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An Integrated Approach for Designing Healthcare Facilities with a Location-Inventory Model

Hathairat Poomisirisawat[1], Sirirat Suwatcharachaitiwong[1,2,*], Nikorn Sirivongpaisal[1,2]

[1]*Graduate Program in Logistics and Supply Chain Engineering, Department of Industrial and Manufacturing Engineering, Faculty of Engineering, Prince of Songkhla University, Songkhla 90110, Thailand*
[2]*Smart Industry Research Center, Department of Industrial and Manufacturing Engineering, Faculty of Engineering, Prince of Songkhla University, Songkhla 90110, Thailand*

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ABSTRACT

Getting services at public hospitals in Thailand requires outpatients to visit doctors and receive medicines and medical supplies at the dispensary as the final step of the treatment process. This often leads to congestion issues in hospitals. Therefore, the workload should be distributed outside the hospital to alleviate congestion. Presently, outpatients of public hospitals can participate in the “Taking Medicine Nearby House” project to increase convenience and relieve congestion in the hospital. This study addresses the Location-Inventory (LIP) problem, specifically focusing on “pharmacies,” by determining the optimal number and locations to meet patient needs. This approach aims to increase patients' accessibility. Additionally, the right inventory level for each pharmacy must be considered to reduce operating costs. Therefore, a mathematical model is developed to simultaneously solve the location and inventory problems using an exact method. The model is processed using the Lingo program to facilitate efficient problem-solving. This study benefits congestion mitigation in public hospitals and ensures greater patient access and proper pharmacy inventory management by the integrated solution. The results in actual implementation within the healthcare system will improve operational efficiency and raise the standard of patient care.

Keywords: Facility location problem; Inventory management; Location inventory problem; The exact method; The taking medication near house project

1. Introduction

To access public health services or public hospitals in Thailand, patients must follow the procedures designed by the service provider. This process may be complex and delayed, affecting patient

***Corresponding author:** sirirat.su@psu.ac.th
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services. Usually, medical facilities in Thailand treat an average of 148 million people every year [1]. For a large public hospital, there are 1,200 patients receiving services per day, which is considered a very large number. In general, when an outpatient visits the hospital, every patient from several departments must receive medicines and medical supplies at the dispensing department as the final step of treatment [2]. This often creates a bottleneck and congestion in the process. This congestion problem affects patients' satisfaction with treatment and impacts the efficiency of the treatment, also.

Therefore, it is an interesting issue and is expected to reduce patient congestion in hospitals if the service stage at the dispensing department could be removed under the concept of distributing some work processes outside the hospital.

Currently, the National Health Security Office (NHSO) has initiated a project named [3] "The Taking Medicine Nearby House Project" to reduce overcrowding of patients in the National Health Security System by distributing medicines to hospital patients through pharmacies. The target group for this project includes four categories of chronic patients: those with diabetes, asthma, hypertension, and psychiatric conditions. Patients participating in the project can conveniently pick up their medicine at pharmacies located near their residences [3]. "The Taking Medicine Nearby House Project", illustrated in Fig. 1, has the procedure as follows: when patients are treated at the hospital and enroll in the project to receive their medication at the pharmacy for the next appointment, the hospital will collect patient prescription information and send it to the allocated pharmacy. The pharmacy will then process the information and order the medicine from the wholesale pharmacy. Subsequently, the medicine is prepared for each patient. When the appointment time arrives, the patient will visit the allocated pharmacy to pick up their medicine.

According to preliminary information, there are currently sixteen pharmacies participating in the Taking Medicine Nearby House Project, with a total of 1,114 patients.

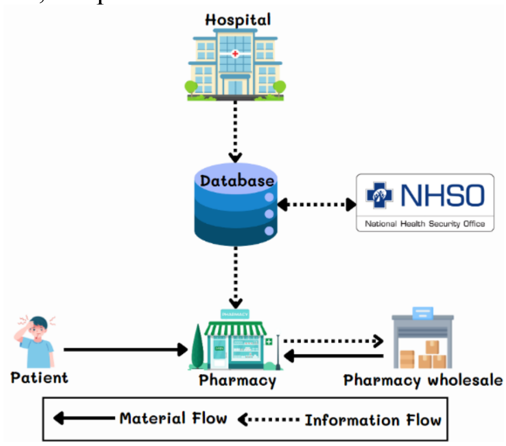

Fig 1. Project procedure.

