Renovation of Mercy Family Health Center

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Abstract: The design of healthcare facilities has to provide a comfortable environment for the patient as well as acceptable waiting and processing times to serve the patient. In this paper, we redesign the layout of a real world healthcare facility (Mercy Family Health Center) to explicitly reduce the back and forth flows of the patients in the existing area and consequently reduce the patient's waiting time. We propose two different alternatives. We use mixed integer programming (MIP) as the basis of our design.

Keywords: Facility Layout, forecast Method, MIP algorithm.

1. INTRODUCTION

In mid-1990's a few high-profile medical errors brought healthcare quality and patient safety to the fore. Using engineering tools for advance studies in transportation and financial service areas and the success of these studies bring the healthcare experts starting to take notice that engineering tools have proven effective in the service sector. Thus, the uses of engineering tools-which have long proven useful in the other service industries-, seem to be a good solution for some of the health systems' problems. Some of these problems are related to the structure of the healthcare systems. Therefore, hospital and healthcare facility design must be sensitive and responsive to the marketplace changes. "Failure to anticipate or respond to the market spells disaster" by Miller, *et al.* (2002). The need for flexibility is intensified by the technological nature of the healthcare industry. Healthcare facilities must adapt to changing patient populations and changing patient needs. In Janet R. Carpmans' addressed by Miller, *et al.* (2002), she calls a dynamic design "a socially responsible health facility design". The design approach is positive responses from the users on physical, intellectual, and emotional levels.

One of the most important problems that some of the healthcare systems are facing to, is the unnecessary flows of the patient that exist in the healthcare facilities which are mostly related to the inefficient layout design of the facility. In this study, we address this type of problem and by using engineering techniques such as operation research tools, we obtain a solution. Mixed integer programming (MIP) is used to model the problem. The lessons learned from this project can be applied to other real world healthcare facilities. The audience of this paper could be the healthcare administrators and operational managers who have experienced similar problems in their facilities.

The organization of this paper is as follows. In section 2, we describe our case study facility, its problems and the solutions that were generated to solve these problems. Two alternatives will be developed and evaluated. In section 3, we conclude the paper.

2. A CASE STUDY

2.1 Mercy Family Health Center

Mercy Family Health center is an outpatient clinic serving with compassion, accountability, respect, excellence and quality services. It is located in Chicago and is the first chartered hospital in the state of Illinois. Its vision is to serve the sick and uneducated people in need with quality healthcare regardless of their ability to pay. Its mission is to foster an environment of healing, providing access and needed care with compassion and excellence to the diverse communities it serves. The clinic provides a wide array of primary care services including: Adult Medicine, Women Health Services, Pediatric and Genetic Counseling, and Specialties (allergy, rheumatology, cardiology, etc.). 25% of the residents near the south side of Chicago who need hospitals care come to Mercy Hospital for various medical needs.

2.2 Problem and Causes

Mercy Family Health Center has a typical traditional layout (Figure 1). The east side of the building consists of the administrative offices, the pharmacy, and the Pediatrics department with its own receptions' area and waiting area. The west side of the building consists of the Continuity Medical Clinics (General Practices), OB/GYN, and Specialties Practices with one waiting area and receptions' area in the middle. This study concentrates on the west side of the building.

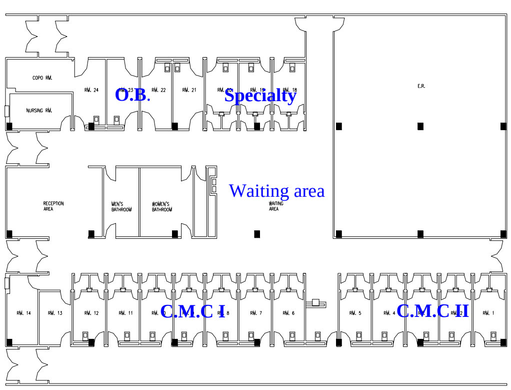

Figure 1: The original layout of the Facility

The centrally located waiting area is the major problem. Although the clinic is divided into various departments, patients are not classified separately in the waiting area. This causes an uncomfortable situation for the patients who are waiting to be served. Access to the examination rooms brings a lot of flow in the area which is absolutely unnecessary. Therefore, the patient is served more slowly and the waiting time for the patients is increased.

