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Health Information System: Graph Theory Modelling Of an Efficient Hospital - Pharmacy Drug Availability Management System

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ABSTRACT

This work has targeted accessibility and availability of drugs and surgical materials from a geographical network of pharmaceutical companies for a source hospital where emergency cannot be jettisoned. The use case is an healthcare system where drug availability is of utmost priority. Graph Theory, combined with geographical positioning system (GPS) were used for modelling of a single source Hospital with multiple vertices of pharmaceutical companies that are in stock of the needed drugs and surgical materials. The implementation of this research was done using server-side, scripting and style languages on MySQL database management system and the result of an optimised Dijkstra used has been presented in section 8 of this paper.

Keywords: Graph Theory, Modelling, Dijkstra Algorithm, Geographical Positioning System

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1. INTRODUCTION

Health Information System (HIS) is immensely transforming the face of healthcare across the world, thus making healthcare more convenient and accessible to both the healthcare team and also to the patients (Elikwu et., 2020). The major pillar of HIS is Information and Communication Technology (ICT), it is the bedrock on which all HIS innovations are implemented (Alotaibi & Federico, 2017). Medical doctors now have access to medical records of patients with the use of Electronic Health Record (EHR) (Boonstra et al., 2022). This is a digital version of the traditional paper Health Record System. They also have the liberty to update the record by recording their prescriptions on the EHR.

The Pharmacy Department is a place where prescribed drugs are dispensed. They, also like doctors have the permission to retrieve the patient's record and thereafter dispense drugs prescribed by the doctors. However, when certain drugs are not available, there should be a platform that links the hospital to the neighboring pharmacies, this should help identify pharmacies that are legally registered with the government, that have the brand of the drugs in question as well as the required dosage and that is closest to the hospital. The proposed platform (drug information system) is a system that provides drugs data for the patient/patient relative, doctors and pharmacists.

Drug availability is very important both to the hospitals and to the patients, because there have been records of cases where patients' health issues got complicated due to unavailability of drugs at the right time. Some may have the mind to get the drugs at a particular pharmacy and after spending long hours on the queue will find out that, the drug is not available. The process of getting drugs can be a tedious one especially if there is no exact pharmacy to visit nearby and the fear of getting drugs from unlicensed drug store can be frustrating as well.

Graph theory perfectly models the interactions between the hospital pharmacy and the pharmacies within the community with its node, edge, vertex and lines. Graph theory is an old subject area, but one that has many fascinating modern applications. Graph theoretical ideas are highly utilized in Computer Science areas such as Data Mining, Image Segmentation, Clustering, Image Capturing, and Networking (Ferozuddin and Khidir, 2011). A tremendous powerful combinatorial methods exists in graph theory which have been used repeatedly to prove important and distinguished results in a variety of areas in mathematics (Besjana, 2015), the application areas includes operation research, computational biology, traffic modelling, molecular biology, public health data mining, etc. Paths, walks and circuits in graph theory are used in tremendous applications such as database design, resource networking which leads to the development of new algorithms and new theorems that can be used in various applications.

1.1 Problem Statement

A lot of times, patients or relatives of patients are thrown into confusion while attempting to purchase certain drugs. This often leads to death when the needed drugs cannot be obtained in good time or when original products cannot be purchased. Obscurity of information about location and proximity of registered pharmacies, records and quantity of available drugs per time make it difficult for hospitals to recommend any particular pharmacy within the community. Graph theory modeling of this concept does not exist in literature.

1.2 Aim and Objectives of the Study

The aim of this study is to develop a model that identifies cost effective pharmacies with available prescribed drug within a geographical location using Global Positioning System (GPS).

The objectives include:

i. To conduct a literature review on applications of graph theory.
ii. To design an algorithm for the drug search process
iii. To develop a graph theory model for the algorithm in ii
iv. To translate the algorithm in ii into a program.

1.3 Significance Of The Study

The treatment process of most (if not all) hospital patients would not be complete without the administration of drugs, hence, the essence and importance of pharmacies in hospital environment and across the communities. It is not surprising that prescribed drugs may not be found around the hospital environment and this situation has led to some sad occurrences. There have been cases whereby a care giver will rush to a nearby pharmacy and after spending quite some time on the queue, only to get to the purchasing desk and discover that the drug is not available. So, if this experience repeats itself in multiple pharmacies and the drug was eventually not gotten, what will be the condition of the patient, most especially in cases of emergency? How about the case of getting a drug and it was discovered not to be original probably because the pharmacy is not a licensed one. Though, it may be possible to get it returned but what if a dosage or more has been taken before the discovery? Hence the availability of reliable and timely information is key in human health.