Selecting existing drugstores to be an operation unit in the project incurs related costs, both fixed costs including opening fees, and variable costs including transportation, packaging, and inventory costs. Each pharmacy will serve as the hospital's drug dispensing department so it must prepare medications for patients and dispense medicines when patients need them. The challenges faced in opening pharmacies for service are mainly about the uneven distribution of participating pharmacies [4] and the issue of overlapping pharmacies in nearby areas. Consequently, selecting the right number and location of drugstores and setting the inventory level of each store are concerns for the success of the project.

From the supply chain standpoint, location selection and inventory management are crucial. The location problem is related to the identification of the number of facilities to be located to serve the target customers. Inventory management is crucial in healthcare due to the substantial budget required for inventory costs, for example, constituting around 10% of annual healthcare expenditures in the United States [5]. Over or under-inventory levels are not good due to either creating high holding inventory costs or affecting the quality of treatment, respectively. Therefore, the right quantity of inventory corresponding to the patient's needs affects the efficiency of the project.

Therefore, this study is focused on the Location-Inventory Problem, which involves selecting the location of service units and determining the necessary number of openings/closings. This decision aims to avoid high costs in the system while still providing services effectively. It pertains to determining which service units should be located to appropriately serve patients in different areas. This consideration is coupled with inventory planning because the products involved are drugs and medical supplies, impacting the treatment of patients concerning storage conditions. Consequently, it is essential to determine the quantity required to be prepared to meet the needs of each patient. Therefore, planning for the appropriate amount of inventory in pharmacies is a crucial aspect in the design of drug and medical supply service systems.

Initially, it was found that there were relatively few studies that studied the Location Inventory Problem in health care. Especially in the case of the "Taking Medicine Nearby House Project" in Thailand, there will be a noticeable difference because, in many countries, most patients who see a doctor will receive a prescription from the doctor. The patient can submit the prescription to buy medicine at any pharmacy or use the home delivery service after uploading the prescription to the home healthcare service company [6]. However, in Thailand, the hospital will distribute the patient's prescription to selected pharmacies that are joint operation units in the project, only. Therefore, in inventory management, it is necessary to be ready to dispense medicines like receiving medicines at the hospital.

2. Literature Review

The location inventory problem involves determining the number of locations, along with the placement of service locations, as well as allocating services and managing the inventory of these service locations. Srizongkhram et al. [7] addressed the medical inventory problem, which causes high costs, by enhancing the warehouse management policy to include ABC analysis. This approach is suitable when applied to inventory management to reduce inventory costs and includes simulation-based optimization methods using ARENA with the OptQuest tool. Shang, Xiaoting, et al. [8] organized the healthcare provision system considering the Vendor-Managed Inventory (VMI) strategy for shipping various types of products under an uncertain environment. Kaur and Anjali [9] considered selecting inventory policies and evaluated issues related to inventory policy selection by applying Grey Relative Analysis (GRA) to achieve the lowest inventory management costs.

Location overlap problems arise because patients have numerous options in their immediate area. Orders with inappropriate quantities and timing may lead to overflow, or insufficient medicine supply to meet demand, requiring patients to travel for medication later, resulting in wasted time. If it is inconvenient for the patient to return for the medicine, it can lead to missed doses, impacting the efficiency of treatment. Kelle et al. [10] improved existing inventory management policies by defining new order points and order levels to control the automated ordering system. This process takes into consideration the limitations of storage space and explores the potential effects that may arise from product management under uncertainty.

