Harvard Vanguard Medical Associates (HVMA)
Obstetrics Pelvic Ultrasound Accessibility and Location Optimization

Design Team
Jonathan Ben-Avi, Alejandro Hoyos,
Georg Michelet, Daniela Pachon

Design Advisor
Prof. James Benneyan
Sponsor
Susan Haas, HVMA
Onur Uzunlar, MSc

Abstract
Harvard Vanguard Medical Associates (HVMA) is a non-profit, multi-specialty medical group practice with offices all across eastern Massachusetts. Currently only 4 of their 15 medical centers offer ultrasound screening. HVMA aims to reduce the traveling distance for their ultrasound patients by finding the optimal location of the facilities where the scans are performed. Ultimately, HVMA aims to know if it is better to relocate the current units, expand to new facilities, or do a combination of the two. The overall goal of relocating/expanding units is to increase the access to care. The solution path pursued to solve this problem consists of an optimization model followed by a post processing of the solution using probability distributions. The optimization model is a mixed integer-programming problem, which includes elements from Location/Allocation, as well as Assignment Problems. The objective function minimizes the patients traveling distance to each facility, along with the constraints and parameters, which are solved using IBM ILOG CPLEX Optimization Studio (CPLEX) software. The model provides a deterministic solution to the problem. To introduce variability to the solution provided by the CPLEX model, the solution obtained from the optimization model is processed using a Poisson probability distribution. This provides the probabilities of both under-utilization and over-capacitating of each facility providing the basis for cost analysis. The success of the project is measured along the triple aim of healthcare: reduced costs, increased accessibility and improved continuity of care. Essentially, this project provides a decision tool to help HVMA in their decision-making process.

For more information, please contact j.benneyan@neu.edu.
The Need for Project

Harvard Vanguard Medical Associates (HVMA) Obstetrics & Gynecology department aims to find the optimal locations of where ultrasound scans are performed in order to reduce patients’ traveling distance.

HVMA currently offers ultrasound scans to their patients at four of their fifteen locations (Burlington, Kenmore, Quincy, and Wellesley). Currently, they own 6 ultrasound machines however, to satisfy the demand, they have to rent extra machines and staff. Despite this, they are not able to meet the actual demand for ultrasound scans and are forced to outsource patients to private clinics that can perform the scans. In order to improve the current system, HVMA wants to know whether they should expand ultrasound care to more facilities, if the current facilities should be relocated, and where these facilities should be located.

The Design Project Objectives and Requirements

The Design Project Objectives and Requirements

The objectives of this project will follow the triple aim measures of healthcare improvement. That means reduced costs, increased accessibility to care, and improved continuity of care.

The most prevalent objective is the increase in accessibility of care for the patients. This is done through decreasing the average travel distance each patient has to travel to receive care, hence making care more accessible. Furthermore the quality of care will be increased, as there will be improved continuity of care. This means patients will not have to travel to different facilities to receive ultrasound scans and they will stay within the HVMA system; where they are familiar with the nurses, doctors and processes, as opposed to being outsourced to a private clinic for a scan. HVMA also wants to reduce costs through the reduction of renting extra equipment, staff and outsourcing to private clinics, as well as the increased revenue by being able to accept these patients.

Design Requirements of the CPLEX model

The model has certain requirements in order to flow correctly and yield an optimal solution for different scenarios. The CPLEX model will take every variable, parameter, constraint, and the function given to provide the best possible solution. The following are some of the essential requirements of the model: Xij and Yj are binary variables used in the model,. Xij refers to the whether zip code I is assigned to location j or...
not, $Y_j$ refers to whether a unit is assigned to location $j$ or not. Each facility needs to have at least two ultrasound machines, due to the fact that one doctor can proctor between two and three units. In order to run the scenarios featuring the current locations and their units, the total current number of units at facility $j$ has to be greater than or equal to the equipment available at that facility $j$. To be able to meet the total demand and avoid over-capacitating, the total workload assigned to location $j$ cannot be larger than the capacity at location $j$. Total number of equipment available can not exceed the planned number of ultrasound units.

**Design Concepts Considered**

Five different candidate design concepts were considered when deciding on the solution path. The best path was found through thorough research and discussion. Five different candidates were studied and considered in order to find an approach to obtain an optimal solution for the problem. The first candidate was C++, which is a programming language. After browsing for other alternatives it was decided that in this instance IBM ILOG CPLEX optimization software would be a better fit for this project and our objectives. It is a user-friendly software and designed to solve these kinds of problems.

