A Multi-objective Mixed-Integer Programming Model for a Multi-Section Operating Theatre Facility Layout

Abdelahad Chraibi[1,2], Said Kharraja[1], Ibrahim H. Osman[3] and Omar Elbeqqali[2]
[1]*University of Lyon, University of Saint-Etienne, Laboratory of Signal and Industrial Process Analysis (LASPI), Roanne, France*
[2]*University Sidi Mohamed Ben Abdellah, Faculty of Science Dhar El Mahraz, Laboratory of Informatics Image Processing and Numerical Analysis (LIIAN), Fez, Morocco*
[3]*Suliman S. Olayan's School of Business, Business Information & Decision Systems, American University of Beirut, Beirut, Lebanon*

Keywords: Operating Theatre, Facility Layout Problem, Mixed Integer Programing, Multi-Section Layout, Multi-Goal Formulation.

Abstract: The operating theater layout problem (OTLP) in a hospital aims to determine for a set of facilities their positions and orientations on the floor-layout of departments in a hospital subject to a set of constraints on distances, available areas, and non-overlapping facilities according to international medical standards and specifications. The OTLP has two main objectives: a quantitative objective to minimize the interdepartmental travel costs among facilities and a second qualitative objective to maximize the closeness rating among facilities. In this paper, a mixed integer linear programming (MILP) model is proposed for OTLP. The MILP model is validated on two illustrative cases to determine the positions as well as the orientations of facilities in a two-dimensional space for a two-floor hospital using commercial optimization software.

1 INTRODUCTION

The health care sector is one of the fastest growing sectors in the world and in particular in France where the current political, economic and social conditions are the driving factors for hospitals to streamline costs and improve quality of health care services due to increased health care demands from an aging population. As a consequence, hospitals are conducting studies to establish better health management tools to control the rapid increase in health care cost as well as to improve the efficiency of the health care system. In this regards, the operating theater layout problem (OTLP) has a significant impact on the cost efficiency performance of any hospital and associated health care services.

The OTLP consists of a set of n activities or services to be placed on the floor-layout of departments in a hospital. The positions and orientations for each facility must be determined subject to a set of constraints on distances, available areas, and non-overlapping facilities according to international medical standards and specifications, (Tompkins et al., 2010).

The OT is one of the most critical and expensive resources in hospitals (Guerriero and Guido 2011), since 60–70% of all hospital admissions are due to surgical interventions. They also account to more than 40% of the total expenses of a hospital (Denton et al. 2007). Such high expenses attracted the attention of hospital management to look into studying the efficiency of the operating theater.

The facility layout design of plants in manufacturing systems aims to arrange in an effective layout to minimize the material handling costs. However, the design of OTLP in hospitals has different objectives beyond classical manufacturing requirements, it aims to find a layout design that reduces operating expenses and the duration of the health care process, enhances the quality of work environment, increases the staff effectiveness, improves patient and staff satisfaction and optimizes the resources utilization.

In this paper, we will focus our research on the OTLP in order to develop an optimal OT facility layout respecting the standard guidelines and specifications (Sehulster et al, 2003, AIA, FGI); to

Chraibi A., Kharraja S., H. Osman I. and Elbeqqali O..
A Multi-objective Mixed-Integer Programming Model for a Multi-Section Operating Theatre Facility Layout.
DOI: 10.5220/0004832401960204
In *Proceedings of the 3rd International Conference on Operations Research and Enterprise Systems* (ICORES-2014), pages 196-204
ISBN: 978-989-758-017-8

minimize the movement cost; making distinction between patients, doctors, medical and non-medical staff travel cost; (the movement cost is considered to be proportional to travel frequency and distance between activities); to maximize the desired closeness among activities; and to develop a decision making support system based on the above mentioned specifications, international standards and optimization methods.

Section II presents a state of the art literature review. Section III introduces the problem statement and our mathematical model and in Section IV our computational results are presented. Finally, section V contains conclusions and future research perspectives.

2 LITERATURE REVIEW

The FLP can be classified in two categories according to the problem according to the arrangement of facilities: equal-area or un-equal area layout problems. The un-equal area FLP category can also be subdivided primarily into two more groups based on the plan layout representations: a *discrete* plan layout - the plant site is divided into equal-area rectangular units, and each group of units on the grid is assigned to a facility; and a *continuou*s plan layout- facilities can be placed anywhere within the plan layout without any overlap among them. The FLP aims to find an efficient non-overlapping arrangement of n facilities in a given plant. Generally, the material handling costs is used to measure the efficiency of the facility layout. Minimizing the total cost of material transportation and maximizing the total closeness rating between each two departments are the common objectives used in FLP (Meller et al., 1996).