2. REVIEW OF RELATED WORKS

Plethora of authors have worked on modeling of concepts using Graph Theory. According to Bath et al., (2009), Graph Theory can be used as a tool for data mining in public health and to examine associations between deprivation and poor health. Bath et al., (2005) utilized Maximum Common Sub graph (MCS) algorithm to evaluate the group based program called RApid Similarity CALculator (RASCAL) to identify geographic areas with similar demographic attributes. This is related to our work as we seek to identify particular locations too.

Shih-Yi (2009) presented the use of mathematical graph theory to represent large scale data on bio-molecular interactions. Protein interaction networks, metabolic networks as well as transcriptional regulatory networks were modeled. Tamura et al. (2011) showed applications of graph/network theory to several problems in communications and focused on the existence or non-existence of efficient algorithms to solve them. The authors also concentrated on Multi-hop wireless network and node colouring of graph and building multilayer brain graphs is another approach for performing multimodal data analysis. Mathematical model was used to drive and exploit natural-language expressed biomedical knowledge for repurposing existing drugs towards diseases for which they were not initially intended (Di Matteo et al., 2014).

This helped to create a network of knowledge presentations, capturing the essential entities occurring in a variety of publications and connecting them into a graph. The paper presents a novel framework to apply social network and graph theoretic methods on modern health care data to analyze and understand chronic disease progression to enable all stakeholders to take appropriate preventive measures. The paper introduces a novel approach that incorporates concepts of social network analysis and graph theory into healthcare data (Khan et al., 2016). Chakraborty et al. (2018) present the graph, which is made up of nodes, as a kind of social network where each person or organization represents a node. The users or people involved are referred to as nodes or vertices, and any relationship between the users due to common interests or mutual friendship is referred to as an edge.

Wei, et al. (2017) discussed graph structure analysis and distance calculating in their paper "Study of biological networks using graph theory." The exact expression of several important eccentric related indices of hyper tree network and X-tree are determined. A comprehensive research on how graph theory can be applied in various fields of computer science such as data mining, image processing, data structure, operating system, network software and security, information retrieval system and software engineering was carried out by Dakineni et al. (2017). Graph theory approaches in health care inventory system was reviewed by Priyan and Gurusany (2017). Various Graph theory studies applied to health care and their classification based on application type and on the graph theory technique employed was identified.

Balamnigan and Zubar (2013) developed a decision making approach which was utilized for making decision in future direction of treatment. Analysis of the patient previous history information using graph theory for better understanding of patient health condition and proposing a decision making model for deciding future treatment and analysis. Hence, the inability to access patient previous records will pose a challenge to decision making.

Yu et al. (2018) presented a comparative review of articles for building graphs to summarize brain connectivity. Furthermore, a graph convolutional network (GCN) algorithm called "PharmaSage", was developed, which used graph convolutions to generate embedding for pharmacy products, which were then used in a downstream recommendation task (Hell et al., 2020). A detailed discussion of graph theory parameters in relation to small group learning was done by Chai et al., (2019). The work succeeded in modeling the participants of the group as nodes and the connection as edge. This work is part of the pillars of our study.

3. METHODOLOGY

As used in graph theory, the term graph does not refer to data charts, such as line graphs or bar graphs. Instead, it refers to a set of vertices (that is, points or nodes) and of edges (or lines) that connect the vertices. When any two vertices are joined by more than one edge, the graph is called a multi-graph. A graph without loops and with at most one edge between any two vertices is called a simple graph. Unless stated otherwise, graph is assumed to refer to a simple graph. When each vertex is connected by an edge to every other vertex, the graph is called a complete graph. When appropriate, a direction may be assigned to each edge to produce what is known as a directed graph, or digraph.

