A Proposed Solution Framework for the Operating Room Scheduling Problems

Zakaria Y. Abdelrasol, Nermine Harraz, Amr Eltawil

***Abstract*—Health care is becoming one of the fast growing industries in both, the developed and developing countries. Operating rooms provide a large portion of hospital revenue; hence, scheduling operation room surgeries is very important to maximize profits. This paper reviews the three operating room scheduling problems: the case mix problem, the master surgery scheduling problem and the surgery scheduling problem. Also, the paper introduces a research framework for an integrated planning method for the three problems. Also, the framework includes a broad system dynamics model to analyze the relationship between the different hospital's departments and the operating rooms.**

***Keywords*—Case-mix, master surgery scheduling, surgery scheduling, dynamic programming, simulation. system dynamics.**

I. Introduction

HEALTH care is one of the largest industries in the developed and developing countries. In Egypt there are $4 billion dedicated to healthcare public expenditures in 2013 [1], which accounts around 5.15% of its gross domestic product (GDP). In Canada; health-care costs doubled over the past decade and will cross the $200 billion this year with 11.6% of its gross domestic product (GDP) [1].

The main challenges facing healthcare systems in Egypt nowadays include; limited resources with higher cost of medical technology and medication, higher demand and customer expectations and shortage in planning and management decision support tools specially with the complexity of healthcare systems; hence healthcare organizations should increase emphasis on process optimization in order to control and minimize operating costs and improve the provided services level.

Operating rooms (ORs) demand and its relation to other departments in the hospital presents a large share of hospital care services and expenditure resulting in an estimated 40% of hospital revenue. This makes the scheduling of ORs an important problem to study in order to meet hospital goals.

Z. Y. Abdelrasol, is with the Department of Industrial Engineering and Systems Management, Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt. He was with Industrial Engineering Department, Faculty of Engineering, Fayoum University, Fayoum, Egypt, (e-mail: zakaria.abdelgawad@ejust.edu.eg).

N. Harraz, is with the Department of Industrial Engineering and Systems Management, Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt. She is on leave from the Production Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt, (e-mail: nermine.harraz@ejust.edu.eg).

A. Eltawil, is with the Department of Industrial Engineering and Systems Management, Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt. He is on leave from the Production Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt, (e-mail: eltawil@ejust.edu.eg).

In this concern, it is necessary to schedule the ORs, in such a way that the operations/surgeries are carried out with maximal efficiency. The increase in efficiency of ORs schedule has a bearing of the number of surgery cases, the cost or profit, utilization of resources and waiting time of patients, which, in turn, are widely accepted indicators of ORs efficiency.

The problems of ORs scheduling can be divided into three different and related problems as shown in Fig. 1, namely (i) the Case Mix Problem (CMP), (ii) the Master Surgery Scheduling Problem (MSSP), and (iii) the Surgery Scheduling Problem (SSP). The CMP refers to the time of a resource (e.g., ORs) allocated to each surgical specialty in order to minimize the total costs or maximize the total revenues or how the available ORs time is divided over the different surgeons. This stage takes place on the strategic level of hospital management as it determines for which ailments capacity will be preserved for a long time horizon. In MSS problem, the ORs time is allocated to these surgical specialties over the scheduling window (typically, a week) in order to maximize and level resources utilization. Finally, SSP refers to assigning each surgical case a start time, a day, and an OR with the target of minimizing the waiting time and maximizing resources utilization.

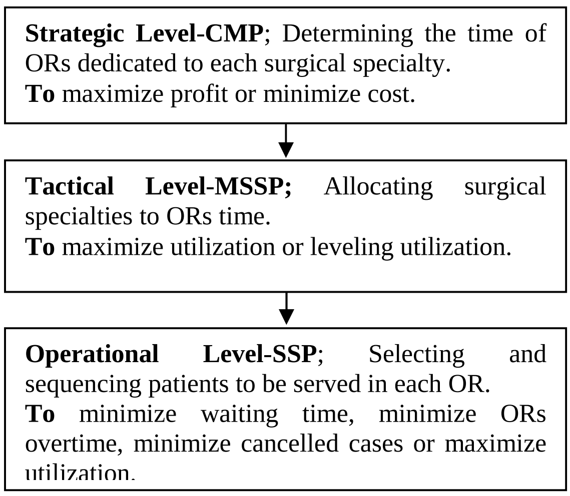

Fig. 1 The three ORs scheduling problems and decision levels

For more illustration, the following example will describe each of the ORs scheduling problems and the relation between them. In this example; an OR is available for 8 hours a day, 5 days a week with total of 40 working hours per week. There

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

are six surgeon groups (SG) (a surgical group consists of surgeons of the same surgical specialty). How can these 40 hours divided to those six SG? This question is what the CMP answers. With the consideration of many factors like; demand to each SG, cost and profit for each specialty, CMP determine the number of OR hours dedicated to each SG Table I. The second question is, how can these dedicated times assigned to ORs time scale along the week? This question is what the MSSP answers Fig. 2, for example the 12 hours which dedicated to SG 1 have been allocated to Sunday from 8:00 to 12:00, Tuesday from 13:00 to 17:00 and Thursday from 8:00 to 12:00. In the third decision level, the operational level, cases which related to SG 1 are assigned to one of these three time sessions and are sequenced according to many criterions, for example; arrival time, processing time, or severity index.