Three of the most popular modeling approaches for the FLPs are the quadratic assignment (Koopmans et al., 1957), the mixed-integer programming (Montreuil, 1990), and integer linear formulation and heuristics for the graph theoretical approaches (Osman et al., 2002); (Osman et al., 2003); (Osman, 2006); (Hassan and Hogg, 1987).

The Quadratic Assignment Problem (QAP) is a special formulation for FLP. It assumes a fixed known set of locations, equal areas for each facility and one-to-one matching between facilities and locations. In recent times, efforts are made to solve QAP using heuristic procedures. Different types of solutions were proposed in the literature to solve QAP: an evolutionary search heuristic, Ramkumar et al., (2007); simulated annealing method combined with ant colony, Jingwei et al., (2012) and other approaches including construction methods, limited enumeration methods, tabu search, genetic algorithms as well as their hybrids. For more details, we refer to Commander (2003).

Montreuil (1990) extended the QAP formulation to a **mixed-integer programming** (MIP) formulation to minimize the material handling cost within a plant. Generally the QAP is used for discrete representation, while the MIP is used for the continuous one. In Hathhorn et al., (2013), authors presented a multi-goal approach to minimize both the material handling and facility building costs and proposed a lexicographic ordering technique to handle the multiple objectives.

While the objective of MIP and QAP is to minimize the material handling cost within a plant, the objective of the **graph-theoretic approach** is to maximize the weighted sum of desirable measures among adjacent facilities (departments). In graph-theoretic approaches, it is assumed that the closeness ratings (desirable measures) between departments are known. Each department is then represented by a node in a graph and department adjacency relationships are represented by an arc connecting the two adjacent departments. The objective function is to maximize the weight sum of adjacencies between department pairs (Osman, 2006).

FLP has wide applications ranging from: an OT to a whole hospital, an assembly line to the baggage department in an airport, an existing warehouse to an office. In OT, the facility layout design involves the determination of how to design the physical layout of OT of activities to provide the best support for production of health care services. There is literature on FLP in hospitals but a few in the OTFL design.

Motaghi et al., (2011) used heuristic techniques (Diamond Algorithm) in Shafa hospital to optimize the hospital layout. The application of the layout improvement has increased the efficiency of the hospital by 45%. Assem et al., (2012) applied the FLP to the OTFL. They improved the design of OT by generating a block layout based on a graph theoretic method called SPIRAL which is a qualitative approach to maximize the interdepartmental adjacency of the graph layout.

Padgaonkar (2004) developed a multi-floor facility layout for hospitals to minimize the moving cost of four entities: patients, doctors, medical, and non-medical staff. These entities have various difficulties and cost factors, for which various alternative layouts were developed and the best strategy was selected. Barrett (2008) used a modified systematic layout planning approach to assess the clinic's space usage, operation levels, and flow and activity patterns and identified a number of opportunities for improvement. Feyzollahi et al., (2009) have designed a model for the location of hospital service units and assessment of their efficiency on the basis of QAP mathematical model. Lin et al., (2013) proposed an approach for designing and optimizing OTFL in hospitals. First, a systematic layout planning (SLP) is applied to design OTFL and they applied fuzzy constraint theory to comprehensively evaluate the layout schemes.

Given the advantage and disadvantage of various reviewed approaches, MILP is deemed best for the OTFL formulation. The MILP approach has been widely used in the industrial domain, but it has never been applied to OTFL to the best of our knowledge. Hence, it is the basis for our motivation to explore its applicability for OTFL context.

3 PROBLEM STATEMENT

Building a new facility for hospital is an expensive process which requires a significant amount of resources to complete. Further, once construction of the facility is completed, it is very difficult to restructure to correct bad design layout without incurring additional cost and loss of revenue during re-work process, especially in re-design of healthcare facilities. Therefore, the design phase of a healthcare project is of prime importance. The placement of departments (activities in our case study) or other units such as corridors or aisles in a facility has to be carefully determined. Many of the problems faced in the delivery of healthcare services are directly related to poor building designs of the interactions among services. Therefore, managers and designers must adopt an integrated and comprehensive approach to support the decision-making process in building design (Tzortzopoulos et al., 2008).

Finding an optimal OTFL to minimize the various costs requires the following specification of requirements: the number of sections, the land area required by the facility, the number of corridors within the facility, the length, width and orientation of each activity, the activity and corridors allocations to each section and placement of the activities and corridor within each floor.