Many patients who come to Mercy for general health care carry contagious disease, i.e. fever, flu. The packed waiting area can be the best place to spread these diseases. It is highly recommended by physicians that Obstetrics patients do not sit among others with contagious diseases since they might be more vulnerable to some viruses.

Currently the departments that are closely related are located far away from each other. For example, the eye examination room is set diagonally on the opposite side of the Specialties practice area, which includes Ophthalmology. An eye patient is first served at Specialties area, and then walks across the waiting area to the eye exam room, again back to the Specialties area. It unnecessarily increases the process time and the flow over the area. While other specialties patients have to wait for a longer time to be served.

Some of the spaces that are related to the other parts of the hospital facility are unnecessarily located in this area which again increases the flow in the whole clinic area.

The administrative personnel of the health care center are aware that old structures not only merely fail to serve the patients adequately but fail in what even the most reluctant healthcare providers have come to recognize as a medical marketplace. The most obvious product in the medical marketplace is excellence in healthcare, and a facility's reputation for excellence is a strong incentive to healthcare consumers to select that institution over another. The most important factors that influence the potential consumers are the design of the facility and the patient amenities that the design offers.

2.3 Solutions

Our first step is to maximize the space in order to enhance flexibility and the capability of handling more patients. This can be reached by removing redundant departments. It also eliminates the unnecessary flows in the clinic area. The second step is to reorganize all the departments. Each department will have its own exam rooms and waiting area. The reason for breaking the waiting area into smaller units is to reduce the patients' flows and therefore make the clinic operations more efficient. Also, if the related areas become closer, the physicians' travel time between units

will be shorter and this will improve the service. A modern healthcare facility is no longer a warehouse for the sick. According to the location of each practice area, separate waiting areas are created for each. Since the patients should stay in the waiting area as brief as possible, the waiting area should be comfortable and cheerful. In this layout, patients are classified and directed to the corresponding waiting area. This is especially desired for the obstetrics clinic to provide patients with privacy and direct attention. Besides decreasing the flow of patients from the waiting area to the exam rooms, this creates a small private healthcare atmosphere. Comfort level increases. Small waiting areas are more accessible for clinicians. It is as if the healthcare center was several private practices combined.
Patients are more likely to choose up-to-date with stat-of-the-art clinics over the traditional clinics. The new design emphasizes on creating a friendly, non-threatening, yet functional hospital environment. The new facility layout will be de-institutionalized.
According to the relationship between departments and the importance of their closeness a from-to-chart for the flow of the patient (Table 1) was generated. Departments are defined by the following numbers in the chart.

1. COPO room
2. Nursing room
3. O.B. department
4. Specialty department
5. Dummy area
6. Eye exam room
7. E.R.
8. Hallway I
9. Reception area
10. Waiting area for O.B. department
11. Bathroom
12. Waiting area for Specialty department
13. Hallway II
14. C.M.C department I
15. Waiting area for C.M.C
16. C.M.C department II

Flows can be measured quantitatively in terms of the amount of the patients moved between departments. The chart most often used to record these flows is a from-to-chart (Tompkins, *et al.* 2003). The from-to-chart is a square matrix which lists all departments down the row and across the column following the overall flow pattern. The numbers in table 1 show the average number of the patients between departments per day. This average is calculated regarding to available information of the number of visitors per day in one year.