TABLE I
EXAMPLE OF A CASE MIX PROBLEM

SGs	Dedicated Hours
SG 1	12
SG 2	10
SG 3	4
SG 4	6
SG 5	4
SG 6	4

<table>
<tr><th></th><th>Sun.</th><th>Mon.</th><th>Tues.</th><th>Wed.</th><th>Thur.</th></tr>
<tr><td>8:00-9:00</td><td rowspan="4">SG 1</td><td rowspan="4">SG 2</td><td rowspan="2">SG 2</td><td rowspan="2">SG 3</td><td rowspan="4">SG 1</td></tr>
<tr><td>9:00-10:00</td></tr>
<tr><td>10:00-11:00</td><td rowspan="2">SG 6</td><td rowspan="2">SG 5</td></tr>
<tr><td>11:00-12:00</td></tr>
<tr><td>12:00-13:00</td><td colspan="5"></td></tr>
<tr><td>13:00-14:00</td><td rowspan="2">SG 3</td><td rowspan="4">SG 4</td><td rowspan="4">SG 1</td><td rowspan="4">SG 2</td><td rowspan="2">SG 6</td></tr>
<tr><td>14:00-15:00</td></tr>
<tr><td>15:00-16:00</td><td rowspan="2">SG 5</td><td rowspan="2">SG 4</td></tr>
<tr><td>16:00-17:00</td></tr>
</table>

Fig. 2 Example of a MSS problem

In ORs planning and scheduling literature, a surgical case is called an operation, an intervention, a surgical patient or a procedure. Surgery cases can be classified by different ways, patients are grouped into emergency, urgent, and elective classes [2], [3]. Emergency cases have to be performed within two hours of decision to operate, whereas urgent ones within few hours. Elective cases, that occur quite frequently, are the only ones that can be planned in advance and usually performed to suit both patient and surgeon. Another way for classification is to group the surgical patients to category A, category B, or category C [4]. Category A is typically as elective cases in the first classification. Category B involves elective cases that occur rather seldom. Category C is typically as emergency cases in the first classification.

There are many review papers that discussed the ORs scheduling problems, recently Guerriero and Guido [5] presented a structured literature review on how Operational Research can be applied to the surgical planning and scheduling processes. They classified the research contributions by distinguishing three different decision levels, i.e., strategic, tactical and operational. Cardoen et al. [6] applied a “descriptive fields” based classification, each of which analyzes the manuscripts from a different perspective that is problem or technically oriented. Brailsford and Vissers [7] analyzed the papers presented at ‘‘Operational Research Applied to Health Services’’ (ORAHS) meetings over the 35 years of its existence. They proposed a two-way framework for analysis, where one dimension is the nine stages of the product life cycle and the other dimension is a three-level classification into broad application areas referring to processes at different levels in healthcare: Patients & Providers, Units & Hospitals, and Regional & National.

The aim of this paper is threefold. First, the paper presents a short literature review and a classification of ORs scheduling problems. The literature review and classification is structured depending on the three stages that can be distinguished in developing ORs schedules; CMP, MSSP, and SSP followed by the integration of these three problems and finally multiple department integration. By the end of the literature review sections, Fig. 3 summarizes these five sections. Second, we present a gap analysis and define a recommended research direction. Third, the proposed research framework to tackle the defined problem is presented.

The remainder of the paper will be structured as follows. Section 2 contains a focused literature on the first ORs scheduling problem, CMP. In Section 3 the second ORs scheduling problem will be reviewed, MSSP. The subsequent section reviewed the third ORs scheduling problem, SSP, followed by a discussion of the integrated work for the three problems and finally multiple department integration problems will be reviewed. Section 7 provides a gap analysis, followed by presenting the proposed approach framework. Finally conclusion section has been provided.

II. The Case Mix Problem (CMP)

This stage takes place on the strategic level of hospital management; generally, the literature on this level is relatively sparse. Guerriero and Guido [5] pointed out many references in the strategic level, but most of these references discussed the case mix problem on the hospital level (The hospital case mix selection problem (HCMSP)), so it is mainly related to financial and economic studies not to the ORs scheduling problems, [8]- [10] and it will not discussed here. The remaining literature can be categorized into two groups according to demand certainty. The first category contains the papers with certain demand which represent the large portion of the CMP literature so it will be discussed in details; the related papers are summarized in Table II. The second one considers the variation and uncertainty on surgical demand even from a statistical viewpoint or as a newsvendor problem.

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

TABLE II
CASE MIX PROBLEM REFERENCES SUMMARY

Ref.	Authors/Year	Objective Function	Considered Resources	Techniques
[11]	Ma and Demeulemeester (2013).	• Maximize overall financial contribution.	OR Blocks, Beds.	ILP.
[12]	Testi et al. (2007).	• Maximize total benefit.	OR Blocks	BPP - Binary LP.
[13]	Ma et al. (2009).	• Maximize profits.	OR Blocks, Beds.	ILP and B&P.
[14]	Blake and Carter (2002).	• Minimize profit deviation.	OR Blocks, Beds.	LGP.
[15]	Mulholland et al. (2005).	• Maximize hospital total margins plus professional payments.	OR Blocks, ICU Beds, Wards' Beds.	LP, Excel LP Solver.
[16]	Kuo et al. (2003).	• Maximize professional revenues. • Minimized value for hospital costs.	OR Blocks.	LP, Excel LP Solver.

A. CMP with Certain Demand

Ma and Demeulemeester [11] proposed a multilevel integrative approach consisting of three stages, namely the case mix planning phase, the master surgery scheduling phase and the operational performance evaluation phase. In this section, the first phase only (CMP) will be discussed; the hospital is assumed as a deterministic system. An optimal case mix pattern and number of beds assigned to each ward have been determined in order to maximize the overall financial contribution. They considered the total number of available beds and the total number of OR blocks as capacity constraints.

Testi et al [12] developed a three-phase hierarchical approach for the weekly scheduling of ORs. In this section the first phase only (CMP) will be discussed. They solved a bin packing-like problem (BPP) in order to select the number of sessions to be weekly scheduled for each ward; in order to maximize the total benefits.

Ma et al. [13] proposed a methodology for the CMP to maximize hospital profits under ORs blocks and wards' beds capacity constraints. A mathematical model is developed to produce an optimal case mix pattern and a corresponding resource allocation scheme. Two exact methods, integer linear programming (ILP) and branch-and-price (B&P), are deployed to solve the constructed model.