Given a set of activities, their areas and the available space, the OTFL seeks to determine the optimal placement of the set of activities within the available space subject to non-overlapping activities on the floor plan layout while optimizing the value of the objective function. To find the optimal placement, a multi-goal Mixed Integer Programming model is proposed to solve the multi-section in the OTFL The main objectives are minimizing the traveling costs for the considered entities (doctors, patients, medical and non-medical staff) and maximizing the closeness ranking among activities to accommodate health services within the optimally layout of such activities.

The idea of this formulation came from the multi-floor layout problem, using elevators to move between the two floors. In this study, floors are represented by adjacent sections. In addition to the assumption used for a single floor layout in Chraibi et al., (2013), we assume that the following for the two-floor layout:

- The maximum number of corridors and their orientation are given. In the solution, corridors are used to travel between two activities in the same section, and to transit from one to the other section.
- The location of a corridor is a decision variable.
- The corridors are aligned using a vertical structure, i.e. they have the same x coordinates on any section they service to insure the entrance to the OT unit, crossing between section and the exit from the OT unit.
- No relationships of activities with the outside world are allowed.
- An activity cannot be split among multiple sections (floors).
- Transition between sections can only occur through corridors.
- The shape and area of the activities are given. For each activity, the associated decision variables are its location and its horizontal or vertical orientation.

a. Definitions of Sets:

- Let N= { a_i ; i=1,2,…,n } be the set of n activities in a department,
- Let K= { e_k ; k=1, …,4} be the set of k entity types: doctor, patient, medical staff or non-medical staff.
- Let S= {ε_s ; s=1, 2,…,t } be the set of sections: outer, restricted, Aseptic, disposal….
- Let C= {θ_c; c=1, 2,…,r } be the set of corridors: clean, public, .
- Let U_i be a set of a single element denoting the section to which activity a_i is belonging.
- Let U_c be a set of single element denoting the section to which corridor θ_c is belonging.

b. Definition of Parameters:

α_i :	Length of activity 'a_i'
β_i :	Width of activity 'a_i'
l_c, d_c:	Dimensions of corridor θ_c
F_{ijk}:	Number of trips between activity 'a_i' to activity 'a_j' made by an entity type 'e_k'
φ_{ijk}:	Moving difficulty between activity 'a_i' to activity 'a_j' made by an entity type 'e_k'
σ_k:	Cost factor assigned to entity 'e_k'
x_{max}:	Maximum length of the department ;
y_{max}:	Maximum width of the department ;
R_{ij}:	Desirable relationship value between activity 'a_i' to activity 'a_j';
ρ_1, ρ_2:	Weights for each sub-objective function.
Xl_s,Xr_s,	X and Y boundary coordinates of sections

c. Definition of Decision Variables:

Ω_i	{ 1 if length (α_i) of activity a_i is parallel to x_axis (horizontal orientation) 0 otherwise
μ_{ij}	{ 1 if 'a_i' and 'a_j' are fully adjacent 0 otherwise
V_{ijc}	{ 1 if traffic between activities 'a_i' and 'a_j' travels through corridor θ_c 0 otherwise
t_{ij}	{ 1 if activity 'a_i' and 'a_j' are assigned to the same section 0 otherwise
t_{ic}	{ 1 if activity 'a_i' and corridor θ_c are assigned to the same section 0 otherwise
v_{is}	{ 1 if activity 'a_i' is assigned to section ε_s 0 otherwise
v_{cs}	{ 1 if corridor θ_c is assigned to section ε_s 0 otherwise
z_{ij}^x	{ 1 if activity 'a_i' is strictly to the right of activity 'a_j' 0 otherwise
z_{ij}^y	{ 1 if activity 'a_i' is strictly above activity 'a_j' 0 otherwise
El_{ic}, Er_{ic}	{ 1 if activity 'a_i' is strictly to the right (r) (or left (l) of corridor θ_c) 0 otherwise
Ea_{ic}, Eb_{ic}	{ 1 if activity 'a_i' is strictly above (a) or below (b) corridor θ_c 0 otherwise
x_i , y_i:	x and y coordinates of the geometric center of gravity activity 'a_i'
x_c ,y_c :	coordinates of the geometrical center of corridor θ_c
l_i:	x-length of activity 'a_i' depending on whether α_i or β_i is parallel on x-axis
d_i:	y-length of activity 'a_i' depending on whether α_i or β_i is parallel on y-axis
Xp_{ij}:	x-distance between activity 'a_i' and 'a_j'
Yp_{ij}:	y-distance between activity 'a_i' and 'a_j'

d. Definition of Constraints:

