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COLLEGE OF ENGINEERING

PHYSICIAN SCHEDULING IN WOMEN'S HOSPITAL

BY

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ABSTRACT

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Title: Physician Scheduling in Women's Hospital

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In this project, a physician scheduling problem arising from the operations of the Obstetrics and Gynecology Department at Hamad Women's Hospital in Qatar has been studied. The essence of the physician scheduling problem lies in assigning physicians with different experience levels to a set of predetermined shifts to achieve a set of clinical/non-clinical duties over a defined time horizon while considering a large set of conflicting rules and constraints including, and not limited, to hospital rules, physicians' requirements, shift coverage requirements, seniority-based workload rules, physicians' preferences, and workload balance aspects.

The focus of this research project is to develop schedule for physicians (labor specialists and inpatient ward specialists) within Obstetrics and Gynecology Department at Hamad Women's Hospital for on-call shifts (evening shift and night shift) beside regular working shift (morning shift) while respecting all hard constraints, satisfying a wide range of soft constraints as far as possible, and most importantly balancing the workload among the physicians. Both labor specialists and inpatient ward specialists are the main service providers in this hospital, and therefore optimizing their work-shifts assignments would

indirectly assist in providing a better service to female patients in Qatar and would result in meeting both the hospital and the physicians' satisfaction.

In this work, the problem is formulated as mathematical programming model and solved by AIMMS optimization software. Optimal physicians' schedules were generated, and the proposed model was tested on real data provided from the Obstetrics and Gynecology Department in Qatar. A comparison between the resulting optimal schedules and the manual schedules used currently by the hospital was conducted. Then, a sensitivity analysis was performed in order to test the robustness of the obtained physicians' schedules of the proposed model. The proposed approach demonstrated that high quality schedules that satisfy all the constraints and mainly ensure balanced workload among the physicians can be generated with less time and effort required compared to the schedules prepared manually by the chief specialist in Women's Hospital.

DEDICATION

I dedicate this research project to my family, who have provided me with all the support and constant encouragement throughout the entire master's degree studies. Besides, I would like to dedicate this research work to Qatar, as applying this research in reality would contribute to the enhancement of its healthcare sector.

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1. Chapter 1: Introduction

1.1. Background

Enhancing the quality of health care services provided to its patients becomes very significant, as it is considered one of the main objectives the health care institutions seek to achieve. Currently, healthcare administration uses certain strategies and techniques for the sake of optimizing the individual assignments including nurses, physicians, and other medical personnel in order to improve and deliver as efficient medical service as possible.

This project uses operations research techniques to formulate and solve to optimality the physicians scheduling problem arising at Hamad Women's hospital and most importantly to automate the scheduling generation process. Operations research tool uses logical and mathematical techniques to generate optimal solutions.

Physician scheduling is assigning physicians with different seniority levels to different work-shifts/duties over a defined planning horizon. Indeed, physician scheduling is a complex task which requires considering a large number of conflicting constraints related to various aspects such as; shift coverage requirements, physicians' staffing requirements as per the seniority level, number of shifts that should be assigned to each physician, limits on the number of consecutive work hours and consecutive shifts assigned, vacation periods, weekend-off requests, physicians' preferences to work-shifts and vacation, as well as the fair distribution of on-duty and off days among the physicians (Beaulieu et al., 2000).

Developing computerized optimal physician schedules that respect all the afore-mentioned constraints would be a better/efficient alternative to the current manual procedure of creating such schedules; in terms of the solution quality (workload balance), effort required, and development time. Hence, this project aims at generating computerized optimal physicians' schedules using operations research techniques.

1.2. Problem Description

The scheduling of physicians within Obstetrics and Gynecology department at Women's Hospital becomes more complex over time, due to the large number of conflicting rules and constraints, the variability of service times among physicians, as well as the wide range of female patient care services such as labor rooms, inpatient wards rounds, operation theatres, out-patient clinics, etc. Therefore, preparing an efficient schedule is hard if not even impossible when performed manually.

Women's hospital is one of Hamad Medical Corporation's hospitals that seeks to improve the health and wellbeing of women in Qatar through offering a wide range of dedicated clinical care and services for female patients including gynecology and obstetrics, day surgery, ante-natal, post-natal intensive care and newborn screening. Women's hospital is concerned primarily with providing Obstetrics and Gynecology services for more than 17,000 each year which makes it one of the busiest hospitals at Hamad Medical Corporation in Qatar (Healthcare in Qatar, 2017). Obstetrics and Gynecology are two distinct medical specialties that deal with the female patients. Obstetrics is a branch of medicine specializes in the care of women during both

the pregnancy (the antenatal care of the fetus) and childbirth (the postnatal care of the mother to ensure she is recovering well). However, Gynecology is another branch of medicine specializes in the diagnosis and treatment of any disorder or of disease related to the female reproductive organs ("Women's Hospital," n.d).

The purpose behind this project is to analyze and solve a physician scheduling problem that arises in Obstetrics and Gynecology department at Hamad Women's Hospital. Delivering optimal physician schedules that cover patient demand while respecting the hospital work-rules, meeting physicians' requirements, satisfying shift coverage requirements, and most importantly ensuring the workload balance among the physicians would be achieved in this project through automating the schedule generation process using operation research techniques. Hence, this project attempts to generate high quality physician schedules (workload balance) as a better/efficient alternative to the current manually prepared schedules that require a lot of effort and time from the chief specialist at Woman's Hospital who is in charge of performing this duty.

In Women's hospital, physicians are partitioned into four categories according to their seniority levels: residents, specialists, senior specialists and consultants. Residents are physicians with low experience level who belong to the most junior category of physicians and are still in training, and therefore residents cannot work at critical units. Typically, after medical students complete their medical school, they enter a (3-5 years) residency program for specialized training in different departments at a hospital. Whereas specialists and senior specialists are certified physicians who have already finished residency program

and completed advanced education and clinical training in a specific area of medicine (in this project, Obstetrics and Gynecology area), however senior specialists have higher level of experience compared to specialists. Basically, there are duties in Obstetrics and Gynecology department that can be shared between specialists and senior specialists, while some duties are assigned to senior specialists only. Consultants are physicians of the highest seniority rank who are highly experienced in a particular area of medicine (in this project, Obstetrics and Gynecology area). Consultants are clinical decision makers, where other groups of physicians like residents, specialists, and senior specialists work under their supervision and they are often assigned to critical cases.

Obstetrics and Gynecology department at Women's Hospital consists mainly of inpatient wards, labor rooms, operation theatres, and outpatient clinics. The standard working days of this department are five days per week (form Sunday to Thursday). The working shifts in this department includes regular working shift (morning shift) that starts from 7:00 am till 3:00 pm, evening shift that starts from 3:00 pm till 10:00 pm, night shift that starts from 10:00 pm till 7:00 am the next day, and 24-hr duty as well as 12-hr duty in weekends. Basically, on-call duty is a duty that starts after the regular working shift (after 3:00 pm) including the 24-hr. duty and the 12-hr. duty in weekends, i.e., evening shifts and night shifts are typically called on-call shifts, in addition to the 24-hr. duty and the 12-hr. duty in weekends.

During regular working shift (7:00 am-3:00 pm), the physicians in Obstetrics and Gynecology department are divided into five teams; where each team consists of certain number of consultants, senior specialist, specialist, and residents. Each team is assigned multiple clinical duties during regular working shift in weekdays, including, outpatient clinics, labor rooms, operation theatres, inpatient ward rounds, etc. All physicians must work during regular working shift, unless they are on post-call. It is worth mentioning that, only labor rooms and inpatient wards run during on-call shift, in addition to the operation theatres but only when emergency cases arise unexpectedly.

This report aims at developing monthly schedules for both labor specialists and ward specialists as they are considered the main service providers in Women's Hospital. Labor specialists work only at labor rooms, and they are responsible for overseeing and assisting women during the process of natural delivery, however ward specialists work only at inpatient wards, and they are responsible for taking care of female patients who resides at inpatient wards whether before or after delivery. Basically, 15 physicians need to be scheduled within Obstetrics and Gynecology department and they are divided as follows;

- 10 labor specialists need to be assigned to labor rooms for three different types of work-shifts; morning shift, evening shift and night shift. However, the work-shifts must be equally distributed among labor specialists.

- 5 inpatient ward specialists need to be assigned to inpatient wards for three different types of work-shifts; morning shift, evening shift and night shift. However, the work must be equally distributed among ward specialists.

Hence, this report is concerned with assigning 10 labor specialists and 5 ward specialists at Obstetrics and Gynecology department in Women's Hospital to on-call shifts (evening shift and night shift) and regular working shift (morning shift) over one-month period, while ensuring the balanced distribution of work-shifts among the specialists, and ultimately this would result in meeting both the hospital and the physicians' satisfactions. In fact, the current physicians' schedules are created manually by a chief specialist in the Women's Hospital which take him/her one full day work to design. Therefore, this project seeks to automate the physician schedule generation process through using mathematical modeling, for the purpose of creating higher quality schedules (that ensure the balanced workload among the physicians in the first place) in comparison to the current ones, with reducing the time and effort required for preparing such schedules.

1.3. Project Scope

The focus of this project is to apply mathematical modeling to accommodate large number of conflicting rules and constraints for the sake of developing optimal monthly schedules for physicians (labor specialists and ward specialists) within Obstetrics and Gynecology Department at Hamad Women's Hospital, which would mainly ensure the balanced distribution of the work-shifts among the physicians and would ultimately result in meeting both the hospital and the physicians' satisfactions.

1.4. Project Objectives

The key objective of this project is to develop optimal monthly schedules for labor specialists and ward specialists at Hamad Women's hospital through using mathematical modeling. The mathematical model would primarily balance the workload among the physicians. Additionally, the proposed model should:

- Respect the hospital rules and polices

- Meet the physicians' requirements

- Satisfy shift coverage requirements

- Ensure the workload balance among physicians

- Automate the schedule generation process

Besides, this project aims to generate higher quality physician schedules (workload balance) that would meet both the hospital and physicians' satisfactions with less computational time and effort required in comparison to the current manually prepared schedules.

2. Chapter 2: Literature Review

Many research papers studied and solved the problem of physician scheduling in different health care departments using various operation research techniques. The relevant previous studies concerned primarily on assigning physicians with different seniority levels to predetermined work-shifts while respecting work rules and wide range of conflicting hard and soft constraints over a specified time horizon with ensuring the optimum usage of available resources. It discussed, modeled and solved physician scheduling problems to come up with either feasible or optimal schedules where the main objectives of the majority of these research papers are on reducing the total cost either through optimizing the number of available physicians or through minimizing the total assigned overtime hours subject to restrictions specified by the labor agreement, or maximizing physicians' preferences and satisfaction, or maximizing the fairness among physicians through minimizing the sum of deviations from goal/soft constraints.

The following provides an overview of the commonly used scheduling methods and models, the major objectives and goals behind optimizing the current schedules, the seniority level considerations, the constraints and regulations often incorporated into the developed models, the number and types of work-shifts considered, and the results/findings achieved. Based on the review conducted, it becomes clear that the key factors of the physician scheduling problem are: the seniority level, the main physician clinical duties, and the work-rules or constraints that should be met. In this work, a review on the published articles related to physician scheduling problem is provided. This review is divided into

four main categories:

- Literature Papers based on Planning Period and methodology

- Literature Papers based on Seniority Levels

- Literature Papers based on Constraints

- Literature Papers based on Work Shifts

2.1. Literature papers based on Planning Period and Methodology

The planning period in physician scheduling is about creating a schedule over a specified period of time, i.e. it is the period of time a physician schedule is covering. Planning period can be divided into three types; Short-term planning period, Mid-term planning period, and long-term planning period. Based on the literature review conducted, it was found that, some research papers developed physician schedules for short-term planning period that is between 2 and 4 weeks, others developed schedules for long-term planning period that is at least six months, while others developed mid-term physician schedules which lies between one month and 6 months.

2.1.1. Short-term period physician scheduling using Mathematical Programming

The studies of Sherali et al. (2002), Topaloglu (2006), Topaloglu (2009), Day et al. (2006), Bard et al. (2014), Brunner et al. (2009), Brunner et al. (2010), and Stolletz and Brunner (2012), have developed physician schedules for different departments at different hospitals with different objectives for short-term planning period using different

mathematical programming approaches.

Sherali et al. (2002), have studied the problem of assigning work-night shifts to residents with different seniority levels for 4-5-week time period, while taking into account departmental staffing requirements and residents' preferences. The problem was formulated as a mixed-integer programming model. The developed model was solved through heuristic solution procedures as well as by a commercial package CPLEX for the sake of comparison. It was found that heuristic procedures utilize the inherent network structure of the problem which improves the problem solvability, ensure the robustness in solving all problems, as well as it is capable of solving highly constrained problems that turn out to be technically infeasible. Moreover, the schedules developed reduces the time and effort required to prepare such schedules compared to the manual schedules.

While, Topaloglu (2006), has formulated a short-term scheduling problem of emergency medicine residents in a major Turkish local hospital and specifically over a monthly planning horizon using goal programming model. Analytical hierarchy process (AHP) was used in this paper in order to compute the relative importance values of the soft constraints which were dealt with as coefficients of the deviations from the soft constraints in the objective function of the proposed mathematical model. Large number of conflicting rules were taken in to account while constructing the schedules such as the hospital working rules and the residents' requirements in accordance to their experience levels for the day and night shifts. The resulting schedules were tested and compared with the actual hospital schedules which generated manually by the chief resident and it was shown that

the schedules generated by the proposed model are much better in terms of the solution quality, the computation time and the effort required.

In another study for Topaloglu (2009) a multi-objective programming model was formulated for scheduling residents with different seniority levels for a monthly planning horizon as well, while adhering the hospital working rules, and satisfying a large set of hard and soft constraints. The objective function of this model was to reduce soft-constraints violations by minimizing deviational variables associated with the soft constraints. The proposed model was tested on real data in a pulmonary unit of a local hospital through using sequential and weighted methods. The findings indicated that fairer shift schedules can be generated within a few seconds in comparison to the manually prepared schedules.

Hence, the studies of Topaloglu (2006) and Topaloglu (2009) have tested their proposed models on a real case of a hospital, and the findings indicated that high quality schedules can be generated within a few seconds.

In 2006, in Surgery Departments, Day et al. have formulated an integer programming model for 4-weeks long work period that seeks to assign residents with different levels of experience, who are rotating through 4 hospitals during the weekdays work-hours between 6:00 am and 6:00 pm to cover mainly surgical services. This operation research algorithm used by the authors in order to provide a rational scheduling solution that would assign 56 residents to a total of 80-hours per week per resident. The optimization

software ILOG was used to solve the formulated model. As a result, a weekly schedule that satisfy all the surgical service requirements along with the Residency Review Committee (RRC) rules was generated. The authors concluded that using operation research technique for solving scheduling problems ensures the robustness of the model as it can accommodate changes in resident numbers, and hospital service requirements.

However, Bard et al. (2014), have proposed a network model based goal program for creating monthly clinic schedules for house-staff (interns and residents). The primary objective of the proposed model was to maximize the number of clinic duties assigned to the house-staff each month. A comparative study for the academic year 2012–2013, indicated that the schedules obtained from the proposed network approach are of high efficiency, from the solution quality (increase in the number of clinic-duties scheduled per month) and computational time point of view.

At a German university hospital, Brunner et al. (2009), have introduced an implicit formulation for the flexible shift scheduling problem of physicians using mixed integer program where shifts are generated implicitly, i.e., shifts are built period by period over the day. In this research paper, physicians are allocated to duties over a planning period that can extend over several weeks. The aim of this research was to develop a flexible shift schedule for physicians that minimizes the total overtime hours assigned to meet the forecasted demand under the rules specified by the labor regulations. While constructing the flexible shift schedules, various constraints which govern physicians in German hospitals were taken into account. The formulated model was solved by CPLEX solver and

it was tested on real data provided from an anesthesia department, and the findings demonstrated that high quality schedules can be generated with less time and effort required compared to the manual techniques of schedules preparation.

In 2010, Brunner et al. have conducted another study about flexible shift scheduling problem and proposed a methodology to solve the problem which allow flexible start times, shift durations and overtime to meet the demand for biweekly or monthly time period too, while primarily satisfying both system-wide and individual constraints. The scheduling problem was formulated as a mixed-integer program that aims to minimize the total assignment cost including, paid out time, overtime, and the use of external resources while considering labor regulations. Large number of constraints associated with the legal restrictions, the staffing requirements and rules, and the physicians' preferences were taken into account. Instead of having a predetermined set of several shift types, the proposed model generates shifts and break assignments implicitly. A branch and price algorithm was used to generate the optimized schedules, and the solution approach was tested on real data provided by anesthesia department of a hospital, and the findings showed the efficiency of the branch and price algorithm in solving the problem and its ability to generate optimal schedules that can extend to 6 weeks at a time.

The flexible shift scheduling problem was formulated again in 2012 by Stolletz and Brunner, however this time with using a reduced set covering approach. In this paper, schedules were designed in such a way that physicians are assigned to shifts and days-off to cover the demand over a planning period of two weeks. The aim of this paper was to

minimize operating cost (through minimizing the total assigned overtime hours subject to restrictions specified by the labor agreement). The authors have developed a reduced set covering formulation that requires shift templates to be produced for a single day and the rules considered were modeled as linear program.

Both Brunner et al. (2010) and Stolletz and Brunner (2012) have used approaches that allow full flexibility in terms of shift starting times and durations, as well as break periods placements, however the findings demonstrated that the efficiency of the reduced set covering approach used by Stolletz and Brunner (2012) in comparison to implicit modeling approach that used by Brunner et al. (2010). Besides, Stolletz and Brunner (2012), extended the formulation to incorporate fairness aspects.

2.1.2. Short-term period physician scheduling using Heuristics and Meta-Heuristics

While the studies of Banet (2010), Wang et al. (2007), Puente et al. (2009), Lo and Lin (2011), and Ryan et al. (2013), have developed physician schedules for short-term planning period using heuristic and meta-heuristics approaches.

In 2010, Banet as well conducted a research paper for the purpose of developing a heuristic tool for physicians' scheduling in an outpatient center over a time horizon of one week. The developed heuristic tool produced initial feasible solution using a greedy assignment algorithm, and then the obtained solution was improved through using the simulated annealing meta-heuristic. Because many outpatient clinics do not possess

optimization software for solving physician scheduling problem like LINGO or CPLEX, this paper proposed a heuristic solution procedure that can be programmed and solved in familiar software, such as Microsoft Excel and Visual Basic for Applications (VBA). The goal of this study was to allocate physicians to specific time slots they request with the objectives of maximizing physicians' satisfaction and balancing patient load, as well as ensuring the fair distribution of work among slots while meeting the work regulations and space capacity constraints. The performance of the heuristic method established in this study was tested through solving a set of randomly generated data as well as with doing a comparison between the obtained results and the optimal values resulted by using LINGO, and it was concluded that the heuristic solution can provide satisfactory results within minutes.

Although, the study of Wang et al. (2007), have solved the resident scheduling problem over a monthly planning horizon, it was achieved through adopting the evolutionary approach to propose a genetic algorithm that search for optimal schedules. Their study aimed to minimize the penalties from violating the constraints considered in the study. Beside the well-known genetic operators, dynamic mutation operator was proposed for solving and minimizing the cost associated with the resident scheduling problem. Various experiments were conducted to evaluate the solution quality for different scenarios, and it was shown that the combination of the dynamic mutation and the two-point crossover produces the best schedules for this problem. Hence, it was indicated that the developed algorithm performs efficiently in looking for optimal schedules.

Also, Puente et al. (2009), have applied genetic algorithms to automate the generation of monthly work schedules for medical doctors at Hospital Emergency Department in Spain; due to the difficulty in solving this problem with exact mathematical methods. This research has been conducted due to the following reasons: the growth of the medical doctors in these hospital services, the growth of the workload that may lead to fatigue, and the work system of the emergency department could be exported to any other sector that have similar features. Combining shift scheduling with 24-h duties as well as balancing the workload among all the doctors together with incorporating large number of constraints, led the researchers to apply a weighting and ranking system to each of the soft constraints to identify their relative importance to the solution that was developed through using Delphi-study. Both hard and soft constraints associated with this scheduling problem were identified, then encoding type of "doctor-shift view" was chosen to allocate medical doctors to work-shifts, after that, a heuristic schedule builder used to comply with the constraints yields initial feasible solutions. Next, a specific crossover operator was used along with a repair function to generate new populations of feasible solutions. After optimum solution has been reached, the resulting schedule was discussed in terms of the level of satisfaction of the soft constraints. The goal was to assign medical doctors in such a way that it would meet hard constraints while achieving high-quality results with respect to soft constraints. The resulting schedule demonstrated was of high quality as a more balanced shift-assignment among medical doctors was achieved, as well as the emergency department requirements were met. The solution was implemented, and it achieved a high degree of satisfaction.

However, Lo and Lin (2011), used a meta-heuristic method to look for the most suitable work-shift assignment for emergency department physicians and the work-schedules were performed periodically once or twice a month. The authors have proposed a Particle Swarm Optimization based intelligent physicians' scheduling system for solving the assignment problem as it assists hospital administrators in making decisions. The proposed system incorporated both hard and soft constraints. This research used penalty function method and included infeasible solutions while searching for the optimal solution, however penalties were added to the objective function in case of constraint-violations. Hence, the aim of the developed system was to minimize the overall penalties of constraint-violations. The results obtained from the implementing the proposed system in a hospital in Northeast Taiwan, demonstrated the effectiveness of the system as it fulfilled the physicians' satisfaction, met all hard constraints considered in the study as well as the soft constraints but with quite limited violations, and accelerated the process of searching for the optimal solution. Hence, the proposed system confirmed its capability to generate satisfactory work-schedules in which emergency departments physicians are assigned to proper work-shifts efficiently and effectively.

While at the University of Virginia hospital, Ryan et al. (2013), have developed a fully-integrated software system for the purpose of generating preference based schedules in internal medicine for medical interns and residents over 4-week planning period, while satisfying a large set of constraints such as coverage requirements, educational requirements, federal regulations, and medical students preferences for specialties and vacations. The purpose behind developing such a system was to relieve the chief resident

from the complex and time-consuming task of manual schedule preparation. This medical optimization scheduling system is functioning this way: first, it collects the preference information from interns, residents and the chief resident through a web based interface, second, it stores the collected information through using SQL database, third, it optimizes the stored information that is obtained from residents, interns, and the chief resident through running a linear programming solver named Gurobi. The system demonstrated to produce schedules in minutes that are comparable and often superior to those created manually. It was shown that the schedules produced met 100% of residents and interns vacation requests while considering inpatient and outpatient clinic preferences of medical students.

2.1.3. Mid-term period physician scheduling using Mathematical Programming

However, Carter and Lapierre (2001), studied a mid-term physician scheduling problem. They have analyzed and examined the existing scheduling rules for emergency rooms physicians in six different hospitals in Montreal (Canada) area. A general mathematical formulation was developed for scheduling physicians over a three month-time horizon. The authors have classified the existing schedule types into three categories (the acyclic schedules, the cyclic schedules with rotation, and the cyclic schedules without rotation) and presented the technique used to prepare the schedule for each category. An application of two different cases was described; one with simple scheduling rules and the other has complex scheduling rules. As a result, it was shown how to modify the current scheduling regulations to develop techniques which generate higher quality schedules in

shorter period of time.

2.1.4. Long-term period physician scheduling using Mathematical Programming

The studies of Beaulieu et al. (2000), Cohn et al. (2006), GüLer (2013), Bruni and Detti (2014) and Ferrand et al. (2011) have developed physician schedules for different departments at different hospitals with different objectives for Long-term planning period using different mathematical programming approaches.

Beaulieu et al. (2000), have prepared schedules for emergency room physicians in a major hospital of the Montr´eal region over a six-month planning horizon using a multi-objective mathematical program while considering large number of conflicting rules, including seniority rules, ergonomic rules, compulsory rules, distribution rules, goal rules, restrictions on the number of consecutive shifts or work hours, vacations and days-off, physicians' preferences, etc. The objective function of this model was to minimize the total deviations associated with the goal constraints. The model was solved using commercial branch-and-bound solver. The proposed approach demonstrated its capability to generate better schedules than those created via human experts in terms of the solution quality, the computation time and the effort required.

While in the paper of Cohn et al. (2006), the focus was on scheduling 10-20 medical residents with different seniority levels to on-call shifts among three different hospitals through using mathematical programming techniques for 1-year time period at Boston

University School of Medicine, while considering a large set of hard constraints, hospitals requirements residents' preferences, as well as educational and personal requirements. Three different calls were involved in the proposed schedule: primary call, back-up call, and extra on-calls. The purpose behind assigning residents to on-call shifts was to provide residents with training and to provide staffing for the hospital. The significant issue that this paper has mainly focused on is the difficulties faced in defining a measurable objective function associated with applying mathematical programming techniques. The results indicated that high quality schedules produced with less time and effort required compared to the schedules developed manually by the chief residents.