Blake and Carter [14] proposed linear goal programming (LGP) models in order to allocate resources in Toronto' Mount Sinai Hospital. The case mix model identified a mix and volume of cases for all doctors that are economically feasible for both the hospital and its associated providers. The model also identifies, from among the many case mixes that could be selected, the particular case mix that comes closest to achieving physicians' desired mix.

Mulholland et al. [15] presented a linear programming (LP) model to optimize financial outcomes for both the hospital and physicians under the capacity constraints of general care beds, ICU beds, operating room times and recovery room times. Microsoft Excel Solver was used to determine the optimal mix of surgical procedures to maximize hospital total margins plus professional payments and to apply a sensitivity analysis study.

Kuo et al. [16] used linear programming (LP) to optimize allocation of OR time among a group of surgeons based on professional fee generation. The LP Solver routine in Microsoft Excel was used to determine the optimal mix of surgeries that maximize professional receipts, for more investigation they performed a sensitivity analysis study.

B. CMP with Uncertain Demand

In the CMP and due to the uncertainty in demand/ SGs workloads, the optimally allocated time must balance the costs of allocating too much time, which typically translates to idle time for ORs and staff, with the costs of allocating too little time, which typically translates to overtime charges. This issue has been tackled by two approaches; from a statistical viewpoint [17], [18] and by addressing the CMP as a newsvendor problem [19], [20] and, very recently [21].

III. Master Surgery Scheduling Problem

The problem addressed at the tactical level concerns the development of a surgery schedule, is a MSS, which usually is cyclically constructed in a given planning period (usually 1–3 months to one year). A MSS defines the allotted time blocks (TBs) of each OR to several SGs every day as shown in Fig. 2; historical data and actual/forecast demand (e.g., in terms of waiting list and appointment requests for surgeries) are used as input.

The decision of dedicating ORs time to SGs can be taken by one of three strategies [22]; Block-Scheduling, modified block scheduling and open-scheduling. In block-scheduling, a set of TBs is assigned to specific SGs, generally for some weeks or months. Surgical cases are arranged in TBs and none of these can be released. On contrary, open-scheduling allows assigning surgical cases to an available OR, at the convenience of surgeons. An empty schedule is filled up with surgical cases by following the order of arrival time. In modified block scheduling, as an integration of the block and open scheduling, the block-scheduling strategy can be modified in two ways to increase its flexibility; Some TBs are booked and others are left open, or unused TBs are released at some time before surgery [23]. However block and open scheduling strategies are mentioned clearly and applied widely in the literature, no one mentioned directly that he/she applied modified block scheduling in MSSP.

Although open-scheduling should be discussed in MSSP

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

level as an alternative to block-scheduling, Guerriero and Guido [5] discussed open-scheduling even with SSP problem or in the integration section. This can be explained by noticing that open-scheduling strategy used usually with SSP and rarely applied as stand-alone decision, on the contrary block-scheduling strategy can be applied to construct the master surgery schedule (MSS). Next, the most recent papers for both block-scheduling and open-scheduling will be discussed.

A. MSS with Block-Scheduling Strategy

Block-scheduling strategy has been applied to construct MSS by many authors. Most recently, Ma and Demeulemeester [11] firstly chose the optimal patient mix and volume that can bring the maximum overall financial contribution under the given resource capacity. Then they constructed a balanced MSS in order to improve the patient service level by minimizing the total expected bed shortage. Originally Testi et al. [12] firstly solved a bin packing-like problem in order to select the number of sessions to be weekly scheduled for each ward. Then they applied a blocked-scheduling for determining optimal time tables. Finally, Beliën and Demeulemeester [24] presented the first attempt to achieve perfect bed occupancy leveling.

All these surveyed papers dealt with deterministic data. Often many cancellations take place because the intrinsic stochastic nature of the system. Van Houdenhoven et al. [25] already proved that the actual OR utilization can be increased by applying the Regret-Based Random Sampling algorithm. They aimed to minimize the planned slacks while surgical case durations varies according to normal distribution. Stochastic Length Of Stay (LOS) for intensive care unit ICU and medium care unit MCU are considered by Adan et al. [26] for the setting of the Thorax Centre Rotterdam, and used to compare their approach with that of Vissers et al. [27] that considered deterministic LOSs for ICU and MCU.

B. MSS with Open-Scheduling Strategy

With regard to open-scheduling, there are no TBs can be reserved for a particular surgeon. Many authors applied open-scheduling strategy; recently Liu et al. [28].They applied only the open-scheduling strategy and developed a heuristic algorithm. This algorithm comes from the dynamic programming (DP) idea by aggregating states to avoid the explosion of the number of states. The objective was to maximize the operating rooms' use efficiency and minimize the overtime cost. Fei et al. [29] modeled the problem of weekly ORs scheduling as ILP and solved it by a column-generation-based heuristic procedure. Then the daily scheduling problem has been treated as a two-stage hybrid flow-shop problem and solved by a hybrid genetic algorithm. The main objective functions were; minimizing the idle time and overtime and maximizing the ORs utilization.

IV. Surgery Scheduling Problem

The third and final hierarchical stage is mainly devoted to define a schedule of elective surgeries (i.e., off-line scheduling). Few papers considered on-line scheduling, aimed at modifying an existing schedule since urgent and emergency arrivals. The literature in this level is very large, it can be classified by regard to solving technique to; mathematical and heuristic models and simulation models. Firstly very recent papers considered mathematical or heuristics model will be presented, followed by a detailed discussion about simulation studies.

