachba 2022). Ultimately, efficient warehouse location optimization plays a significant role in enhancing competitiveness and streamlining supply chain operations (Díaz et al. 2021).

Warehouse construction under demand uncertainty is a critical aspect of supply chain management, as highlighted in various research papers. Studies have shown that uncertainty considerations strengthen decision-making processes and increase confidence levels (Zhang et al. 2024). Furthermore, the development of on-demand warehousing systems has emerged as a solution to mitigate warehouse capacity constraints during uncertain times, showcasing significant cost-saving effects and effective feasible solutions within reasonable computational times (Thi et al. 2020). The evolution of automated warehouses has also been influenced by demand factors under the backdrop of big data, emphasizing the importance of layout, equipment, technology, and site selection demands in construction planning (Lee et al. 2024).

Studies have shown that integrating production quantity determinants in warehouse layout design can significantly impact space utilization and handling activities (Thi et al. 2020). Furthermore, research on continuous review inventory models highlights the importance of minimizing costs by determining optimal reorder points based on demand uncertainty, which can lead to more efficient inventory policies (Halkos et al. 2014).

The Capacitated facility location model is a mathematical optimization technique used to determine the best possible locations for constructing new facilities, considering constraints on their capacity. The main goal of this model is to reduce the total cost, which includes various elements such as expenses related to establishing new factories, transporting goods from factories to customers, and other possible factors such as fixed costs and penalties for not meeting demand requirements. The main objective of this paper is to optimize warehouse location in a supply chain for enhancing customer satisfaction, reducing transportation costs, fixed costs, and improving overall efficiency. This paper also aims at exploring the optimization blood center location in supply chain under uncertainty in demand.

This scenario focuses on a regional blood bank network that needs to decide where to place new blood donation and processing centers to meet the demand of various hospitals.

2. Methodology

Due to the continuous and rapid development of Saudi Arabia's population, there's a significant rise in demand for blood donation and distribution services. Meeting all of this demand presents challenges related to warehouse capacity, location, and transportation costs. These factors vary based on the specific quantity and location of demand in each region.

This paper proposes and develops a mixed-integer linear programming (MILP) model to address this problem. The model, built using Python and the PuLP library, aims to identify optimal blood center locations that minimize total transportation and fixed costs while meeting all demands. Table 1 outlines the notation used in this study. We ran the Python code to generate the necessary data frames for potential blood center locations and customer bases.

Table 1. The notation used in this study

Sets	*Parameters*
N: *Set of customer locations (i)*	A_j *: The fixed annual cost to operate a blood donation and processing center at location j.*
O: *Set of cities warehouse locations (j)*	H_{ij}*: The transportation cost per unit of blood from a donation center j to customer (hospital) i.*
	U_j *: The maximum annual capacity of a blood center at location j in terms of collected and processed blood units.*
	b_i*: The annual demand for blood units from customer (hospital) i.*

Variables
X_{ij}*: The number of blood units shipped from blood center j to customer (hospital) i.*
y_j*: Binary variable, =* $\begin{cases} 1 \text{ if blood center is opened at location } j \\ 0, \text{otherwise} \end{cases}$

$$Minimize \sum_{j=1}^{O} A_j * y_j + \sum_{i=1}^{N}\sum_{j=1}^{O} H_{ij} * x_{ij} \quad (1)$$

$$\sum_{j=1}^{O} x_{ij} = b_i \ , \forall\, i \in N \quad (2)$$

$$\sum_{i=1}^{N} x_{ij} \le U_j * y_j \ , \forall\, j \in O \quad (3)$$

$$0 \le x_{ij} \le b_i * y_j \ , \forall\, i \in N , \forall\, j \in O \quad (4)$$

$$x_{ij} \ge 0 \ , \forall\, i \in N , \forall\, j \in O \quad (5)$$

$$y_j = bin \ , \forall\, j \in O \quad (6)$$

The primary objective is to optimize the number and location of blood center warehouses to meet customer demand while minimizing the total costs, which include both fixed costs for establishing the facilities and variable transportation costs. This problem is formulated as a minimization model, as shown in Equation (1). The problem can be formulated as a minimization model. To satisfy customers' demands, Equation (2) ensures that each warehouse serving a customer location meets the entire demand. In a capacitated problem, each facility has a maximum capacity (U_j) that limits the quantity of units (X_{ij}) that can be delivered to a customer. The quantity of blood units delivered from warehouse j to customer i must not exceed the annual demand of customer i (b_i), with the total flow from the warehouse constrained by its capacity. The annual demand (b_i) for each customer location is determined based on the population of the respective town, with an additional error term based on a uniform distribution to account for demand uncertainty. The flow chart for the Capacitated Warehouse Location optimization methodology is shown in Fig 1.