Any processing done with graphs might be categorized as a “graph algorithm”. We can implement a function in this way by visiting the nodes, we visit each node to search for a drug and we stop searching when we find the actual drug. The Hospital and Pharmacies represent the vertices and the connecting lines, the edges represent the cost of the distance among the various vertices. The search will begin from the current node (the hospital), visits all adjacent vertices, and continues until all vertices are visited. As seen in figure 1, each pharmacy is represented a node and are labelled P1 to P7. The search will proceed by navigating through the edges using Dijkstra shortest path algorithm to determine the pharmacy that is closest to the hospital where the patient is located.

Fig 1 illustrates the group of pharmacies that have been confirmed to be in stock of the searched drugs, with the cost to each pharmacy also shown. According to the Dijkstra's algorithm (or Dijkstra's Shortest Path First algorithm), unvisited vertices consist of all vertices which are represented in fig 1. Dijkstra algorithm rule allows for each vertex to be visited only once while the shortest distance and shortest path are being determined and no Vertex is permitted to be unvisited, the procedure is illustrated in algorithm 1. In real life, accurate distance can be obtained using Google Maps. The current node, which is the Hospital is assigned value zero as shown in Table 1. All adjacent pharmacies cost are thereafter calculated using the formula:

Let G be a graph with vertex V; such that source vertex *s*; target vertex *v* and connecting link (Edge) E which are non-negative.

In this case, vertex V denotes all the pharmacies, P1,P2,P3,P4,P5,P6,P7,H. The source vertex s is the originating (current) vertex, which is vertex H. The connecting link are the cost of the distance which are all non-negative. At initialization, d_s , the cost of the current vertex is set to zero and all other vertices d_v set to infinity as shown in Algorithm 1 and Table 1 and processes the interactions further as shown in the Algorithm 1

G | s,v ∈ V ; output $\mathrm{d}_v, \mathrm{p}_v$ ∀ v ∈ V (1)

Dijkstra determines the distance d_v of shortest path from s to v and its penultimate vertex p_v for every v in V

Algorithm 1

Initialize [Q] // the priority queue of all the vertices is set to empty initially,
$For\ every\ v\ in\ V$
    $\mathrm{d}_v \leftarrow \infty;\ \mathrm{p}_v \leftarrow null$
    Insert [Q, v, d_v] // this is to initialize the vertex priority in the priority queue
    $\mathrm{d}_s \leftarrow 0;$
    Decrease [Q, s, d_s] // this update priority of s and d_s
    $\mathrm{V_T} \leftarrow \emptyset$
$For\ i \leftarrow 0\ to\ |\mathrm{V}| - 1\ do$
    $u^* \leftarrow DeleteMin[Q]$ // delete the minimum priority element
    $\mathrm{V_T} \leftarrow \mathrm{V_T} \cup \{u^*\}$
For every vertex u in $V - \mathrm{V_T}$ that is adjacent to u^* do
    If ($\mathrm{d}_{u^*} + w[u^*, u] < \mathrm{d}_u$)
        $d_u \leftarrow \mathrm{d}_{u^*} + w[u^*, u];$
        $\mathrm{p}_u \leftarrow u^*;$
        Decrease [Q, u, d_u]

This process continues until all Djikstra table is developed as shown in the table 1. Table 2 shows each Pharmacy and its adjoining Pharmacies.