This study aims to design a drug service system with a focus on distributing drugs to patients through pharmacies. In this research, appropriate pharmacy locations will be determined, including inventory planning in each pharmacy. This issue involves the concept of the location inventory problem [11], as identified in past research. The objective is generally to determine the appropriate number and location of each Distribution Center (DC) and allocate customers to each DC along with a schedule of inventory services, as depicted in Fig. 2.

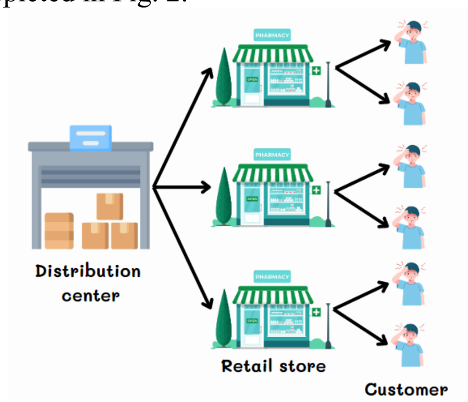

Fig 2. Concept of the Location Inventory Problem.

Jayaraman [12] analyzed the interrelationship among three elements: the location of the service facility, transportation, and inventory. By designing a distribution network that illustrates the relationship among all three elements, a mathematical model is formulated to answer questions such as how many locations should exist, where each location should be situated, and how customer needs should be allocated to each service location. Firoozi et al. [13] addressed the inventory problem of shared locations, involving two key decisions: making inventory control decisions and facility location decisions through LIP network analysis to determine the correct quantity and location of Distribution Centers (DCs), and allocate retailers to DCs, including controlling DC inventory. The objective is to achieve the lowest total cost for the entire system. Mehdi et al. [14] considered the inventory optimization problem within a multi-level supply chain network characterized by uncertain demand. The objective is to create a model that effectively incorporates essential features of inventory planning decisions under demand uncertainty. Ozsen and Uzsoy [15] considered a dual-tier supply chain where the factory is solely responsible for producing and delivering to multiple retailers. The goal is to find the appropriate distribution center (DC) location in the network with the lowest total cost of facilities and inventory. Yang, Ng and Cheng [16] considered the impact of a distribution center on a supplier-managed inventory management system (VMI) consisting of one manufacturer, one DC, and n dealers by providing a system performance evaluation model based on the network distribution scale, including cost factors that affect building location. Schmitt [17] researched service level risks in a multi-layered supply chain to prevent process interruptions and evaluate strategies, and to ensure the protection of customer service systems during process interruptions. Nozick and Turnquist [18] analyzed the impact of safety inventory costs on locating Distribution Centers (DCs) by proposing a one-to-one inventory replacement model. Shen et al. [19] addressed the location and inventory issues arising when each retailer has different needs by considering safety stock to achieve an appropriate level of service. The goal is to determine which retailers should function as distribution centers and how to allocate other retailers to these distribution centers. Snyder et al. [20] analyzed the model and identified risks to optimize location, inventory, and allocation under random parameters amidst uncertainty. Rashid et al. [21] analyzed inventory control systems under the supplier's service period and uncertain demand. The model is solved using queueing theory. Erlebacher and Meller [22] considered strategic decisions regarding the number and location of distribution centers serving customers. The objective is to maintain an acceptable level of service while reducing operating costs.

3. Problem Description and Model Development

In the current situation, there are 16 pharmacies participating in the project to receive medicine near patient homes. Initially, the analysis will mainly focus on diabetic patients because the location of 97.5% of patients is known, and they account for 23.5% of patients with four groups of chronic diseases, which is the second-highest proportion of patients. There were 208 diabetic patients who participated in the taking medicine nearby house project according to data on locating diabetic patients. To study the distribution of patients, it was found that 198 patients could be located out of 208 cases, accounting for 95.19%, and they were distributed in the area of Hat Yai District, Songkhla. Therefore, the objective of developing the mathematical model is to find the location of a suitable pharmacy that can cover patients in the project to receive medicines near their homes, which will be allocated among pharmacies to create the lowest cost for the entire system. This includes managing inventory to have sufficient quantities to meet patient needs.