Due to the fact that Mathematical Programming provides a deterministic solution to the problem, it is necessary to see how the solution will behave when variability is introduced. In order to observe this, creating a simulation model using ARENA software was considered first. This would provide a stochastic scenario and a way to view performance over time. Due to the complexity of constructing this model, however, it was decided that Visual Basics should be used instead. After further research, it was found that rather than simulating the solution and running the model a number of times to find the probabilities of over-capacity and under-utilization, exact probabilities could be calculated using probability methods. Utilizing a Poisson probability distribution will yield the same solution as using simulation in ARENA or Visual Basics and at the same time it is less time consuming and provides the exact probabilities for over-capacitating and under-utilization. By using the probability distribution and CPLEX, all the data is be linked to an excel file and the scenarios are run simultaneously, making the process of obtaining the solutions much more efficient and productive.
Recommended Design Concept

After examining all the candidate design options, the solution path chosen included a deterministic solution followed by a post processing of the solution using probabilities with a Poisson distribution to understand how the system would behave overtime. The first section of the solution was developed in CPLEX. Specifically for this project, the mathematical model consisted of an objective function whose main goal was to minimize the distance traveled by the patients who needed to have an ultrasound scan performed. The program would examine every hospital available to do ultrasounds and would assign patients accordingly based on their zip-code proximity. Within the code, the formula as well as several constraints and parameters were included in order to obtain the optimal solution. Numerous scenarios were run; each with a slight variation in the constraints in order to display all the potential improved states of the current process for example; keeping 3 of the units in their current facilities and relocating 1, or keeping 2 of the units in their current facilities and relocating 2 while also buying/renting two additional ultrasound machines. The different zip-codes were stored in an excel file that was called from the CPLEX model. When the model is run, the results are displayed in an Excel file that is able to compute the probabilities of over-capacitating and under-utilization in the hospitals chosen in the CPLEX optimal solution. These probabilities are calculated using the Excel Poisson function. Once the probabilities are calculated, another sheet in the same Excel file is in charge of estimating the costs and revenues.
Financial Issues

In order to decide between buying ultrasound equipment and hiring staff versus renting a thorough cost analysis of the two options was completed for each scenario.

The fact that HVMA outsources patients to private clinics means they lose out on potential revenues as well as having a high over-capacitating cost. In addition to this they face high renting costs for the extra ultrasound machines and staff they need to rent in order to meet demand. To reduce costs, HVMA aims to lower both the over-capacitating cost as well as the under-utilization cost. The under-utilization cost refers to the cost of having idle doctors (MDs), nurses and equipment. Over-capacitating refers to the lost revenue for each patient not being able to receive an ultrasound scan at an HVMA facility. The under-utilization cost was calculated based on the amount of time a sonographer (nurse who performs scan) and a doctor (reads the scan) remained idle, the cost is the summation of their salaries per encounter. The over-capacity cost was calculated based on HVMA’s revenue per appointment multiplied with the expected number of patients that were lost due to limited capacity. Alternative scenarios were calculated based on the decision of buying equipment and hiring staff versus renting. In all scenarios the rate of over-capacitating and under-utilizing was calculated using the Poisson probability distribution. In the scenario of buying equipment and hiring staff, the cost was calculated as follows: cost of buying the equipment + annual cost of staff (yearly salary of both sonographer and MD) + under-utilization + over-capacity. For renting, the cost was calculated as follows: cost of renting per year + annual salary of an MD + under-utilization + over-capacity. Once these costs are obtained it is possible to see the annual cost of each scenario and decide which scenario is better over time (10 year span).

Recommended Improvements

Further work that can be done on this project includes additional cost analysis and development of the model. Other areas that also relate to the accessibility of care can be examined to improve the process. i.e. Scheduling.

The future scope of this project includes having a more intricate cost analysis, including the expansion costs to each facility as these might differ, currently only the cost of equipment and staff is considered. Additionally variability can be included in the optimization model, meaning it will be a non-linear programming model. Initially, HVMA had also expressed some concern regarding both scheduling of the patients and doctors, but this was not in the scope of this project.