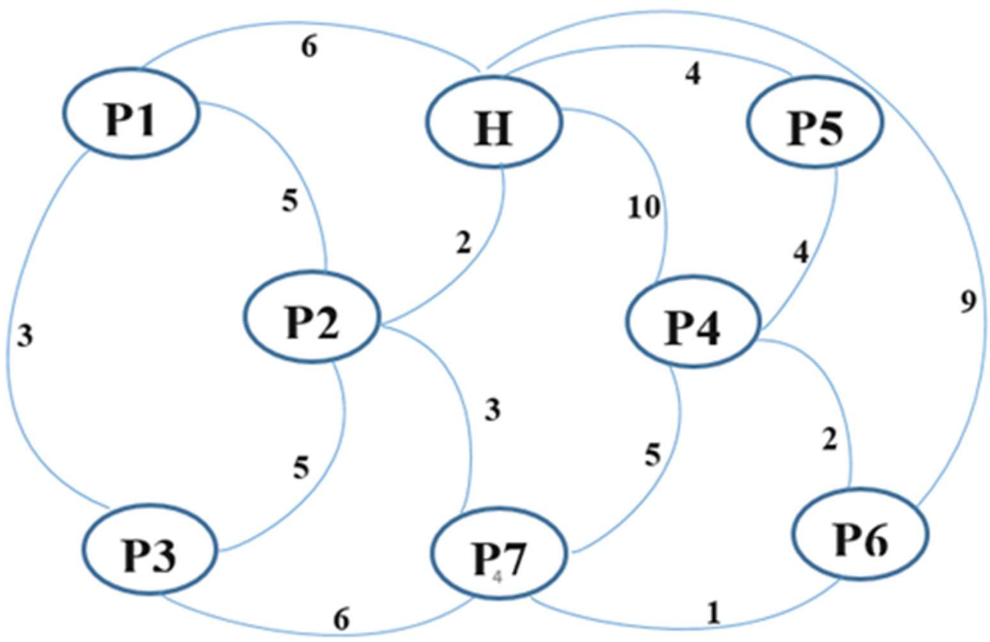


Fig 1 : Undirected Graph illustrating Hospital-Pharmacy Relationship

Table 1: Djiksra Algorithm Implementation on Fig 1

H	P1	P2	P3	P4	P5	P6	P7	
H	**O**	∞	∞	∞	∞	∞	∞	∞
P2	X	9	**2**	∞	10	4	9	∞
P5	X	7	X	7	10	**4**	9	5
P7	X	6	X	7	8	X	6	**5**
P1	X	**6**	X	7	8	X	6	X
P6	X	X	X	7	8	X	**6**	X
P3	X	X	X	**7**	8	X	X	X
P4					8			

Table 2: Representation of Current Vertices and their Adjoining Vertices

CURRENT PHARMACY	ADJACENT PHARMACIES				
H	P1	P2	P4	P5	P6
P2	P1	P3	P7		
P5	P4				
P7	P6	P4	P3		
P1	P3				
P6	P4				
P3					

The shortest distance is the smaller number between the two distance costs of the last viable row in the table, in this case, it is value 7 at point (P3, P3). The shortest path between the Hospital and the nearest pharmacy is derived by observing the point of change when the value 7 is traced up. There is a change at (P2, P3) with the value of ∞ (infinity). The minimum number on the row of change is picked, which is value 2 at point (P2, P2). This is further traced up till there is a change again to value ∞, the change occurring at (H, P2). The minimum value which is zero is identified thereafter on the new row at interval (H, H). It can be observed from Table 1 that the minimum values selected on the rows are found on points (P3, P2, H). when this is reversed, our shortest path becomes (H, P2, P3).

3.1 Compatibility Graph and its Connectivity

The patient usually approaches the doctor who shall prescribe the drugs and look for nearest pharmacies to the patient's location where the drug is available using Google map. To study the hospital-pharmacies communication at an arbitrary intersection, it has to be modeled mathematically by using a simple graph for the drug collection data problem. The set of edges of the underlying graph will represent the communication link between the set of nodes i.e. distances of the pharmacies. In the graph representing the pharmacies, the drug search which can move simultaneously at an intersection without any conflict will be joined by an edge to find the closest pharmacy by an edge.

The graph obtained thus is a connected graph and will be referred as the compatibility graph of the intersection corresponding to the drug search problem. In order to define a cut-set and the connectivity of the compatibility graph, the underlying graph G considered as $G = (V, E)$ where $V(G)$ denotes the set of vertices of G and $E(G)$ denotes the set of edges of G. A cut-set F is a set of edges whose removal from G leaves G disconnected. Also it results in the increase in the number of components of G by one. Each cut-set of the compatibility graph G consists of a certain number of edges. The number of edges in the smallest cut-set i.e. the cut-set with fewest numbers of edges is defined as the edge connectivity of G. The vertex connectivity of the compatibility graph G is defined as the minimum number of vertices whose removal from G leaves the remaining graph disconnected.

3.2 Use Case Diagram

As seen in figure 2, the use case diagram composed of 3 actors, The Doctor, The Pharmacist and The patient/relative. The Doctor is capable to log in, prescribe drugs and log out of the Drug Availability Management System Application. The pharmacist is also capable to log in, manage drugs which also extend to add and delete drugs and log out of the Drug Availability Management System Application.