Table 1: From-to-Chart

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	30	240	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	30	30	0	0	0	30	0	0	30	0	30	30	0	30
3	0	0	0	0	0	0	0	719	719	719	240	0	0	0	0	0
4	0	0	0	0	0	40	0	476	476	0	159	476	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	40	40	0	0	40	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	1195	719	1195	476	0	0	0	0
9	0	0	0	0	0	0	0	0	0	719	5	476	759	0	759	0
10	0	0	0	0	0	0	0	0	0	0	180	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	120	180	0	180	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	759	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	759	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	759
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

2.4 Alternative I

The first alternative is focused on the renovation of the existing facility in terms of existing number of patients in recent year assuming that the number of the patient will not change over years (fixed number of visits in future). Based on the number of the patients who visits each department in one working day, a value is allocated to the area of their waiting area. It is assumed that each waiting area has to be close to their related department because of their strong relationships. All the operation areas that have interaction with each other should be close enough. Due to the management restrictions, some of the current areas are fixed and cannot be moved. Considering this as assumption, to an MIP model is generated (Tompkins, *et al.* 2003) to redesign the layout of the clinic. The objective is to minimize the patients' movements between departments.
Layout algorithms can be classified according to their objective functions. There are two basic objectives: one aims at minimizing the sum of flows times distances while the other aims at maximizing an adjacency score. Generally speaking, the former, that is, the "distance-based" objective is more suitable when the input data is expressed as a from-to-chart.
In this study, we consider the distance-based objective. Mathematically, the objective function can be written as

$$\min z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} c_{ij} d_{ij} \qquad (1)$$

Where m denotes the number of departments, f_{ij} denotes the flow from department i to department j (expressed in average number of patients moved per day between departments), d_{ij} is the distance from department i to j. In the MIP model distance is measured rectilinearly between the centers of department i and j, and c_{ij} denotes the relative weight of a unit of patient moved from department i to department j. We assume that in this specific problem c_{ij} =1 which means the weights of the flows between the departments are equal. Therefore, the objective function minimizes the total flow of the patients between departments in the facility.

Since it is assumed that all the departments of this problem are rectangular, a mixed integer programming (MIP) can be used for solving the addressed problems in this paper.

Treating the department dimensions as decision variables, the layout problem can be formulated as follows. The decision variables and the parameters that are used in this model are:

Decision variables

α_i: The *x*-coordinate of the center of department i

β_i: The *y*-coordinate of the center of department i

x_i': The *x*-coordinate of the left (or west) side of department i

x_i'': The *x*-coordinate of the right (or east) side of department i

y_i': The *y*-coordinate of the bottom (or south) side of department i

y_i'': The *y*-coordinate of the top (or north) side of department i

z_{ij}^x =1: If department i strictly to the east of department j (zero otherwise).

z_{ij}^y =1: If department i strictly to the north of department j (zero otherwise)

α_{ij}^+: If *x*-coordinate of the center of department i is in the east of department j

α_{ij}^-: If *x*-coordinate of the center of department i is in the west of department j

β_{ij}^+: If *y*-coordinate of the center of department i is in the north of department j

β_{ij}^-: If *y*-coordinate of the center of department i is in the south of department j

Parameters

B_x: The building length (measured along *x*-coordinate)

B_y: The building width (measured along *y*-coordinate)

M : A large number

L_i^l: The lower limit on the length of department i

L_i^u: The upper limit on the length of department i

W_i^l: The lower limit on the width of department i

W_i^u: The upper limit on the width of department i

The above parameter and variable definitions lead to the following model:

$$Min z = \sum_i \sum_j f_{ij} c_{ij} (\alpha_{ij}^+ + \alpha_{ij}^- + \beta_{ij}^+ + \beta_{ij}^-) \quad (2)$$

Subject to:

$$L_i^l \le (x_i'' - x_i') \le L_i^u \quad \text{for all } i \quad (3)$$

$$W_i^l \le (y_i'' - y_i') \le W_i^u \quad \text{for all } i \quad (4)$$

$$P_i^l \le (x_i'' - x_i' + y_i'' - y_i') \le P_i^u \quad \text{for all } i \quad (5)$$

$$0 \le x_i' \le x_i'' \le B_x \quad \text{for all } i \quad (6)$$

$$0 \le y_i' \le y_i'' \le B_y \quad \text{for all } i \quad (7)$$

$$\alpha_i = 0.5\, x_i' + 0.5\, x_i'' \quad \text{for all } i \quad (8)$$

$$\beta_i = 0.5\, y_i' + 0.5\, y_i'' \quad \text{for all } i \quad (9)$$

$$\alpha_i - \alpha_j = \alpha_{ij}^+ - \alpha_{ij}^- \quad \text{for all } i \ne j \quad (10)$$