- **Orientation constraints (activities and corridors)**

The values of the variables l_i and d_i depend on the activity 'a_i' orientation in the plane. When the activities are placed, if the longer side is parallel to the x-axis, then the activity orientation is horizontal, otherwise it is vertical:

$$l_i = \alpha_i \Omega_i + \beta_i (1 - \Omega_i) \qquad \forall i \qquad (1)$$

$$d_i = \alpha_i + \beta_i - l_i \qquad \forall i \qquad (2)$$

- **Sections constraints**

Constraints (3) ensure that each activity is assigned to only one section. Constraints (4), (5), and (6) are used to obtain the value of t_{ij}. If two activities 'a_i' and 'a_j' are allocated to the same section ($v_{is} = v_{js}$), then constraint (4) will have t_{ij} =1, while constraints (5) and (6) remain inactive. Else, if activities 'a_i' and 'a_j' are allocated to different sections, then constraint (4) is inactive and constraints (5) and (6) will ensure that t_{ij}=0.

$$\sum_{s=1}^{S} v_{is} = 1 \qquad \forall i \qquad (3)$$

$$t_{ij} \geq v_{is} + v_{js} - 1 \quad \forall\, i = 1, \dots, N-1;\; j = i+1, \dots, N;\; \forall s \qquad (4)$$

$$t_{ij} \leq 1 - v_{is} + v_{js} \quad \forall\, i = 1, \dots, N-1;\; j = i+1, \dots, N;\; \forall s \qquad (5)$$

$$t_{ij} \leq 1 + v_{is} - v_{js} \quad \forall\, i = 1, \dots, N-1;\; j = i+1, \dots, N;\; \forall s \qquad (6)$$

- **Corridors Constraints**

Constraint (7) ensures that the routing of the flow between two activities is through the corridors in the case when they are not assigned to the same section.

$$\sum_{c=1}^{C} V_{ijc} = 1 - t_{ij} \quad \forall\, i = 1, \dots, N-1;\; j = i+1, \dots, N \qquad (7)$$

The corridors must have common boundaries to route flows between the two sections, and common boundaries with the entrance or the exit of the section to facilitate the communication with the outside. So constraints (8) and (9) assure the adjacency between corridors. Constraint (10) forces the corridors to be vertically aligned to insure the traveling between sections. Constraint (11) makes sure that each corridor is assigned to only one section.

$$y_{c1} - y_{c2} \geq \frac{d_{c1} + d_{c2}}{2} \quad \forall\, c1, c2 \in C \tag{8}$$

$$y_{c2} - y_{c1} \geq \frac{d_{c1} + d_{c2}}{2} \quad \forall\, c1, c2 \in C \tag{9}$$

$$x_{c2} = x_{c1} \quad \forall\, c1, c2 \in C \tag{10}$$

$$\sum_{s=1}^{S} v_{cs} = 1 \qquad \forall\, c \tag{11}$$

- **Activities Non-overlapping Constraints**

When two activities 'a_i' and 'a_j' occupy the same section, they should be separated in the x-direction or the y-direction. These restrictions can be imposed using Equations (12) and (13):

$$x_i - x_j + X_{max}\left(1 - z_{ij}^{x}\right) \geq \frac{l_i + l_j}{2} \quad \forall\, i, j \neq i \tag{12}$$

$$y_i - y_j + Y_{max}\left(1 - z_{ij}^{y}\right) \geq \frac{d_i + d_j}{2} \quad \forall\, i, j \neq i \tag{13}$$

to guarantee the non-overlapping at least one of the following inequalities must be active:

$$z_{ij}^{x} + z_{ji}^{x} + z_{ij}^{y} + z_{ji}^{y} \geq 1 \quad \forall\, i = 1, \dots, n-1;\ j = i+1, \dots, n \tag{14}$$

$$z_{ij}^{x} + z_{ji}^{x} \leq 1 \quad \forall\, i = 1, \dots, n-1;\ j = i+1, \dots, n \tag{15}$$

$$z_{ij}^{y} + z_{ji}^{y} \leq 1 \quad \forall\, i = 1, \dots, n-1;\ j = i+1, \dots, n \tag{16}$$

- **Bounding Constraints**

Constraints (17) through (21) indicate that activities have to be allocated within the appropriate section space defined by the corners (0, 0) and (Xr_s, Yt_s), while (22) through (24) insure the same bounding for corridors.