The patient/relative is also capable to log in, search nearest pharmacy by using Google maps, locate pharmacy, search drugs, get drugs and log out of the Drug Availability Management System Application.

Pharmacist's session:

i. The pharmacist will log in to the pharmacy dashboard on the dug availability system as shown in fig 3.
ii. The pharmacist will then open the manage drugs button to either add or delete drugs. This action will reflect on hospital dashboard.
iii. The patient/relative will search for nearest pharmacy where the drug is available on the system using his location (this can be achieved by connecting to Google maps to access the pharmacy location).
iv. The pharmacist will log out.

Patient's/relative's session:

i. The patient/relative will log in to the dug availability system as depicted in fig 4
ii. The patient/relative will search for nearest pharmacy where the drug is available on the system using his location (this can be achieved by connecting to Google maps to access the pharmacy location).
iii. The patient/relative will locate pharmacy by following routes indicated on the Google maps
iv. The patient/relative will get drugs from the pharmacy
v. The patient/relative will log out.

USE CASE DIAGRAM OF DRUG INFORMATION SYSTEM

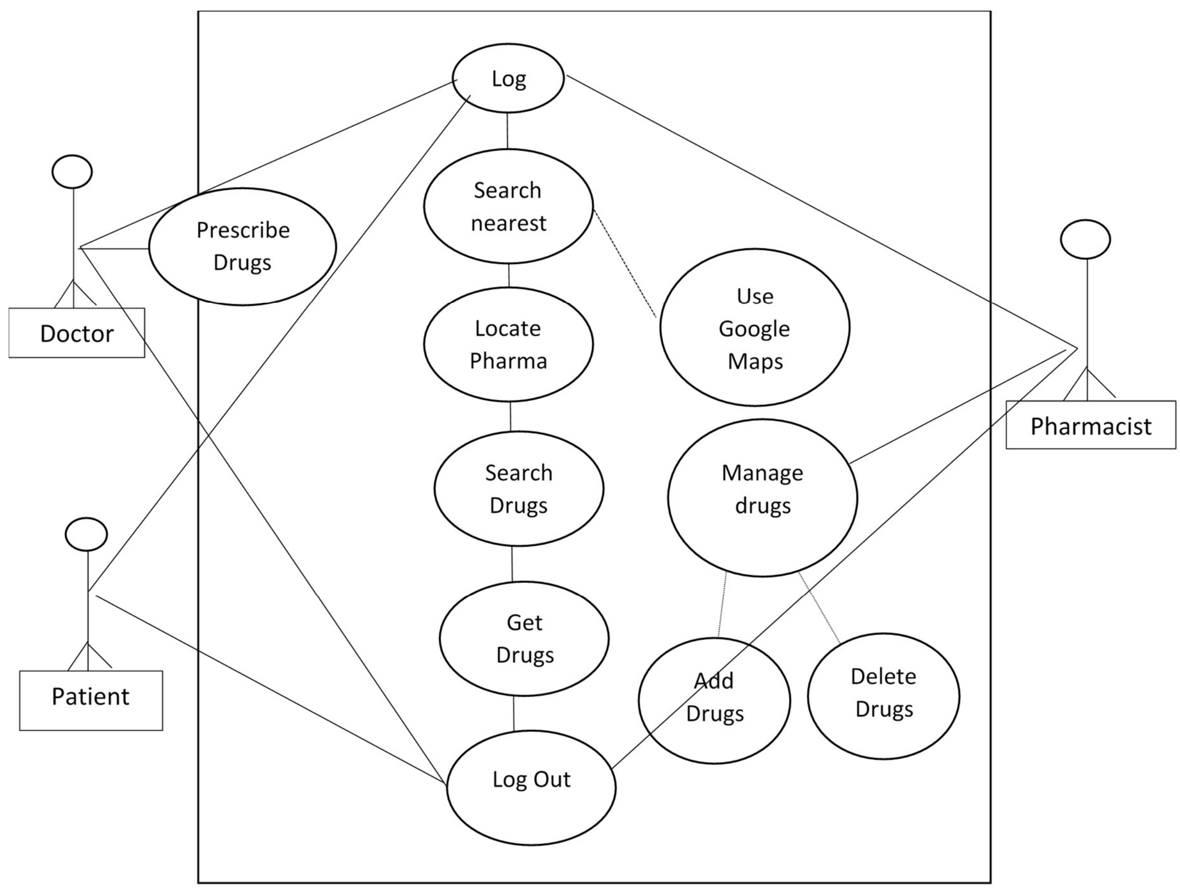
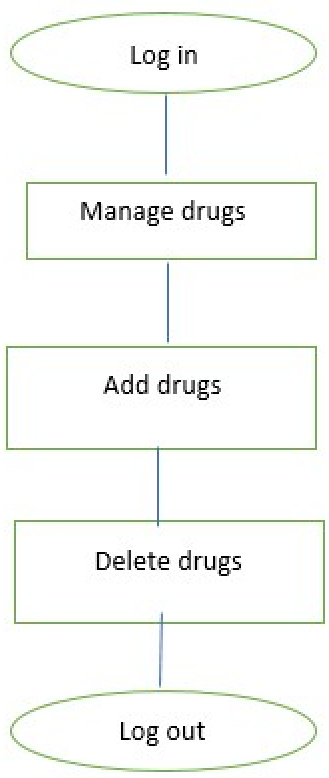