In a physical medicine and rehabilitation (PMR) department of Bezmialem Vakif University Medical School in Turkey, Güler (2013) proposed a hierarchical goal programming model for assigning residents and specialists to outpatient clinics over 6 months planning period. The model is hierarchical, meaning monthly schedule is to be developed first and then the daily schedule. It also used Analytical hierarchy process (AHP) to integrate the experiences of (PMR) department into the proposed model. The constraints considered in the problem were formulated as hard and soft constraints and the objective function of the developed model was to minimize the deviations from the soft constraints. This study was conducted because the (PMR) department was not satisfied with the existing manual schedules as they are subject to frequent changes as well as they are not capable of satisfying the preferences of the residents. Hence, the proposed model addressed these issues while ensuring the minimum number of outpatient clinics assignment. This study is concerned with assigning 6 residents and 7 specialists to three different types of

outpatient clinics in the (PMR) department; general outpatient clinic, branch outpatient clinic, and rheumatology outpatient clinic. The proposed model aimed to minimize the frequent changes within the schedules, allow the residents to work with specialists until they graduate from the residency program, satisfy the residents' preferences, and respect the departmental requirements. The author created schedules for 60 months and the results indicated that the model achieved all the aforementioned goals and satisfied all the considered constraints.

In Italy, Bruni and Detti (2014) have formalized the general aspects of the physician scheduling problem in health care departments that concerns with assigning a number of duty shifts to a number of physicians considering several types of requirements. The problem is non-deterministic polynomial-time hardness, where a flexible mixed integer linear programming formulation was proposed which permits easy modifications and introduced enough flexibility for different scenarios. This formulation was solved by a standard Branch-and-Cut procedure for several planning horizons even beyond the standard needs (between 6-months and 1-year). A real-world case study in some of the departments of one of the biggest Italian university hospitals was considered, and a comparison was conducted between the schedules obtained from the proposed approach and the existing schedules. The results demonstrated the effectiveness of the proposed approach from the schedule quality (workload balancing) and from the computational time point of view.

In a branch of the emergency department at Cincinnati Children's Hospital Medical Center, Ferrand et al. (2011) have studied the scheduling problem of physicians through using integer programming to construct cyclic schedules that can be repeated throughout the year. In this paper, cyclic schedules were built due to the complaints received from physicians that their schedules are too erratic. The proposed model incorporated large number of different rules and constraints, and it aimed to minimize the sum of all deviations from soft constraints. The model was programmed in AMPL and solved with CPLEX. Depending on their surveys with physicians, it was demonstrated that the optimized schedule delivered more fair and well-balanced work patterns that meet the satisfaction.

2.1.5. Long-term period physician scheduling using Heuristics and Meta-Heuristics

The studies of Cohn (2007), Carrasco (2010), and Brunner and Edenharter (2011) have developed physician schedules for Long-term planning period using heuristics approaches.

Cohn (2007), has studied the resident scheduling problem of a multi-criteria nature. The author has developed on-call schedules for medical residents who serve multiple hospitals over a one year-planning horizon, while considering various work rules, hospital requirements, shift requirement, residency requirements, hard constraints, and a number of competing metrics (physicians' preferences), through generating a complete set of Pareto optimal solutions; so that residents can select their preferred schedule from the set. In comparison with the optimization problems that assigns weights (represent preferences) in

the objective function, it was found that the feasibility problems with fixed bounds on the metrics (preferences) are easier to solve. Hence, the computational results demonstrated the tractability of this approach.

However, Carrasco (2010), has used a simple procedure that combines random and greedy strategies with heuristics for assigning guard shifts regularly to the physicians in pediatric department in a Spanish hospital over a long-term period while satisfying the work rules and allowing performing the programmed tasks. This paper concerned with assigning on-call duties to one supervisor and one assistant as well as one supervisor and two assistants during weekdays, and in the weekends respectively. The algorithm has been implemented in Java and distributed under the terms of the GNU General Public License.

While, Brunner and Edenharter (2011) have studied the long-term scheduling problem of physicians with different seniority level in German hospitals through using flexible shifts. The problem was formulated as a mixed-integer program and solved by column generation based heuristic approach. The model treats shifts implicitly when creating timetables which allows more flexibility in the scheduling process. The objective function of the developed model was to minimize the total number of physicians assigned into different duties subject to several labor agreements, legal restrictions and staffing policies. The goal of this paper was to find the right composition of physicians with different seniority levels. The proposed model was tested on real data provided by anesthesia department of a hospital, and the results show the efficiency of the model when two seniority levels (residents and specialists) are considered.

2.2. Literature papers based on Seniority Levels

The seniority level term in healthcare sector refers to the experience level of a physician. Typically, physicians are classified into categories based on their level of experience, and they are allocated to work-shifts according to these levels. While developing physician schedules that considered general rules and aspects which commonly used in different departments in hospitals, physicians should be partitioned into groups in such a way that each group is homogeneous in terms of competence and contractual duties (Bruni and Detti, 2014). Besides, the general tendency is to schedule physicians into less number of work-shifts as they gain seniority. Some physician scheduling research papers have considered different seniority levels as their basis, where the challenge lies in assigning different duties to each category of physicians according to the level of experience so that the quality of a schedule developed would mainly reflect how well the schedule established conforms to the different seniority rules.

The studies of Topaloglu (2009), Ryan et al. (2013), Bard et al. (2014), Carrasco (2010), Brunner and Edenharter (2011), Brunner et al. (2010), Puente et al. (2009), Gendreau et al. (2006), Carter and Lapierre (2001), Beaulieu et al. (2000), Topaloglu (2006), Sherali et al. (2002), and Day et al. (2006) have considered different experience levels as their basis while solving the physician scheduling problem, however with slight differences.

2.2.1. Physician scheduling based on Two-seniority levels

Topaloglu (2009), Ryan et al. (2013) and Bard et al. (2014), have divided medical residents and only medical residents into two groups without considering the other types of physicians like fellows, specialists, consultants, etc.

According to Topaloglu (2009), the seniority level of medical residents was specified as per the number of years spent in residency program. In his paper, residents were classified into two groups: senior group and non-senior group. Senior group encompasses second-year residents, third-year residents, and fourth-year residents, whereas first-year residents and unit's rotation residents (rotators) constitute the non-senior group. Also, Ryan et al. (2013) have considered two types of medical students; residents and interns, when creating preference based schedules for internal medicine via fully-integrated software system. Similarly, Bard et al. (2014), have portioned the physicians into two categories according to their years of education in the residency program, while constructing clinic schedules: first post-graduate year (interns), second and third post-graduate year (residents).

However, Carrasco (2010) has developed schedules for pediatric department in a Spanish hospital for 20-30 physicians of different seniority levels; senior physicians and junior physicians. The differentiation is made between junior and senior physicians, but not for the seniority level of the residents. In other words, his study was based on the seniority level of different types of physicians and not only associated with the seniority level of residents. In his paper, the tasks physicians can perform are determined based on

the category a physician belongs to, for instance a senior physician can be allocated to supervision tasks, whereas a junior physician cannot be allocated for these tasks. Similar to Carrasco (2010) , Brunner and Edenharter (2011) have established long-term schedules for physicians with two different experience levels: residents (physicians with low experience) and specialists (certified physicians with high experience).

The studies of Brunner et al. (2010), Puente et al. (2009), Gendreau et al. (2006), Carter and Lapierre (2001), and Beaulieu et al. (2000), have considered two types of physicians as well; full-time physician and part-time physicians.

Brunner et al. (2010) focused on creating a flexible shift schedule using branch and price. Whereas, Puente et al. (2009), Gendreau et al. (2006), Carter and Lapierre (2001), and Beaulieu et al. (2000), have created schedules for emergency rooms. Both studies; Gendreau et al. (2006) and Carter and Lapierre (2001), have scheduled a full-time physician to work an average of 28 hours per week, and a part-time physician to work an average of 8 to 16 hours per week. However, the research of Beaulieu et al. (2000), was based on scheduling 20 physicians in the emergency room, where 15 of them working full-time physicians, and among them five with less than three years of experience.

2.2.2. Physician scheduling based on Three or more seniority levels

In contrast to the aforementioned papers, the studies of Topaloglu (2006) and Sherali et al. (2002) have classified residents into three groups; but with different names and staffing requirements.

Topaloglu (2006), has divided the emergency medicine residents into three groups according to their training level: the highest seniority level resident, the average seniority level resident and the lowest seniority level resident. Likewise, Sherali et al. (2002), have prepared night-shift schedules for around 50-100 residents with three different levels of experience; senior residents, junior residents, and rotators (residents from other departments). Day et al. (2006) as well, have based their study on the seniority level of residents while constructing resident schedules in the department of surgery under the constraints of the 80 hours' work week. However, Day et al. (2006), have classified residents according to their experience level in the residency program into five groups: first-year residents, second-year residents, third-year residents, fourth-year residents, and fifth-year residents.

2.3. Literature papers based papers on Work Shift

According to the past research papers that studied physician scheduling problem, there are two main types of scheduling; rosters and flexible scheduling. A roster, is a combination of predetermined shifts (A set of consecutive periods in a day, i.e. its length represents the duration it covers) and days-off assignments (Purnomo and Bard, 2007).

However, a flexible schedule, is a schedule that allows to assign a physician to shifts (With different lengths, various starting times and break periods) at every predefined period in the time horizon while satisfying physician preferences, requests and regulations, instead of starting with a predetermined number of shift types and start times (Brunner et al., 2009).

The majority of relevant research papers have constructed models based predetermined number and type of shifts; such as three 8-hours shifts, two 12-hours shift, 24-hours duty and usually different combinations are used in hospitals to satisfy the demand in a particular day.

2.3.1. Physician scheduling based on Three-work-shifts

The papers of Beaulieu et al. (2000), Lo and Lin (2011), Ferrand et al. (2011) have constructed the models related to physician scheduling based on three 8-h shifts.

The paper of Beaulieu et al. (2000) focused on constructing schedules for physicians in emergency rooms, with three working shifts; day shift, evening shift, and night shift. Likewise, Lo and Lin (2011) have considered three shifts while preparing schedules for emergency department physicians using a Particle Swarm Optimization based intelligent physicians' work scheduling system; day shift that starts from 7:00 am till 15:00 pm, evening shift that starts from 15:00 pm till 23:00 pm, and night shift that starts from 23:00 pm till 7:00 am the next day. Similar to Beaulieu et al. (2000), and Lo and Lin (2011), Ferrand et al. (2011) have developed emergency rooms cyclic schedules with three work-shifts per day; morning shift that starts at 8:00 am till 4:00 pm, evening shift that

starts at 4:00 pm till 12:00 am, and overnight shift that starts at 12:00 am till 8:00 am the next day.

2.3.2. Physician scheduling based on Two-work-shifts

While, the studies of Topaloglu (2006), Wang et al. (2007), Banet (2009), Bard et al. (2014), and Ryan et al. (2013) constructed physician scheduling models based on an explicit representation of two-working shifts only.

Topaloglu (2006), has assigned emergency medicine residents into day and night shifts for a monthly time period in a major local hospital while fulfilling residents' requirements and the working rules. The work shifts in the emergency rooms of this hospital were divided into two shifts: the 10-hour day shift, that is between 8:00 am and 6:00 pm, and the 14-hour night shift, that is between 6:00 pm and 8:00 am the next day. Also, Wang et al. (2007), have considered two working shifts for scheduling residents using a genetic algorithm to search for the optimal schedules; day shift and night shift. In similar fashion, Banet (2009), has developed schedules for physicians in outpatient centers through using a heuristic method, in which two working shifts are assigned to physicians; morning shifts and afternoon shifts. The schedule developed is of a standard five-day work week and consists of ten total slots with a duration of four hours for each slot. Likewise, in the study of Bard et al. (2014), it was considered that clinics run during week days (Monday-Friday) where each day is divided into two clinics; morning clinic and evening clinic. Additionally, the paper of Ryan et al. (2013) has considered two working-shifts; which are day shift and night shift while developing preference based physician schedules.

2.3.3. Physician scheduling based on Tow-work-shifts and a 24-hr duty

However, Topaloglu (2009) has developed physician schedules based on two work-shifts and a 24-h duty.

Topaloglu (2009) concerned in his study of resident scheduling problem with assigning weekdays duties and weekend day duties to medical residents who are categorized into different groups as per the seniority levels. The working shifts in his study includes regular working shift which is between 7:00 am and 5:00 pm during weekdays, night shift which is between 5:00 pm and 7:00 am during weekdays, and 24-hour shift on the weekends. While, the paper of Puente et al. (2009), differs slightly as they have considered a combination of three shifts (morning shift from 8:00 am till 3:00 pm, afternoon shift from 3:00 pm till 10:00 pm, and night shift from 10:00 pm till 8:00 am the next day) and a 24-h duty while studying the assignment problem of medical doctors in an emergency department.

2.3.4. Physician scheduling based on On-call shift

While the studies of Sherali et al. (2002), Cohn et al. (2006), Cohn (2007), and Carrasco (2010) considered only on-call shift while developing physician schedules.

Sherali et al. (2002), have prepared night-shift schedules (on-calls) through mixed integer programming model for residents with different seniority levels. Cohn et al. (2006) as well, have prepared schedules for on-call shifts at night that starts from 5 pm until 8 am the next day for medical residents with different seniority levels through mathematical

programming techniques at Boston University School of Medicine. Similarly, in another study of Cohn (2007), on-call working shift schedules were developed for residents through generating a complete set of Pareto optimal solutions. Besides, Carrasco (2010) has scheduled 20-30 physicians to on-call shifts during weekdays as well as to one full day shift during weekend days and holidays in a pediatric department in a Spanish hospital over a long-term period. In this pediatric department, On-call shift involves two different tasks, while weekend shift involves three different tasks. His research paper concerned with assigning one supervisor and one assistant to on-call duties at nights every midweek day (Monday-Friday), as well as, assigning one supervisor and two assistants to cover on-call duties for one full day shift (24 hours) in the weekends and holidays.

2.3.5. Physician scheduling based on flexible shifts

Whereas few papers have addressed the shift-scheduling problem with implicit modeling approaches.

Brunner et al. (2009), have presented an implicit formulation for the flexible shift scheduling problem using mathematical programming techniques, where the schedules developed allow full flexibility in terms of different lengths, various starting times and brake periods placements while respecting labor rules and satisfying physicians' preferences.In another study, Brunner et al. (2010) have solved a mid-term physician scheduling flexible shift where the proposed model generates shifts and break assignments implicitly using branch and price methodology. However, Stolletz and Brunner (2012), have used different modeling approach to solve the same flexible shift scheduling problem

that is a reduced set covering approach. Besides, Stolletz and Brunner (2012), extended the formulation to incorporate fairness aspects. In addition to that, the paper of Brunner and Edenharter (2011) introduced a model that can treat shifts implicitly which allow more flexibility in the scheduling process and it was solved by column generation based-heuristic. Also, Bruni and Detti (2014), have constructed flexible schedules that allow easy modifications for different situations through using a flexible discrete optimization approach.

2.4. Literature papers based on Constraints

Most of research papers that studied physicians scheduling problem considered a wide range of conflicting hard and soft constraints. Hard constraints are the constraints that must be respected, while soft constraints are the constraints that can be violated when necessary/no feasible solution is found. Besides, some papers considered ergonomic constraints as well while building physicians scheduling models as they ensure the health of physicians and avoid over-load duties. Additionally, some papers incorporated fairness criteria into their model which aims to ensure the balance distribution of on/0ff-duties among physicians.

In the study of Topaloglu (2006), the proposed multi-objective programming model for emergency medicine residents scheduling problem accommodates both hard and soft constraints. A large set of conflicting rules were involved into the proposed model while constructing the schedules, such as the restrictions on the number of assigned day shifts and night shifts to each resident, number of consecutive work-hours, staffing requirements

in accordance to the seniority level of residents, number of consecutive day shifts and night shifts allocated to each resident, vacation periods, weekend off and balanced distribution of responsibilities among the residents.

According to Topaloglu (2009), a wide set of conflicting constraints were considered in his paper while building a shift scheduling model; hard constraint that must be strictly met, and soft constraints that can be violated when necessary. His proposed model for solving the resident scheduling problem takes into account the seniority rules when allocating the weekday shifts and weekends shift duties, shift coverage requirements as well as the resident work preferences.

While building the resident schedules under the constraints of the 80 hours' work week within Surgery Departments, Day et al. (2006), have listed some constraints to be incorporated in the proposed integer programming model. The schedule was developed in such a way that it complies with the requirements of the Residency Review Committee (RRC), general surgery, and specialty surgical services. The followings are the most important constraints used in this problem by the author:

- Residents shall have at least one full day off every 7 days.
- Residents shall have at least 10-hour period of rest between each consecutive duty periods.
- Residents cannot work consciously for more than 24 hours without any break.

However, in the pediatric department in a Spanish hospital, Carrasco (2010), has assigned physicians with different experience levels to on-call shifts during weekdays and to one-full day shift during weekends and holidays in accordance with the following hard constraints:

- Coverage requirements

- Minimum number of days off (minimum interval between the consecutive shifts per physician).

- Workload distribution (should be uniform)

In addition to that, the assignments are asked to satisfy soft constraint as far as possible, some soft constraints are as follows:

- A similar number of shifts should be allocated to physicians with identical profiles.

- The composition of teams should be varied in the same shift and should indicate no preference for particular pairings.

The basic rules that Beaulieu et al. (2000) considered while building schedules for physicians in the emergency room, are categorized into two rules: compulsory rules (rules that must be met) and flexible rules (rules that can be violated when necessary). However, this categorization is based on the physician's flexibility and on the preferences of the hospital. The constraints considered in this paper were partitioned into four classes: compulsory, ergonomic, distribution, and goal constraints. The followings are instances for compulsory, ergonomic, distribution, and goal constraints that were incorporated into the model developed through using a mathematical programming approach:

- Compulsory constraints:

  - limits on the vacations, days-off, or particular shifts requested by physicians

  - physicians cannot be allocated to more than one shift per day

- Ergonomic constraints:

  - A physician should have two or three days of rest after two or three nights worked

  - There should be at least 16 hours between the end of one shift and the beginning of another shift

- Distribution constraints:

  - physicians with high experience level should work during at least one weekend per month.

  - Physicians with low experience level should work during two weekends per month

- Goal constraints:

  - Each physician should be assigned to a specified number of workhours per week.

  - The types of shifts must be fairly distributed among physicians.

However, Gendreau et al. (2006), have introduced generic forms for the constraints encountered in six hospitals in Canada for the purpose of creating schedules for emergency rooms physicians that satisfy large number of constraints as well as reduces the time and efforts required for preparing such schedules. According to this study, the constraints of

the physician scheduling problem in emergency rooms were divided into four classes: supply and demand constraints, workload constraints, fairness constraints, and ergonomic constraints. Supply and demand constraints deal with the availability of the physicians and the requirements of the emergency rooms. While workload constraints deal with the number of work-hours or shifts allocated to physicians during a defined period. However, fairness constraints ensure the balanced distribution of work-load among the physicians with the same seniority level during over defined planning period. Whereas the ergonomic constraints cover numerous regulations ensuring a certain level of quality for the generated schedules such as, the patterns of shifts, the patterns of sequences of shifts, and the patterns of sequences of a given length. Also, four solution techniques that can be applied to this problem were proposed, which are: tabu search, column generation, mathematical programming, and constraint programming.

Whereas, Carter and Lapierre (2001) have developed a general mathematical formulation for emergency rooms physicians in six different hospitals in Canada, where the model considered large number of constraint such as, physicians' requirements, constraints on individual schedules, shift assignments among physicians, and schedule equilibrium. In addition, ergonomic constraints were considered significant and therefore should be taken into account when building schedules, as they manage the circadian rhythm of the physicians.

In the study of Puente et al. (2009), emergency staff scheduling problem was solved by means of genetic algorithm and considered two types of constraints; hard and soft constraints. The hard constraints included primarily the coverage requirements such as, the minimum and maximum number of medical doctors that must be allocated to each work-shift, while soft constraints were related mainly to the time requirements on personal schedule such as, the shift types on the weekend, the balance in workload, and the patterns of the cyclic constraints.

However, during constructing cyclic schedules for emergency rooms physicians, Ferrand et al. (2011) have developed an integer programming model that can accommodate both hard and soft constraints; regulatory constraints and work requirements were formulated as hard constraints, while physician preferences were classified as either hard or soft constraints depending on how significant the physician considered each preference to be. Moreover, circadian rhythm of the physicians was considered while developing the model. Some instances of the regulatory constraints, work requirements, and physician preferences that were considered in this paper are as follows:

- Regulatory constraints**:**
    - 16 hours off at least should be assigned to each physician between two working shifts
- Work requirements**:**
    - The total number of work-shifts allocated to each physician is fixed

- The proportion of work-shifts assigned to each physician is one-third for each type of shift

- Physician preferences**:**

  - Weekend shifts should be batched together, and a fair distribution of weekend shifts should be ensured (hard)

  - If a weekend is off, then the following Monday or the preceding Friday is off (soft)

According to Meskens et al. (2013), daily operating room schedule was established using constraint programming approach, and it mainly considered the surgical team members preferences. The proposed generic model involved constraints that commonly arose in all operating rooms. In addition to that, multiple constraints were incorporated into the proposed model including human resources, material resources, and affinities among surgical team members. The main human resources constraints that were considered are the number and availability of surgical teams (surgeons, nurses and anesthetists), while the number and availability of operating rooms and medical material were considered as the main material resources constraints. The goal of this research was to minimize both the make span and overtime hours, while maximizing affinities among the surgical team members. The results were achieved using this proposed model in a real-life situation and solved with Java.

While the paper of Wang et al. (2007), considered a large set of constraints while studying resident scheduling problem through implementing the evolutionary approach to propose a genetic algorithm that search for optimal schedules, such as the fair constraints, the resident specification constraints, the safe constraints and the Accreditation Council on Graduate Medical Education regulations (ACGME).

Several constraints were considered in the study of Banet (2010) while building schedules for physicians in outpatient centers using heuristic method, the followings are the most important ones:

- Constraints to guarantee all physicians are allocated to the number of time slots they ask for.
- Constraints to guarantee that the total number of examination rooms requested by the scheduled physicians in each time slot does not go beyond the total number of available examination rooms.
- Constraints to determine the ideal patient load.

However, in the study of Bard et al. (2014), both hard and soft constraints were incorporated into the proposed network model. While constructing the clinic schedules, some constrains related to teaming restrictions, on-service requirements, coverage requirements, on-call assignments, rotational, day of the week, Medicine Acute Care Clinic (MACC) requirements, and a conflicting set of ACGME requirements were considered and treated as hard constraints. However, the residents' preferences and interns' preferences,

post-graduate year, and supervisory constraints were viewed as soft constraints or goals that are desirable to meet but can be violated when necessary.

At the University of Virginia hospital, Ryan et al. (2013) have developed preference based schedules for medical interns and residents through developing fully-integrated software system; which respect large number of hard and soft constraints such as; the educational requirements, federal regulations, and coverage requirements for each hospital department, and the physicians' preferences for specialties and vacations. The most important hard constraints that were considered in their paper are as follows:

- Each student shall work once each shift.

- Medical student cannot work for two or more high intensity rotations in a row.

- Residents and Interns cannot be assigned for more than 80 hours in a week.

While, one of the significant soft constraints considered in this paper is:

- Ensuring that residents and interns ae not scheduled to work more than twice in any rotation annually.

In the study of Cohn (2007), a large set of hard constraints and competing metrics (physicians' preferences) were taken into account while building on-call schedules for residents through creating a complete set of Pareto optimal solutions. Some instances for the hard constraints and preferences used in this paper are as follows:

- Hard constraints:

- It must be guaranteed that each resident fulfill a given number of on- call duties over the course of the year, and the number varies depending on the resident type.

- It must be guaranteed that no resident allocated to on-call duty at two different hospitals on the same night.

- It should be guaranteed that each resident is pre-allocated to work specific holidays.

- preferences:

    - Each resident should complete a pre-specified number of calls at each hospital.

    - Residents should be able to place requests for vacation before the start of the scheduling process.

    - It should be ensured that residents can be assigned to on-call duty in a hospital that matches the location where they are.

Both hard constraints and residents' preferences were primarily considered in the research paper of Cohn (2006), in which the aim was to develop on-call secludes for medical residents at Boston University School of Medicine. Some instances of the considered hard constraints in this paper are related to the hospital coverage of on-calls, and the rest periods (spacing) between the scheduled on-call duties for each resident. While, the number of days-off between two consecutive calls for a given resident, and the number of assigned Friday and Saturday calls for each resident are some instances of the

residents' preferences.

In the study of Brunner and Edenharter (2011), a wide range of staffing rules and legal regulations were taken into account. Through using flexible shifts, some of the constraints that were incorporated into the proposed model are related to: the shift starting times, the minimum and maximum shift length, demand coverage with appropriate type of physician's constraints, and restrictions that implicitly defines the shifts in accordance with the labor regulations for physicians with different seniority level.

While the schedules generated by both approaches of Brunner et al. (2010) and Stolletz and Brunner (2012), allow full flexibility at various aspects such as, different shift starting times, different shift durations, break periods placements, the use of planned overtime and on-call service, accommodating physicians' preferences, requests and constraints, with following the labor agreement. However, the results indicated that the reduced set covering formulation used by Stolletz and Brunner (2012) is much more efficient in terms of solution quality and runtime compared to the implicit modeling approach that was used by Brunner et al. (2010). In addition to physicians' preferences (i.e. the length of the work-stretch, the pattern of days-on and days-off, and the preferred partners work together in same duties), the formulation built by Stolletz and Brunner (2012) was extended to incorporate fairness with two measures; One seeks to fairly distribute the on-call services, and the other seeks to fairly assign the working hours among all physicians.

Various of constraints were considered in the study of Bruni and Detti (2014), while solving a physician scheduling problem using A flexible discrete optimization approach. The model developed was satisfied all hard constraints and the general aspects that are commonly considered in different departments in health care sector such as, service requirements, coverage requirements of the departments, and contractual agreements (e.g. unavailability of physicians including rest periods and vacation time), while respecting as far as possible the physicians' preferences, with focusing primarily on balancing the workload among physicians.