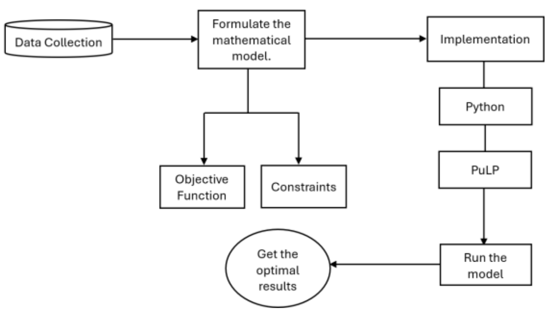

Figure 1. Flow chart illustrating the methodology for optimizing the locations of capacitated blood centers

To visualize the locations of warehouses on a map, the geopandas library can be used, which simplifies this task. With geopandas, it is straightforward to create a GeoDataFrame that includes geospatial information. This can easily represent warehouse locations with their corresponding coordinates on a map. We can access a map of Saudi Arabia through geopandas and plot customers and potential warehouse locations by latitude and longitude, as shown in Fig 2. In addition, the optimal solution obtained in this study is shown in Fig 3.

The distance between two locations can be calculated on the basis of the given latitude, longitude, and earth radius for each region in Saudi Arabia using the haversine formula, as expressed in Equation (7), as shown in (Distance on a Sphere: The Haversine Formula, 2021)

$$Haversine\ (\theta) = sin^2\left(\frac{\theta}{2}\right), \text{where } \theta \text{ is latitude} \quad (7)$$

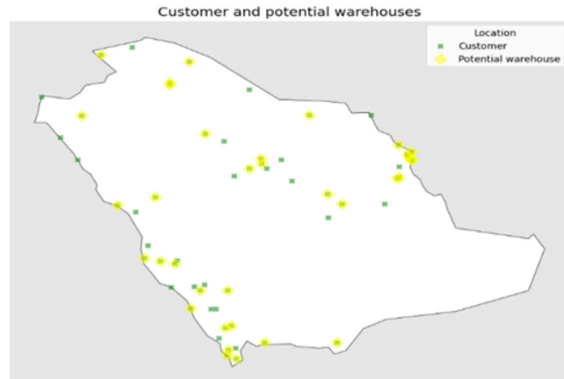

Figure 2. The presentation of customer and potential warehouse

To investigate the effect of collaborations between warehouses to meet the demand for each region in Saudi Arabia, we simulated the environment in which warehouses must meet the uncertain demand for each region using their existing capacities.

```
Result - Optimal solution found

Objective value:                4345802.59098526
Enumerated nodes:               0
Total iterations:               0
Time (CPU seconds):             0.05
Time (Wallclock seconds):       0.08

Option for printingOptions changed from normal to all
Total time (CPU seconds):       0.06   (Wallclock seconds):       0.10
```

Figure 3. The optimal solution obtained in this study

3. Numerical Results

The codes are run using objective function, indicating increased costs. Warehouse sites to be established and the optimal blood center sites are shown in Figures 4 & 5. The model indicates that 19 blood centers should be built, which indicates that only around 54% of potential warehouses should be enough to meet hospital needs.

Figure 5. The potential warehouses established in this study

Based on the optimal solution obtained, Fig 6 shows the optimal sites of warehouses established, which can meet demand in the selected area at the minimum costs.