A. Mathematical and Heuristics Models for the SSP

Vijayakumar et al. [30] addressed a SSP experienced at a publicly-funded hospital and conceptualize this multi-period, multi-resource, priority-based case scheduling problem as an unequal-sized, multi-bin, multi-dimensional dual bin-packing problem. A mixed integer programming (MIP) model and a heuristic based on the first fit decreasing algorithm are presented. The applied approach led to substantial savings, 20% reduction in number of days and up to 20% increase in operating room utilization. Fei et al. [29] and Jebali et al. [31] considered surgeon agendas and recovery beds availability in open-scheduling systems. The first step of the approach proposed in [31] assigns surgeries to ORs such that overtime, under-time, and patient waiting time are minimized. The problem is mathematically represented as an MIP. Then the sequencing problem is formulated as a two stage hybrid flow shop, whose objective is to minimize the total overtime.

As a trial to consider the stochastic nature of SSP, Denton et al. [32] tackled the uncertainty in surgery duration by developing a two-stage stochastic MIP model, for a daily schedule of single OR. The authors assumed that the total OR schedule duration is known in advance, whereas uncertainty in surgery duration has been represented by a set of scenarios. Hans et al. [33] presented another contribution dealing with uncertainty in surgery times. The objective is to schedule surgeries, such that the risk of overtime and cancellations is minimized and OR utilization is improved. Simulated Annealing (SA) is used as optimization techniques. The emergency surgeries are not taken into account but it has been considered in [34].

B. Simulation Models for the SSP

Due to the stochastic nature of SSP, simulation models have been increasingly recognized as a valuable tool to handle this problem. The stochastic nature stems from many factors, for example, the dynamic arrivals especially for emergency cases, stochastic operating time. This tendency is confirmed by the scientific contributions reviewed in what follows.

Simulation models are widely used in the SSP literature. The simulation studies in this problem can be classified regard to its purpose to many categories. The main two categories are; system performance evaluation and new heuristics evaluation. There are many papers published in those two groups. Firstly, recent papers from the first category will be presented followed by the second category contributions in more details.

With regard to system performance evaluation, most recently Ma and Demeulemeester [11] have been applied a simulation model to evaluate the operational performance of the case mix and capacity decision that was obtained from CMP and MSSP under the uncertainty condition. Moreover, they studied the effect of variation on bed capacity and LOS. Another example can be shown in [35]. A discrete event simulation model is developed to evaluate the performance of ORs activity scheduling. The authors chose OR utilization rate, throughput and the number of overruns as performance measures to evaluate ward productivity on different operative scenarios. Moreover, they compared the actual schedule with the one obtained by booking the ORs on the basis of a blocked-scheduling criterion.

The use of simulation model to evaluate the performance of sequencing rules has been considered in [12], [36]-[39]. A summary of these papers can be found in Table III.

Testi et al. [12] firstly studied the CMP followed by MSSP then finally the sequencing problem is addressed in the last phase, by using classical scheduling rules; the longest processing time (LPT), the shortest processing time (SPT) and the longest waiting time (LWT). The behavior of these rules has been analyzed by using a simulation environment.

Dexter et al. [36] tackled the On-line scheduling and uncertainty problem, in an open-scheduling system. They carried out a simulation study to compare the performance of several scheduling algorithms on real data in terms of OR utilization. The simulation experiments showed that the Best Fit Descending procedure with fuzzy constraints most likely maximizes OR utilization.

Marcon and Dexter [37] have investigated how sequencing surgical cases can affect the performance of the ORs and post anesthesia care unit (PACU). Specifically, the sequence in which a surgeon performs cases in an OR on one day is taken into account and different sequencing rules, borrowed from the classical scheduling theory, are considered and tested.

The idea of applying scheduling rules to the surgery sequencing step has been also exploited in [38], where, differently from [37], it is assumed that the duration of each operation is affected by uncertainty. The aim is to maximize OR utilization, considering that a preparation phase is executed before surgery and its duration is affected by the sequence of surgeries in a given OR (sequence dependent setup times (SDS)). A novel dispatching rule, Longest Expected Processing with Setup Time (LEPST) has been defined and compared with two other classical rules, Longest Expected Processing Time First (LEPT) and Shortest Expected Processing Time First (SEPT). Computational experiments showed that LEPST significantly outperformed the other two algorithms.

Different scheduling policies have been presented by Harper [39] that developed a simulation model for hospital resource planning; such as beds, operating theatres and nurses. System performance has been evaluated by considering different case studies and in particular several ORs scheduling policies; first come first served (FCFS), longest operation times first (LTF), shortest operation times first (STF), and longest time first followed by shortest first after a user-defined cut-off time (LTSC)).

V. THE INTEGRATION OF THE THREE PROBLEMS

As mentioned previously, ORs scheduling problem can be divided into three separated and related problems called; CMP, MSSP and SSP. Every decision made at a given problem influences those of the next one. This specific issue has been explicitly studied in only a few papers. In this section, only papers which integrated the three problems will be discussed. To the best of our knowledge, there are only two references that have been integrated the three problems [11] and [12].

Originally, Testi et al. [12] develop a three-phase, hierarchical approach for the weekly scheduling of ORs. This approach has been implemented in one of the surgical departments of a public hospital located in Genova (Genoa), Italy. They suggested an integrated way for ORs scheduling in order to improve its overall efficiency in terms of overtime and throughput as well as waiting list reduction. In the CMP they solved a bin packing-like problem in order to select the number of sessions to be weekly scheduled for each ward/specialty. Then, in MSSP, they used a blocked-scheduling method for determining optimal time tables, by defining the assignment between wards and ORs. Lastly, they used the simulation software environment in order to analyze different sequencings of surgical activities.