$$x_i + \frac{l_i}{2} \leq Xr_s \quad \forall\, s, i \text{ where } s = U_i \tag{17}$$

$$y_i + \frac{d_i}{2} \leq Yt_s \quad \forall\, s, i \text{ where } s = U_i \tag{18}$$

$$x_i - \frac{l_i}{2} \geq Xl_s \quad \forall\, s, i \text{ where } s = U_i \tag{19}$$

$$y_i - \frac{d_i}{2} \geq Yb_s \quad \forall\, s, i \text{ where } s = U_i \tag{20}$$

$$x_c + \frac{l_c}{2} \leq Xr_s \quad \forall\, s, c \text{ where } s = U_c \tag{21}$$

$$y_c + \frac{d_c}{2} \leq Yt_s \quad \forall\, s, c \text{ where } s = U_c \tag{22}$$

$$x_c - \frac{l_c}{2} \geq Xl_s \quad \forall\, s, c \text{ where } s = U_c \tag{23}$$

$$y_c - \frac{d_c}{2} \geq Yb_s \quad \forall\, s, c \text{ where } s = U_c \tag{24}$$

- **Corridors & Activities Non-overlapping Constraints**

Constraints (25) to (29) provide the non-overlapping between an activity 'a_i' and a corridor θ_c if they occupy the same section, or to be in different sections.

$$\left(x_c + \frac{l_c}{2}\right) \leq x_i + \frac{l_i}{2} + X_{max}(1 - Er_{ic}) \quad \forall\, i, c \text{ where } U_i = U_c \tag{25}$$

$$\left(x_c - \frac{l_c}{2}\right) + X_{max}(1 - El_{ic}) \geq x_i + \frac{l_i}{2} \quad \forall\, i, c \text{ where } U_i = U_c \tag{26}$$

$$\left(y_c + \frac{d_c}{2}\right) \leq y_i + \frac{d_i}{2} + Y_{max}(1 - Ea_{ic}) \quad \forall\, i, c \text{ where } U_i = U_c \tag{27}$$

$$\left(y_c - \frac{d_c}{2}\right) + Y_{max}(1 - Eb_{ic}) \geq y_i + \frac{y_i}{2} \quad \forall\, i, c \text{ where } U_i = U_c \tag{28}$$

$$Er_{ic} + El_{ic} + Ea_{ic} + Eb_{ic} \geq 1 \quad \forall\, i, c \text{ where } U_i = U_c \tag{29}$$

- **Distance Constraints**

Distance between any two activities will be calculated using constraints (30) to (35):

$$Xp_{ij} \geq (x_i - x_c) + \left(x_c - x_j\right) \quad \forall\, i, c \text{ where } U_i = U_c \tag{30}$$

$$Xp_{ij} \geq (x_i - x_c) + \left(x_j - x_c\right) \quad \forall\, i, c \text{ where } U_i = U_c \tag{31}$$

$$Xp_{ij} \geq (x_c - x_i) + \left(x_c - x_j\right) \quad \forall\, i, c \text{ where } U_i = U_c \tag{32}$$

$$Xp_{ij} \geq (x_c - x_i) + \left(x_j - x_c\right) \quad \forall\, i, c \text{ where } U_i = U_c \tag{33}$$

$$Yp_{ij} \geq \left(y_i - y_j\right) \quad \forall\, i = 1, \dots, n-1;\ j = i+1, \dots, n \tag{34}$$

$$Yp_{ij} \geq \left(y_j - y_i\right) \quad \forall\, i = 1, \dots, n-1;\ j = i+1, \dots, n \tag{35}$$

e. Objective Functions

The goal of the FLP is to provide the best placement of the activities within the available space. This goal is achieved using a composite of two objective functions. The first one is denoted the quantitative objective and the second one is denoted the qualitative objective. Meller (1996) gives a literature overview on the different types of objective functions: quantitative, qualitative and weighted combined objectives.

The quantitative objective of the FLP is to minimize the material handling cost. It is proportional to the rectilinear distance, travel frequency, trip difficulty rating, and baseline travel cost:

$$\boldsymbol{F_1} = \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{4} \boldsymbol{F_{ijk}}(\boldsymbol{Xp_{ij}} + \boldsymbol{Yp_{ij}})(\boldsymbol{\varphi_{ijk}} * \boldsymbol{\sigma_k}) \quad (36)$$

While:

$\boldsymbol{F_{ijk}}$ is the *travel frequency* attribute. It represents the number of trips made from activity 'a_i' to activity 'a_j' by an entity type 'e_k'.

$\boldsymbol{\varphi_{ijk}}$ is the *trip difficulty* rating. It represents the difficulty of an entity 'e_k' to move from activity 'a_i' to activity 'a_j'. It is proportional to the required resources and provided effort.