$$\beta_i - \beta_j = \beta_{ij}^+ - \beta_{ij}^- \quad \text{for all } i \ne j \quad (11)$$

$$x_j'' \le x_i' + M(1 - z_{ij}^x) \quad \text{for all } i \ne j \quad (12)$$

$$y_j'' \le y_i' + M(1 - z_{ij}^y) \quad \text{for all } i \ne j \quad (13)$$

$$z_{ij}^{x} + z_{ji}^{x} + z_{ij}^{y} + z_{ji}^{y} \geq 1 \quad \text{for all } i < j \qquad (14)$$

$$\alpha_i, \beta_i \geq 0 \quad \text{for all } i \qquad (15)$$

$$x_i', x_i'', y_i', y_i'' \geq 0 \quad \text{for all } i \qquad (16)$$

$$\alpha_{ij}^{+}, \alpha_{ij}^{-}, \beta_{ij}^{+}, \beta_{ij}^{-} \geq 0 \quad \text{for all } i \neq j \qquad (17)$$

$$z_{ij}^{x}, z_{ij}^{y} \quad \text{0/1 integer} \quad \text{for all } i \neq j \qquad (18)$$

In this model, we assumed 6 out of 16 departments (Hallway I, Hallway II, Nursing room, COPO, Reception area, and E.R.) are fixed and can not be moved. The objective function includes 148 variables and the constraints are more than 1000 (exactly 1088). It is also assumed that z_{ij}^{x} and z_{ij}^{y} variables must be an integer and binary number. The result for the objective function value (the optimal amount of patient flow) in this model is equal to 876,806.2. The produced layout is shown in figure 2.

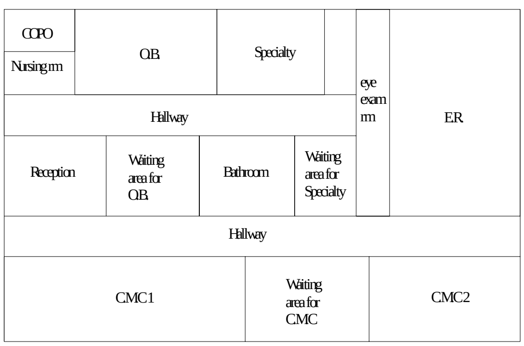

Figure 2: New layout result for alternative I

2.5 Alternative II

The second alternative is based on the number of the patients that are going to visit the Mercy Family Health Center in the future. The number of the visitors to this center in the future can be calculated based on one of the forecasting methods. Statistical studies in the previous years shows that the number of the visitors of this healthcare clinic behaves as a linear trend. Therefore based on the linear behavior of the flow, double exponential smoothing method (Holts' Method) (Nahmias, *et al.* 2005) is used as a forecast method.

Table 2 shows the increase in the number of the visitors in general based on the calculated forecast (Table 2).

Table 2: Total number of forecasted future patients visits

Year	Demand	Forecast
2000	8372	8130
2001	7914	7946
2002	6956	7860
2003	7335	7849
2004	7951	7953
2005		8058
2006		8162
2007		8267
2008		8685

The other three tables show the increases in the number of the visitors in each main department (O.B. Department (Table 3), Specialty Department (Table 4), and C.M.C department (Table 5)).

Table 3: Forecasted future Patient visits of O.B. Department

Year	Demand	Forecast
2000	5317	5223
2001	5027	5102
2002	4418	5029
2003	4659	5007
2004	5050	5060
2005		5116
2006		5172
2007		5228
2008		5451

Table 4: Forecasted future Patient visits of Specialties Department

Year	Demand	Forecast
2000	5037	5079
2001	4762	4945
2002	4185	4846
2003	4413	4799
2004	4784	4829
2005		4868
2006		4907
2007		4947
2008		5104

Table 5: Forecasted future patient visits of C.M.C. Department

Year	Demand	Forecast
2000	3335	3355
2001	3152	3267
2002	2771	3203
2003	2922	3174
2004	3167	3195
2005		3222
2006		3249
2007		3276
2008		3383

Based on the forecast numbers of future visits, new space requirements were defined for the areas of different departments and their corresponding waiting areas. All other assumptions are similar to those of Alternative I. Accordingly a new MIP model is generated and solved. The definition of the decision variables and the parameters are similar to those of the first model.