2.5. Summary of Literature Review

The table below summarizes the major points addressed in the previous studies on physician scheduling problem.

Table 1. *Summary of Literature*

Research Paper	Reference	Methodology			Time Horizon			Seniority Level			Constraints				Work-shift Type		
		Mathematical programming	Heuristics	Meta-Heuristics	Short	Midterm	Long	One	Two	Three or More	Hard	Soft	Ergo	Two	Three or More	On-Call	Flexible
A flexible discrete optimization approach to the physician scheduling problem	Bruni & Detti (2014)	√					√				√	√					√
A mathematical programming approach for scheduling physicians in the emergency room	Beaulieu et al. (2000)	√					√		√		√	√	√		√		
A multi-objective programming model for scheduling emergency medicine residents	Topaloglu (2006)	√			√					√	√	√		√			
A network-based approach for monthly scheduling of residents in primary care clinics	Bard et al. (2014)	√			√				√		√	√		√			
A Particle Swarm Optimization Approach for Physician Scheduling in a Hospital Emergency Department	Lo & Lin (2011)			√	√						√	√			√		

*Continued

A shift scheduling model for employees with different seniority levels and an application in healthcare	Topaloglu (2009)	√		√		√		√	√			√	
Building Cyclic Schedules for Emergency Department Physicians	Ferrand et al. (2011)	√			√		√	√		√		√	
Constructing Pareto-Optimal Residency Call Schedules	Cohn (2007)		√		√		√	√			√		
Fair optimization of fortnightly physician schedules with flexible shifts	Stolletz & Brunner (2012)	√		√			√	√					√
Flexible shift scheduling of physicians	Brunner et al. (2009)	√		√			√	√					√
Genetic Algorithm for Resident Physician Scheduling	Wang et al. (2007)		√	√			√	√		√			
Heuristic scheduling for clinical physicians	Banet (2010)		√	√			√	√		√			
Hierarchical goal programming model for scheduling the outpatient clinics	GüLer (2013)	√			√	√	√	√		√			
Hospital resident scheduling problem	Sherali et al. (2002)	√		√	√		√	√			√		
Long term staff scheduling of physicians with different experience levels in hospitals using column generation	Brunner & Edenharter (2011)		√		√	√	√	√					√

Continued

Title	Reference														
Long-term staff scheduling with regular temporal distribution	Carrasco (2010)		√					√	√		√	√		√	
Medical doctor rostering problem in a hospital emergency department by means of genetic algorithms	Puente et al. (2009)		√		√				√		√	√	√	√	
Midterm scheduling of physicians with flexible shifts using branch and price	Brunner et al. (2010)	√			√				√		√	√			√
Multi-objective operating room scheduling considering desiderata of the surgical team	Meskens et al. (2013)	√									√	√			
Physician Scheduling in Emergency Rooms	Gendreau et al. (2006)	√	√	√					√		√	√	√		
Preference Based Scheduling for Medical Residents and Interns at the University of Virginia	Ryan et al. (2013)		√		√				√		√	√		√	
Using Mathematical Programming to Schedule Medical Residents	Cohn et al. (2006)	√				√					√	√			√
Scheduling the Resident 80-Hour Work Week: An Operations Research Algorithm	Day et al. (2006)	√			√					√	√	√	√		
Scheduling Emergency Room Physicians	Carter & Lapierre (2001)	√					√		√		√	√	√		

2.6. Most relevant Scientific Literature

The followings are the most three closely related papers to the studied physician scheduling problem in the existing theoretical literature,

Topaloglu and Ozkarahan (2011) have developed a mixed-integer programming model for solving a resident scheduling problem that involves allocating residents with different experience levels; according to their years of education in the residency program to different predetermined shifts over a 4-week planning period while considering primarily the Accreditation Council for Graduate Medical Education (ACGME) requirements and other additional required working rules and hard constraints. The objective of this study was to develop schedules that minimizes the sum of deviations associated with the number of residents according to their service level. The solution approach developed for solving the proposed mixed-integer programming model was based on column generation technique that produces feasible schedules via constraint programming. In his study three types of working shifts were considered while generating residents' schedules: day shift (7:00am–7:00pm), night shift (7:00pm–7:00am), and 24-h shift. The model proposed incorporates primarily hard constraints; the total working hours, the night on-call, the day-off, and the rest period. Beside to those constraints, additional constraints were incorporated into the proposed model and they are as follows: the maximum number of working-hours a resident is allowable to work per week, minimum and maximum number of assigned successive working-days, minimum number of nights-off between successive night on-calls, minimum and maximum number of night on-calls

as per to the experience levels, seniority-based workload rules and off-day rules were incorporated into the proposed model. The solution approach has been tested on real data provided from a hospital, and the findings showed that high quality schedules can be generated within a few seconds.

In the Anesthesia and Reanimation Department of Bezmialem Vakif University Medical School (BUMS) in Turkey, Güler et al. (2013) have proposed a goal programming model for assigning day shifts, on-call shifts at nights and weekend shifts to residents with different seniority levels for a monthly planning horizon as well. In Turkey, two sections are working under this department: intensive care unit and surgery room. The residents' preferences and coverage requirements of those two sections were considered in the first place for developing the schedules. The objective of this goal programming model was to satisfy all soft constraints considered in this study by minimizing the deviations from the soft constraints. Also, it was mentioned that the Anesthesia and Reanimation Department in Turkish hospitals have two working shifts during weekdays: the day shift which starts at 08:00 am and finishes at 18:00 pm, and the night shift which starts at 18:00 pm till 08:00 am the next day. However, the shifts in weekend days cover the whole day, i.e., a medical resident who is on-duty on weekend days (Saturday/Sunday) works for 24 hours continuously. Güler et al. (2013), have addressed two classes of constraints in the problem of the resident scheduling as mentioned earlier: hard constraints and soft constraints. The most important hard constraints that were addressed in this paper are associated with: respecting the regulations of the department and hospital, covering the requirements of the intensive care unit as well as the surgery room, covering the number of on-call shifts, and

preventing the block shifts. While the most important constraints that has been formulated as soft constraints in this paper are related to: residents' desires such as; maximizing the number of weekends-off, and allocating on-duty shifts to the same social groups. The results indicated that the proposed goal programming model can provide high quality schedules within a few seconds and with less effort, which represented by reducing the tandem shifts, maximizing the number of weekends-off, and scheduling residents in the same social group to the same shift.

Within a Surgery Department of a local government hospital, Gunawan and Lau (2013) have proposed three mathematical programming models for generating a master schedule for the physicians over a one week planning horizon from (Monday-Friday) for the sake of simplicity, where the focus was on assigning specific duties to physicians into defined time slots, with satisfying as many conflicting constraints and physicians' preferences as possible while ensuring the optimal use of available physicians. The paper of Gunawan and Lau (2013) has considered two working-shifts; which are day shift and night shift while developing master physician schedules. Different settings of the master physician scheduling problem were addressed by Gunawan and Lau (2013) in a Surgery Department and accordingly Model I, Model II a, Model II b, and Model III were developed using mathematical programming. Model I (base model) was concerned with minimizing the overall number of unscheduled activities in an unconstrained setting. Then, Model IIa and Model IIb were developed as extensions of the base model by meeting the physicians' ideal schedule as much as possible (increasing physicians' preferences) and satisfying ergonomic constraints for all physicians while minimizing the overall number of

unscheduled activities respectively. Finally, Model III was extended and formulated as a bi-objective mathematical programming model (combining the two-problem settings Model II a and Model II b into one) that concerned with maximizing the total number of ideal scheduled activities and minimizing the total number of unscheduled activities subject to ergonomic constraints. The authors solved all the afore-mentioned models through CPLEX solver and it was indicated that the solution approach can create such schedule with less time and effort required.

3. Chapter 3: Project Methodology

For any project to be conducted successfully, a right methodology should be selected and followed properly. While selecting a methodology for solving a problem, several factors should be considered including, the size of the project, timing, level of accuracy required for findings, complexity of the problem, availability of data. Hence, this project was carried out through the following steps:

1. **The current physician scheduling problem arising at Women's Hospital in Qatar was studied and well understood.**

After conducting a comprehensive review on physician scheduling problems, some meetings with a specialist in women's hospital, Dr. Eiman Azzam, were arranged. All relevant data to the studied physician scheduling problem including the set of physicians, the set of clinical duties, set of shifts, and most importantly the regulations and constraints governing the work in the hospital were understood and collected.

2. **Operations research techniques was used to formulate the studied physician scheduling problem.**

Indeed, there are many physician scheduling approaches that can be used in order to formulate and solve the problem. Mathematical programming, heuristics and meta-heuristics are the most common methods used for solving the physician scheduling problem.

Mathematical programming approach seeks to minimize or maximize objective functions subject to constraints on the variables. It guarantees optimality and provides the best available solution of the objective function based on the considered constraints. Mathematical programming involves several programming like: Linear programming, integer programming, goal programming, constraint programming, column generation, branch-and-bound and branch-and-price. (Mathematical Optimization Society, 2010)

However, heuristic methods do not guarantee optimality for a specific problem; but they provide good solutions that are close to being optimal. Heuristic methods are usually easy to use and can provide good solutions quickly. When problems are complicated and not possible to solve for an optimal solution, heuristic methods are usually used as they can search for a feasible solution that is at least reasonably close to being optimal (Hillier and Lieberman, 2006).

While, metaheuristics are general solution methods that manage the interaction between local improvement procedures and higher-level strategies to establish a process that can escape from local optimal and do robust search of feasible region. Metaheuristics involves several approaches like Local search, Tabu search, and Genetic algorithms (Hillier and Lieberman, 2006).

In this report, a mathematical model was developed by using mathematical programming to formulate the scheduling problem, respecting various rules and constraints including hospital requirements, physicians' requirements, workload rules, and shift

coverage requirements. The developed model considered both hard constraints that must be strictly met, and soft constraints that can be violated when necessary, and most importantly it ensured the balanced distribution of work-shifts assignments among the physicians (work-load balance constraints).

3. **The formulated model was solved, and the monthly final schedules were generated through AIMMS optimization software.**

AIMMS was used in this project due to its effectiveness; i.e., it assists decision-makers to make timely good decisions and accordingly respond quickly to changing conditions as today the environment we live in is becoming increasingly dynamic and complex. AIMMS, Advanced Interactive Multidimensional Modeling System, is a software that is designed for modeling and solving optimization problems. It is considered one of the most important algebraic modeling languages and it consists of a well-integrated development environment and a graphical end-user environment ("AIMMS," n.d.).

In addition to that, AIMMS is available for MS Windows, and it provides Application Interface (API) which allows connectivity with other environments or languages. Also, AIMMs can read and save data from and to spreadsheets. Moreover, it has a direct link to CPLEX and Gurobi solvers. Other features AIMMS offered is, the Special Ordered Sets type 2 (SOS2) that contributes in facilitating the formulation of piecewise linear functions, as well as, the branching priorities of binary variables are provided by AIMMS and can be manually set (Podhradsk´y, 2010).

On the other hand, AIMMS optimization software has some limitations. AIMMS does not support the Model export/import to MPS/LP files, however it only stores the model in a text-file with certain formatting. Another limitation is regarding Java connectivity; AIMMS can be accessed from other applications through using Component Object Model (COM) objects, while Java does not provide a satisfying connectivity with COM objects. Also, the syntax of AIMMS is "set-oriented" and the AIMMS integrated development environment (IDE) does not allow the user to program the model, as all parameters, variables, and constraints must be declared and the deceleration procedure consumes time. For example, for declaring one variable through using AIMMS, the user has to first click on the "new variable" button, then the user has to set the variable name, after that the user should select a range for the variable through clicking on the "range" button, then he/she should set the variable domain and then before closing the dialog box the user should click on "commit and close" button, and this process is much more time consuming. Regarding the code clarity, the model code cannot be directly modified, and therefore building a large-scale model would be complicated as many variables and constraints need to be inserted. As for Non-linear functions, AIMMS cannot solve non-linear functions of a decision variable, hence the user must reformulate absolute value and similar functions by himself. However, the poor documentation and the shortage of suitable IDE and are the serious disadvantages of AIMMS software (Podhradsk´y, 2010).

Indeed, AIMMS software is capable of dealing with very complex problems; hence it helps organizations to make better decisions regarding their strategy, planning, operations or even the entire supply chain through offering sophisticated analytics,

modeling, optimization and data visualization. AIMMS allows its users to easily adjust and optimize their strategy, plans and even their daily operational challenges. Thus, AIMMS software was used in this project for the purpose of solving physician scheduling problem ("AIMMS," n.d.).

4. **The resulting schedules were analyzed, evaluated and compared with the manual schedules that are currently used by the hospital.**

The comparison conducted was primarily in terms of the solution quality (balanced distribution of the workload), the computational time and effort required to build the schedules, the physicians' satisfaction, and the impact on both the patients care and the hospital performance. Moreover, sensitivity analysis was performed in order to test the robustness of the outcomes of the proposed model.

4. Chapter 4: System Description and Data Collection

The main key factors of the physician scheduling problem are: the seniority level, the main physician clinical-duties, and the hospital work-rules or constraints that should be met. In the following, each factor is defined and explained in detail.

4.1. Seniority level

The seniority level term in healthcare institutions refers to the experience level of a physician. Typically, physicians are divided into groups based on their level of experience, and they are assigned to duties according to these levels. In Hamad Women's Hospital, physicians are categorized into: residents, specialists, senior specialists, and consultants. This project focuses on creating schedules for one type of physicians; specialists (labor specialists and inpatient ward specialists) within Obstetrics and Gynecology Department at Hamad Women's Hospital.

4.2. Main physician clinical-duties

Typically, physicians are doing clinical and non-clinical duties, however the focus of this project is only on clinical duties. Basically, there are five main clinical duties within Obstetrics and Gynecology Department and they are described as follows:

4.2.1. Inpatient activity

Inpatient activity is a term refers to the case where physicians are responsible for looking after and following up the residing patients in the hospital. These patients reside in specific rooms in Ward Π, Ward III, Ward IV, Ward V, and Ward VI. The services of this activity are to be delivered by the five teams. This activity includes several sub-activities which are as follows:

- **Grand rounds** (available only during regular working shift in weekdays)**,** are daily teaching rounds. The purpose of these rounds is to teach residents how to handle certain cases such as antenatal cases and gynae cases. It is delivered by women's hospital teams during regular working shift (7am-3pm) in weekdays and each team handles this activity once per week. It is covered by 5 specialists, and 4-5 consultants (1 specialist and 1 consultant from each team of the five teams of Women's hospital)

- **Antenatal ward rounds,** this activity covers medical examinations and treatments for female patients who suffer from vomiting, stomach cramps, and such health problems during pregnancy.

- **Gynecology Section,** in this activity physicians provide care to patients with gynecologic problems such as miscarriage, bleeding during pregnancy, ovarian tumor, and any other disorder or diseases related to the female reproductive organs.

- **High dependency unit**, in this activity physicians provide extensive care to patients (high risk pregnancies) than in a normal ward, but not to the point of intensive care.

Note: The three above described activities (Antenatal ward rounds, Gynecology Section, and High dependency unit) are delivered altogether by 4 and the same specialists and 1 ward specialist (1 specialist from each team of the five teams) for 5 consecutive days during regular working shift in weekdays, unless they are post call off.

- **Oncology Section** (Opens only in weekdays), in this activity physicians provide care to patients with oncologic problems related to the female reproductive organs. This activity is delivered by 1 and the same specialist, and 2 and the same consultants (from the five teams) for 5 consecutive days during regular working shift in weekdays.

- **Postnatal wards rounds,** this activity is responsible for looking after and providing care to the mother and her newborn baby right after childbirth. This activity is delivered by 4 and the same specialists (from each team of the five teams) for 5 consecutive days during regular working shift in weekdays.

- **Circumcision activity** (available only during regular working shift), this activity covers the practice of circumcising a newborn baby. It is covered by 1 and the same specialist (from the five teams) for 5 consecutive days during regular working shift in weekdays.

However, during on-call shift (a shift starts after 3:00 pm):

- All Inpatient Wards are covered by 1 ward specialist every 8 hours and 1 consultant who is in charge of covering the whole department as well every 8 hours during weekdays.

- While, in the weekends, the inpatient wards are covered by 1 ward specialist every 8 hours and 1 consultant who is in charge of covering the whole department as well, but every 12 hours.

4.2.2. Day care unit

Day care unit is designated to treating female patients-during pregnancy-who do not reside in the hospital by supplying the needed medicine, making blood test or ultrasound or giving certain injections. This unit works from 7:00am to 3:00pm- during regular working shift-in weekdays only (i.e. Day care unit opens only during regular working shift). Physicians from the five teams are the ones who are responsible for the activities of this unit. This activity is covered by 1 and the same specialist, and 1 and the same consultant (from the five teams) for 5 consecutive days during regular working shift in weekdays.

4.2.3. Outpatient clinic activity

Outpatient clinics are designed to provide treatments and medical checkups to female patients who are not residing in the hospital. Obstetrics and Gynecology clinics start at 7:00am till 3:00pm-during regular working shift-in weekdays, however, no clinics are

held on weekends. In order to meet the requirements, each clinic is held by 2 and the same specialists, 2-4 and the same senior specialists, and 3 and the same consultants (from the five teams) twice a week during regular working shift in weekdays. < Each team must cover 2 clinics per week>

4.2.4. Labor ward activity

In this activity, physicians are responsible for overseeing and assisting during the process of delivering the babies naturally. This activity is covered by 2 labor specialists, 1-2 senior specialists, and 1-2 consultants depending on the severity of case (from the five teams) once a week during regular working shift in weekdays. However, during on-call shift (a shift starts after 3:00 pm):

- In weekdays, it is covered by 2 labor specialists every 8 hours, 1 senior specialist every 16 hours (not always) and 1 consultant every 8 hours who is in addition to this activity responsible for the all activities run in the department.

- While, in weekends, labor rooms during on-call-shift are also covered by 2 labor specialists every 8 hours, 1 senior specialist but every 24 hours (not always) and 1 consultant who is in charge of covering the whole department as well but every 12 hours.

4.2.5. Operation theaters

In this activity physicians are responsible for performing cesarean delivery in cases where natural delivery would put the baby or mother at risk. In addition to that, physicians in this activity are responsible for performing operations for treating diseases and disorders related to female reproductive organs. It covers obstetric, gynecologic and oncologic operations. Operation theatres consist of 3 rooms; 2 rooms are designed to perform operations for elective cases, and 1 room is designed to perform operations for emergency cases. Each team has a pre-arranged list of obstetrics, gynecology and oncology cases named elective cases. In other words, each team has a list of patients who have been set to undergo certain operations at a specific time. 2 specialists, 2-3 consultants, 1-2 senior specialists (from the five teams) according to the severity of the case are scheduled to handle the elective cases once per week in weekdays during regular working shift. Each team has 1 operative day (elective cases) per week, and no operations for elective cases are performed in weekends. While, operations for emergency cases in both weekdays and weekends are practiced by one and the same ward/labor specialist who is taking care of that patient (emergency case) at inpatient wards or labor rooms.

4.3. Constraints and Assumptions

A wide range of conflicting rules and constraints should be taken into account while modeling the physician scheduling problem. Typically, constraints are divided into two categories; hard constraints and soft constraints. Hard constraints, are the constraints that should be adhered to strictly, while soft constraints are the constraints that can be violated when necessary/no feasible solution is found. The followings are the most important

constraints followed by the Obstetrics and Gynecology Department at Hamad Women's Hospital and they are described according to the constraint category and according to the seniority level of the physicians.

4.3.1. Labor Room Specialists and Inpatient Ward Specialists

4.3.1.1. Hard constraints

1. The total number of workhours assigned to each labor room specialist and to each Inpatient ward specialist is set as 40 hours per week (5 work-shifts/ week) at most.

2. A labor specialist/ward specialist can be assigned to two consecutive on-call duties.

3. Adequate number of specialists must be available to cover the demand in each work shift.

4. A specialist cannot have more than one activity/task in any shift.

5. Each specialist on labor room team must be assigned to 3 work-shifts at labor rooms per 5 days; one morning labor room shift, and two on-call shifts; one evening labor room shift (3:00 pm-10:00 pm) and one-night labor room shift (10:00 pm-7:00 am) at different days. <labor room team cosmists of 10 labor specialists>

6. 2 labor specialists must be assigned to each shift at labor rooms.

7. Each labor specialist must have two consecutive off-days after any night duty.

8. Each specialist on ward team must be assigned to 3 work-shifts at inpatient wards per 5 days; one morning round shift, and two on-call shifts, one evening round shift (3:00 pm-10:00 pm) and one-night round shift (10:00 pm-7:00 am) at different days. <ward team cosmists of 5 ward specialists>

9. Only 1 ward specialist must be assigned to each shift at inpatient wards.

10. Each ward specialist must have two consecutive off-days after any night duty.

4.3.1.2. Soft constraints

1. A labor specialist and a ward specialist can be assigned at most three times in two consecutive weekends. (means either consecutive Friday and Saturday in the same week, or consecutive Friday and Saturday in two consecutive weeks)

2. Specialist's preferences should be satisfied as much as possible.

4.3.1.3. List of Assumptions

- Total number of labor room specialists is 10.

- The total working hours per month is typically 144 hours and 160 hours at most.

- The total number of morning duties (at labor rooms) assigned to each specialist on labor room team is around 6 duties per month at most.

- The total number of on call duties (evening/night) assigned to each specialist on labor room team is around 12 per month at most (6 evening duties and 6-night duties at labor rooms).

- Since each labor room specialist is assigned to 6 morning duties (at labor rooms) and 12 on-call duties (at labor rooms), then

  o It is assumed that $(6*8 \text{ hrs.})/144 = 33.33\%$ of his/her working time is allocated to morning duties (at labor Rooms).

  o It is assumed that $(12*8 \text{ hrs.})/144 = 66.66\%$ of his/her working time is allocated to on-call duties (at labor Rooms).

- Total number of ward specialists is 5.

- The total working hours per month is typically 144 hours and 160 hours at most.

- The total number of morning duties (at inpatient wards) assigned to each specialist on ward team is around 6 duties per month at most.

- The total number of on call duties (evening/night) assigned to each specialist on ward team is around 12 per month at most (6 evening duties and 6-night duties at inpatient wards).

- Since each ward specialist is assigned to 6 morning duties (at inpatient wards) and 12 on-call duties (at inpatient wards), then
  - It is assumed that (6*8 hrs.)/144 = 33.33% of his/her working time is allocated to morning duties (at inpatient wards).
  - It is assumed that (12*8 hrs.)/144 = 66.66% of his/her working time is allocated to on-call duties (at inpatient wards).

- The overtime work is out of the scope.

- Non-clinical type of activities is out of the scope.

4.3.2. Senior Specialists

4.3.2.1. Hard constraints

1. The total number of workhours assigned to each senior specialist is set as 40 hours per week at most.

2. Each senior specialist can be assigned to morning duties (at areas like, labor rooms, operation theatres, outpatient clinics), to on-call duties (at labor rooms only) and cannot be assigned to inpatient wards.

3. Around 1-2 senior specialists are assigned to only one morning shift at labor rooms (1 labor room per week).

4. Around 1-2 senior specialists are assigned to only one morning shift at operation theatres (1 operative day per week).

5. Around 2-4 senior specialists are assigned to only one morning shift at outpatient clinics (2 clinics per week).

6. When a senior specialist has an on-call duty, he/she cannot be assigned to work in the morning. The on-call duty for senior specialist starts from 3:00 pm till 7:00 am the next day.

7. Each senior specialist must have one day off after an on-call duty.

8. Each senior specialist can be assigned to either 3 on-call duties (3:00 pm-7:00 am) in weekdays per month, or to two on-call duties (3:00 pm-7:00 am) in weekdays and one 24-hr duty in weekends per month.

9. Only 1 senior specialist can be scheduled to cover all labor rooms during an on-call shift (not always).

10. Labor rooms can be covered without a senior specialist both in weekdays and weekends during on-call shift.

11. A senior specialist cannot have more than one activity/task in any shift.

12. A senior specialist cannot be assigned to two consecutive on-call duties.

13. The minimum on-call shift duration for senior specialist is 16 consecutive hours.

4.3.2.2.   Soft constraints

1. A senior specialist cannot be scheduled to work for two consecutive weekends.

2. Senior Specialist's preferences should be satisfied as much as possible.

4.3.2.3.   List of Assumptions

- Total number of senior specialists is 9.

- The total working hours per month is 160 hours at most.

- Each senior specialist can be assigned to either 3 on-call duties (3:00 pm-7:00 am) in weekdays per month, or to two on-call duties (3:00 pm-7:00 am) in weekdays and one 24-hr duty in weekend per month.

  - If the senior specialist is assigned to 3 on-call duties (3:00 pm-7:00 am) in weekdays per month, then

    - It is assumed that $(3*16 \text{ hrs.})/160 = 30\%$ of his/her working time is allocated to on-call duties (at labor rooms).

- It is assumed that (112 hrs.)/160 = 70% of his/her working time is allocated to morning duties (at areas like, labor rooms, clinics, operation theatres).
  - o If the senior specialist is assigned to 2 on-call duties (3:00 pm-7:00 am) in weekdays and another 1 on-call duty (24-hr) in weekends per month, then
    - It is assumed that (2*16+24 hrs.)/160 = 35% of his/her working time is allocated to on-call duties (at labor rooms).
    - It is assumed that (104 hrs.)/160 = 65% of his/her working time is allocated to morning duties (at areas like, labor rooms, clinics, grand rounds, operation theatres).
- The overtime work is out of the scope.
- Non-clinical type of activities is out of the scope.