Most recently, Ma and Demeulemeester [11] proposed a multilevel integrative approach to the ORs planning problem. It consists of three stages, namely the CMP, the MSSP and the operational performance evaluation phase. At the CMP, the optimal patient mix that can maximize the overall financial contribution has been determined. Then, in order to improve the patient service level potentially, the total expected bed shortage due to the variable length of stay of patients is minimized through reallocating the bed capacity and building balanced MSS at the MSSP. After that, the performance evaluation is carried out at the operational stage through simulation analysis. The three stages are interacting and are combined in an iterative way to make sound decisions both on the patient case mix and on the resource allocation.

VI. MULTIPLE DEPARTMENTS INTEGRATION

In the 1980s it became clear that the reductionist method made famous by F.W. Taylor was causing the American manufacturing industry to lose perspective of their overall factory. The approach, which focused principally on analyzing individual components, failed to accurately account for their interactions. This narrow view was further compounded by the academic community which thrived on using reductionism for analyzing complex systems, ever the while increasing the gap between their research and actual practice. In contrast, Japanese manufactures focused on the system as a whole and sought to understand and exploit how individual components interacted and contributed to the overall goal of the system. This holistic approach allowed Japanese plants to become simpler, more flexible and more efficient than their American counterparts.

TABLE III
SIMULATION WORK WITH SCHEDULING RULES SUMMARY

Ref.	Authors/Year	Objective Functions	Assumptions	Scheduling Rules
[12]	Testi et al. (2007).	• Number of operations (Yearly). • Overruns and shifted operations. • Bed utilization rates.	• Only elective case considered. • Uncertainties demand and LOS. • Beds and OT resources considered.	LWT, LPT, SPT.
[36]	Dexter et al. (1999).	• ORs utilization.	• Elective Cases	10 rules.
[37]	Marcon and Dexter (2006).	• Over utilized OR time • Completion time • Percentage days with delay.	• Deterministic durations.	7 rules.
[38]	Arnaout and Sevag (2008).	• Minimizing the makespan.	• Stochastic operation duration. • SDS.	LEPST, LEPT, SEPT.
[39]	Harper (2002).	• ORs occupancy level. • Beds occupancy level.	• Demand Uncertainty. • Variability in LOS.	FCFS, LTF, STF, LTSC.

Regard to the holistic approach, Vanberke et al. [40] presented an exhaustive survey reviewing the quantitative health care models which they encompass multiple hospital departments. They provided general overviews of the relationships that exist between major hospital departments and how researchers manipulated these relationships. The most powerful approaches in systems holistic studies are; discrete event simulation and system dynamics (SD).

A. Simulation Models for Multiple Departments Integration

Discrete event simulation has been applied widely to investigate these relationships, for example, Sobolev et al. [41] presented a "Statecharts Paradigm" as a method for constructing a discrete-event simulation model of the perioperative process to ensure the impact of the surgery schedule on adjacent processes is accounted for.

B. System Dynamics Models for Multiple Departments Integration

Other authors described more general models by applying a SD approach [42] and [43]. The SD model connects the departure rates (outflows) of one department with the arrival rates (inflow) of other departments, resulting in a model that is sensitive to the fact that a small change to one part of the system can have considerable impact elsewhere. Lane et al. [42] applied a SD approach to investigate the interaction between wards and emergency department and ORs because both services forward their inpatients to bed wards. They experiment the whole system performance under different number of beds and arrival patterns, similarly, Taylor and Lane [43].

VII. CURRENT GAPS IN THE LITERATURE

According to the literature, there are many issues that can be tackled. These issues will be classified according to the problem which it is related to.

A. Case Mix Problem Related Gaps

1) Generally, the literature in CMP is sparse and the issue of uncertain cases demand has been tackled only by statistical approaches and it still open direction to be tackled with stochastic models.
2) Due to the nature of CMP, its solution should be integer numbers. Large number of variables results in a huge integer program even for a hospital of regular size and no commercial ILP software (e.g., ILOG CPLEX) can solve it effectively [11]. Presenting a dynamic programming and meta-heuristics models for this problem, represent an interesting field for further contributions.

B. Master Surgery Scheduling Problem Related Gaps

1) However, MSSP has attracted great research interest; few authors introduced probabilistic constraints for tackling the uncertainty mainly in surgery demand and LOS.
2) In open scheduling, there are two decisions to be taken. The first one consists of assigning operations to ORs. The second decision deals with operations sequencing in each of the ORs. Routing and scheduling rules can be imported from production management field and adapted to ORs environment, such rules can be found in Shalaby et al. [44].
3) However open-scheduling strategy is more flexible and tends to find a better assignment of the surgical cases than the block one [45], the open-scheduling systems are rarely adopted in health care [46], whereas the block-scheduling systems are the most commonly used. Considering open-scheduling strategy, while solving the ORs scheduling problems, is still open direction.
4) However modified block-scheduling strategy has the advantages of both block-scheduling and open-scheduling as a combination of them, it has been rarely applied in literature.

C. Surgery Scheduling Problem Related Gaps

1) The mathematical models presented in the SSP literature are generally difficult to be solved optimally. Consequently, in order to address instances of large size and more realistic assumptions, future research should be devoted to developing efficient heuristic solution approaches.