$\boldsymbol{\sigma_k}$, is the *baseline travel* cost. It represents the cost factor assigned to entity 'e_k' which depends on the human resources involved. Its assumed that $\boldsymbol{\sigma_{doctor}} > \boldsymbol{\sigma_{medical\ staff}} > \boldsymbol{\sigma_{non-medical\ staff}} > \boldsymbol{\sigma_{patient}}$ (The value of this parameter is detailed in Chraibi et al., 2013).

The qualitative objective is to maximize the subjective closeness rating by considering vital factors such as international standards. Qualitative factors are easily analyzed in a closeness rating chart, which is essentially a grid that qualitatively evaluates the desired closeness between activities.

The used rates are relative to the strength of the closeness: absolutely necessary (A), very important (E), important (I), ordinary importance (O), unimportant (U) and undesirable (X). These rates are subjectively defined based on (Muther and Wheeler, 1962).

The qualitative objective function is expressed by:

$$\boldsymbol{F_2} = \sum_{i=1}^{N} \sum_{j=1}^{N} \boldsymbol{R_{ij}\mu_{ij}} \quad (37)$$

Where:

R_{ij}: Relationship value that expresses the need for proximity i.e. If two activities have a strong positive relationship, they are considered adjacent, thus we consider the rank A. The AEIOUX rates are respectively considered equal to 16, 8, 4, 2, 0 and -2 (see Figure 1).

μ_{ij}: Adjacency coefficient that expresses the proximity of each two activities in the final layout:

Fully adjacent (μ_{ij}=1): Two activities are fully adjacent when they are facing each other directly.

Non-adjacent (μ_{ij}=0): If the activities don't share any point or when they can't be seen together in the same area (septic/aseptic area).

The final objective function that we considered is a weighted sum of the two objective functions shown above:

$$\boldsymbol{min:\ F = \rho_1 F_1 - \rho_2 F_2}$$

$$\boldsymbol{F} = \boldsymbol{\rho_1} \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{4} \boldsymbol{F_{ijk}}(\boldsymbol{Xp_{ij}} + \boldsymbol{Yp_{ij}})(\boldsymbol{\varphi_{ijk}} * \boldsymbol{\sigma_k}) - \boldsymbol{\rho_2} \sum_{i=1}^{N} \sum_{j=1}^{N} \boldsymbol{R_{ij}\mu_{ij}} \quad (38)$$

To facilitate computation, we choose

$$\rho_1 = \rho_2 = 0.5.$$

4 EXPERIMENTS

In this section, we validated the proposed formulation using previously published two data instances available in the literature (Chraibi et al., 2013) on OTFL optimization. We used ILOG CPLEX 12.2 software to solve the model using Windows 7 platform, Intel5® Core ™ i5-2410M CPU@ 2.30GHz and 6Go of RAM. For all instances, the followings settings were used: $\rho_1 = \rho_2 = 0.5$, $\sigma_{doctor} = 80$, $\sigma_{medical\ staff} = 60$, $\sigma_{non-medical\ staff} = 40$ and $\sigma_{patient} = 20$ are used.

The data instance are of dimension consisting of eleven activities. The placements of these activities in the appropriate sections are affected by OT international standards in addition to physical dimensions - a set of specific practices and procedures performed under carefully controlled conditions with the goal of minimizing contamination by pathogens.

In this work, we only consider the restricted and aseptic zone; the trip is assured by corridors that make possible traveling between the four zones.

Table 1: Instance 1 with eleven activities.

Nomination	Dimensions	
	αi	βi
Induction 1	8.6	4
Induction 2	8.6	5
OR1	8.6	7.2
OR2	7.6	6.4
OR3	8.6	7.2
OR4	7.6	6.4
Scrub room	3.4	8.6
PACU	13.4	8.6
Decontamination	4.6	8.6
Cleaning room	3.6	8.6
Arsenal	4.4	8.6
Corridor 1	2.4	21
Corridor 2	2.4	13.6

(a) activities dimensions

Nomination	Orientation		Optimal location	
	li	di	xi	yi
Induction 1	8,6	4	15,3	15,6
Induction 2	8,6	5	15,3	26,5
OR1	8,6	7,2	4,3	17,3
OR2	7,6	6,4	15,3	20,8
OR3	8,6	7,2	4,3	24,5
OR3	7,6	6,4	4,3	31,3
Scrub room	8,6	3,8	15,3	31,3
PACU	8,6	13,6	4,3	6,8
Decontamination	8,6	4,6	15,3	11,3
Cleaning room	8,6	3,6	15,3	2,8
Arsenal	8,6	4,4	15,3	6,8
Corridor 1	2.4	21	9.8	24,1
Corridor 2	2.4	13.6	9.8	6,8