4.3.3. Consultants

4.3.3.1.   Hard constraints

1. The total number of workhours assigned to each consultant is set as 40 hours per week at most.

2. Each consultant is assigned to morning duties (at areas like, clinics, grand rounds, operation theatres, inpatient wards, labor rooms, hysteroscopy) and to on-call duties (cover the whole department).

3. A consultant can have more than one activity/task during morning shift.

4. Each consultant must be assigned to an on-call duty once per month to cover all the Obstetrics and Gynecology Department; either in weekdays (3:00 pm-10:00 pm or 10:00 pm-7:00 am) or to a 12-hr on-call in weekends (7:00 am-7:00 pm or 7:00 pm-7:00 am).

5. Only 1 consultant must be scheduled to cover the whole Obstetrics and Gynecology Department during an on-call shift (3:00 pm-10:00 pm).

6. Only 1 consultant must be scheduled to cover the whole Obstetrics and Gynecology Department during an on-call shift (10:00 pm-7:00 am).

7. In weekends, consultants can have a 12-hr shift once per month; 1 consultant must be assigned to cover all the Obstetrics and Gynecology Department from 7:00 am-7:00 pm, another consultant must be scheduled to cover all the Obstetrics and Gynecology Department from 7:00 pm-7:00 am the next day.

8. A consultant can have more than one activity/task during on-call shift. (e.g. on-call consultant is responsible to cover the whole department).

9. A consultant cannot be assigned to two consecutive on-call duties.

10. Each consultant must have one day-off after any night duty.

4.3.3.2. Soft constraints

1. A consultant cannot be scheduled to work for two consecutive weekends.

2. Consultant's preferences should be satisfied as much as possible.

4.3.3.3.   List of Assumptions

- Total number of consultants is 60.

- The total working hours per month is typically 136 hours and 160 hours at most.

- Each consultant must be assigned to an on-call duty (either 3:00 pm-10:00 pm or 10:00 pm-7:00 am) in weekdays once per month, or can be assigned to a 12-hr duty in weekends once per month.

  o If the consultant is assigned to 1 on-call duty in weekdays (8 hrs.) per month, then

     ▪ It is assumed that (1*8 hrs.)/136 = 5.88% of his/her working time is allocated to on-call duties (cover the whole Obstetrics and Gynecology Department).

     ▪ It is assumed that (128 hrs.)/136= 94.1% of his/her working time is allocated to morning duties (at areas like, clinics, grand rounds, operation theatres, inpatient wards, labor rooms, hysteroscopy).

  o If the consultant is assigned to 1 on-call duty in weekends (12 hrs.) per month, then

     ▪ It is assumed that (12 hrs.)/136 = 8.82% of his/her working time is allocated to on-call duties (cover the whole Obstetrics and Gynecology Department).

     ▪ It is assumed that (124 hrs.)/136 = 91.18% of his/her working time is allocated to morning duties (at areas like, clinics, grand

rounds, operation theatres, inpatient wards, labor rooms, hysteroscopy).

- The overtime work is out of the scope.

- Non-clinical type of activities is out of the scope.

5. Chapter 5: Mathematical Modeling

5.1. Physician Scheduling Model Description

This research project uses operations research, and particularly mathematical programming to formulate the studied physician scheduling problem. It presents a mathematical model that consists of linear formulations which represents the main clinical duties achieved by both labor specialists and ward specialists within Obstetrics and Gynecology Department at Hamad Women's Hospital in Qatar.

Both labor specialists and ward specialists are the main service providers in the Obstetrics and Gynecology department at Women's Hospital. Typically, labor specialists are responsible for overseeing and assisting women during the process of natural delivery at labor rooms. While, ward specialists are typically responsible for taking care of female patients who resides at inpatient wards whether before or after delivery. Basically, 15 specialists need to be scheduled within Obstetrics and Gynecology department and they are divided as follows:

- 10 labor specialists, and they are responsible for working at labor rooms.

- 5 inpatient ward specialists, and they are responsible for working at inpatient wards.

Labor specialists are assigned to labor rooms to cover three different types of work-shifts, which are morning shift (7:00am-3:00pm), evening shift (3:00pm-10:00pm), and night shift (10:00pm-7:00am). All labor specialists should be assigned for these three shifts in each month. In each day, two labor specialists should be assigned to cover only one shift.

Also, each labor specialist can be assigned at most once a day; meaning that a labor specialist cannot be assigned to more than one shift in the same day. In addition, all labor specialists should be assigned to work-shifts in the order of morning shift, then evening shift, and then night shift. Moreover, each labor specialist should be assigned for two consecutive off-days after any assigned night shift. Furthermore, after the assigned two consecutive off-days, a labor specialist should be assigned to a morning shift and not to any other types of shifts. However, the work-shifts must be equally distributed among labor specialists.

On the other hand, ward specialists are assigned to inpatient wards to cover three different types of work-shifts, which are morning shift (7:00am-3:00pm), evening shift (3:00pm-10:00pm), and night shift (10:00pm-7:00am). All ward specialists should be assigned for these three shifts in each month. In each day, one ward specialist should be assigned to cover only one shift. Also, each ward specialist can be assigned at most once a day; meaning that a ward specialist cannot be assigned to more than one shift in the same day. In addition, all ward specialists should be assigned to work-shifts in the order of morning shift, then evening shift, and then night shift. Moreover, each ward specialist should be assigned for two consecutive off-days after any assigned night shift. Furthermore, after the assigned two consecutive off-days, a ward specialist should be assigned to a morning shift and not to any other types of shifts. However, the work-shifts must be equally distributed among ward specialists.

This project proposes a mathematical programming model that satisfies the hospital requirements, physicians' requirements, seniority-based workload rules, shift coverage requirements, and most importantly balances the distribution of work-shifts among the specialists. Workload balance means all physicians from certain category should be assigned to the same number of duties/shifts in a defined period of time. In other words, beside satisfying the considered hard and soft constraints, the total number of duties/shifts assigned to a physician should be as equivalent as possible to the others from the same category. Hence, the proposed model seeks to assign labor specialists and ward specialists to three different types of work-shifts (morning shift, evening shift, and night shift) fairly over a month period.

5.2. Physician Scheduling Mathematical Model

In the following, a mathematical programming model is developed to formulate the above described problem.

5.2.1. Parameters

- ls: Set of labor specialists

  $ls = \{1.2.3. \ldots \ldots \ldots \ldots \ldots . n\}$ Indexed by LS

- ws: Set of ward specialists

  $ws = \{1.2.3. \ldots \ldots \ldots \ldots \ldots . m\}$ Indexed by WS

- d: Set of days

  $d = \{1.2.3. \ldots \ldots \ldots \ldots \ldots . g\}$ Indexed by D

- t: Set of work-shifts

  t= {Morning shift, Evening shift, Night shift, free shift1, free shift 2} = {1 ,2, 3, 4, 5}   Indexed by T

- Average number of assignments per shift per labor specialist over a month period, is shown below:

$$\alpha_{ls.t} = \frac{number\ of\ days\ in\ a\ month*3\ (\frac{shifts}{day})}{number\ of\ Labor\ specialists*(\frac{1\ shift}{2\ labor\ speialists})}$$

$$\alpha_{ls.t} = \frac{30*3\ (\frac{shifts}{day})}{10*(\frac{1\ shift}{2\ labor\ speialists})} = 18\ duty$$

- To make it fair, each labor specialist should be assigned for 6 morning shifts, 6 evening shifts, and 6-night shifts.

$$\alpha_{ls.Morning\ shift} = 6, \alpha_{ls.Evening\ shift} = 6, \alpha_{ls.Night\ shift} = 6$$

- Average number of assignments per shift per ward specialist over a month period, is shown below:

$$\beta_{ws.t} = \frac{number\ of\ days\ in\ a\ month*3\ (\frac{shifts}{day})}{number\ of\ Ward\ specialists*(\frac{1\ shift}{1\ Ward\ speialists})}$$

$$\beta_{ws.t} = \frac{30*3\ (\frac{shifts}{day})}{5*(\frac{1\ shift}{1\ Ward\ speialists})} = 18\ duty$$

- To make it fair, each ward specialist should be assigned for 6 morning shifts, 6 evening shifts, and 6-night shifts.

$$\beta_{ws.Morning\ shift} = 6, \beta_{ws.Evening\ shift} = 6, \beta_{ws.Night\ shift} = 6$$

5.2.2. Decision Variables

$$X_{ls.t.d} = \begin{cases} 1, \text{if labor specialist (ls) is assigned on day (d) to a shift in period } (t) \\ \quad \text{at labor rooms} \\ 0, \text{otherwise} \end{cases}$$

$$X_{ws.t.d} = \begin{cases} 1, \text{if ward specialist (ws) is assigned on day (d) to a shift in period } (t) \\ \quad \text{at inpatient wards} \\ 0, \text{otherwise} \end{cases}$$

5.2.3. Deviational Variables

○ $\alpha_{ls.t}^+$, $\alpha_{ls.t}^-$: positive and negative deviational variables that depend on labor specialists and shifts.

○ $\beta_{ws.t}^+$, $\beta_{ws.t}^-$: positive and negative deviational variables that depend on ward specialists and shifts.

5.2.4. Objective Function

The objective function of this mathematical programming model is to minimize the sum of deviations (negative and positive deviations) with respect to target values of workload balance/fairness constrains. These deviation variables are subject to the constraints that are associated with the balanced distribution of work-load (work-shifts) among both labor specialists and ward specialists in a month time period, while taking into account all other constraints. The objective function is represented mathematically below in equation (1) as follow;

$$Min \; \sum_{ls=1}^{n}\sum_{ws=1}^{m}\; \sum_{t=1}^{5} \; (\alpha_{ls.t}^{+} + \alpha_{ls.t}^{-} + \; \beta_{ws.t}^{+} + \beta_{ws.t}^{-}) \qquad\qquad (1)$$

5.2.5. Constraints

Followings are the hard and soft constraints that have been made in this physician assignment problem. The first constraint in equation (2) below limits the number of labor specialists that are assigned to a single work-shift to two labor specialists only. The second constraint in equation (3), ensures that a labor specialist cannot have more than one work-shift in the same day. Equation (4) ensures the assignment of each labor specialist to three consecutive shifts per five days; in the order of morning shift, then evening shift, then night shift. Also, the constraint in equation (4) ensures the assignment of each labor specialist to two consecutive off-days after any assigned night shift. In addition to that, equation (4) enforces each labor specialist to be assigned to a morning shift the day after the assigned second day-off. Regarding ward specialists, the fourth constraint in equation (5) below limits the number of ward specialists that are assigned to a single work-shift to one ward

specialist only. While, equation (6), ensures that a ward specialist cannot have more than one work-shift in the same day. Equation (7) ensures the assignment of each ward specialist to three consecutive shifts per five days; in the order of morning shift, then evening shift, then night shift. Also, the constraint in equation (7) ensures the assignment of each ward specialist to two consecutive off-days after any assigned night shift. In addition to that, equation (7) enforces each ward specialist to be assigned to a morning shift the day after the assigned second day-off. However, equation (8) ensures the none-negativity of the deviational variables. The constraint in equation (9) ensures the balanced distribution of the three types of the work-shifts (morning shift, evening shift, night shift) among all labor specialists. Similarly, the last constraint in equation (10) ensures the balanced distribution of the three types of the work-shifts (morning shift, evening shift, night shift) among all ward specialists.

5.2.5.1. <u>Hard constraints</u>

$$\sum_{ls=1}^{n} X_{ls.t.d} \geq 2 \qquad\qquad \forall \, d\epsilon D, \forall \, t \, \epsilon \, T \qquad\qquad (2)$$

1. In each day, two labor specialists only are assigned to only one shift.

$$\sum_{t=1}^{5} X_{ls.t.d} \leq 1 \qquad\qquad \forall \, d\epsilon D, \forall \, ls \, \epsilon \, LS \qquad\qquad (3)$$

2. A labor specialist cannot have more than one shift in the same day.

$$X_{ls.t.d} - X_{ls.t+1.d+1} \geq 0 \qquad\qquad \forall \, d\epsilon D, \forall \, ls \, \epsilon \, LS, \forall \, t \, \epsilon \, T \qquad (4)$$

3. Each labor specialist must be assigned to three consecutive shifts per five days; in the order of morning shift, then evening shift, then night shift. Also, each labor specialist should be assigned to two consecutive off-days after any assigned night shift. In addition to that, each labor specialist should be assigned to a morning shift the day after any assigned second day off.

$$\sum_{ws=1}^{m} X_{ws.t.d} \geq 1 \qquad\qquad \forall\, d\epsilon D, \forall\, t\, \epsilon\, T \qquad\qquad (5)$$

4. In each day, one ward specialist only is assigned to only one shift.

$$\sum_{t=1}^{5} X_{ws.t.d} \leq 1 \qquad\qquad \forall\, d\epsilon D, \forall\, ws\, \epsilon\, WS \qquad\qquad (6)$$

5. A ward specialist cannot have more than one shift in the same day.

$$X_{ws.t.d} - X_{ws.t+1.d+1} \geq 0 \qquad\qquad \forall\, d\epsilon D, \forall\, ws\, \epsilon\, WS, \forall\, t\, \epsilon\, T \qquad (7)$$

6. Each ward specialist must be assigned to three consecutive shifts per five days; in the order of morning shift, then evening shift, then night shift. Also, each ward specialist should be assigned to two consecutive off-days after any assigned night shift. In addition to that, each ward specialist should be assigned to a morning shift the day after any assigned second day off.

$$\alpha_{ls.t}^{+}, \alpha_{ls.t}^{-}, \beta_{ws.t}^{+}, \beta_{ws.t}^{-} \geq 0 \qquad\qquad \forall\, ls\epsilon LS, \forall\, ws\, \epsilon\, WS, \forall\, t\epsilon\, T \qquad (8)$$

7. The none-negativity of the deviational variables.

5.2.5.2.   Workload balance constraints (soft constraints)

$$\sum_{d=1}^{g}(X_{ls.t.d}) - \alpha_{ls.t}^{-} + \alpha_{ls.t}^{+} = \alpha_{ls.t} \qquad\qquad \forall\ ls\epsilon LS, \forall\ t\epsilon\ T \qquad\qquad \textbf{(9)}$$

1. Balanced distribution of shifts among all labor specialists

$$\sum_{d=1}^{g}(X_{ws.t.d}) - \beta_{ws.t}^{-} + \beta_{ws.t}^{+} = \beta_{ws.t} \qquad\qquad \forall\ ws\epsilon WS, \forall\ t\epsilon\ T \qquad\qquad \textbf{(10)}$$

2. Balanced distribution of shifts among all ward specialists

It is worth mentioning that, no research paper from the previous papers provided a physician scheduling model that is exactly the same as the aforementioned proposed model. In other words, no published paper used an exact set of constraints that I have used for building the proposed model. Hence, a comparison between the aforementioned proposed model and the models found in literature papers could not be conducted.

6. Chapter 6: Results and Discussion

6.1. Results

Figure (1) represents the optimal physician schedule obtained through using AIMMS optimization software as an application of the afore-described mathematical model. The schedule was constructed for 10 labor specialists work at labor rooms within Obstetrics and Gynecology Department at Hamad Women's Hospital in Qatar for one-month planning period while considering wide range of constraints.

d	s	Morning	Evening	Night	free1	free2
Day01	LS01				✔	
	LS02	✔				
	LS03				✔	
	LS04					✔
	LS05			✔		
	LS06					✔
	LS07		✔			
	LS08	✔				
	LS09		✔			
	LS10			✔		
Day02	LS01					✔
	LS02		✔			
	LS03					✔
	LS04	✔				
	LS05				✔	
	LS06	✔				
	LS07			✔		
	LS08		✔			
	LS09			✔		
	LS10				✔	
Day03	LS01	✔				
	LS02			✔		
	LS03	✔				
	LS04		✔			
	LS05					✔
	LS06		✔			
	LS07				✔	
	LS08			✔		
	LS09				✔	
	LS10					✔
Day04	LS01		✔			
	LS02				✔	
	LS03		✔			
	LS04			✔		
	LS05	✔				
	LS06			✔		
	LS07					✔
	LS08				✔	
	LS09					✔
	LS10	✔				

Continued

Day	LS	1	2	3	4	5
Day05	LS01	☐	☐	☑	☐	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☑	☐	☐	☐
Day06	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☐	☑	☐	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☑	☐	☐
Day07	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☐	☐	☑	☐
Day08	LS01	☑	☐	☐	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☐	☐	☐	☑
Day09	LS01	☐	☑	☐	☐	☐
	LS02	☐	☐	☐	☑	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☑	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☑	☐	☐	☐	☐
Day10	LS01	☐	☐	☑	☐	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☑	☐	☐	☐
Day11	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☐	☑	☐	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☑	☐	☐
Day12	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☐	☐	☑	☐

Continued

Day	LS	1	2	3	4	5
Day13	LS01	✔				
	LS02			✔		
	LS03	✔				
	LS04		✔			
	LS05					✔
	LS06		✔			
	LS07				✔	
	LS08			✔		
	LS09				✔	
	LS10					✔
Day14	LS01		✔			
	LS02				✔	
	LS03		✔			
	LS04			✔		
	LS05	✔				
	LS06			✔		
	LS07					✔
	LS08				✔	
	LS09					✔
	LS10	✔				
Day15	LS01			✔		
	LS02					✔
	LS03			✔		
	LS04				✔	
	LS05		✔			
	LS06				✔	
	LS07	✔				
	LS08					✔
	LS09	✔				
	LS10		✔			
Day16	LS01				✔	
	LS02	✔				
	LS03				✔	
	LS04					✔
	LS05			✔		
	LS06					✔
	LS07		✔			
	LS08	✔				
	LS09		✔			
	LS10			✔		
Day17	LS01					✔
	LS02		✔			
	LS03					✔
	LS04	✔				
	LS05				✔	
	LS06	✔				
	LS07			✔		
	LS08		✔			
	LS09			✔		
	LS10				✔	
Day18	LS01	✔				
	LS02			✔		
	LS03	✔				
	LS04		✔			
	LS05					✔
	LS06		✔			
	LS07				✔	
	LS08			✔		
	LS09				✔	
	LS10					✔
Day19	LS01		✔			
	LS02				✔	
	LS03		✔			
	LS04			✔		
	LS05	✔				
	LS06			✔		
	LS07					✔
	LS08				✔	
	LS09					✔
	LS10	✔				
Day20	LS01			✔		
	LS02					✔
	LS03			✔		
	LS04				✔	
	LS05		✔			
	LS06				✔	
	LS07	✔				
	LS08					✔
	LS09	✔				
	LS10		✔			

Continued

Day	LS	1	2	3	4	5
Day21	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☐	☑	☐	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☑	☐	☐
Day22	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☐	☐	☑	☐
Day23	LS01	☑	☐	☐	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☐	☐	☐	☑
Day24	LS01	☐	☑	☐	☐	☐
	LS02	☐	☐	☐	☑	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☑	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☑	☐	☐	☐	☐
Day25	LS01	☐	☐	☑	☐	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☑	☐	☐	☐
Day26	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☐	☑	☐	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☑	☐	☐
Day27	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☐	☐	☑	☐
Day28	LS01	☑	☐	☐	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☐	☐	☐	☑

Continued

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Figure 1. Computerized optimal labor specialists schedule.

Figure (2) represents the optimal physician schedule obtained through using AIMMS optimization software after solving mathematical model. The schedule was constructed for 5 ward specialists work at inpatient wards within Obstetrics and Gynecology Department at Hamad Women's Hospital in Qatar for one-month planning period while considering wide range of constraints.

Continued

Day	ws	C1	C2	C3	C4	C5
Day09	ws1	☑	☐	☐	☐	☐
	ws2	☐	☐	☐	☑	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☐	☑	☐	☐
	ws5	☐	☑	☐	☐	☐
Day10	ws1	☐	☑	☐	☐	☐
	ws2	☐	☐	☐	☐	☑
	ws3	☑	☐	☐	☐	☐
	ws4	☐	☐	☐	☑	☐
	ws5	☐	☐	☑	☐	☐
Day11	ws1	☐	☐	☑	☐	☐
	ws2	☑	☐	☐	☐	☐
	ws3	☐	☑	☐	☐	☐
	ws4	☐	☐	☐	☐	☑
	ws5	☐	☐	☐	☑	☐
Day12	ws1	☐	☐	☐	☑	☐
	ws2	☐	☑	☐	☐	☐
	ws3	☐	☐	☑	☐	☐
	ws4	☑	☐	☐	☐	☐
	ws5	☐	☐	☐	☐	☑
Day13	ws1	☐	☐	☐	☐	☑
	ws2	☐	☐	☑	☐	☐
	ws3	☐	☐	☐	☑	☐
	ws4	☐	☑	☐	☐	☐
	ws5	☑	☐	☐	☐	☐
Day14	ws1	☑	☐	☐	☐	☐
	ws2	☐	☐	☐	☑	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☐	☑	☐	☐
	ws5	☐	☑	☐	☐	☐
Day15	ws1	☐	☑	☐	☐	☐
	ws2	☐	☐	☐	☐	☑
	ws3	☑	☐	☐	☐	☐
	ws4	☐	☐	☐	☑	☐
	ws5	☐	☐	☑	☐	☐
Day16	ws1	☐	☐	☑	☐	☐
	ws2	☑	☐	☐	☐	☐
	ws3	☐	☑	☐	☐	☐
	ws4	☐	☐	☐	☐	☑
	ws5	☐	☐	☐	☑	☐
Day17	ws1	☐	☐	☐	☑	☐
	ws2	☐	☑	☐	☐	☐
	ws3	☐	☐	☑	☐	☐
	ws4	☑	☐	☐	☐	☐
	ws5	☐	☐	☐	☐	☑
Day18	ws1	☐	☐	☐	☐	☑
	ws2	☐	☐	☑	☐	☐
	ws3	☐	☐	☐	☑	☐
	ws4	☐	☑	☐	☐	☐
	ws5	☑	☐	☐	☐	☐
Day19	ws1	☑	☐	☐	☐	☐
	ws2	☐	☐	☐	☑	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☐	☑	☐	☐
	ws5	☐	☑	☐	☐	☐
Day20	ws1	☐	☑	☐	☐	☐
	ws2	☐	☐	☐	☐	☑
	ws3	☑	☐	☐	☐	☐
	ws4	☐	☐	☐	☑	☐
	ws5	☐	☐	☑	☐	☐
Day21	ws1	☐	☐	☑	☐	☐
	ws2	☑	☐	☐	☐	☐
	ws3	☐	☑	☐	☐	☐
	ws4	☐	☐	☐	☐	☑
	ws5	☐	☐	☐	☑	☐
Day22	ws1	☐	☐	☐	☑	☐
	ws2	☐	☑	☐	☐	☐
	ws3	☐	☐	☑	☐	☐
	ws4	☑	☐	☐	☐	☐
	ws5	☐	☐	☐	☐	☑
Day23	ws1	☐	☐	☐	☐	☑
	ws2	☐	☐	☑	☐	☐
	ws3	☐	☐	☐	☑	☐
	ws4	☐	☑	☐	☐	☐
	ws5	☑	☐	☐	☐	☐
Day24	ws1	☑	☐	☐	☐	☐
	ws2	☐	☐	☐	☑	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☐	☑	☐	☐
	ws5	☐	☑	☐	☐	☐

Continued

Figure 2. Computerized optimal inpatient ward specialists schedule.

6.2. Discussion

This project proposed a mathematical model to solve a complex physician scheduling problem arising at Women's Hospital in Qatar which incorporates a large number of constraints including the hospital requirements, physicians' requirements, workload rules, shift coverage requirements, and most importantly considers the workload balance among the physicians. The proposed model implemented for 10 labor specialists and 5 ward specialists; whom need to be assigned equally to three different types of work-shifts (morning shift, evening shift, and night shift) over a month time period at labor rooms and inpatient wards respectively within Obstetrics and Gynecology Department.

AIMMS optimization software is used in this project in order to generate optimal computerized physician schedules that relieve the chief specialist who is in charge of this duty at Woman's Hospital from the complex and time-consuming task of manual schedule preparation, as well as to deliver a higher quality schedule (i.e., ensuring equal/ balanced work-shift assignments among the physicians).

The main deliverable of this project is the computerized physician schedules that mainly balance the distribution of work-shifts (morning shift, evening shift, and night shift) among the labor specialists and ward specialists for a one-month period. These schedules are established while respecting Women's hospital requirements and policies, physicians' requirements, workload rules, and shift coverage requirements to eventually meet both the hospital and the physicians' satisfactions.

6.2.1. Detailed analysis of the resulting optimal Labor Specialists schedule

According to the above figure (1) that shows the obtained optimized schedule for labor specialists, it is noticed that all constraints incorporated into the proposed model are well satisfied. From the obtained schedule, figure (1), it can be clearly seen that, in each day only two labor specialists are assigned to only one morning-shift, as well as only two labor specialists are assigned to only one on-call shift; meaning two labor specialists are allocated to one evening on-call and another two labor specialists are allocated to one night on-call. For instance, labor specialist number three (LS03) and labor specialist number eight (LS08) are assigned to a morning shift on Day01. Another example, on Day10, labor specialist number 6 (LS06) and labor specialist number 10 (LS10) are assigned together to

cover an evening shift. And the same case for labor specialist number 4 (LS04) and labor specialist number 5 (LS05) are assigned together to cover a night shift on Day02. This scenario is the same for the rest of the labor specialists.