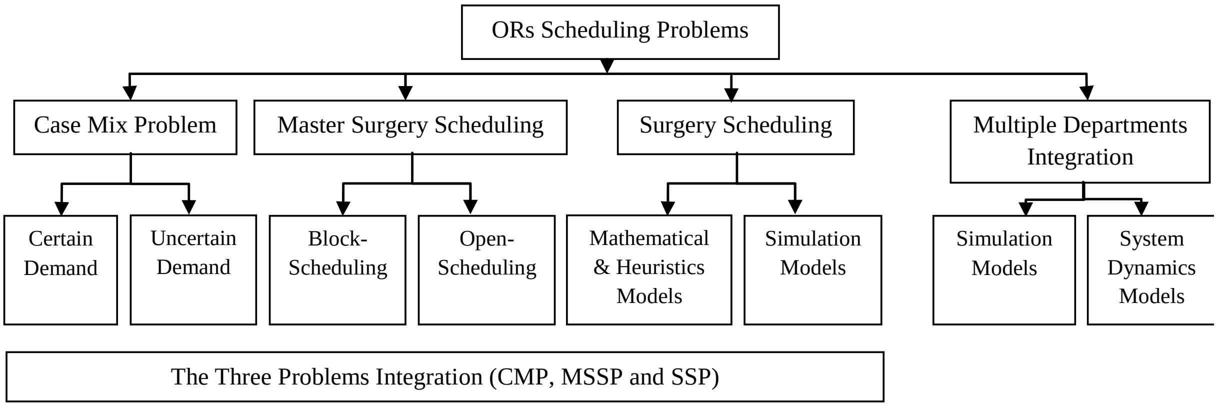

Fig. 3 Problems classification summary

2) The trade-off between, obtaining an optimal solution for approximated and simplified problem and getting a good enough solution for system with more realistic assumption, needed to be solved. For example, to the best of our knowledge, no one considered breakdowns and resources uncertainty.
3) Proposing new scheduling rules considering more technical factors, for example, risk based sequencing, surgeon preferences based sequencing or a decreasing order of act severity, represent interesting field for further contributions.
4) It is generally assumed that urgent/emergency surgeries can be performed in any of the available ORs and should be performed as soon as possible. Consequently, when an urgent surgery arrives, elective surgeries are rescheduled. Very few papers have addressed this specific problem since off-line approaches are often devised. On-line scheduling of urgent cases and the consequent rescheduling of elective surgeries represent interesting fields for further research.

D. The Integration of the Three Problems Related Gaps

1) To the best of our knowledge, only two papers integrated the three problems [11] and [12]. Only one of them applied feedback loop to re-optimize the three decisions [11]. The integration problem is still an open area to be solved simultaneously.

E. Multiple Departments Integration Related Gaps

1) As simulation approaches is efficient in specific problem investigation while system dynamics is a perfect holistic approach. There is an urgent need to integrate both of them to investigate the system comprehensively.
2) One of the powerful points in system dynamics is its ability to consider a qualitative factors and performance measures. Using a system dynamics model to investigate, human "affects/emotions", customer satisfaction and general human factors studies represents interesting direction for future research.

VIII. PROPOSED RESEARCH FRAME WORK

In this section; a proposed frame work to tackle the ORs scheduling problems will be presented. Generally, this proposal aims to consider more realistic assumptions to present efficient solutions to the considered problem. The frame work can be divided into three stages as shown in Fig. 4. In the first one, the CMP will be tackled, followed by surgeries allocation and sequencing in the second stage. Finally, investigate the relation between different hospital departments and ORs and how to consider other department bottleneck while solving the ORs scheduling problems.

A. The First Stage-The Case Mix Problem

This work will be the first attempt to solve the CMP with the objective of minimizing the total cost and maximizing the total profit under demand uncertainty. A dynamic programming (DP) approach will be developed to solve this problem.

DP is a mathematical technique that is based on the idea of separating a decision making problem into smaller sub-problems [47]. The benefit of using DP is that it requires less computational effort compared to exhaustive enumeration in which all possible solutions to a given decision making problem are evaluated. Stochastic DP model will presented to consider the demand uncertainty. The optimal case mix solution will be considered as a constraint while solving the next stage problems.

B. The Second Stage-Surgeries Allocation and Sequencing

In this stage, there are to sub-problems; allocation problem and sequencing problem. In the first one, cases are allocated to an OR among the available ORs. Modified-block scheduling and open scheduling strategies will be used to allocate elective cases to ORs, while emergency cases will be allocated by different routing rules. In the second sub-problem, cases which allocated to ORs will be sequenced according to several sequencing rules. Taking into account many realistic assumptions like, dynamic arrivals, stochastic times and equipments breakdowns, a simulation model will be built to capture the system and to test the proposed scheduling rules.