Fig 2: Use Case diagram representing the Hospital Pharmacy Interaction

Pharmacist session



Patient/relative session

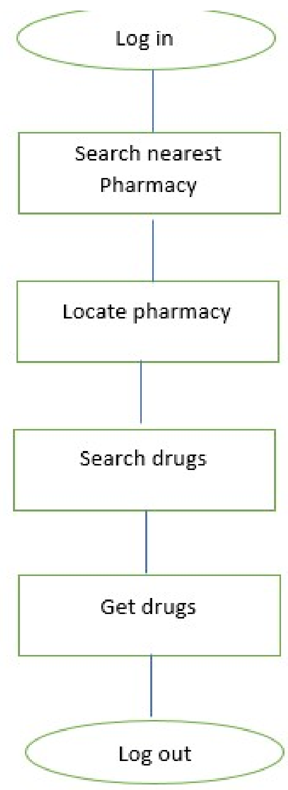


Fig 3: Pharmacist's session flowchart   Figure 4: Patient's/relative's session flowchart

4. SYSTEM IMPLEMENTATION AND RESULTS

The application for this model was implemented using Google map API, Php, Javascript, CSS and HTML programming language. The home page welcomes the user who is either the doctor, pharmacist, patient/relative. To access the main drug or pharmacies database, it is imperative the user must be registered and signed up into the system by providing certain details. There is also the 'administrator' user who coordinates the dashboard, drug list, pharmacy list, drug/pharmacy search, and reports from the backend. It is assumed that the application is domiciled in any originating hospital.

Figure 5 illustrates how the drug search can be conducted. The user can search for a drug by typing the name of the drug in the search box and then click the search button. The result of the drug search is displayed in figure 6. The result against "paracetamol" search as searched for will also include all available pharmacies where paracetamol can be found including the pharmacy contact details and address.

Figure 6 shows a drug search and all available pharmacies with the drug in stock. It alllows a user to get the pharmacy address via the use of Google maps. The user can access the location by clicking the pharmacy address indicated. This will link the user to Google maps platform, and establish a route to the pharmacy address from the user's address. Figure 7 illutrates the pharmacy location which links the user to the pharmacy address using Google Maps. When a user click the pharmacy address link, it will direct the user to the location on Google maps, it will also show other nearest pharmacies. The patient/relative can use this information to locate the pharmacy and to check for directions and expected time to reach the pharmacy