The model minimizes the objective function to find the optimal solution for the total flow of the patients moving between the depatments. Objective function for this alternative includes 144 variables and the constraints are more than 1000 (exactly 1084). The result for the objective function value in this model is equal to 725,473.5. The layout is shown in figure 3.

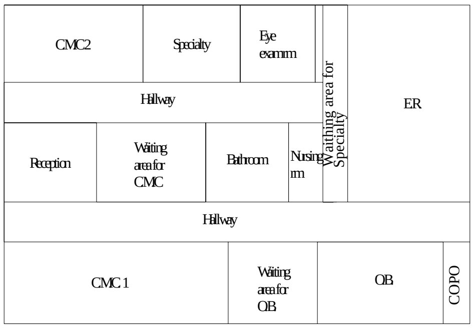

Figure 3: New layout result for alternative II

3. CONCLUSION

In this Study, some of the existing problems in the Mercy Family Health Center are addressed (the large and disorganized waiting area, far distance between the departments that are strongly related and have strong relationships with each other, and finally utilizing the unused space). All these problems increase the flow of the patients between the departments. Therefore, process and waiting time for each patient increase. Consequently, the clinic space becomes an uncomfortable place for patients who are suffering from illness. As we know patient discontent is against the hospital beliefs and policies. To solve the problem, MIP model is used as a tool to redesign the layout of the clinic. Explicitly, we used the objective of minimizing the patient flow.

In the first alternative the current flow of the visitors in the recent year is used and based on that the new layout is generated which gives the optimal solution related to the assumptions. In the second alternative, the forecast data is used and with the same assumptions as of the first alternative, another layout is generated with corresponding optimal solution for the total flow of the patient. The result of the first alternative satisfies the hospital request comparing to the budget that they have allocated to renovation of the clinic. Both alternatives explicitly minimize the total flow of the patients as well as implicitly decrease the waiting and service time. In this way the physicians are more available to give service to the patients. However the result of the first alternative satisfied the hospital request, with a comparison of the two alternatives, we suggested them to use the second alternative instead of the first one. The reason is that the second alternative result can be used in long term and will be less as it considers the growth in the future number of patients.

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REFERENCES

Dettenkofer M., Seegers S., Antes G., Motschall E., Schumacher M., and F.D. Daschner, "Does the architecture of hospital facilities influence nosocomial infection rates? A systematic review", Infection Control and Hospital Epidemiology, 25 (1), 21-25, Jan 2004

Douglas C.H., and M.R. Douglas, "Patient-friendly hospital environments: exploring the patients' perspective", Health Expectations, 7 (1), 61-73, Mar 2004.

Douglas C.H., and M.R. Douglas, "Patient-centered improvements in healthcare built environments: perspectives and design indicators", Health Expectations, 8 (3), 264-276, Sep 2005.

HicK J.L., Hanfling D., Burstein J.L., DeAtley C., Barbisch D., Bogdan G.M., and S. Cantrill, "Healthcare facility and community strategies for patient care surge", Annals of emergency Medicine, 44 (3), 253-261, Sep 2004.

Mercy Hospital and medical Center, http://www.mercy-chicago.org/

Miller R.L., E.S. Swensson, "Hospital and Healthcare Facility Design", Second Edition, 2002, W.W. Norton and Company, Inc

Nahmias S., "Production and Operations Analysis", Fifth Edition, 2005, McGraw-Hill Irwin

Stevenson W.J., "Operation Management", Eighth Edition, 2005, McGraw-Hill Irwin

Tompkins J.A. White, Y.A. Bozer, and J.M.A. Tanchoco, "Facilities Planning", Third Edition, 2003, John Wiley & Sons, Inc