(b) Orientation and optimal location results

Instance 1: Large activities and more relationships are considered. This example gives the optimal layout with eleven activities. In contrary situation to the first instance, the induction rooms are considered to be independent activities where the OR1 and OR2 share the induction room1 while the OR3 and OR4 share the induction room2. The scrub room is also shared by all the activities in the aseptic section. Xmax and Ymax are fixed to 20 and 34.6, respectively (See Table1.a). Table 1.b shows the optimal solution that was obtained after 23.06 sec. Figure 1 shows the optimal OT layout for this configuration. Using the continuous representation, we tested to solve the OT LP with only the quantitative objective function. The resulting layouts are more satisfactory than in (Chraibi et al. 2013), both in term of quality, time processing and the respect of entities flow.

In addition, the use of weighted criteria function proved that the results were best in both responding to our objectives and in computation time. Several improvement works are planned such as to use of heuristics for large sized OT.

5 CONCLUSIONS

In this paper, a new mixed integer linear programing (MILP) model was introduced to find the optimal solution to the Operating Theater Layout Problem, which consists of laying medial service activities on two-floor levels in two-dimensional space.

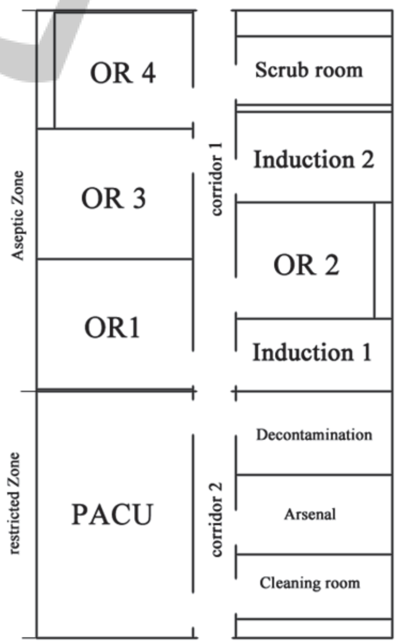

Figure 1: Instance 1 optimal layout.

The MILP model was able to determine simultaneously the position and the orientation of each activity, the distribution of the set of activities among floors, the location of corridors and lifts in the final OT layout while minimizing the total traveling cost and maximizing the desirable closeness of activities to each other according to international standards.

The proposed model was validated on two typical instances from the literature. In our numerical experiments, we observed that the computation time increases as the number of department increases until it reaches the maximal number of facilities. The MILP model was able to generate optimal solutions for thirteen activities within seconds on a personal computer.

For future direction, the authors are investigating other options such as (a) calculating distances based on originating input and final destination output point, (b) considering the relationship between activities and the outside environment, (c) applying the model to a larger sized instances of OT layout (d) considering activities with non-rectangular shape and (e) using other heuristics and meta-heuristics to solve large sized instances.

REFERENCES

AIA (American Institution of Architecture), Guidelines for Design and Construction of Health Care Facilities. http://www.aia.org.

Assem, M., Ouda, B., & Abdel Wahed, M., (2012). Improving Operating Theatre Design Using Facilities Layout Planning. Cairo International *Biomedical Engineering Conference (CIBEC)*, Cairo, Egypt, December 20-21, 2012.

Barrett, A. (2008). Optimization of facility design and workflow process at the phlebotomy clinic of Toronto general hospital. Toronto: University of Toronto

Chraibi, A., Kharraja, S., Osman, I.H., and Elbeqqali, O. (2013). A mixed integer programming formulation for solving Operating Theatre layout problem: a multi-goal approach. *Proceedings of IESM 2013, Rabat, Morocco*, October 27-30th.

Commander, C. W. (2003). A survey of the quadratic assignment problem, with applications (*Doctoral dissertation, UNIVERSITY OF FLORIDA*).

Denton, B., Viapiano, J., & Vogl, A. (2007). Optimization of surgery sequencing and scheduling decisions under uncertainty. *Health Care Management Science*, 10 (1), 13–24.

Feyzollahi, M., Shokouhi, A., Modarres Yazdi, M., & Tarokh, M. (2009). Designing a model for optimal hospital unit layout. *Pajoohandeh Journal*, 14(4), 191–198.

FGI (Facility guideline institution), Guidelines for Design and Construction of Health Care Facilities. http://www.fgiguidelines.org.