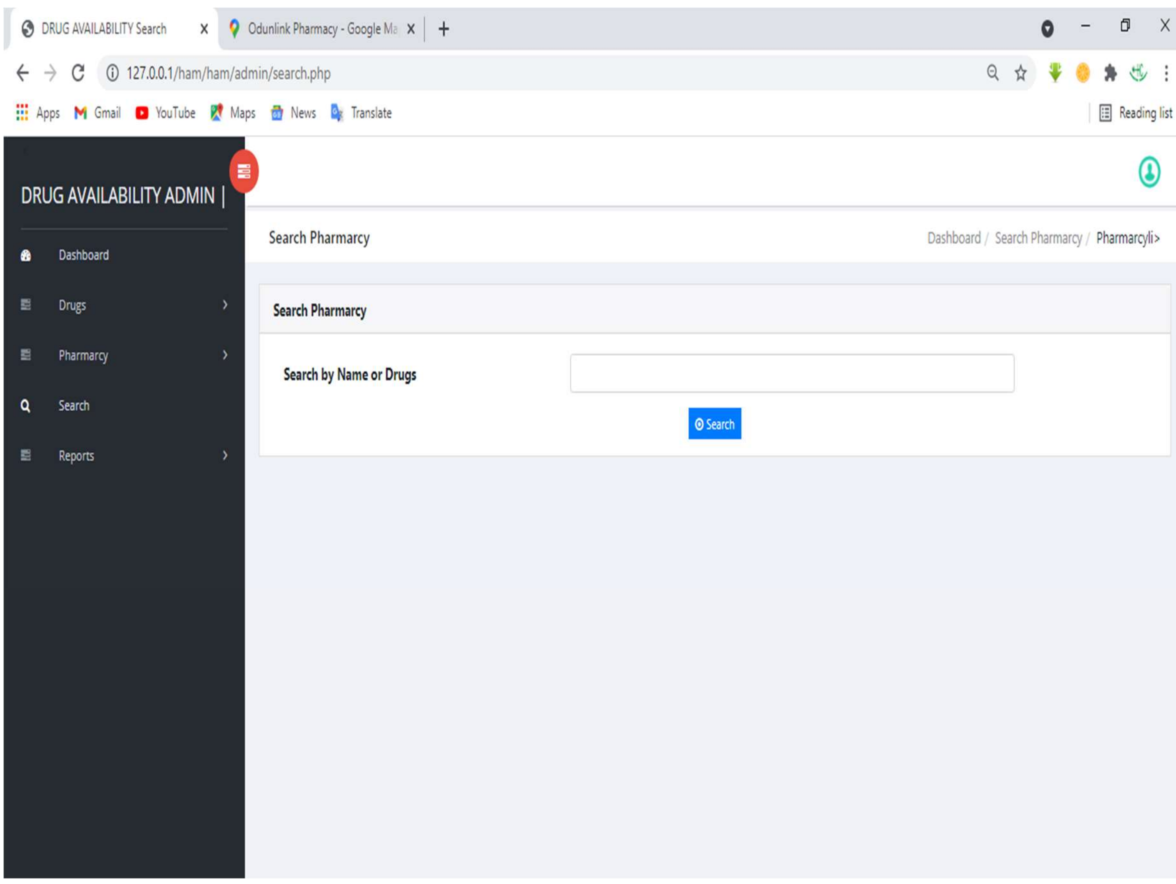


Figure 5 : Drug and Pharmacy search page of the Drug Availability Management System

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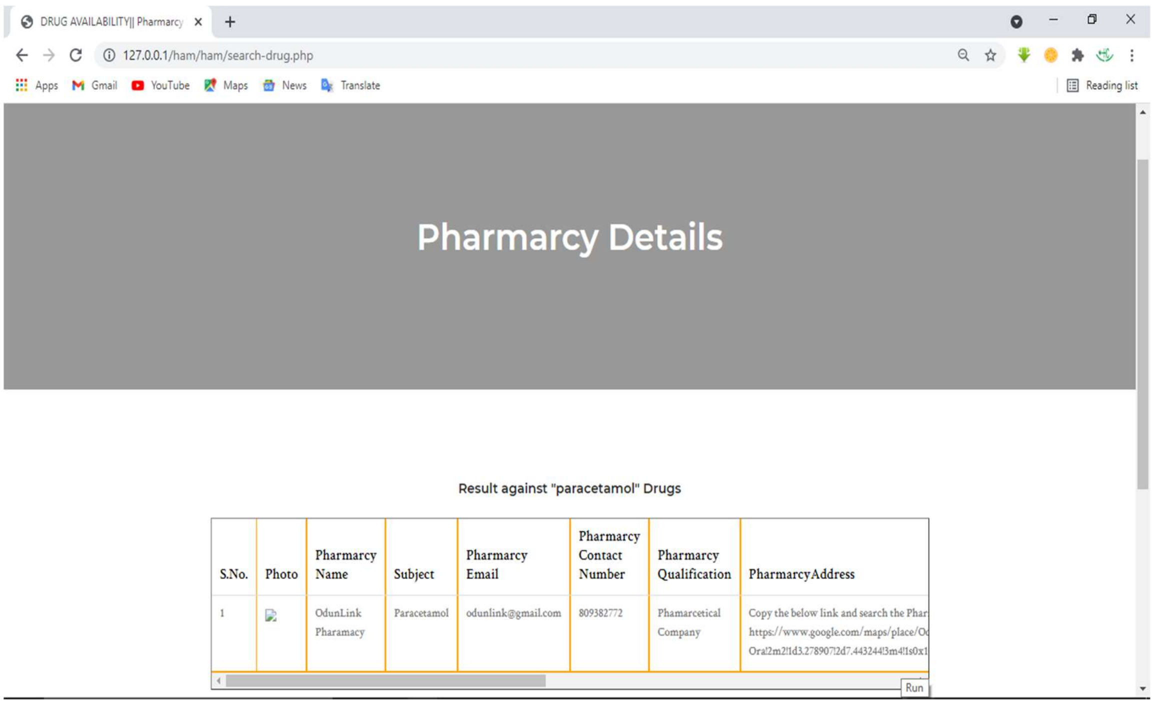