The Conceptual Framework, as shown in Fig. 3, for location and inventory problems defines the correlation with the following distinct decisions:

- Location of Retail Stores (Pharmacies): Determining the appropriate number and location of retail stores (pharmacies).
- Allocation of Customers (Patients) to Retail Stores (Pharmacies): Covering as many patients as possible by allocating them to retail stores (pharmacies) under the specified distance criteria. This involves distributing patients' accessibility to retail stores (pharmacies) to ensure an appropriate number of customers (patients) receive services in each store.
- Inventory Management of Each Retail Store (Pharmacy): Setting the inventory level of each retail store (pharmacy) to meet patient needs.

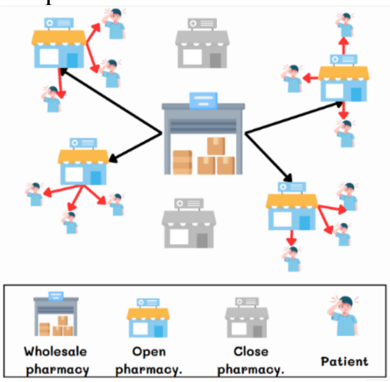

Fig 3. The Conceptual Framework.

The purpose of the model is to determine the number and location of pharmacies with the right inventory level corresponding to patients' demand which yields the minimum total system cost. It is based on collected data from the project, in which the model adopts the following assumptions:

- There is a cost associated with opening a pharmacy, and the cost of opening each pharmacy is the same.
- The number of patients is known, and the demand for each patient is known, with a definite period for coming to receive medicines. Therefore, lead time and demand are fixed, and safe stock is not considered.
- Wholesale pharmacy will have only one location.
- Wholesale pharmacy will not face shortages of products, and each shipment can send unlimited quantities.
- The ordering cost and the holding cost of the pharmacy are the same.
- The drug demand of each patient is reckoned by the average drug consumption of every patient.
- The demand of each pharmacy depends on the number of (patients assigned to the pharmacy.

The model development method used in this study aims to solve location and inventory management problems at the minimum total cost. It essentially encompasses the fixed cost of opening a pharmacy, transportation costs from the distribution center to the retail store, travel costs for patients, and inventory costs (ordering costs, holding costs). In the mathematical model, there are model indices and variable parameters as follows:

Indices

i Pharmacy.

j Patient.

Parameters

F Fixed costs associated with opening a pharmacy.

A Ordering cost each time (baht/order).

H Inventory holding cost (baht/unit).

D Quantity of drug demand for each diabetes patient (unit/person).

P The number of patients that each pharmacy can accommodate (set at 20% of the patients).

O_i Order quantity for each pharmacy (units/store).

t_i Transportation costs from the wholesale drug store to each pharmacy (baht/meter).

c_{ij} The cost of travel from the location of each patient to each pharmacy (baht/meter).

s_i Distance from the wholesale drug store to each pharmacy (meters).

s_{ij} Distance from the location of each patient to the pharmacy(meters).

Ψ Frequency of receiving medicines (every three months).

X_i Binary Variable, Equal to 1 if the pharmacy is open for service. Equals 0 if the pharmacy is closed.

Y_{ij} Binary Variable, Equal to 1 if the patient is assigned to a pharmacy that is open. Equal to 0 is not assigned to a pharmacy that is open.

The mathematical model for solving location and inventory management problems has an objective function.

Objective function

$$\text{Min} \sum_i FX_i + \Psi \sum_i t_i s_i X_i + \Psi \sum_i \sum_j c_{ij} s_{ij} Y_{ij} + \Psi \left(\sum_i \sum_j A \frac{DY_{ij}}{O_i} + \sum_i H \frac{O_i X_i}{2} \right) \quad (3.1)$$