Besides, the above schedule, figure (1), shows that no labor specialist is having more than one duty in the same day. For example, labor specialist number three (LS03) is assigned on Day01 to a morning shift and not assigned to any other shift at the same day. Another example, on Day01 labor specialist number five (LS05) is assigned to an evening shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the labor specialists.

Another observation from figure (1) is that, each labor specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each labor specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, on Day01, labor specialist number eight (LS08) is assigned to a morning shift, then on the following day (Day02), labor specialist number eight (LS08) is assigned to an evening shift, then the day after (Day03), labor specialist number eight (LS08) is assigned to a night shift, then labor specialist number eight (LS08) is assigned to free shifts on two consecutive off-days (on Day04 and Day05). Another example, on Day02, labor specialist number one (LS01) is assigned to a morning shift, then on the following day (Day03), labor specialist number one (LS01) is assigned to an evening shift, then the day after (Day04), labor specialist number one (LS01)

is assigned to a night shift, then labor specialist number one (LS01) is assigned to free shifts on two consecutive off-days (on Day05 and Day06). This scenario is the same for the rest of the labor specialists.

Moreover, the above schedule, figure (1), illustrates that a labor specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, labor specialist number eight (LS08) is assigned to two consecutive off-days on Day04 and Day05, then, the next day on Day06, labor specialist number eight (LS08) is assigned to a morning shift and not to any other type of shifts. Another example, labor specialist number one (LS01) is assigned to two consecutive off-days on Day05 and Day06, then, the next day on Day07, labor specialist number one (LS01) is assigned to a morning shift and not to any other type of shifts. This scenario is the same for the rest of the labor specialists.

Regarding the fairness aspect, the above schedule, figure (1), clearly presents the distribution of work-load (morning shifts and on-call shits) among the labor specialists. The total number of the morning shifts, evening shifts and night shifts assigned to each labor specialist during the weekdays and the weekends over a one-month period is equivalent between the labor specialists.

As the Average number of Morning shifts assigned to each labor specialist in a month time period is equal to 6, it can be clearly seen from the above schedule, figure (1), that all labor specialists are assigned to 6 morning duties over a month period. For example,

labor specialist number seven (LS07) is assigned to morning shifts on days: Day02, Day07, Day12, Day17, Day22, and Day27; meaning that starting from the first day on the month (Day01) till the end of the month (Day30), labor specialist number seven (LS07) is assigned to a total of 6 morning shifts. The same behavior is also observed for the others.

In addition, since the Average number of Evening shifts assigned to each labor specialist in a month time period is equal to 6, it can be observed from the schedule in figure (1), that the total number of labor specialists' evening shifts is equal to 6. For example, labor specialist number seven (LS07) is assigned to evening shifts on days: Day03, Day08, Day13, Day18, Day23, and Day28; which means that labor specialist number seven (LS07) is assigned to a total of 6 evening shifts over the month. The same behavior is also observed for the others.

Furthermore, the Average number of Night shifts assigned to each labor specialist in a month time period is equal to 6. Hence, it can be noticed from the schedule in figure (1), that the total number of labor specialists' night shifts is equal to 6. For example, labor specialist number seven (LS07) is assigned to night shifts on days: Day04, Day09, Day14, Day19, Day24, and Day29; i.e., labor specialist number seven (LS07) is assigned to a total of 6-night shifts over the month. The same behavior is also observed for the others.

Thus, the balanced distribution of the workload among the labor specialists is clearly illustrated in the above obtained schedule (figure 1) for all duties (morning shifts, evening shifts, and night shifts) over a month.

6.2.2. Detailed analysis of the resulting optimal Inpatient Ward Specialists schedule

According to the above figure (2) that shows the obtained optimized schedule for ward specialists, it is noticed that all constraints incorporated into the proposed model are well satisfied. From the obtained schedule, figure (2), it can be clearly seen that, in each day only one ward specialist is assigned to one morning-shift, as well as only one ward specialist is assigned to one on-call shift; meaning one ward specialist is allocated to one evening on-call and another one ward specialist is allocated to one night on-call. For instance, only ward specialist number four (WS04) is assigned to a morning shift on Day01. And the same case for ward specialist number one (WS01), as he/she is the only one who assigned to cover an evening shift on Day04. Another example, only ward specialist number two (WS02) is assigned to cover a night shift on Day07. This scenario is the same for the rest of the ward specialists.

In addition, the above schedule, figure (2), shows that no ward specialist is having more than one duty in the same day. For instance, ward specialist number five (WS05) is assigned on Day04 to a morning shift and not assigned to any other shift at the same day. Another example, on Day04 ward specialist number one (WS01) is assigned to an evening shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the ward specialists.

Another observation from figure (2) is that, each ward specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each ward specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, on Day03, ward specialist number one (WS01) is assigned to a morning shift, then on the following day (Day04), ward specialist number one (WS01) is assigned to an evening shift, then the day after (Day05), ward specialist number one (WS01) is assigned to a night shift, then ward specialist number one (WS01) is assigned to free shifts on two consecutive off-days (on Day06 and Day07). This scenario is the same for the rest of the ward specialists.

Moreover, the above schedule, figure (2), illustrates that a ward specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, ward specialist number one (WS01) is assigned to two consecutive off-days on Day06 and Day07, then, the next day on Day08, ward specialist number one (WS01) is assigned to a morning shift and not to any other type of shifts. This scenario is the same for the rest of the ward specialists.

Regarding the fairness aspect, figure (2) clearly presents the distribution of work-load (morning shifts and on-call shifts) among the ward specialists. The total number of the morning shifts, evening shifts and night shifts assigned to each ward specialist during the weekdays and the weekends over a one-month period is equivalent between the ward specialists.

As the Average number of Morning shifts assigned to each ward specialist in a month time period is equal to 6, it can be noticed from the above schedule, figure (2), that all ward specialists are assigned to 6 morning duties over a month period. For example, ward specialist number four (WS04) is assigned to morning shifts on days: Day01, Day06, Day11, Day16, Day21, and Day26; meaning that starting from the first day on the month (Day01) till the end of the month (Day30), ward specialist number four (WS04) is assigned to a total of 6 morning shifts. The same behavior is also observed for the others.

Also, since the Average number of Evening shifts assigned to each ward specialist in a month time period is equal to 6, it can be observed from the schedule above, figure (2), that the total number of ward specialists' evening shifts is equal to 6. For example, ward specialist number four (WS04) is assigned to evening shifts on days: Day02, Day07, Day12, Day17, Day22, and Day27; which means that ward specialist number four (WS04) is assigned to a total of 6 evening shifts over the month. The same behavior is also observed for the others.

Furthermore, the Average number of Night shifts assigned to each ward specialist in a month time period is equal to 6. Hence, it can be noticed from the schedule above, figure (2), that the total number of ward specialists' night shifts is equal to 6. For example, ward specialist number four (WS04) is assigned to night shifts on days: Day03, Day08, Day13, Day18, Day23, and Day28; i.e., ward specialist number four (WS04) is assigned to a total of 6-night shifts over the month. The same behavior is also observed for the others.

Hence, it is clearly observed from the above obtained schedule (figure 2) that the distribution of the workload (morning shifts, evening shifts, and night shifts) is balanced among all the ward specialists over a month.

6.2.3. Comparison of the balanced workload distribution/allocation among Labor Specialists

The table (2) below represents a summary of the current schedule that is created manually by Obstetrics and Genecology department at Hamad Women's Hospital for 10 labor specialists over one-month time period. It illustrates the total number of the morning shifts and on-call shifts (Evening shifts and Night shifts) that each labor specialist is assigned to in weekdays and weekend days over one-month period at labor rooms.

Table 2. *Summary of the Manual Labor Specialists Schedule by Obstetrics and Gynecology Department at Hamad Women's Hospital for 1-Month Period*

Labor Specialist (LS)	Weekdays			Weekends			$\sum$ Morning shift	$\sum$ Evening on-calls	$\sum$ Night on-calls	$\sum$ work-shifts	$\sum$ off-days
	Regular working shift	On-call shift		Regular working shift	On-call shift						
	$\sum$ Morning shift (7:00am-3:00pm)	$\sum$ Evening on-call (3:00pm-10:00pm)	$\sum$ Night on-call (3:00pm-10:00pm)	$\sum$ Morning shift (7:00am-3:00pm)	$\sum$ Evening on-call (3:00pm-10:00pm)	$\sum$ Night on-call (3:00pm-10:00pm)					
LS (1)	5	4	4	2	2	1	7	6	5	18	12
LS (2)	5	4	4	1	2	2	6	6	6	18	12
LS (3)	5	4	4	2	2	2	7	6	6	19	11
LS (4)	3	5	4	1	1	2	4	6	6	16	14
LS (5)	4	4	5	2	2	1	6	6	6	18	12
LS (6)	4	4	5	2	1	2	6	5	7	18	12
LS (7)	4	4	4	2	2	2	6	6	6	18	12
LS (8)	3	3	4	1	2	1	4	5	5	14	16
LS (9)	4	6	4	2	1	2	6	7	6	19	11
LS (10)	5	3	5	1	2	1	6	5	6	17	13

The table (3) below represents a summary of the optimized computerized schedule that has been obtained by solving the mathematical model using AIMMS optimization software for 10 labor specialists over one-month period. It illustrates the total number of the morning shifts and on-call shifts (Evening shifts and Night shifts) that each labor specialist is assigned to in weekdays and weekend days over one-month period at labor rooms.

Table 3. *Summary of the Computerized Optimal Labor Specialists Schedule by AIMMS for 1-Month Period*

Labor Specialist (LS)	Weekdays			Weekends			∑ Morning shift	∑ Evening on-calls	∑ Night on-calls	∑ work-shifts	∑ off-days
	Regular working shift	On-call shift		Regular working shift	On-call shift						
	∑Morning shift (7:00am-3:00pm)	∑ Evening on-call (3:00pm-10:00pm)	∑ Night on-call (3:00pm-10:00pm)	∑Morning shift (7:00am-3:00pm)	∑ Evening on-call (3:00pm-10:00pm)	∑ Night on-call (3:00pm-10:00pm)					
LS (1)	4	4	5	2	2	1	6	6	6	18	12
LS (2)	4	5	5	2	1	1	6	6	6	18	12
LS (3)	4	5	5	2	1	1	6	6	6	18	12
LS (4)	5	4	4	1	2	2	6	6	6	18	12
LS (5)	4	4	4	2	2	2	6	6	6	18	12
LS (6)	5	4	4	1	2	2	6	6	6	18	12
LS (7)	5	5	4	1	1	2	6	6	6	18	12
LS (8)	5	5	4	1	1	2	6	6	6	18	12
LS (9)	4	4	5	2	2	1	6	6	6	18	12
LS (10)	4	4	4	2	2	2	6	6	6	18	12

Table 4. *Comparison Table of Morning Shifts Assignments in Weekdays and Weekend days among Labor Specialists*

Labor Specialist (LS)	One-month			
	∑ Morning shift (Current Schedule)		∑ Morning shift (Optimized Schedule)	
	Weekdays	Weekends	Weekdays	Weekends
LS (1)	5	2	4	2
LS (2)	5	1	4	2
LS (3)	5	2	4	2
LS (4)	3	1	5	1
LS (5)	4	2	4	2
LS (6)	4	2	5	1
LS (7)	4	2	5	1
LS (8)	3	1	5	1
LS (9)	4	2	4	2
LS (10)	5	1	4	2

The table above shows a comparison between the computerized optimal schedule and the current manual schedule in terms of the distribution of the Morning shifts among labor specialists at labor rooms in weekdays and weekend days over one-month period.

The target is to assign each labor specialist to 6 morning shifts in both weekdays and weekends over a one-month period. From the above table, in the optimized schedule, six labor specialists are assigned for 4 morning shifts and four labor specialists are assigned for 5 morning shifts in weekdays. However, labor specialists who are assigned for 4 morning shifts in weekdays, are assigned for 2 morning shifts in the weekends. Also, labor specialists who are assigned for 5 morning shifts in weekdays, are assigned for 1 morning

shift in the weekends. Hence, the obtained schedule assigns each labor specialist to 6 morning shifts which matches the target and therefore provides balanced distribution of the morning shifts among all labor specialists during weekdays and weekends over one-month period.

In contrast, in the manual schedule the number of assigned morning duties is varying among labor specialists, since labor specialists 5,6 ,7 and 9 are assigned for 4 morning shifts in weekdays and for 2 morning shifts in weekends, and labor specialist 2 and 10 are assigned for 5 morning shifts in weekdays and for 1 morning shift in weekends. However, all labor specialists (5, 6, 7, 9 ,2 and 10) are assigned for a total of 6 morning shifts over a month period. Whereas, labor specialists 1 and 3 are assigned for 5 morning shifts in weekdays and for 2 morning shifts in weekends, meaning each of them is assigned for 7 morning shifts over a month. While labor specialist 4 and 8 are assigned for only 3 morning shifts in weekdays and for only 1 morning shift in weekends, to end up with only 4 morning shifts assigned to each of them over a month.

This is obviously considered unfair and can be distributed efficiently as illustrated in the obtained optimized schedule. In addition, it is worth mentioning here that the manual scheduling procedure can be affected by human errors which results in unbalanced distribution of the duties among the physicians.

Table 5. *Comparison Table of the Overall Number of Morning Shifts Assigned to each*

Labor Specialist

Labor Specialist (LS)	One-month	
	Regular working shift	
	∑ Morning shift (Current Schedule)	∑ Morning shift (Optimized Schedule)
LS (1)	7	6
LS (2)	6	6
LS (3)	7	6
LS (4)	4	6
LS (5)	6	6
LS (6)	6	6
LS (7)	6	6
LS (8)	4	6
LS (9)	6	6
LS (10)	6	6

Figure 3. Comparison chart of the overall number of morning shifts assigned to each

labor specialist.

The above table and chart represent a summary of the total number of the morning shifts that each labor specialist is assigned to over a one-month period. They illustrate a comparison between the computerized optimal schedule and the current manual schedule in terms of the distribution of the Morning shifts among labor specialists at labor rooms for one-month time period.

As shown above in the optimized schedule, all labor specialists are assigned for 6 morning shifts over a month period which matches the target. On the other hand, in the manual schedule the number of assigned morning shifts is unstable/varying among the labor specialists, since labor specialist 1 and 3 are assigned for 7 morning shifts, and labor specialist 4 and 8 are assigned for only 4 morning shifts, however the rest are assigned for 6 morning shifts. This is clearly considered unfair and can be better distributed as illustrated in the obtained optimized schedule. This reflects how better and fairer is the obtained schedule in comparison to the manual schedule. It is concluded that the manual scheduling procedure can be influenced by human errors and so leads to unbalanced allocations among the physicians.

Table 6. *Comparison Table of Evening Shifts Assignments in Weekdays and Weekend days among Labor Specialists*

Labor Specialist (LS)	One-month			
	∑ Evening shift (Current Schedule)		∑ Evening shift (Optimized Schedule)	
	Weekdays	Weekends	Weekdays	Weekends
LS (1)	4	2	4	2
LS (2)	4	2	5	1
LS (3)	4	2	5	1
LS (4)	5	1	4	2
LS (5)	4	2	4	2
LS (6)	4	1	4	2
LS (7)	4	2	5	1
LS (8)	3	2	5	1
LS (9)	6	1	4	2
LS (10)	3	2	4	2

The table above shows a comparison between the computerized optimal schedule and the current manual schedule in terms of the distribution of the Evening shifts among labor specialists at labor rooms in weekdays and weekend days over one-month period

The target is to assign each labor specialist to 6 evening shifts in both weekdays and weekends over a one-month period. By looking at the table above, it is obvious that in the optimized schedule, six labor specialists are assigned for 4 evening shifts and four labor specialists are assigned for 5 evening shifts in weekdays. However, labor specialists who are assigned for 4 evening shifts in weekdays, are assigned for 2 evening shifts in the weekends. Also, labor specialists who are assigned for 5 evening shifts in weekdays, are

assigned for 1 evening shift in the weekends. It can be clearly seen that, the obtained schedule assigns each labor specialist to 6 evening shifts which matches the target and therefore provides fair distribution of the evening shifts among all labor specialists during weekdays and weekends over a one-month period.

On the other hand, in the manual schedule the number of assigned evening duties is unstable among labor specialists, as labor specialists 1, 2, 3,5, 6 and 7 are assigned for 4 evening shifts in weekdays and for 2 evening shifts in weekends except labor specialist 6 is assigned for only 1 evening shift in weekends. While labor specialists 8 and 10 are assigned for 3 evening duties in weekdays and for 2 evening duties in weekends. However, labor specialist 4 and 9 are assigned for 5 and 6 evening shifts respectively in weekdays and for only 1 evening shifts in weekends. To sum it up, the manual schedule assigns 3 labor specialists for 5 evening shifts, 1 labor specialist for 7 evening shifts, and the rest for 6 evening shifts over a one-month period.

This is clearly considered unfair and this might be happened due to the human errors while doing the scheduling manually. Thus, it should be better distributed as illustrated in the obtained optimized schedule.

Table 7. *Comparison Table of the Overall Number of Evening Shifts Assigned to each*

Labor Specialist

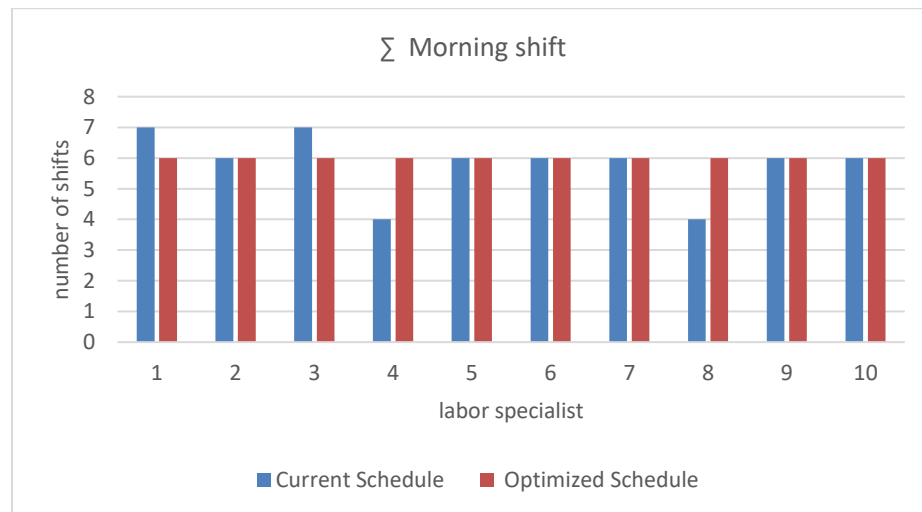| Labor Specialist (LS)	One-month	
	On-call shift	
	$\sum$ Evening shift (Current Schedule)	$\sum$ Evening shift (Optimized Schedule)
LS (1)	6	6
LS (2)	6	6
LS (3)	6	6
LS (4)	6	6
LS (5)	6	6
LS (6)	5	6
LS (7)	6	6
LS (8)	5	6
LS (9)	7	6
LS (10)	5	6
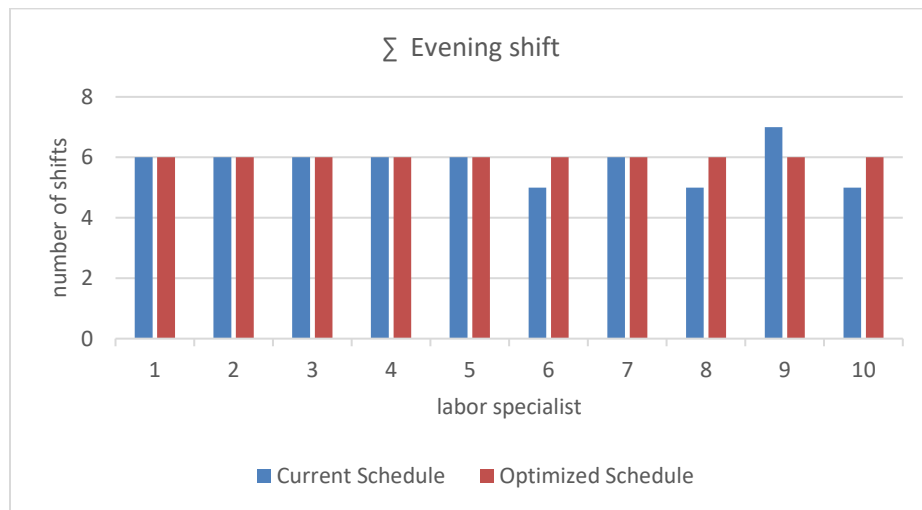
Figure 4. Comparison chart of the overall number of evening shifts assigned to each labor specialist.

The above table and chart represent a summary of the total number of the evening shifts assigned to each labor specialist over a one-month period. They show a comparison between the computerized optimal schedule and the current manual schedule based on the distribution of the Evening shifts among labor specialists at labor rooms for one-month time period.

It can be clearly seen that, the obtained computerized schedule provides more balanced allocation of the evening shifts among the labor specialists, since all labor specialists are assigned for 6 evening shifts which matches the target. While, in the manual schedule the number of assigned evening shifts is a bit unstable among labor specialists, as labor specialist 6, 8 and 10 are assigned for only 5 evening shifts and labor specialist 9 is assigned for 7 evening shifts, however the rest are assigned for 6 evening shifts. This indicates how better and balanced is the obtained schedule in comparison to the manual schedule.

Table 8. *Comparison Table of Night Shifts Assignments in Weekdays and Weekend days among Labor Specialists*

Labor Specialist (LS)	One-month			
	∑ Night shift (Current Schedule)		∑ Night shift (Optimized Schedule)	
	Weekdays	Weekends	Weekdays	Weekends
LS (1)	4	1	5	1
LS (2)	4	2	5	1
LS (3)	4	2	5	1
LS (4)	4	2	4	2
LS (5)	5	1	4	2
LS (6)	5	2	4	2
LS (7)	4	2	4	2
LS (8)	4	1	4	2
LS (9)	4	2	5	1
LS (10)	5	1	4	2

The table above shows a comparison between the computerized optimal schedule and the current manual schedule in terms of the distribution of the Night shifts among labor specialists at labor rooms in weekdays and weekend days over one-month period.

The target is to assign each labor specialist to 6-night shifts in both weekdays and weekends over a one-month period. From the table above, it is noticed that in the optimized schedule, six labor specialists are assigned for 4-night shifts and four labor specialists are assigned for 5-night shifts in weekdays. However, labor specialists who are assigned for 4-night shifts in weekdays, are assigned for 2-night shifts in the weekends. Also, labor specialists who are assigned for 5-night shifts in weekdays, are assigned for 1-night shift

in the weekends. Hence, the resulting schedule allocates each labor specialist to 6-night shifts which matches the target and therefore provides balanced distribution of the night shifts among all labor specialists during weekdays and weekends over a one-month period.

Whereas, in the manual schedule the number of assignments is varying slightly among labor specialists, as labor specialists 1, 2, 3, 4, 7, 8 and 9 are assigned for 4-night shifts in weekdays and for 2-night shifts in weekends except labor specialist 1 and 8 are assigned for only 1-night shift in weekends. While labor specialists 5, 6 and 10 are assigned for 5-night shifts in weekdays and for only 1-night shift in weekends except labor specialist 6 is assigned for 2-night shifts in weekends. To sum it up, the manual schedule assigns 2 labor specialists for 5-night shifts, 1 labor specialist for 7-night shifts, and the rest for 6-night shifts over a one-month period.

It is clear that, the distribution of the assignments in the current schedule is considered unbalanced and this might be resulted due to the human errors when performing the scheduling manually. Thus, the assignments should be distributed as illustrated in the obtained schedule, as it provides fairness among all the labor specialists.

Table 9. *Comparison Table of the Overall Number of Night Shifts Assigned to each*

Labor Specialist

Labor Specialist (LS)	One-month	
	On-call shift	
	∑ Night shift (Current Schedule)	∑ Night shift (Optimized Schedule)
LS (1)	5	6
LS (2)	6	6
LS (3)	6	6
LS (4)	6	6
LS (5)	6	6
LS (6)	7	6
LS (7)	6	6
LS (8)	5	6
LS (9)	6	6
LS (10)	6	6
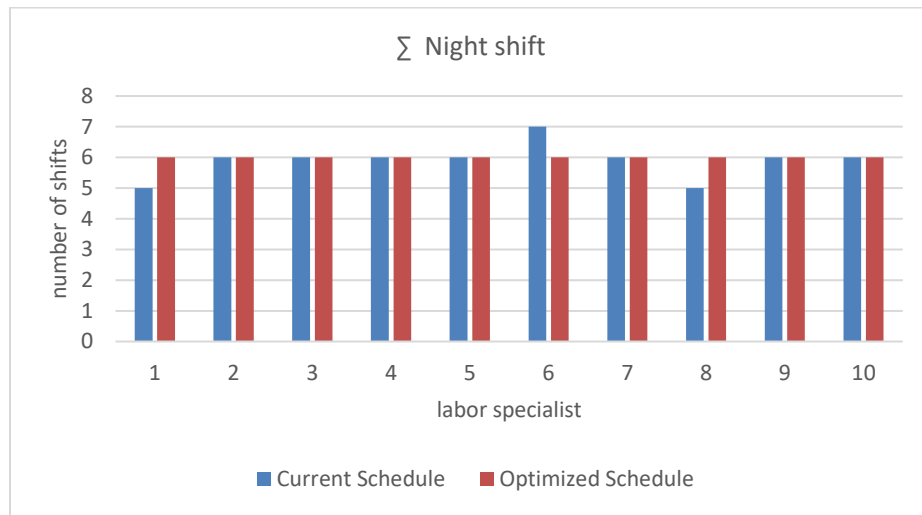
Figure 5. Comparison chart of the overall number of night shifts assigned to each labor specialist.