Guerriero, F., & Guido, R. (2011). Operational research in the management of the operating theatre: A survey. *Health Care Management Science*,14, 89–114.

Hassan, M., & Hogg, G. L. (1987). A review of graph theory application to the facilities layout problem. *Omega*, 15(4), 291-300.

Hathhorn, J., Sisikoglu, E., & Sir, M. Y. (2013). A multi-objective mixed-integer programming model for a multi-floor facility layout. *International Journal of Production Research*, (ahead-of-print), 1-17.

Jingwei, Z., Ting, R., Husheng, F., Jinlin, Z., & Ming, L. (2012, May). Simulated annealing ant colony algorithm for QAP. In *Natural Computation (ICNC), 2012 Eighth International Conference on* (pp. 789-793). IEEE.

Koopmans, T. C., & Beckmann, M. (1957). Assignment problems and the location of economic activities. *Econometrica: Journal of the Econometric Society*, 53-76.

Lin, Q. L., Liu, H. C., Wang, D. J., & Liu, L (2013). Integrating systematic layout planning with fuzzy constraint theory to design and optimize the facility layout for operating theatre in hospitals. *Journal of Intelligent Manufacturing*, 1-9.

Maryam, H., Lei, W., Yuet, W., & Houshang, D. (2006, May). Renovation of mercy family health center. In *Information Control Problems in Manufacturing* (Vol. 12, No. 1, pp. 665-670).

Meller, R. D., & Gau, K. Y. (1996). Facility layout objective functions and robust layouts. *International journal of production research*, 34(10), 2727-2742.

Montreuil, B., (1990), A modeling framework for integrating layout design and flow network design, *Proceedings of the Material Handling Research Colloquium*, pp. 43-58.

Motaghi, M., Hamzenejad, A., & Riyahi, L. (2011). Optimization of hospital layout through the application of heuristic techniques (Diamond Algorithm) in Shafa hospital. *International Journal of Management of Business Research*, 1(3), 133–138.

Osman, I.H., Al-Ayoubi, B., and Barake, M.A. (2003). A greedy random adaptive search procedure for the weighted maximal planar graph problem. *Computers and Industrial Engineering*. Vol. 45, 635-651.

Osman, I.H. (2006). A tabu search procedure based on a ranked-roulette diversification for the weighted maximal planar graph problem. *Computers and Operations Research*. Vol. 33: 2526-2546.

Osman, I.H., Hasan, M. and Abdullah, A. (2002). LP-based meta-heuristics for the weighted maximal planar graph problem. *Journal of Operational Research Society*, Vol. 53, 10, 1142-1149.

Padgaonkar, A. S. (2004). Modeling and analysis of the hospital facility layout problem. New Jersey: New Jersey Institute of Technology.

Ramkumar, A. S., Ponnambalam, S. G., & Jawahar, N. (2007, September). An evolutionary search heuristic for solving QAP formulation in facility layout design. In *Evolutionary Computation, 2007. CEC 2007. IEEE Congress on* (pp. 4005-4011). IEEE.

Sehulster, L., Chinn, R. Y., Arduino, M. J., Carpenter, J., Donlan, R., Ashford, D. & Cleveland, J. (2003). Guidelines for environmental infection control in health-care facilities. *Morbidity and Mortality Weekly Report Recommendations and Reports RR*, 52(10).

Tarkesh, H., Atighehchian, A., & Nookabadi, A. S. (2009). Facility layout design using virtual multi-agent system. *Journal of Intelligent Manufacturing*, 20, 347–357

Tompkins, J. A., White, J. A., Bozer, Y. A., and Tanchoco, J. M. A., Facilities Planning, Wiley, New York, New York, 4th edition (2010).

Tsai, R. D., Malstrom, E. M., & Kuo, W. (1993). Three dimensional palletization of mixed box sizes. *IIE transactions*, 25(4), 64-75.

Tzortzopoulos, P. et al. 2008. Design for Operational Efficiency–Linking Building and Service Design in Healthcare Environments. In: *Proceedings: ELAGEC-II Encuentro Latino-Americano De Gestion Y Economia De La Construccion*, Santiago, Chile, January, 24–25.

Vos, L., Groothuis, S., & van Merode, G. G. (2007). Evaluating hospital design from an operations management perspective. *Health care management science*, 10(4), 357-364.

Wahed, M. A., Ouda, B. K., & Elballouny, M. (2011). Evaluation of an Operating Theater Design by a Software Program (OTDA: Operating Theater Design Analyzer). *International Journal of Database Management Systems*, 3(3).