Subject to

$$\sum_i Y_{ij} = 1; \ \forall j \quad (3.2)$$

$$\sum_j Y_{ij} \le P; \ \forall i \quad (3.3)$$

$$X_i \ge Y_{ij}; \ \forall ij \quad (3.4)$$

$$\sum_j DY_{ij} \ge O_i; \ \forall i \quad (3.5)$$

$$X_i = \{0, 1\}; \ \forall i \quad (3.6)$$

$$Y_{ij} = \{0, 1\}; \ \forall ij \quad (3.7)$$

The objective function (3.1) represents the total cost of the system, comprising four terms. Term 1 is the fixed cost of opening the pharmacy. Terms 2 and 3 represent the transportation cost from the wholesale drugstore to the pharmacy and the cost of the patient traveling to the pharmacy. The cost per unit distance of transportation from the wholesale drugstore to the pharmacy is calculated from vehicle depreciation, maintenance costs, labor costs, and fuel costs. The cost per unit distance of the patient traveling to the pharmacy is calculated from maintenance and fuel costs. Term 4 encompasses the costs associated with inventory management, including ordering costs and holding costs.

Constraint (3.2) specifies that one patient can receive service from only one store. Constraint (3.3) dictates that each pharmacy can accommodate no more than the P patients allocated to the pharmacy. Constraint (3.4) ensures that patient must receive service only in pharmacies that are open for service. Constraint (3.5) guarantees that the quantity of goods in each pharmacy is greater than or equal to the required demand in each store. Constraints (3.6) and (3.7) define the binary values of the service location opening-closing variables and the variables of service access for each patient in that location, respectively.

4. Results and Analyses

This research employs a case study of the "Taking Medicine Nearby House" project, specifically with type 1 pharmacies in Hat Yai District, Songkhla. The target group comprises four categories of chronically ill patients: diabetic, high blood pressure, asthma, and psychiatric conditions. Patients participating in project can conveniently pick up their medicines at pharmacies located near their residences. The analysis will primarily focus on diabetic individuals.

This study involves allocating each patient to the pharmacy that is closest to their residence based on specific conditions such as distance to minimize the cost of traveling for patients to the pharmacy. To achieve this, information about the distance between each patient's residence and the location of each pharmacy, as well as the distance between the wholesale pharmacy and individual pharmacies is necessary. This information is obtained from the ArcGIS program, which measures actual road distance, presented in Tables 1 and 2, respectively.

Table 1. Information regarding the distance between the patient's residential location and each individual pharmacy.

	i / *j*	Pharmacy			
		ID 1	ID 2	ID…	ID 16
Patient	ID 1	10,932	10,583	….	12,279
	ID 2	5,964.1	5,615.1	….	7,311.7
	ID 3	7,379.4	7,624.2	….	9,153.6
	ID	….	….	….	….
	ID 198	14,073	10,665	….	12,318

Table 2. Information regarding the distance between the wholesale pharmacy and each individual pharmacy.

Distance	Pharmacy ID 1	Pharmacy ID 2	Pharmacy ID …	Pharmacy ID 16
Dc	4,341.7	0	…	3,529.6

The mathematical model was solved using LINGO 16 on a CPU Core i5 with 2 GB of RAM.

After running the Lingo software, the processing time is 10 seconds, all results will be examined, beginning with the total cost of the entire system. The total cost of the entire system is presented in Table 3.

Table 3. The total cost of the entire system.

The total cost of the entire system		
Fix cost for Pharmacy	60,500	baht
Transportation cost of Dc to pharmacy	522	baht/time
Transportation cost of patient to pharmacy	2,262	baht/time
Holding cost	27,138	baht/time
Ordering cost	1,562	baht/time
Total cost	91,984	baht

From the information in Table 3, it is found that the total costs of the entire system in the case of diabetic patients consist of fixed costs for opening a drug store amounting to 60,500 baht, costs of transporting goods from the wholesale drug store to the pharmacy totaling 522 baht, patient travel costs totaling 2,262 baht, product holding costs of pharmacies serving patients amounting to 27,138 baht/time, and the cost of ordering products for pharmacies serving patients totaling 1,562 baht/time. Therefore, the total costs amount to 91,984 baht. If considering the costs in each store, the number of patients allocated to each store, including inventory cost management, the information mentioned above is presented in Table 4.