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

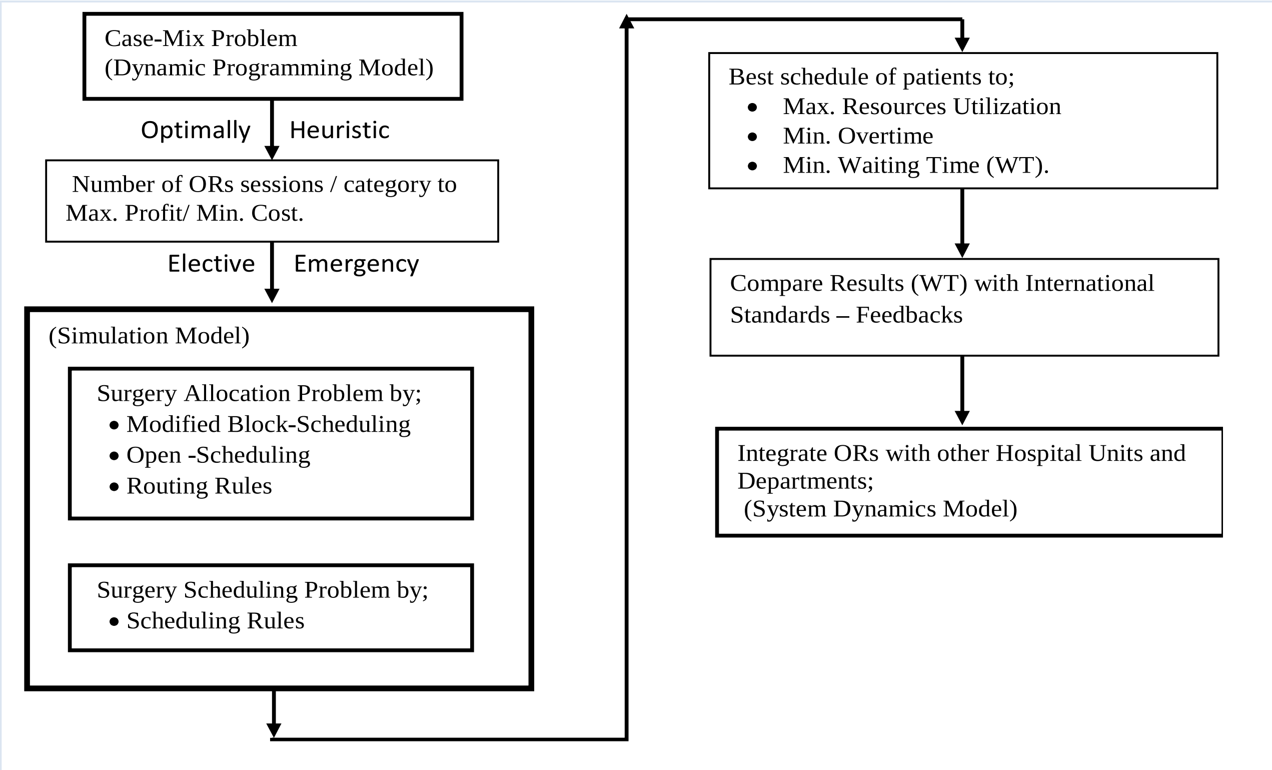

Fig. 4 Basic flow chart for the proposed research frame work

C. The Third Stage- Multiple Departments Integration

In this stage, a SD model will be built to investigate the effect of ORs scheduling problems results on the neighborhood departments (downstream and upstream). As a result of this stage, an answer to the question of, how can we improve not only ORs performance but the whole system performance, will be presented.

IX. Conclusion

This paper illustrated a research framework to solve the operating rooms scheduling problems and the hospital's departments integration problem. The proposed framework is based on operations research and system dynamics. The expected model is a generic solution that can be adapted to different cases with objective to maximize short term as well as long term profits.

Acknowledgment

This research project is sponsored by the Egyptian ministry of higher education grant and the Japanese International Cooperation Agency (JICA) in the scope of the Egypt Japan University of Science and Technology (E-JUST).

References

[1] www.guardian.co.uk/news/datablog/2012/jun/30/healthcare-spending-world-country.
[2] M. Karpiel, “Using patient classification systems to identify ambulatory care costs”, Healthcare Financial Management, vol. 48, pp. 30–37, 1994.
[3] D. Pham and A. Klinkert, “Surgical case scheduling as generalized job shop scheduling problem”, European Journal of Operational Research, vol. 185, pp. 1011–1025, 2008.
[4] J. Van Oostrum, M. Van Houdenhoven, J. Hurink, E. Hans, G. Wullink and G. Kazemier, “A master surgical scheduling approach for cyclic scheduling in operating room departments”, OR Spectrum, vol. 30, pp. 355–374, 2008.
[5] F. Guerriero and R. Guido, “Operational research in the management of the operating theatre: a survey”, Health Care Management Science, vol. 14, pp. 89–114, 2011.
[6] B. Cardoen, E. Demeulemeester and J. Beliën, “Operating room planning and scheduling: A literature review”, European Journal of Operational Research, vol. 201, pp. 921–932, 2010.
[7] S. Brailsford and J.Vissers, “OR in healthcare: A European perspective”, European Journal of Operational Research, vol. 212, pp. 223–234, 2011.
[8] M. S. Feldstein, “Economic analysis for health service efficiency: econometric studies of the British National Health Service”, Amsterdam: North-Holland Publishing Company; 1967.
[9] H. Baligh and D. Laughhun, “An economic and linear model of the hospital”, Health Services Research, vol. 4, pp. 293–303, 1969.
[10] M. E. Hatcher and C. Connelly, “A Case Mix Simulation Decision Support System Model for Negotiating Hospital Rates”, Journal of Medical Systems, vol. 12, pp. 341-363, 1988.
[11] G. Ma and E. Demeulemeester, “A multilevel integrative approach to hospital case mix and capacity planning”, Computers & Operations Research, vol. 40, pp. 2198–2207, 2013.
[12] A. Testi, E. Tanfani and G. Torre, “A three-phase approach for operating theatre schedules”, Health Care Management Science, vol. 10, pp. 163–172, 2007.
[13] G. Ma, J. Beliën, E. Demeulemeester and L. Wang, “Solving the strategic case mix problem optimally by using branch-and-price algorithms”, International Conference on Operational Research Applied to Health Services (ORAHS), vol. 35, Belgium, July 2009.
[14] J. T. Blake and M. W. Carter, “A goal programming approach to strategic resource allocation in acute care hospitals”, European Journal of Operational Research, vol. 140, pp. 541–561, 2002.
[15] M. W. Mulholland, P. Abrahamse and V. Bahl, “Linear programming to optimize performance in a department of surgery”, The American College of Surgeons, vol. 200, pp. 861–868, 2005.