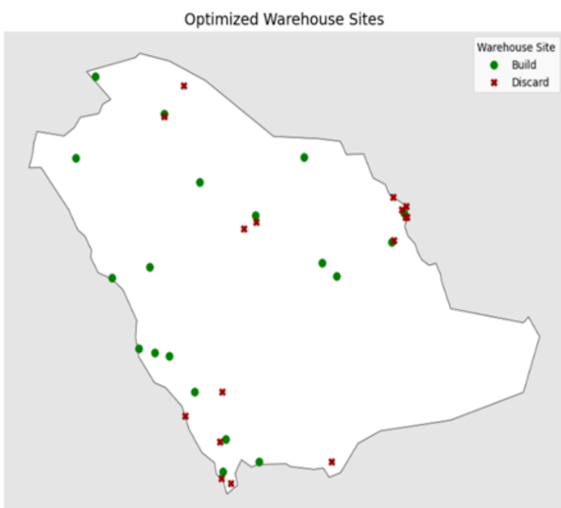

Figure 4. The optimal sites of warehouses established in this study

Fig 7 shows the optimal distribution of units required to meet demand for cities in Jazan. It indicates that the warehouse established in Aldarb is considered to be the hub site to meet the needs of customers located in Sabya, which indicates that the model can help to determine the area that need warehouse to be established in to minimize the total transportation cost

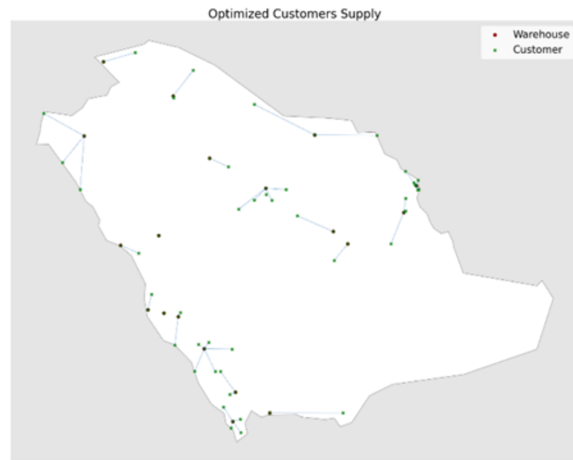

Figure 6. The optimal sites of warehouses connected to area demanded

and fixed cost of establishing warehouses and can also help to meet customer needs.

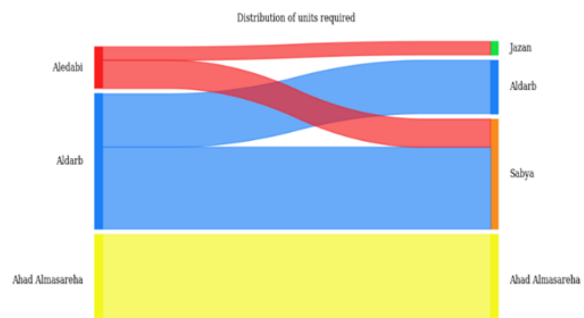

Figure 7. The optimal distribution of units required for the area demanded

4. Conclusion

This study successfully applied a Mixed-Integer Linear Programming (MILP) model to optimize the capacitated warehouse location problem, specifically for the blood donation and distribution network in Saudi Arabia. The model provides a robust framework for identifying the optimal locations for new blood centers, ensuring efficient resource allocation while meeting capacity and demand constraints. The results of this case study demonstrate that the proposed MILP model can significantly reduce operational costs by minimizing transportation and facility establishment expenses, while simultaneously improving the overall efficiency of the blood supply chain. The findings offer a valuable tool for strategic decision-making by the Saudi Arabian health authorities, enabling them to enhance the responsiveness and reliability of their blood distribution network.

Building on this foundational work, future research could explore several extensions to the current model.

One potential area is to incorporate non-linear objective functions, such as those related to economies of scale or more complex cost structures, for a more nuanced analysis. Additionally, the problem could be reframed as a multi-objective optimization problem. This would allow for the simultaneous consideration of other crucial factors beyond cost, such as maximizing service levels (e.g., minimizing average travel time for donors and patients) or minimizing environmental impact (e.g., reducing carbon emissions from transportation). Integrating these objectives would provide a more comprehensive and sustainable solution for the blood supply chain network.

References

Babar, M. M., Syed, A. J., Asim, S., Khan, A. R., & Hai, M. A., 2022. Development of an Algorithm based on the Optimization of space, time and resources of the warehouse using Genetic Algorithms. In *2022 3rd International Conference on Innovations in Computer Science & Software Engineering (ICONICS)*, pp. 1-8. IEEE.