Table 4. Cost used in each store in the case of service opening.

Pharmacy	Open (✓) / Close (✕)	Number of patients allocated	Fixed costs for opening the service	Inventory management costs	Transportation cost for Pharmacy	Total cost
ID 1	✕	0	0	0	0	0
ID 2	✓	8	5,500	1,238	0	6,738
ID 3	✓	36	5,500	5,076	51	10,627
ID 4	✓	10	5,500	1,513	33	7,046
ID 5	✓	16	5,500	2,335	40	7,875
ID 6	✓	12	5,500	1,787	3	7,290
ID 7	✓	40	5,500	5,624	46	11,170
ID 8	✕	0	0	0	0	0
ID 9	✓	32	5,500	4,528	27	10,055
ID 10	✓	20	5,500	2,883	29	8,412
ID 11	✕	0	0	0	0	0
ID 12	✕	0	0	0	0	0
ID 13	✓	10	5,500	1,513	92	7,105
ID 14	✓	10	5,500	1,513	17	7,030
ID 15	✕	0	0	0	0	0
ID 16	✓	4	5,500	690	183	6,373

From the information in Table 4, it is found that out of the 16 pharmacies participating in the project, 11 pharmacies were selected to be allocated to patients. The number of patients allocated to each store is shown in the table. There is a cost for opening services in each store, consisting of fixed costs for opening the service, inventory management costs (including the cost of ordering products and product holding costs) and transportation costs.

5. Discussion

In the comparative analysis of the existing situation of the "Taking Medicine Nearby House" project in Hat Yai District, Songkhla Province, two types of operations are involved: Model 1 and Model 3 [2].

Model 1 is carried out through the hospital. Hospitals purchase and prepare medicines for patients and deliver them to pharmacies in the network. Pharmacies will only dispense medicines to patients.

In contrast, the third model involves pharmacies purchasing drugs through wholesale pharmacies. The medicine is then prepared and administered to the patient. For this research, we consider only one wholesale pharmacy. However, in reality, pharmacies can buy medicines from other sources. This study, therefore, focuses on Model 3, which aims to alleviate hospital workload more efficiently than Model 1.

For a cost-benefit analysis of implementing the proposed solutions, in the long run, it can reduce costs related to waiting times while receiving services at the hospital. Most patients are admitted in the morning, meaning that each patient spends an average of 3 hours and 18 minutes receiving services at a public hospital. If the minimum wage is 340 baht per day, working 8 hours per day, patients will lose an average daily income of 140 baht per visit. However, if patients choose to receive services at the pharmacy, they can do so at a convenient time without affecting their working hours. On average, it takes each patient 47 minutes to receive service from a pharmacy [2].

6. Conclusions

This article proposes a solution to the location-inventory problem that considers how to select the appropriate pharmacy location and plan the right inventory level of the selected pharmacy, simultaneously. A mathematical model was established to minimize the total travel distance, covering as many patients in the "Taking Medicine Nearby House" project as possible, and accessing retail stores (pharmacies) so that there is an appropriate number of customers (patients) receiving services in each store. This study has shown that the proposed mathematical model can be applied in the "Taking Medicine Nearby House" project in Hat Yai District, Songkhla.

Through the mathematical model of the location inventory problem, a case study of diabetic patients can be solved using the exact method with this problem size. However, when the number of pharmacies or the number of patients gets bigger and still uses the Lingo program to solve the problem, it was observed that the time required for calculations increased with the problem size. Obtaining the solution when having 90 pharmacies and 200 patients took more than 50 hours.

For future research, a method applied to metaheuristics can increase the efficiency of finding solutions. This method can help in calculating the results to cover as many patients as possible and to ensure an appropriate number of patients are served at each store. It takes less time to calculate, and the results are acceptable.

The mathematical model may need additional conditions and must consider various quality factors, such as covering as many patients as possible and accessing to ensure an appropriate number of patients receive services in each store. This adjustment aims to make the mathematical model more realistic and capable of providing effective solutions to problems, considering the required calculation time, in the future.

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