Coming across the night shifts table and chart, it is observed that the obtained schedule provides more balanced distribution of the night shifts among labor specialists, since all labor specialists are assigned for 6-night shifts. Also, the assignments for night shifts in the obtained schedule matches the target, as the target is to assign each labor specialist to 6-night shifts over a one-month period. While, in the manual schedule the number of assigned night shifts is a bit unstable among labor specialists, as labor specialists 1 and 8 are assigned for only 5-night shifts and labor specialist 6 is assigned for 7-night shifts, however the rest are assigned for 6-night shifts. This shows that the obtained schedule is better than the manual schedule and provides more balanced distribution of the duties among the labor specialists.

Table 10. *Comparison Table of the Overall Number of Worked Weekends Assigned to each Labor Specialist*

Labor Specialist (LS)	One-month	
	∑ weekend duties (Current Schedule)	∑ weekend duties (Optimized Schedule)
LS (1)	5	5
LS (2)	5	4
LS (3)	6	4
LS (4)	4	5
LS (5)	5	6
LS (6)	5	5
LS (7)	6	4
LS (8)	4	4
LS (9)	5	5
LS (10)	4	6
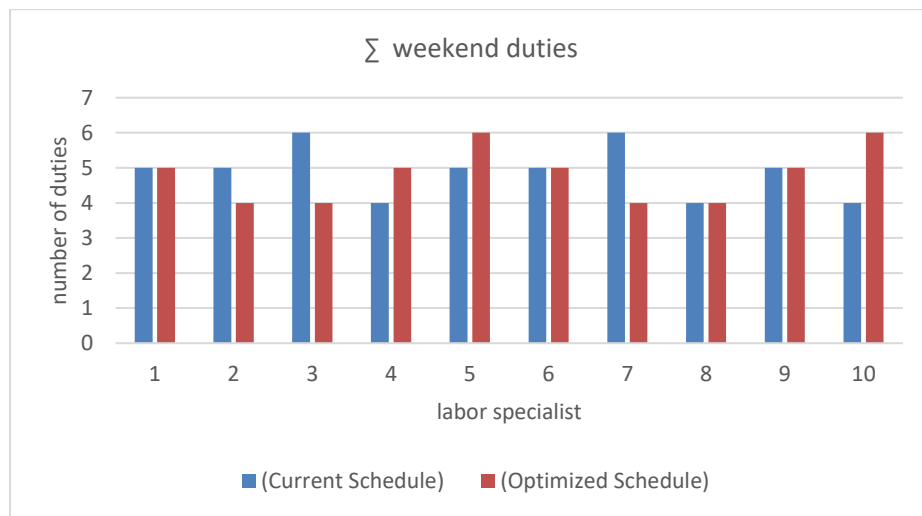
Figure 6. Comparison chart of the overall number of worked weekends assigned to each labor specialist.

Regarding the worked weekends, it can be noticed from the above table and chart, that the distribution of assigned duties in the weekend days among the labor specialists in both schedules is almost the same, as the assignments in both schedules varies between 4,5, and 6 duties for each labor specialist.

It can be seen that, in the obtained schedule four labor specialists are assigned for 4 shifts, and another four labor specialists are assigned for 5 shifts, however only two labor specialists are assigned for 6 shifts in weekend days over a month-period. One might argue that the allocations in weekend days are not fair enough among all the labor specialists, since few of them are assigned to 6 duties while the rest are assigned to 4 and 5 duties only; then it should be said that this is still considered the optimum distribution of the assignments. Indeed, such variation has resulted because the scheduling is made over short duration that is one-month; where the total number of weekend days in the studied one-month is 8 days, and therefore cannot be divided equally between the 10 labor specialists. However, A more balanced workload distribution can be achieved when the scheduling is conducted over a longer period of time. On the other hand, in the manual schedule three labor specialists are assigned for 4 shifts, and five labor specialists are assigned for 5 shifts, however only two labor specialists are assigned for 6 shifts in weekend days over a month-period.

Table 11. *Comparison Table of the Overall Number of Off-Days Assigned to each Labor*

Specialist

Labor Specialist (LS)	One-month	
	∑ off-days (Current Schedule)	∑ off-days (Optimized Schedule)
LS (1)	12	12
LS (2)	12	12
LS (3)	11	12
LS (4)	14	12
LS (5)	12	12
LS (6)	12	12
LS (7)	12	12
LS (8)	16	12
LS (9)	11	12
LS (10)	13	12
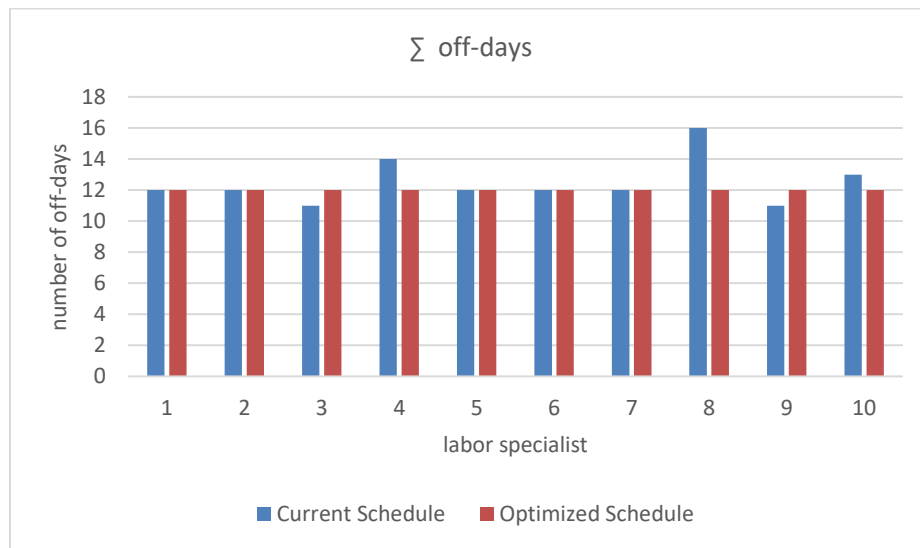
Figure 7. Comparison chart of the overall number of off-days assigned to each labor

specialist.

However, by looking at the off-days table and chart, it can be clearly observed that the computerized schedule provides fairness among labor specialists, as all labor specialists are taking 12 off-days. Whereas, in the current manual schedule the number of off-days is not consistent among labor specialists and varying significantly, since labor specialist 10 is taking 13 off-days, and labor specialist 4 is taking 14 off-days, while labor specialist 8 is taking 16 off-days. In addition, labor specialists 3 and 9 are taking 11 off-days, however the rest are taking 12 off-days. This indicates the improper allocation of the amount of off days among labor specialists, which might be happened due to human errors which leads to unfair assignments among physicians.

6.2.4. Comparison of the balanced workload distribution/allocation among Inpatient Ward Specialists

The table (12) below represents a summary of the current schedule that is created manually by Obstetrics and Genecology department at Hamad Women's Hospital for 5 ward specialists over one-month period. It shows the total number of the morning shifts and on-call shifts (Evening shifts and Night shifts) that each ward specialist is assigned to in weekdays and weekend days over one-month period at inpatient wards.

Table 12. *Summary of the Manual Ward Specialists Schedule by Obstetrics and Gynecology Department at Hamad Women's Hospital for 1-Month Period*

Ward Specialist (WS)	Weekdays			Weekends			∑ Morning shift	∑ Evening on-calls	∑ Night on-calls	∑ work-shifts	∑ off-days
	Regular working shift	On-call shift		Regular working shift	On-call shift						
	∑ Morning shift (7:00am-3:00pm)	∑ Evening on-call (3:00pm-10:00pm)	∑ Night on-call (3:00pm-10:00pm)	∑ Morning shift (7:00am-3:00pm)	∑ Evening on-call (3:00pm-10:00pm)	∑ Night on-call (3:00pm-10:00pm)					
WS (1)	4	4	4	2	2	2	6	6	6	18	12
WS (2)	4	3	4	1	2	2	5	5	6	16	14
WS (3)	5	3	4	1	1	2	6	4	6	16	14
WS (4)	5	3	5	2	1	1	7	4	6	17	13
WS (5)	5	5	4	2	2	1	7	7	5	19	11

The table (13) below represents a summary of the computerized optimal schedule that has been obtained through using AIMMS optimization software for 5 ward specialists over one-month period. It illustrates the total number of the morning shifts and on-call shifts (Evening shifts and Night shifts) that each ward specialist is assigned to in weekdays and weekend days over one-month period at inpatient wards.

Table 13. *Summary of the Computerized Optimal Ward Specialists Schedule by AIMMS for 1-Month Period*

Ward Specialist (WS)	Weekdays			Weekends			∑ Morning shift	∑ Evening on-calls	∑ Night on-calls	∑ work-shift	∑ off-days
	Regular working shift	On-call shift		Regular working shift	On-call shift						
	∑ Morning shift (7:00am-3:00pm)	∑ Evening on-call (3:00pm-10:00pm)	∑ Night on-call (3:00pm-10:00pm)	∑ Morning shift (7:00am-3:00pm)	∑ Evening on-call (3:00pm-10:00pm)	∑ Night on-call (3:00pm-10:00pm)					
WS (1)	4	5	5	2	1	1	6	6	6	18	12
WS (2)	5	4	4	1	2	2	6	6	6	18	12
WS (3)	4	4	5	2	2	1	6	6	6	18	12
WS (4)	4	4	4	2	2	2	6	6	6	18	12
WS (5)	5	5	4	1	1	2	6	6	6	18	12

Table 14. *Comparison Table of Morning Shifts Assignments in Weekdays and Weekend days among Ward Specialists*

Ward Specialist (WS)	One-month			
	∑ Morning shift (Current Schedule)		∑ Morning shift (Optimized Schedule)	
	Weekdays	Weekends	Weekdays	Weekends
WS (1)	4	2	4	2
WS (2)	4	1	5	1
WS (3)	5	1	4	2
WS (4)	5	2	4	2
WS (5)	5	2	5	1

The table above is comparing the computerized optimal schedule to the current manual schedule in terms of the distribution of the Morning shifts among ward specialists at inpatient wards in weekdays and weekend days over one-month period.

The target is to assign each ward specialist to 6 morning shifts in both weekdays and weekends over a one-month period. From the above table, in the optimized schedule, three ward specialists are assigned for 4 morning shifts and two ward specialists are assigned for 5 morning shifts in weekdays. However, ward specialists who are assigned for 4 morning shifts in weekdays, are assigned for 2 morning shifts in the weekends. Also, ward specialists who are assigned for 5 morning shifts in weekdays, are assigned for 1 morning shift in the weekends. Hence, the obtained schedule assigns each ward specialist to 6 morning shifts which matches the target and therefore provides balanced distribution

of the morning shifts among all ward specialists during weekdays and weekends over one-month period.

However, in the manual schedule, the assignments of the morning shifts among the ward specialists is almost similar to the obtained schedule, as two ward specialists are assigned for 4 morning shifts, while the rest are assigned for 5 morning shifts in weekdays. Similar to the obtained schedule, the number of the morning shifts assigned to each ward specialist in the manual schedule varies between 1 and 2 morning shifts in weekend days. However, by looking at the overall number of the morning shifts assigned to each ward specialist in the manual schedule, it can be observed that distribution of the workload is unbalanced, as ward specialists 4 and 5 are assigned to a total of 7 morning shifts, while ward specialist 2 is assigned to only 5 morning shifts, and the rest are assigned to a total of 6 morning shifts over a month. Hence, this is considered unfair and the assignments of the morning shifts should be better distributed as illustrated in the obtained schedule.

Table 15. *Comparison Table of the Overall Number of Morning Shifts Assigned to each*

Ward Specialist

Ward Specialist (WS)	One-month	
	Regular working shift	
	∑ Morning shift (Current Schedule)	∑ Morning shift (Optimized Schedule)
WS (1)	6	6
WS (2)	5	6
WS (3)	6	6
WS (4)	7	6
WS (5)	7	6
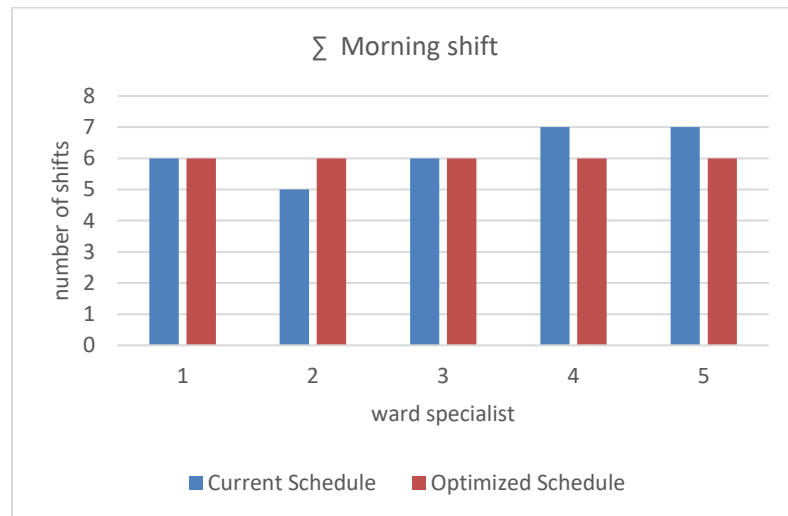
Figure 8. Comparison chart of the overall number of morning shifts assigned to each

ward specialist.

The above table and chart represent a summary of the total number of the morning shifts that each ward specialist is assigned to over a one-month period. They illustrate a comparison between the computerized optimal schedule and the current manual schedule in terms of the distribution of the Morning shifts among ward specialists at inpatient wards for one-month time period.

As mentioned earlier, the target is to assign each ward specialist to 6 morning shifts over a one-month period. And from the above two illustrations, it is observed that the optimized schedule assigns each ward specialist to 6 morning shifts which matches the target and therefore provides balanced distribution of the morning duties among all ward specialists over a one-month period. On the other hand, in the manual schedule the number of assigned morning shifts is unstable/varying among the ward specialists, since ward specialists 4 and 5 are assigned for 7 morning shifts, and ward specialist 2 is assigned for only 5 morning shifts, however the rest are assigned for 6 morning duties. This is clearly considered unfair and can be better distributed as illustrated in the obtained schedule. This reflects how better and fairer is the obtained schedule in comparison to the manual schedule. It is concluded that the manual scheduling procedure can be influenced by human errors and so leads to unbalanced allocations among the physicians.

Table 16. *Comparison Table of Evening Shifts Assignments in Weekdays and Weekend*

days among Ward Specialists

Ward Specialist (WS)	One-month			
	∑ Evening shifts (Current Schedule)		∑ Evening shifts (Optimized Schedule)	
	Weekdays	Weekends	Weekdays	Weekends
WS (1)	4	2	5	1
WS (2)	3	2	4	2
WS (3)	3	1	4	2
WS (4)	3	1	4	2
WS (5)	5	2	5	1

The table above shows a comparison between the computerized optimal schedule and the current manual schedule in terms of the distribution of the Evening shifts among ward specialists at inpatient wards in weekdays and weekend days over one-month period.

The target is to assign each ward specialist to 6 evening shifts in both weekdays and weekends over a one-month period. From the above table, in the optimized schedule, three ward specialists are assigned for 4 evening shifts and two ward specialists are assigned for 5 evening shifts in weekdays. However, ward specialists who are assigned for 4 evening shifts in weekdays, are assigned for 2 evening shifts in the weekends. Also, ward specialists who are assigned for 5 evening shifts in weekdays, are assigned for 1 evening shift in the weekends. Hence, the obtained schedule assigns each ward specialist to 6 evening shifts which matches the target and therefore provides balanced distribution of the evening shifts among all ward specialists during weekdays and weekends over one-month

period.

On the other hand, in the manual schedule, the number of assigned evening shifts is unstable and varying significantly among the ward specialists, as three ward specialists are assigned for 3 evening shifts, while one ward specialist is assigned for 5 evening shifts and the other is assigned for 4 evening shifts in weekdays. Similar to the obtained schedule, the manual schedule assigns each ward specialist for 1-2 evening shifts in the weekends. However, by looking at the overall number of the evening shifts assigned to each ward specialist in the manual schedule, it can be noticed that the distribution of the workload is unbalanced, as ward specialists 1 is assigned to a total of 6 evening shifts, ward specialist 2 is assigned to a total of 5 evening shifts, while ward specialist 5 is assigned to a total of 7 evening shifts and the rest are assigned to a total of 4 evening shifts over a month.

Hence, this distribution is considered unfair, and it demonstrates that manual scheduling is inefficient as it is vulnerable to human errors which negatively affects the quality of the schedule. Thus, the distribution in the manual schedule should be replaced by the one obtained in the resulting schedule in order to ensure the fairness among the ward specialists.

Table 17. *Comparison Table of the Overall Number of Evening Shifts Assigned to each*

Ward Specialist

Ward Specialist (WS)	One-month	
	On-call shift	
	$\sum$ Evening shift (Current Schedule)	$\sum$ Evening shift (Optimized Schedule)
WS (1)	6	6
WS (2)	5	6
WS (3)	4	6
WS (4)	4	6
WS (5)	7	6
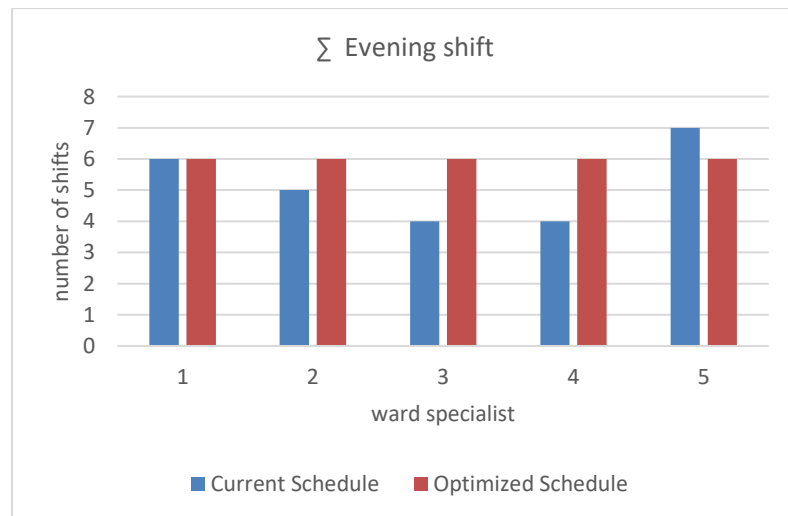
Figure 9. Comparison chart of the overall number of evening shifts assigned to each ward specialist.

The above table and chart represent a summary of the total number of the evening shifts assigned to each ward specialist over a one-month period. They show a comparison between the computerized optimal schedule and the current manual schedule based on the distribution of the Evening shifts among ward specialists at inpatient wards for one-month time period.

It can be clearly seen that, the obtained computerized schedule provides balanced allocation of the evening shifts among the ward specialists, since all ward specialists are assigned for 6 evening shifts. Also, the assignments for evening shifts in the obtained schedule matches the target, as the target is to assign each ward specialist to 6-evening shifts over a one-month period. While, in the manual schedule the number of assigned evening shifts is varying significantly among ward specialists, since ward specialist 1 is assigned for 6 evening shifts, while ward specialist 2 is assigned for 5 evening shifts, and ward specialist 5 is assigned for 7 evening shifts. And the other ward specialists are assigned for 4 evening shifts. This is clearly considered unfair and should be better distributed as illustrated in the obtained schedule. Also, this demonstrated that the manual scheduling procedure is influenced by human errors which in turn leads to unbalanced allocations among the physicians.

Table 18. *Comparison Table of Night Shifts Assignments in Weekdays and Weekend days among Ward Specialists*

Ward Specialist (WS)	One-month			
	∑ Night shift (Current Schedule)		∑ Night shift (Optimized Schedule)	
	Weekdays	Weekends	Weekdays	Weekends
WS (1)	4	2	5	1
WS (2)	4	2	4	2
WS (3)	4	2	5	1
WS (4)	5	1	4	2
WS (5)	4	1	4	2

The table above shows a comparison between the computerized optimal schedule and the current manual schedule in terms of the distribution of the Night shifts among ward specialists at inpatient wards in weekdays and weekend days over one-month period.

The target is to assign each ward specialist to 6-night shifts in both weekdays and weekends over a one-month period. From the above table, in the optimized schedule, three ward specialists are assigned for 4-night shifts and two ward specialists are assigned for 5-night shifts in weekdays. However, ward specialists who are assigned for 4-night shifts in weekdays, are assigned for 2-night shifts in the weekends. Similarly, ward specialists who are assigned for 5-night shifts in weekdays, are assigned for 1-night shift in the weekends. Hence, the obtained schedule assigns each ward specialist to 6-night shifts which matches the target and therefore provides balanced distribution of the night duties among all ward

specialists during weekdays and weekends over one-month period.

On the other hand, in the manual schedule, the assignments of the night shifts among the ward specialists is almost similar to the obtained schedule, as all ward specialists are assigned for 4-night shifts except ward specialist 4 is assigned for 5-night shifts in weekdays. Similar to the obtained schedule, the manual schedule assigns each ward specialist for 1-2-night shifts in the weekends. And, by looking at the overall number of the night shifts assigned to each ward specialist over a month in the manual schedule, it can be clearly seen that the distribution of the workload is almost balanced, as all ward specialists are assigned to a total of 6-night shifts except ward specialist 5 is assigned to a total of 5-night shifts. Hence, it is concluded that almost both schedules provide fairness; in terms of the night shift distribution among the ward specialists.

Table 19. *Comparison Table of the Overall Number of Night Shifts Assigned to each*

Ward Specialist

Ward Specialist (WS)	One-month	
	On-call shift	
	∑ Night shift (Current Schedule)	∑ Night shift (Optimized Schedule)
WS (1)	6	6
WS (2)	6	6
WS (3)	6	6
WS (4)	6	6
WS (5)	5	6
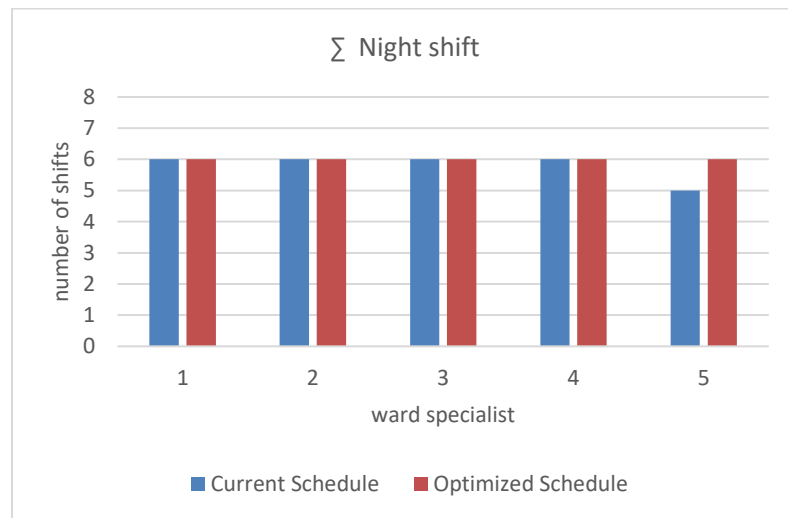
Figure 10. Comparison chart of the overall number of night shifts assigned to each ward

specialist.

Coming across the night shift table and chart, it is concluded that almost both schedules provide fairness among ward specialists. All ward specialists in the obtained schedule are assigned for 6-night shifts and this meets the target; as the target is to assign each ward specialist to 6-night shifts over a one-month period. While, in the manual schedule, all ward specialists are assigned for 6-night shifts except ward specialist 5 is assigned for only 5 night-shifts. Hence, the obtained schedule provides more balanced distribution of the night shifts among the ward specialists in comparison to the manual schedule.

Table 20. *Comparison Table of the Overall Number of Worked Weekends Assigned to each*

Ward Specialist

Ward Specialist (WS)	One-month	
	$\sum$ weekend duties (Current Schedule)	$\sum$ weekend duties (Optimized Schedule)
WS (1)	6	4
WS (2)	5	5
WS (3)	4	5
WS (4)	4	6
WS (5)	5	4
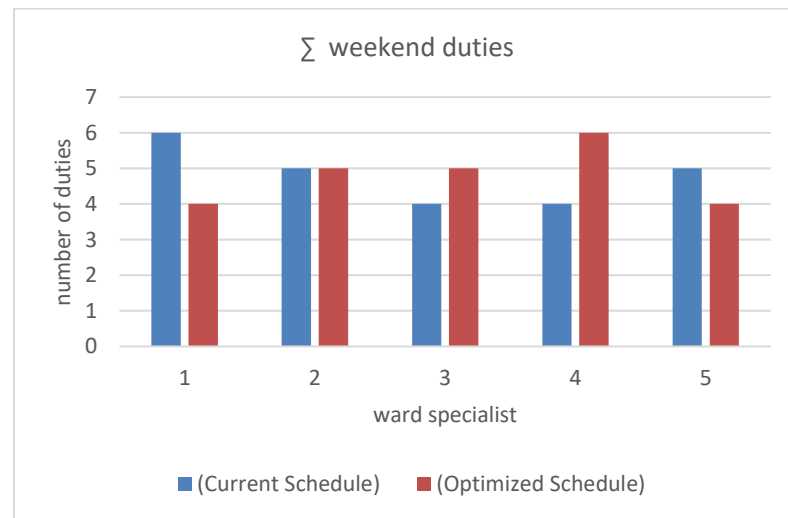
Figure 11. Comparison chart of the overall number of worked weekends assigned to each ward specialist.