Belayachi, N., Yachba, K., & Bouamrane, K., Towards a Decision Support System for Optimizing the Location of Warehouses in a Supply Chain by Using the Bee Colony Algorithm. *International Journal of Organizational and Collective Intelligence (IJOCI)*, *12*(1), pp. 1-16, 2022.

Díaz, J., Rodriguez, H., Fajardo-Calderín, J., Angulo, I., & Onieva, E., Optimization of Warehouse Layout for the Minimization of Operation Times. In *Hybrid Artificial Intelligent Systems: 16th International Conference, HAIS 2021, Bilbao, Spain, September 22–24, 2021,* pp. 649-658, 2021.

Fofou, R. F., Jiang, Z., Gong, Q., & Yang, Y. A Decision-Making Model for Remanufacturing Facility Location in Underdeveloped Countries: A Capacitated Facility Location Problem Approach. *Sustainability*, *14*(22), p. 15204, 2022.

Golabi, M., Shavarani, S. M., & Idoumghar, L. A congested capacitated location problem with continuous network demand. *RAIRO-Operations Research*, *56*(5), 3561-3579, 2022.

Halkos, G., Kevork, I., & Tziourtzioumis, C., Optimal inventory policies with an exact cost function under large demand uncertainty, *MPRA,* 2014.

Jiang, N., & Zhang, H. Improved Adaptive Differential Evolution Algorithm for the Un-Capacitated Facility Location Problem. *Open Journal of Applied Sciences*, *13*(5), pp. 685-695, 2023.

Kao, M. J. On the integrality gap of mfn relaxation for the capacitated facility location problem, *Proceedings of the 2023 Annual ACM-SIAM Symposium on Discrete Algorithms (SODA)*, pp. 1071-1089, 2023.

Lee, J., Ko, C., & Moon, I., E-commerce supply chain network design using on-demand warehousing system under uncertainty. *International Journal of Production Research*, *62*(5), pp. 1901-1927, 2024.

Miao, R., & Yuan, J. A note on LP-based approximation algorithms for capacitated facility location problem. *Theoretical Computer Science*, *932*, pp. 31-40, 2022.

Mhana, A. A., Hegazy Zaher, N. R., & Sayed, H. Solving the Multi-Commodity Single-Stage Capacitated Warehouse Location Problem Using Bat Algorithm, *Journal of University of Shanghai for Science and Technology,* vol. 23, pp. 562-572, 2021.

Ma, Z., An Optimization Algorithm of Overseas Surgical Warehouse Location of Cross-Border Medical Supply Chain Network Based on Parallel Big Data Mining. *Journal of Testing and Evaluation*, *51*(1), 201-214, 2023.

Mankour, I., & Yachba, K., Comparative Study for Facilities Location Problem in Supply Chain Design. *International Journal of Swarm Intelligence Research (IJSIR)*, *13*(1), pp. 1-16, 2022.

Souto, G., Morais, I., Mauri, G. R., Ribeiro, G. M., & González, P. H. A hybrid matheuristic for the two-stage capacitated facility location problem. *Expert Systems with Applications*, *185*, 115501, 2021.

Souto, G., Morais, I., Faulhaber, L., Ribeiro, G. M., & González, P. H. A hybrid brkga approach for the two stage capacitated facility location problem. In *2021 IEEE Congress on Evolutionary Computation (CEC)*, pp. 2007-2014, 2021

Thi, N. T., Phung, P. T. K., & Tham, T. T., Optimizing Warehouse Storage Location Assignment under Demand Uncertainty. In *2020 5th International Conference on Green Technology and Sustainable Development (GTSD)*, pp. 562-568, IEEE, 2020.

Yanhu, H., & Huimin, X. The capacitated location problem of precast concrete component factory. *Journal of Intelligent & Fuzzy Systems*, *44*(6), pp. 10523-10535, 2023.

Zhang, X., Dai, W., & Cai, X., Inventory replenishment decisions with uncertain price and demand. *International Journal of Production Research*, *62*(7), pp. 2663-2682, 2024.

Distance on a sphere: The Haversine Formula. (2021, December 12). Esri Community. https://community.esri.com/t5/coordinate-reference-systems-blog/distance-on-a-sphere-the-haversine-formula/ba-p/902128