[16] P. C. Kuo, R. A. Schroeder, S. Mahaffey and R. Bollinger, “Optimization of Operating Room Allocation Using Linear Programming Techniques”, The American College of Surgeons, vol. 197, pp. 889–895, 2003.
[17] I. Moore, D. Strum, L. Vargas and D. Thomson, “Observations on surgical demand time series: detection and resolution of holiday variance”, Anesthesiology, vol. 109, pp. 408–416, 2008.
[18] F. Dexter and R. Epstein, “Holiday and weekend operating room on-call staffing requirements”, Anesthesia and Analgesia, vol. 103, pp. 1494–1498, 2006.
[19] D. P. Strum, L. G. Vargas, J. H. May and G. Bashein, “Surgical suite utilization and capacity planning: a minimal cost analysis model”, Journal of Medical Systems, vol. 21, pp. 309–322, 1997.
[20] M. Olivares, C. Terwiesch and L. Cassorla, “Structural estimation of the newsvendor model: an application to reserving operating room time”, Management Science, vol. 54, pp. 41–55, 2008.
[21] R. Wachtel and F. Dexter, “Review of behavioral operations experimental studies of newsvendor problems for operating room management”, Anesthesia and Analgesia, vol. 110, pp. 1698–1710, 2010.
[22] P. Patterson, “What makes a well-oiled scheduling system”, OR Manager, vol. 12, pp. 19–23, 1996.
[23] F. Dexter, “A strategy to decide whether to move the last case of the day in an operating room to other empty operating room to decrease overtime labor costs”, Anesthesia and Analgesia, vol. 91, pp. 925–928, 2000.
[24] J. Beliën and E. Demeulemeester, “Building cyclic master surgery schedules with levelled resulting bed occupancy”, European Journal for Operational Research, vol. 176, pp. 1185–1204, 2007.
[25] M. Van Houdenhoven, J. van Oostrum, E. Hans, G. Wullink and G. Kazemier, “Improving operating room efficiency by applying bin-packing and portfolio techniques to surgical case scheduling”, Anesthesia and Analgesia, vol. 105, pp. 707–714, 2007.
[26] I. Adan, J. Bekkers, N. Dellaert, J. Vissers and X. Yu, “Patient mix optimisation and stochastic resource requirements: a case study in cardiothoracic surgery planning”, Health Care Management Science, vol. 12, pp. 129–141, 2009.
[27] J. Vissers, I. Adan and J. Bekkers, “Patient mix optimization in cardiothoracic surgery planning: a case study”, IMA Journal of Management Mathematics, vol. 16, pp. 281–304, 2005.
[28] Y. Liu, C. Chu and K. Wang, “A new heuristic algorithm for the operating room scheduling problem”, Computers and Industrial Engineering, vol. 61, pp. 865–871, 2011.
[29] H. Fei, N. Meskens and C. Chu, “A planning and scheduling problem for an operating theatre using an open scheduling strategy”, Computers and Industrial Engineering, vol. 58, pp. 221–230, 2010.
[30] B. Vijayakumar, P. J. Parikh, R. Scott, A. Barnes and J. Gallimore, “A dual bin-packing approach to scheduling surgical cases at a publicly-funded hospital”, European Journal of Operational Research, vol. 224, pp. 583–591, 2013.
[31] A. Jebali, A. Hadjalouane and P. Ladet, “Operating rooms scheduling”, International Journal of Production Economics, vol. 99, pp. 52–62, 2006.
[32] B. Denton, J. Viapiano and A. Vogl, “Optimization of surgery sequencing and scheduling decisions under uncertainty”, Health Care Management Science, vol. 10, pp. 13–24, 2007.
[33] E. Hans, G. Wullink, M. Van Houdenhoven and G. Kazemier, “Robust surgery loading”, European Journal of Operational Research, vol. 185, pp. 1038–1050, 2008.
[34] M. Lamiri, X. Xie, A. Dolgui and F. Grimaud, “A stochastic model for operating room planning with elective and emergency demand for surgery”, European Journal of Operational Research, vol. 185, pp. 1026–1037, 2008.
[35] A. Sciomachen, E. Tanfani, A. Testi, “Simulation Models for optimal schedules of operating theatres”, International Journal of Simulation Modelling, vol. 6, pp. 26–34, 2005.
[36] F. Dexter, A. Macario and R. Traub, “Which algorithm for scheduling add-on elective cases maximizes operating room utilization?: use of bin packing algorithms and fuzzy constraints in operating room management”, Anesthesiology, vol. 91, pp. 1491–1500, 1999.
[37] E. Marcon and F. Dexter, “Impact of surgical sequencing on post anesthesia care unit staffing”, Health Care Management Science, vol. 9, pp. 87–98, 2006.
[38] J. P. Arnaout and K. Sevag, “Maximizing the utilization of operating rooms with stochastic times using simulation”, Proceedings of the 40th conference on winter simulation, 2008, pp. 1617–1623.
[39] P. Harper, “A framework for operational modelling of hospital resources”, Health Care Management Science, vol. 5, pp. 165–173, 2002.
[40] P. T. Vanberke, R. J. Boucherie, E. W. Hans, J. L. Hurink and N. Litvak, “A Survey of Health Care Models that Encompass Multiple Departments”, International Journal of Health Management and Information, vol. 1, pp. 37–69, 2010.
[41] B. Sobolev, D. Harel, C. Vasilakis and A. Levy, “Using the statecharts paradigm for simulation of patient flow in surgical care”, Health Care Management Science, vol. 11, pp. 79–86, 2008.
[42] D. Lane, C. Monefeldt and J. Rosenhead, “Looking in the Wrong Place for Healthcare Improvements: A System Dynamics Study of an Accident and Emergency Department”, Journal of the Operational Research Society, vol. 51, pp. 518–531, 2000.
[43] K. Taylor and D. Lane, “Simulation applied to health services: opportunities for applying the system dynamics approach”, Journal of Health Services Research & Policy, vol. 3, pp. 226–232, 1998.
[44] M. A. Shalaby, T. F. Abdelmaguid and Z. Y. Abdelrasol, “New Routing Rules for Dynamic Flexible Job Shop Scheduling with Sequence-Dependent Setup Times”, Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, July 3 – 6, 2012.
[45] H. Fei, C. Chu and N. Meskens, “Solving a tactical operating room planning problem by a column-generation based heuristic procedure with four criteria”, Annals of Operations Research, vol. 166, pp. 91–108, 2009.
[46] R. Gabel, J. Kulli, B. S. Lee, D. Spratt and D. Ward, “Operating room management”, London: Butterworth-Heinemann, 1999.
[47] R. Bellman, “Applied dynamic programming”, Princeton, NJ: Princeton University Press, 1962.

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)