Regarding the worked weekends, it can be noticed from the above table and chart, that the distribution of assigned duties in the weekend days among the ward specialists in both schedules is exactly the same, as the assignments in both schedules varies between 4,5, and 6 duties for each ward specialist.

It can be clearly seen that, in the obtained schedule two ward specialists are assigned for 4 duties, and another two ward specialists are assigned for 5 duties, however only 1 ward specialist is assigned for 6 duties. One might argue that the allocations are not fair enough among all the ward specialists, since only one of them is assigned to 6 duties while the rest are assigned to 4 and 5 duties only; then it should be said that this is still considered the optimum distribution of the assignments. Indeed, such variation has resulted because the scheduling is made over short duration that is one-month; where the total number of weekend days in the studied one-month is 8 days, and therefore cannot be divided equally between the 5 ward specialists. However, a more balanced workload distribution can be achieved when the scheduling is conducted over a longer period of time.

Table 21. *Comparison Table of the Overall Number of Off-Days Assigned to each Ward*

Specialist

Ward Specialist (WS)	One-month	
	∑ off-days (Current Schedule)	∑ off-days (Optimized Schedule)
WS (1)	12	12
WS (2)	14	12
WS (3)	14	12
WS (4)	13	12
WS (5)	11	12
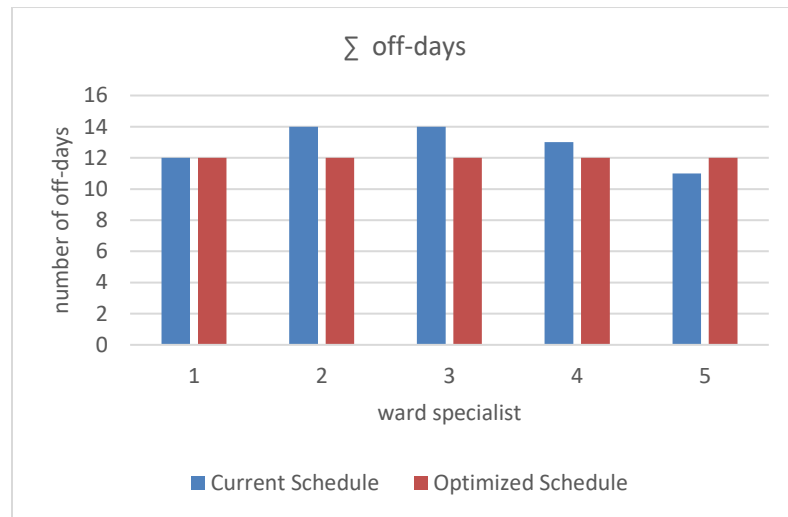
Figure 12. Comparison chart of the overall number of off-days assigned to each ward specialist.

However, by looking at the off-days table and chart, it can be clearly observed that the computerized schedule provides fairness among ward specialists, as all ward specialists are taking 12 off-days over a month. Whereas, in the current manual schedule the number of off-days is not consistent and varying among ward specialists, since ward specialist 4 is taking 13 off-days, and labor specialist 5 is taking only 11 off-days, while only ward specialist 1 is taking 12 off-days. In addition, ward specialists 2 and 3 are taking 14 off-days. This indicates the improper allocation of the amount of off days among ward specialists, which might be occurred due to human errors which causes unbalanced assignments among physicians.

6.2.5. Comparison of the objective function value

Table 22. *Comparison Table of the Overall Number of Off-Days Assigned to each Ward Specialist*

For all Specialists	Objective function	
	Current Schedule	Optimized Schedule
10 (LS) & 5 (WS)	38	0

As mentioned earlier, the objective function of the proposed model is to minimize the sum of deviations (negative and positive deviations) with respect to target values of workload balance/fairness constrains.

The objective function value associated with the current schedules has calculated manually, and as it can be clearly seen from the above table, that the objective's result value for the current manual schedules is 38. Whereas, in the computerized optimal schedules, the objective's result value obtained from AIMMS software is zero. This shows that the schedules generated by the proposed model are of high quality and much better than the current ones as it minimizes the deviations to the maximum extent (to zero). In addition, it has demonstrated that the computerized optimal schedules ensure the balanced and fair distribution of the assignments among the specialists, beside satisfying all other constraints.

7. Chapter 7: Sensitivity Analysis

Sensitivity Analysis is typically conducted in operations research, in order to find out by how much the output of the developed model is being impacted by changing the model parameters. In other words, the purpose behind conducting such analysis is to realize by how much we can change the inputs (data) for the output of the proposed model to remain reasonably unchanged.

Indeed, changing one of the model parameters at a time while fixing the others, might affect the validity of proposed model. An optimal solution will be obtained from AIMMS software, if the number of labor specialists or ward specialists or work-shifts or the number of days has been changed. However, the number of labor specialists should be greater than or equal to 10 labor specialists, as well as, the number of ward specialists should be greater than or equal to 5 ward specialists. While if the number of the labor specialists is less than 10 labor specialists, or the number of ward specialists is less than 5 ward specialists, then there will be no solution by the available codes, as the minimum number for solving this model is 10 labor specialists and 5 ward specialists. Thus, modifications to the proposed model have to be made either by changing the limitations of the constraints (e.g. making each shift to be covered by only one labor specialist instead of 2 labor specialists, however this would change the hospital work-rules) or adding new constraints. Regarding the number of work-shifts, if it has increased to more than 3 work-shifts, there will be no feasible solution by the available codes, so new constraints must be added. While if the number of work-shifts is less than or equal to 3, then there will be

optimal solution. As for the number of days, it is observed that the available codes provide an optimal solution when the number of days varies between 28-31 days over a month.

To illustrate, the proposed model is developed for 10 labor specialists, 5 ward specialists, 3 work-shifts, and for 30 days. As mentioned earlier, the target of the proposed model for labor specialists is set to be as the average number of assignments per shift per labor specialist, which is equal to 18 work-shifts; 6 morning shifts, 6 evening shifts, and 6 night shifts. Similarly, the target for ward specialists is set to be as the average number of assignments per shift per ward specialist, which is equal to 18 work-shifts; 6 morning shifts, 6 evening shifts, and 6 night shifts.

The following discusses how the output of the proposed model is being impacted by changing one of the model parameters such as; the number of labor specialists, ward specialists, the work-shifts, and the number of days. Note that the outputs (specialists' schedules) obtained from conducting this sensitivity analysis are provided in APPRENDIX B.

7.1. The impact of changing the number of Specialists

For labor specialists, When the number is increased to 12 labor specialists, the target will automatically be equal to 15 work-shifts. The target is calculated as follows,

$$\alpha_{ls.t} = \frac{30\ day * 3\ (\frac{shifts}{day})}{12\ labor\ specialist * (\frac{1\ shift}{2\ labor\ speialists})} = 15 \text{ work-shifts; 5 morning shifts, 5 evening}$$

shifts, and 5 night shifts.

It is observed that, in each day only two labor specialists are assigned to only one morning-shift, as well as only two labor specialists are assigned to only one on-call shift; meaning two labor specialists are allocated to one evening on-call and another two labor specialists are allocated to one night on-call. For instance, from figure (24), only labor specialist number six (LS06) and labor specialist number eleven (LS11) are assigned to an evening shift on Day01. The same behavior is also observed for the rest. Hence, the shift coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no labor specialist is having more than one duty in the same day. For example, from figure (24), labor specialist number one (LS01) is assigned on Day01 to a morning shift and not assigned to any other shift at the same day. Another example, on Day01 labor specialist number ten (LS10) is assigned to a night shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Another observation is that, each labor specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each labor specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (24), on Day12, labor specialist number two (LS02) is assigned to a morning shift, then on the following day (Day13), labor specialist number two (LS02) is assigned to an evening shift, then the day after (Day14), labor specialist number two (LS02) is assigned to a night shift, then labor specialist number two (LS02) is assigned to free shifts on two consecutive off-days (on Day15 and Day16). This scenario will be the same for the rest of the labor specialists. However, the off-days for labor specialists can reach to 6 successive off-days after any assigned night shift and not only two consecutive off-days. But at the end, the summation of all the off days for all labor specialists is 15 days, which is exactly the average of total number of off days for all labor specialists

Also, it is noticed that, after the assigned off-days, all labor specialists are not assigned to any on-call shift the next day, however they are assigned to morning shifts the following day. For example, from figure (24), labor specialist number two (LS02) is assigned to consecutive off-days on Day15 till Day20, then, the next day on Day21, labor specialist number two (LS02) is assigned to a morning shift and not to any other type of shifts. This scenario is the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (24), that, the total number of the morning shifts, evening shifts and night shifts assigned to each labor specialist over a one-month period is equivalent between the labor specialists.

As the Average number of Morning shifts assigned to each labor specialist in a month time period is equal to 5, it is observed that all labor specialists are assigned to 5 morning shifts over a month period.

Also, since the Average number of Evening shifts assigned to each labor specialist in a month period is equal to 5, it is observed that the total number of labor specialists' evening shifts is equal to 5.

Furthermore, the Average number of Night shifts assigned to each labor specialist in a month time period is equal to 5. Hence, it is noticed that the total number of labor specialists' night shifts is equal to 5.

Thus, the balanced distribution of the workload among the labor specialists is clearly illustrated in the obtained schedule (figure 24) for all work-shifts (morning shifts, evening shifts, and night shifts) over a month. However, the objective function which aims at minimizing the sum of deviations with respect to target values of workload balance/fairness constrains is equal to 280.

However, for ward specialists, when the number is increased to 6 ward specialists, the target will automatically be equal to 15 work-shifts. The target is calculated as follows,

$$\beta_{ws.t} = \frac{30\ day * 3\ (\frac{shifts}{day})}{6\ ward\ specialist * (\frac{1\ shift}{1 ward\ speialists})} = 15 \text{ work-shifts; 5 morning shifts, 5 evening}$$

shifts, and 5 night shifts.

It is observed that, in each day only one ward specialist is assigned to only one morning-shift, as well as only one ward specialist is assigned to only one on-call shift; meaning one ward specialist is allocated to one evening on-call and another one ward specialist is allocated to one night on-call. For instance, from figure (25), only ward specialist number two (WS02) is assigned to a morning shift on Day02. The same behavior is also observed for the rest. Hence, the shift coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no ward specialist is having more than one duty in the same day. For example, from figure (25), ward specialist number one (WS01) is assigned on Day01 to an evening shift and not assigned to any other shift at the same day. Another example, on Day01 ward specialist number five (WS5) is assigned to a night shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Another observation is that, each ward specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each ward specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (25), on Day13, ward specialist number four (WS04) is assigned to a morning shift, then on the following day (Day14), ward specialist number four (WS04) is assigned to an evening shift, then the day after (Day15), ward specialist number four (WS04) is assigned to a night shift, then ward specialist number four (WS04) is assigned to free shifts on two consecutive off-days (on Day16 and Day17). This scenario will be the same for the rest of the ward specialists. However, the off-days for ward specialists can reach to 7 successive off-days after any assigned night shift and not only two consecutive off-days. But at the end the summation of all the off days for all ward specialists is 15 days, which is exactly the average of total number of off days for all ward specialists

Also, it is noticed that, after the assigned off-days, all ward specialists are not assigned to any on-call shift the next day, however they are assigned to morning shifts the following day. For example, from figure (25), ward specialist number four (WS04) is assigned to consecutive off-days on Day16 till Day22, then, the next day on Day23, ward specialist number four (WS04) is assigned to a morning shift and not to any other type of shifts. This scenario is the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (25), that the total number of the morning shifts, evening shifts and night shifts assigned to each ward specialist over a one-month period is equivalent between the ward specialists.

As the Average number of Morning shifts assigned to each ward specialist in a month time period is equal to 5, it is observed that all ward specialists are assigned to 5 morning shifts over a month period.

Also, since the Average number of Evening shifts assigned to each ward specialist in a month period is equal to 5, it is noticed that the total number of ward specialists' evening shifts is equal to 5.

Furthermore, the Average number of Night shifts assigned to each ward specialist in a month time period is equal to 5. Hence, it is observed that the total number of ward specialists' night shifts is equal to 5.

Thus, the balanced distribution of the workload among the ward specialists is clearly illustrated in the obtained schedule (figure 25) for all work-shifts (morning shifts, evening shifts, and night shifts) over a month. However, the objective function which aims at minimizing the sum of deviations with respect to target values of workload balance/fairness constrains is equal to 280.

7.2. The impact of changing the number of Work-Shifts

For labor specialists, when the number of work-shifts is reduced to 2 work-shifts, the target will automatically be equal to 12 work-shifts. The target is calculated as follows,

$$\alpha_{ls.t} = \frac{30\ day*2\ (\frac{shifts}{day})}{10\ labor\ specialist*(\frac{1\ shift}{2\ labor\ speialists})} = 12 \text{ work-shifts; 6 morning shifts, and 6}$$

night shifts.

It is observed that, in some days more than two labor specialists are assigned to a shift, and this indicates that the constraint is not satisfied, as only two labor specialists must be assigned to each shift and not more. For instance, from figure (26), labor specialist number four (LS04), labor specialist number five (LS05), and labor specialist number seven (LS07) are assigned to an Morning shift on Day03. Hence, the shift coverage constraint is not satisfied. However, this case is occurred in four shifts only. This constraint incorporated into the proposed model can be modified by forcing the number of labor specialists assigned to cover a shift to exactly equal 1, instead of the inequality " greater than or equal".

However, it is noticed that no labor specialist is having more than one duty in the same day. For example, from figure (26), labor specialist number one (LS01) is assigned on Day01 to a morning shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Another observation is that, each labor specialist is assigned to two consecutive workdays and to two consecutive off-days per four days. In other words, each labor specialist is assigned to two consecutive shifts per four days; in the order of morning shift, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (26), on Day15, labor specialist number two (LS02) is assigned to a morning shift, then on the following day (Day16), labor specialist number two (LS02) is assigned to a night shift, then labor specialist number two (LS02) is assigned to free shifts on two consecutive off-days (on Day17 and Day18). This scenario is the same for the rest of the labor specialists. However, the off-days for labor specialists can reach to 8 successive off-days and not only two consecutive off-days. But at the end the summation of all the off days for all labor specialists is between 17-18 days, which is close to the average of the total number of off days for all labor specialists

Also, it is noticed that, after the assigned off-days, all labor specialists are not assigned to night shifts, however they are assigned to morning shifts the following day. For example, from figure (26), labor specialist number two (LS02) is assigned to 8 consecutive off-days on (Day17 till Day24) then, the next day on Day25, labor specialist number two (LS02) is assigned to a morning shift and not to any other type of shifts. This scenario is the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (26), that the total number of the morning shifts, and night shifts assigned to each labor specialist over a one-month period is almost equivalent between the labor specialists.

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The Average number of Morning shifts assigned to each labor specialist in a month time period is equal to 6. However, it is observed that eight labor specialists are assigned to 6 morning shifts, while two labor specialists are assigned to 7 morning shifts over a month period.

Furthermore, the Average number of Night shifts assigned to each labor specialist in a month time period is equal to 6. However, it is observed that eight labor specialists are assigned to 6 night shifts, while two labor specialists are assigned to 7 night shifts over a month period.

But at the end the total number of the work-shifts assigned to each labor specialist is varying between 12-13 work-shifts per labor specialist; as 6 labor specialists are assigned for 12 work-shifts, while 4 labor specialists are assigned for 13 work-shifts. Hence, in this case, the workload distribution is almost balanced among the labor specialists.

While, for ward specialists, when the number of work-shifts is reduced to 2 work-shifts, the target will automatically be equal to 12 work-shifts. The target is calculated as follows, $\beta_{ws.t} = \dfrac{30\ day*2\ (\frac{shifts}{day})}{5\ ward\ specialist*(\frac{1\ shift}{1\ ward\ speialists})} = 12$ work-shifts; 6 morning shifts, and 6 night shifts.

It is observed that, in some days more than one ward specialist is assigned to a shift, and this indicates that the constraint is not satisfied, as only one ward specialist must be assigned to each shift and not more. For instance, from figure (27), ward specialist number one (WS01), and ward specialist number five (WS05) are assigned to a morning shift on Day08. Hence, the shift coverage constraint is not satisfied. However, this case is occurred in two shifts only. This constraint incorporated into the proposed model can be modified by forcing the number of ward specialists assigned to cover a shift to exactly equal 1, instead of the inequality " greater than or equal".

However, it is noticed that no ward specialist is having more than one duty in the same day. For example, from figure (27), ward specialist number one (WS01) is assigned on Day02 to a morning shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Another observation is that, each ward specialist is assigned to two consecutive workdays and to two consecutive off-days per four days. In other words, each ward specialist is assigned to two consecutive shifts per four days; in the order of morning shift, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (27), on Day13, ward specialist number three (WS03) is assigned to a morning shift, then on the following day (Day14), ward specialist number three (WS03) is assigned to a night shift, then ward specialist number three (WS03) is assigned to free shifts on two consecutive off-days (on Day15 and Day16). This scenario is the same for the rest of the ward specialists. However, the off-days for ward specialists can reach to 7 successive off-days and not only two consecutive off-days. But at the end the summation of all the off days for all ward specialists is between 17-18 days, which is close to the average of the total number of off days for all ward specialists

Also, it is noticed that, after the assigned off-days, all ward specialists are not assigned to night shifts the next day, however they are assigned to morning shifts the following day. For example, from figure (27), ward specialist number three (WS03) is assigned to 7 consecutive off-days on (Day15 till Day21) then, the next day on Day22, ward specialist number three (WS03) is assigned to a morning shift and not to any other type of shifts. This scenario is the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (27), that the total number of the morning shifts, and night shifts assigned to each ward specialist over a one-month period is almost equivalent between the ward specialists.

The Average number of Morning shifts assigned to each ward specialist in a month time period is equal to 6. However, it is observed that four ward specialists are assigned to 6 morning shifts, while one ward specialist is assigned to 7 morning shifts over a month period.

Furthermore, the Average number of Night shifts assigned to each ward specialist in a month time period is equal to 6. However, it is observed that four ward specialists are assigned to 6 night shifts, while one ward specialist is assigned to 7 night shifts over a month period.

But at the end the total number of the work-shifts assigned to each ward specialist is varying between 12-13 work-shifts per ward specialist; as 3 ward specialists are assigned for 12 work-shifts, while 2 ward specialists are assigned for 13 work-shifts. Hence, in this case, the workload distribution is almost balanced among the ward specialists. However, the objective function which aims at minimizing the sum of deviations with respect to target values of workload balance/fairness constrains among both labor specialists and ward specialists is equal to 560.

7.3. The impact of changing the number of Days

For labor specialists, when the number of days in a month is set to 28 days, then the target will automatically be equal to 16.8 work-shifts. The target is calculated as follows,

$$\alpha_{ls.t} = \frac{28 \, day * 3 \, (\frac{shifts}{day})}{10 \, labor \, specialist * (\frac{1 \, shift}{2 \, labor \, speialists})} = 16.8 \text{ work-shifts; } 5.6 \text{ morning}$$

shifts, and 5.6 evening shifts, and 5.6 night shifts.

It is observed that, in each day only two labor specialists are assigned to only one morning-shift, as well as only two labor specialists are assigned to only one on-call shift; meaning two labor specialists are allocated to one evening on-call and another two labor specialists are allocated to one night on-call. For instance, from figure (28), only labor specialist number three (LS03) and labor specialist number eight (LS08) are assigned to an evening shift on Day01. The same behavior is also observed for the rest. Hence, the shift coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no labor specialist is having more than one duty in the same day. For example, from figure (28), labor specialist number one (LS01) is assigned on Day01 to a morning shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

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Another observation is that, each labor specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each labor specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (28), on Day01, labor specialist number two (LS02) is assigned to a morning shift, then on the following day (Day02), labor specialist number two (LS02) is assigned to an evening shift, then the day after (Day03), labor specialist number two (LS02) is assigned to a night shift, then labor specialist number two (LS02) is assigned to free shifts on two consecutive off-days (on Day04 and Day05). This scenario will be the same for the rest of the labor specialists.

Also, it is noticed that a labor specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, from figure (28), labor specialist number two (LS02) is assigned to two consecutive off-days on Day04 and Day05, then, the next day on Day06, labor specialist number two (LS02) is assigned to a morning shift and not to any other type of shifts. This scenario will be the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (28), that the total number of the morning shifts, evening shifts, and night shifts assigned to each labor specialist over a one-month period is almost equivalent between the labor specialists.

The Average number of Morning shifts assigned to each labor specialist in a month time period of 28 days, is equal to 5.6. However, it is observed that six labor specialists are assigned to 6 morning shifts, while four labor specialists are assigned to 5 morning shifts over a month period.

Also, the Average number of Evening shifts assigned to each labor specialist in a month time period of 28 days, is equal to 5.6. However, it is observed that six labor specialists are assigned to 6 morning shifts, while four labor specialists are assigned to 5 evening shifts over a month period.

Furthermore, the Average number of Night shifts assigned to each labor specialist in a month time period of 28 days, is equal to 5.6. However, it is observed that six labor specialists are assigned to 6 night shifts, while four labor specialists are assigned to 5 night shifts over a month period.

But at the end the total number of the work-shifts assigned to each labor specialist is varying between 16-18 work-shifts per labor specialist; as 2 labor specialists are assigned for 18 work-shifts, while 4 labor specialists are assigned for 17 shifts, and the other 4 labor specialists are assigned for 16 labor specialists. Hence, in this case, the workload distribution is almost balanced among the labor specialists.

For ward specialists, when the number of days in a month is set to 28 days, then the target will automatically be equal to 16.8 work-shifts. The target is calculated as follows,

$$\beta_{ws.t} = \frac{28\ day * 3\ (\frac{shifts}{day})}{5\ ward\ specialist * (\frac{1\ shift}{1\ ward\ speialists})} = 16.8\ \text{work-shifts; 5.6 morning shifts, and}$$

5.6 evening shifts, and 5.6 night shifts.

It is observed that, in each day only one ward specialist is assigned to only one morning-shift, as well as only one ward specialist is assigned to only one on-call shift; meaning one ward specialist is allocated to one evening on-call and another one ward specialist is allocated to one night on-call. For instance, from figure (29), only ward specialist number one (WS01) is assigned to an evening shift on Day01. The same behavior is also observed for the rest. Hence, the shift coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no ward specialist is having more than one duty in the same day. For example, from figure (29), ward specialist number one (WS01) is assigned on Day01 to an evening shift and not assigned to any other shift at the same day. Another example, on Day01 ward specialist number two (WS2) is assigned to a morning shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Another observation is that, each ward specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each ward specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (29), on Day02, ward specialist number four (WS04) is assigned to a morning shift, then on the following day (Day03), ward specialist number four (WS04) is assigned to an evening shift, then the day after (Day04), ward specialist number four (WS04) is assigned to a night shift, then ward specialist number four (WS04) is assigned to free shifts on two consecutive off-days (on Day05 and Day06). This scenario will be the same for the rest of the ward specialists.

Also, it is noticed that a ward specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, from figure (29), ward specialist number four (WS04) is assigned to two consecutive off-days on Day05 and Day06, then, the next day on Day07, ward specialist number four (WS04) is assigned to a morning shift and not to any other type of shifts. This scenario will be the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (29), that the total number of the morning shifts, evening shifts, and night shifts assigned to each ward specialist over a one-month period is almost equivalent between the ward specialists.

The Average number of Morning shifts assigned to each ward specialist in a month time period of 28 days, is equal to 5.6. However, it is observed that three ward specialists are assigned to 6 morning shifts, while two ward specialists are assigned to 5 morning shifts over a month period.

Also, the Average number of Evening shifts assigned to each ward specialist in a month time period of 28 days, is equal to 5.6. However, it is observed that three ward specialists are assigned to 6 evening shifts, while two ward specialists are assigned to 5 evening shifts over a month period.

Furthermore, the Average number of Night shifts assigned to each ward specialist in a month time period of 28 days, is equal to 5.6. However, it is observed that three ward specialists are assigned to 6 night shifts, while two ward specialists are assigned to 5 night shifts over a month period.

But at the end the total number of the work-shifts assigned to each ward specialist is varying between 16-18 work-shifts per ward specialist; as 1 ward specialist is assigned for 18 work-shifts, while 2 ward specialists are assigned for 17 shifts, and the other 2 ward specialists are assigned for 16. Hence, in this case, the workload distribution is almost balanced among the ward specialists. However, the objective function which aims at minimizing the sum of deviations with respect to target values of workload balance/fairness constrains among both labor specialists and ward specialists is equal to 240.

However, when the number of days in a month for labor specialists is set to 31 days,

then the target will automatically be equal to 18.6 work-shifts. The target is calculated as

follows, $\alpha_{ls.t} = \dfrac{31 \, day * 3 \, (\frac{shifts}{day})}{10 \, labor \, specialist * (\frac{1 \, shift}{2 \, labor \, speialists})} = 18.6$ work-shifts; 6.2 morning

shifts, and 6.2 evening shifts, and 6.2 night shifts.