Figure 6 – Result of drug search of the Drug Availability Management System

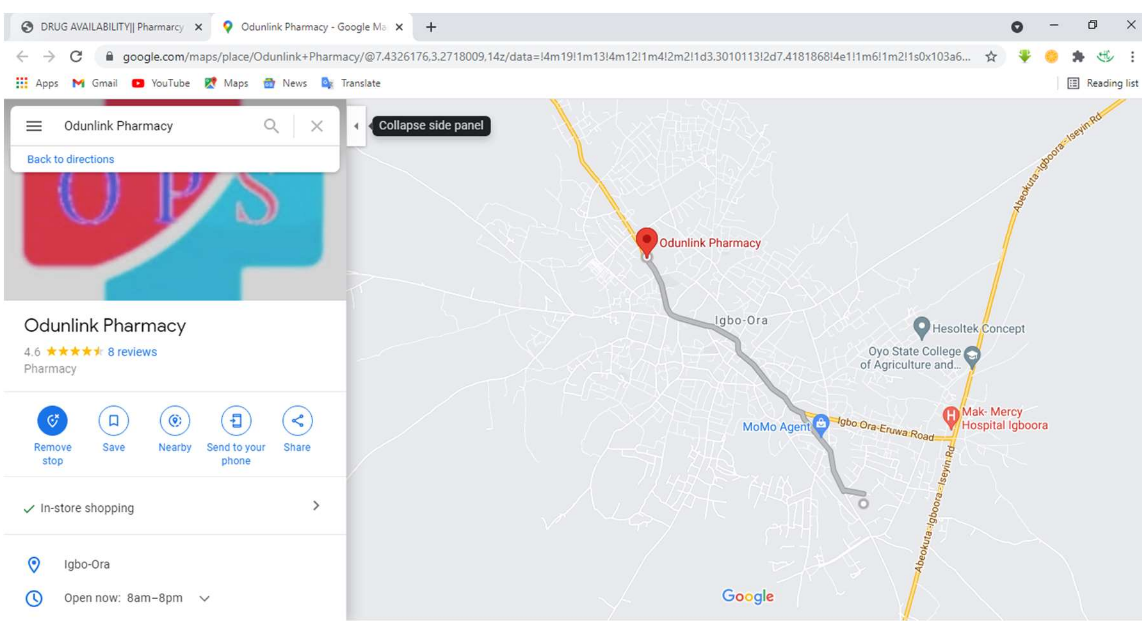

Figure 7 - Figure showing Pharmacy location on Google Map

From the result presented in Figure 6, Odulink Pharmacy was selected as the most cost effective location from the list of pharmacies that has the paracetamol brand that was searched from Mark Mercy Hospital.

5. CONCLUSION

The treatment process of almost all hospital patients would not be complete without the administering of drugs, hence, the importance of registered pharmacies in and around every hospital premise cannot be over emphasized.
In this study, we have presented a graph theory model of the interaction between hospital and pharmacies in stock of the searched-drugs. The model selects the most cost effective route for the patient/relative to access the nearest pharmacy by applying Dijkstra shortest route algorithm.

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