It is observed that, in each day only two labor specialists are assigned to only one

morning-shift, as well as only two labor specialists are assigned to only one on-call shift;

meaning two labor specialists are allocated to one evening on-call and another two labor

specialists are allocated to one night on-call. For instance, from figure (30), only labor

specialist number two (LS02) and labor specialist number three (LS03) are assigned to an

evening shift on Day01. The same behavior is also observed for the rest. Hence, the shift

coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no labor specialist is having more than one duty in the same

day. For example, from figure (30), labor specialist number one (LS01) is assigned on

Day01 to a morning shift and not assigned to any other shift at the same day. This scenario

is the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Another observation is that, each labor specialist is assigned to three consecutive

workdays and to two consecutive off-days per five days. In other words, each labor

specialist is assigned to three consecutive shifts per five days; in the order of morning shift,

then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (30), on Day01, labor specialist number one (LS01) is assigned to a morning shift, then on the following day (Day02), labor specialist number one (LS01) is assigned to an evening shift, then the day after (Day03), labor specialist number one (LS01) is assigned to a night shift, then labor specialist number one (LS01) is assigned to free shifts on two consecutive off-days (on Day04 and Day05). This scenario will be the same for the rest of the labor specialists.

Also, it is noticed that a labor specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, from figure (30), labor specialist number one (LS01) is assigned to two consecutive off-days on Day04 and Day05, then, the next day on Day06, labor specialist number one (LS01) is assigned to a morning shift and not to any other type of shifts. This scenario will be the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (30), the total number of the morning shifts, evening shifts, and night shifts assigned to each labor specialist over a one-month period is almost equivalent between the labor specialists.

The Average number of Morning shifts assigned to each labor specialist in a month time period of 31 days, is equal to 6.2. However, it is observed that two labor specialists are assigned to 7 morning shifts, while eight labor specialists are assigned to 6 morning

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shifts over a month period.

Also, the Average number of Evening shifts assigned to each labor specialist in a month time period of 31 days, is equal to 6.2. However, it is observed that two labor specialists are assigned to 7 morning shifts, while eight labor specialists are assigned to 6 evening shifts over a month period.

Furthermore, the Average number of Night shifts assigned to each labor specialist in a month time period of 31 days, is equal to 6.2. However, it is observed that two labor specialists are assigned to 7 night shifts, while eight labor specialists are assigned to 6 night shifts over a month period.

But at the end the total number of the work-shifts assigned to each labor specialist is varying between 18-19 work-shifts per labor specialist; as 6 labor specialists are assigned for 19 work-shifts, while 4 labor specialists are assigned for 18 shifts. Hence, in this case, the workload distribution is almost balanced among the labor specialists.

Whereas, when the number of days in a month for ward specialists is set to 31 days, then the target will automatically be equal to 18.6 work-shifts. The target is calculated as follows, $\beta_{ws.t} = \dfrac{31\ day * 3\ (\frac{shifts}{day})}{5\ ward\ specialist * (\frac{1\ shift}{1\ ward\ speialists})} = 18.6$ work-shifts; 6.2 morning shifts, and 6.2 evening shifts, and 6.2 night shifts.

It is observed that, in each day only one ward specialist is assigned to only one morning-shift, as well as only one ward specialist is assigned to only one on-call shift; meaning one ward specialist is allocated to one evening on-call and another one ward specialist is allocated to one night on-call. For instance, from figure (31), only ward specialist number one (WS01) is the only ward specialist who assigned to an evening shift on Day01. The same behavior is also observed for the rest. Hence, the shift coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no ward specialist is having more than one duty in the same day. For example, from figure (31), ward specialist number one (WS01) is assigned on Day01 to an evening shift and not assigned to any other shift at the same day. Another example, on Day01 ward specialist number four (WS4) is assigned to a morning shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Another observation is that, each ward specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each ward specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (31), on Day01, ward specialist number four (WS04) is assigned to a morning shift, then on the following day (Day02), ward specialist number four (WS04) is assigned to an evening shift, then the day after (Day03), ward specialist number four (WS04) is assigned to a night shift, then ward specialist number four (WS04) is assigned to free shifts on two consecutive off-days (on Day04 and Day05). This scenario will be the same for the rest of the ward specialists.

Also, it is noticed that a ward specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, from figure (31), ward specialist number four (WS04) is assigned to two consecutive off-days on Day04 and Day05, then, the next day on Day06, ward specialist number four (WS04) is assigned to a morning shift and not to any other type of shifts. This scenario will be the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (31), the total number of the morning shifts, evening shifts, and night shifts assigned to each ward specialist over a one-month period is almost equivalent between the ward specialists.

The Average number of Morning shifts assigned to each ward specialist in a month time period of 31 days, is equal to 6.2. However, it is observed that one ward specialist is assigned to 7 morning shifts, while the rest are assigned to 6 morning shifts over a month period.

Also, the Average number of Evening shifts assigned to each ward specialist in a month time period of 31 days, is equal to 6.2. However, it is observed that one ward specialist is assigned to 7 evening shifts, while the rest are assigned to 6 evening shifts over a month period.

Furthermore, the Average number of Night shifts assigned to each ward specialist in a month time period of 31 days, is equal to 6.2. However, it is that one ward specialist is assigned to 7 night shifts, while the rest are assigned to 6 night shifts over a month period.

But at the end the total number of the work-shifts assigned to each ward specialist is varying between 18-19 work-shifts per ward specialist; as 3 ward specialists are assigned for 19 work-shifts, while the other 2 ward specialists are assigned for 18 shifts. Hence, in this case, the workload distribution is almost balanced among the ward specialists. However, the objective function which aims at minimizing the sum of deviations with respect to target values of workload balance/fairness constrains among both labor specialists and ward specialists is equal to 160.

However, for labor specialist, when the scheduling is developed over 2 months (60 days), then the target will automatically be equal to 36 work-shifts. The target is calculated as follows, $\alpha_{ls.t} = \dfrac{60 \; day * 3 \; (\frac{shifts}{day})}{10 \; labor \; specialist * (\frac{1 \; shift}{2 \; labor \; speialists})} = 36$ work-shifts; 12 morning shifts, and 12 evening shifts, and 12 night shifts.

It is observed that, in each day only two labor specialists are assigned to only one morning-shift, as well as only two labor specialists are assigned to only one on-call shift; meaning two labor specialists are allocated to one evening on-call and another two labor specialists are allocated to one night on-call. For instance, from figure (32), only labor specialist number one (LS01) and labor specialist number nine (LS09) are assigned to an evening shift on Day60. The same behavior is also observed for the rest. Hence, the shift coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no labor specialist is having more than one duty in the same day. For example, from figure (32), labor specialist number one (LS01) is assigned on Day60 to an evening shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Another observation is that, each labor specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each labor specialist is assigned to three consecutive shifts per five days; in the order of morning shift,

then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (32), on Day54, labor specialist number one (LS01) is assigned to a morning shift, then on the following day (Day55), labor specialist number one (LS01) is assigned to an evening shift, then the day after (Day56), labor specialist number one (LS01) is assigned to a night shift, then labor specialist number one (LS01) is assigned to free shifts on two consecutive days (on Day57 and Day58). This scenario will be the same for the rest of the labor specialists.

Also, it is noticed that a labor specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, from figure (32), labor specialist number one (LS01) is assigned to two consecutive off-days on Day57 and Day58, then, the next day on Day59, labor specialist number one (LS01) is assigned to a morning shift and not to any other type of shifts. This scenario will be the same for the rest of the labor specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (32), the total number of the morning shifts, evening shifts, and night shifts assigned to each labor specialist over two months period is perfectly equivalent between the labor specialists.

The Average number of Morning shifts assigned to each labor specialist in two-months period of 60 days, is equal to 12. It is observed that the total number of labor specialists' morning shifts over two-months is equal to 12.

Also, the Average number of Evening shifts assigned to each labor specialist in two-months period of 60 days, is equal to 12. It is noticed that the total number of labor specialists' evening shifts over two-months is equal to 12.

Furthermore, the Average number of Night shifts assigned to each labor specialist in two-months period of 60 days, is equal to 12. It is noticed that all labor specialists are assigned for 12 evening shifts over two-months period.

Hence, the balanced distribution of the workload among the labor specialists is clearly illustrated in the obtained schedule (figure 32) for all duties (morning shifts, evening shifts, and night shifts) over two-month.

Whereas, for ward specialist, when the scheduling is developed over 2 months (60 days), then the target will automatically be equal to 36 work-shifts. The target will automatically be equal to 36 work-shifts. The target is calculated as follows,

$$\beta_{ws.t} = \frac{60\ day * 3\ (\frac{shifts}{day})}{5\ ward\ specialist * (\frac{1\ shift}{1\ ward\ speialists})} = 36 \text{ work-shifts; 12 morning shifts, and 12}$$

evening shifts, and 12 night shifts.

It is observed that, in each day only one ward specialist is assigned to only one morning-shift, as well as only one ward specialist is assigned to only one on-call shift; meaning one ward specialist is allocated to one evening on-call and another one ward specialist is allocated to one night on-call. For instance, from figure (33), only ward specialist number two (WS02) is the only ward specialist who assigned to a morning shift on Day60. The same behavior is also observed for the rest. Hence, the shift coverage constraint incorporated into the proposed model is well satisfied.

Also, it is noticed that no ward specialist is having more than one duty in the same day. For example, from figure (33), ward specialist number two (WS02) is assigned on Day60 to a morning shift and not assigned to any other shift at the same day. This scenario is the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Another observation is that, each ward specialist is assigned to three consecutive workdays and to two consecutive off-days per five days. In other words, each ward specialist is assigned to three consecutive shifts per five days; in the order of morning shift, then evening on-call, then night on-call, and after the assigned night on-call, he/she is assigned to two consecutive off days. For example, from figure (33), on Day55, ward specialist number two (WS02) is assigned to a morning shift, then on the following day (Day56), ward specialist number two (WS02) is assigned to an evening shift, then the day after (Day57), ward specialist number two (WS02) is assigned to a night shift, then ward specialist number two (WS02) is assigned to free shifts on two consecutive days (on Day58 and Day59). This scenario will be the same for the rest of the ward specialists.

Also, it is noticed that a ward specialist taking a second day-off is not assigned to any on-call shift the next day, however he/she is assigned to a morning shift the following day. For example, from figure (33), ward specialist number two (WS02) is assigned to two consecutive off-days on Day58 and Day59, then, the next day on Day60, ward specialist number two (WS02) is assigned to a morning shift and not to any other type of shifts. This scenario will be the same for the rest of the ward specialists. Hence, this constraint is well satisfied.

Regarding the fairness aspect, it is noticed from figure (33), the total number of the morning shifts, evening shifts, and night shifts assigned to each ward specialist over two-months period is perfectly equivalent between the ward specialists.

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The Average number of Morning shifts assigned to each ward specialist in two months period of 60 days, is equal to 12. It is noticed that the total number of ward specialists' morning shifts over two-months is equal to 12.

Also, the Average number of Evening shifts assigned to each ward specialist in two-months period of 60 days, is equal to 12. It is observed that the total number of ward specialists' evening shifts over two-months is equal to 12.

Furthermore, the Average number of Night shifts assigned to each ward specialist in two-months period of 60 days, is equal to 12. It is noticed that all ward specialists are assigned to 12 night shifts over two-months period.

Hence, the balanced distribution of the workload among the ward specialists is clearly illustrated in the obtained schedule (figure 33) for all duties (morning shifts, evening shifts, and night shifts) over two-months. However, the objective function which aims at minimizing the sum of deviations with respect to target values of workload balance/fairness constrains among both labor specialists and ward specialists is equal to zero.

7.4. Short Summary

At the end, it is worth mentioning that, after performing the sensitivity analysis - through running the proposed model for possibly large number of times while changing one model parameter at a time- that the outcomes (obtained physicians' schedules) of the proposed model are robust enough and can ensure the balanced/fair distribution of work-shifts among the physicians.

8. Chapter 8: Conclusion and Future Work

8.1. Conclusion

The primary goal of this project is to apply mathematical programming approach to accommodate wide range of conflicting rules and generate optimized physicians' schedules which would help to meet both the hospital and the physicians' satisfactions in a real-world case (within obstetrics and Gynecology department in Hamad Women's Hospital) and would assist indirectly in delivering a better service to female patients in Qatar.

Realizing and understanding the nature of the problem associated with the current manual physicians' schedule was the first step. Then, a literature review was conducted by presenting different solutions' methodologies used for solving the problem with different objectives set and different types of constraints listed. Next, in accordance with the hospital rules and requirements, physicians' requirements, shift coverage requirements, and physicians' preferences, a set of constraints was listed and classified into hard and soft constraints. Then, the scheduling problem was formulated as a mathematical model to schedule physicians for clinical duties over one-month planning period, while ensuing the balanced distribution of workload among the physicians. After that, the formulated model was solved and executed through using AIMMS optimization software. Then, the resulting schedules were discussed and analyzed, and the computerized optimal schedules were compared with the existing manual ones that are sued in the hospital. Finally, sensitivity analysis was performed for the sake of testing the robustness of the obtained physicians'

schedules of the proposed model. The findings indicated that high quality schedules which satisfy all the aforementioned constraints and particularly ensure the balanced distribution of workload among the physicians can be generated with less time and effort required compared to the existing manually prepared schedules.

8.2. Future Work

Due to limited time, the following is some extensions that can be incorporated into the project;

- The proposed mathematical model is valid only for specialists (labor specialists and ward specialists). However, one can extend the proposed model to incorporate other types of physicians, or develop another mathematical model for the other types of physicians (different seniority levels) within Obstetrics and Genecology department at Hamad Women's Hospital, such as residents and consultants and then integrate the proposed models altogether to come up with an optimized master physician schedule that significantly ensures the workload balance.

- The proposed model generates a static schedule; hence it cannot allow enough flexibility in the scheduling process and cannot be easily adjusted when necessary/urgent need for changes must be made. One example illustrates the need for having adaptable schedule; is, say when a physician is not available for performing the duty he/she is assigned to. It is worth mentioning that such emergency case is more likely to happen. Therefore, one can add new constraints

to the proposed model to address this case while satisfying the other constraints; which would in turn make the schedule more dynamic and flexible.

- The proposed model generates schedules that do not provide any space for specialists' preferences. In other words, once the schedules are generated, they are not flexible enough to accommodate any changes in the assignments to handle specialists' preferences of change. This issue can be solved by adding new constraints (specialists' preferences constraints) to the proposed model while satisfying the other constraints.

- The proposed model provides no solution by the available codes when the number of labor specialists is less than 10, as well as when the number of ward specialists is less than 5. Moreover, no solution would be obtained by the available codes when the number of work-shifts is more than 3. Hence, some adjustments have to be made by adding new constraints to the proposed model.

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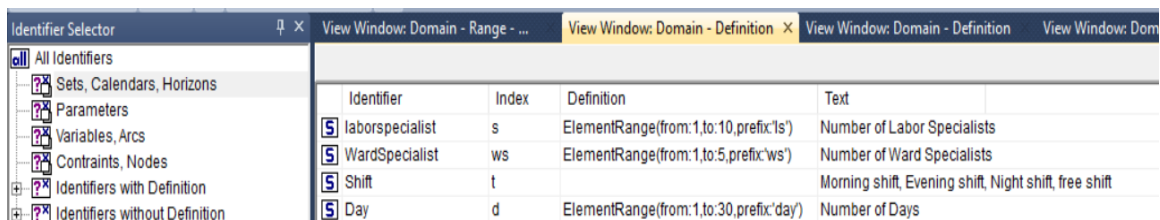Women's Hospital. (n.d.). Retrieved September 28, 2017, from https://healthandmedical.qa/site/womens-hospital/

APPENDICES

APPENDIX A: How to Create Optimal Specialists' Schedules in AIMMS Optimization

Software

The followings are the steps that have been followed in order to generate the computerized optimal specialists' schedules;

1. The figures below show the data case (inputs) which would be available for the chief specialist, who is in charge for developing the schedules at Hamad Women's Hospital. The chief specialist can adjust this data case when needed by changing the following sets and parameters:

   – Number of labor specialists(s)

   – Number of ward specialists(ws)

   – Number of shifts (t)

   – Number of days (d)

   – Average number of assignments per shift per labor specialist (Alfa)

   – Average number of assignments per shift per ward specialist (Beta)

Figure 13. The completed attribute form for the sets.

Figure 14. The completed attribute form for the parameters.

Figure 15. Alpha parameter which represents the average number of assignments per shift per labor specialist over a month period.

Figure 16. Beta parameter which represents the average number of assignments per shift per ward specialist over a month period.

2. The following is the completed attribute form for the variables and the objective function.

Figure 17. The completed attribute form for the variables and the objective function.

3. The following is the he completed attribute form for the constraints.

Figure 18. The completed attribute form for the variables and the objective function.

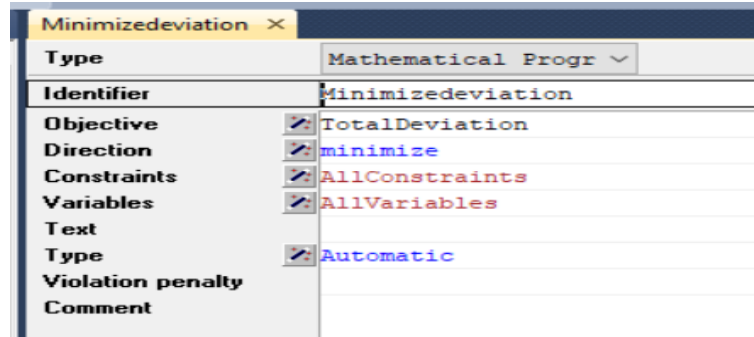4. The figure below shows the completed attribute form of the mathematical program.

Figure 19. The completed attribute form of the mathematical program.

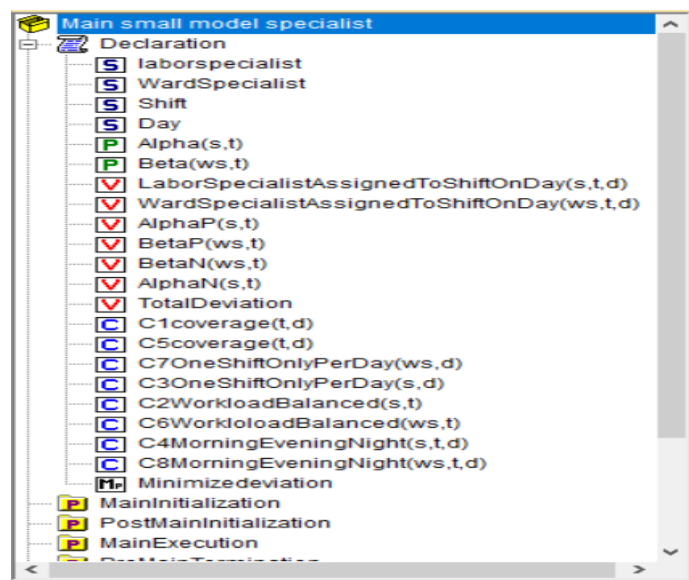5. The following is the AIMMS Model Explorer which displays the final model tree.

Figure 20. The final model-tree.

6. The figure below shows the text representation of the model.

```
[Text Repr] Main small model spec...  ×
Model Main_small_model_specialist {
    Set laborspecialist {
        Text: "Number of Labor Specialists";
        Index: s;
        Definition: ElementRange(from:1,to:10,prefix:'ls');
    }
    Set WardSpecialist {
        Text: "Number of Ward Specialists";
        Index: ws;
        Definition: ElementRange(from:1,to:5,prefix:'ws');
    }
    Set Shift {
        Text: "Morning shift, Evening shift, Night shift, free shift";
        Index: t;
    }
    Set Day {
        Text: "Number of Days";
        Index: d;
        Definition: ElementRange(from:1,to:30,prefix:'day');
    }
    Parameter Alpha {
        IndexDomain: (s,t);
        Text: "Target values, which represent the average number of assignments per shift per Labor specialist over a month period <6>";
    }
    Parameter Beta {
        IndexDomain: (ws,t);
        Text: "Target values, which represent the average number of assignments per shift per Ward specialist over a month period <6>";
    }
    Variable LaborSpecialistAssignedToShiftOnDay {
        IndexDomain: (s,t,d);
        Text: "Decision variable (labor specialist)";
        Range: binary;
    }
    Variable WardSpecialistAssignedToShiftOnDay {
        IndexDomain: (ws,t,d);
        Text: "Decision variable (ward specialist)";
        Range: binary;
    }
    Variable AlphaP {
        IndexDomain: (s,t);
        Text: "positive deviational variable that depend on Labor specialists and shifts";
        Range: nonnegative;
    }
    Variable BetaP {
        IndexDomain: (ws,t);
        Text: "positive deviational variable that depend on ward specialists and shifts";
        Range: nonnegative;
    }
    Variable BetaN {
        IndexDomain: (ws,t);
        Text: "Negative deviational variable that depend on ward specialists and shifts";
        Range: nonnegative;
    }
    Variable AlphaN {
        IndexDomain: (s,t);
        Text: "Negative deviational variable that depend on Labor specialists and shifts";
        Range: nonnegative;
    }
    Variable TotalDeviation {
        Text: "objective function: minimizes the sum of negative and positive deviations with respect to target values of workload balance constrains.";
        Range: free;
        Definition: sum[(s,t,ws), AlphaP(s,t) + AlphaN(s,t) + BetaP(ws,t) + BetaN(ws,t)];
    }
```

Continued

```
Constraint C1coverage {
    IndexDomain: (t,d);
    Text: "In each day, two Labor specialists only are assigned to only one shift";
    Definition: sum[s, LaborSpecialistAssignedToShiftOnDay(s,t,d)  ] >= 2;
}
Constraint C5coverage {
    IndexDomain: (t,d);
    Text: "In each day, one Ward specialist only is assigned to only one shift";
    Definition: sum[ws, WardSpecialistAssignedToShiftOnDay(ws,t,d)  ] >= 1;
}
Constraint C7OneShiftOnlyPerDay {
    IndexDomain: (ws,d);
    Text: "A Ward specialist cannot be assigned to more than one shift in the same day.";
    Definition: sum[t, WardSpecialistAssignedToShiftOnDay(ws,t,d)] <=1;
}
Constraint C3OneShiftOnlyPerDay {
    IndexDomain: (s,d);
    Text: "A Labor specialist cannot be assigned to more than one shift in the same day";
    Definition: sum[t, LaborSpecialistAssignedToShiftOnDay(s,t,d)] <=1;
}
Constraint C2WorkloadBalanced {
    IndexDomain: (s,t);
    Text: "Fair distribution of all shifts among all Labor specialists";
    Definition: sum[(d), LaborSpecialistAssignedToShiftOnDay(s,t,d)] + AlphaP(s,t) - AlphaN(s,t)= ALpha(s,t);
}
Constraint C6WorkloloadBalanced {
    IndexDomain: (ws,t);
    Text: "Fair distribution of all shifts among all Ward specialists";
    Definition: sum[(d), WardSpecialistAssignedToShiftOnDay(ws,t,d)] + BetaP(ws,t) - BetaN(ws,t)= Beta(ws,t);
}
```

```
Constraint C4MorningEveningNight {
    IndexDomain: (s,t,d);
    Text: {
        "Each Labor specialist must be assigned to three consecutive work-days and two consecutive off-days per five days; in the order of morning shift
    }
    Definition: LaborSpecialistAssignedToShiftOnDay(s,t,d) - LaborSpecialistAssignedToShiftOnDay(s,t+1,d+1) >= 0;
}
Constraint C8MorningEveningNight {
    IndexDomain: (ws,t,d);
    Text: {
        "Each Ward specialist must be assigned to three consecutive three consecutive work-days and two consecutive off-days per five days; in the order
    }
    Definition: WardSpecialistAssignedToShiftOnDay(ws,t,d) - WardSpecialistAssignedToShiftOnDay(ws,t+1,d+1) >= 0;
}
MathematicalProgram Minimizedeviation {
    Objective: TotalDeviation;
    Direction: minimize;
    Constraints: AllConstraints;
    Variables: AllVariables;
    Type: Automatic;
}
Procedure MainInitialization {
    Comment: "Add initialization statements here that do NOT require any library being initialized already.";
}
Procedure PostMainInitialization {
    Comment: {
        "Add initialization statements here that require that the libraries are already initialized properly,
        or add statements that require the Data Management module to be initialized."
    }
```

Continued

```
Procedure MainExecution {
    Body: {
        solve Minimizedeviation;
        if (Minimizedeviation.ProgramStatus <>'optimal') then
            empty LaborSpecialistAssignedToShiftOnDay, WardSpecialistAssignedToShiftOnDay, TotalDeviation;
        endif;
    }
}
Procedure PreMainTermination {
    Body: {
        return DataManagementExit();
    }
    Comment: {
        "Add termination statements here that require all libraries to be still alive.
        Return 1 if you allow the termination sequence to continue.
        Return 0 if you want to cancel the termination sequence."
    }
}
Procedure MainTermination {
    Body: {
        return 1;
    }
    Comment: {
        "Add termination statements here that do not require all libraries to be still alive.
        Return 1 to allow the termination sequence to continue.
        Return 0 if you want to cancel the termination sequence.
        It is recommended to only use the procedure PreMainTermination to cancel the termination sequence and let this procedure always return 1."
    }
}
```

Figure 21. Text model.

7. The figure below shows the attribute form of 'Main-Execution' which displays two statements, one to solve the mathematical program, and the other to set the solution to zero when the mathematical program is not optimal.
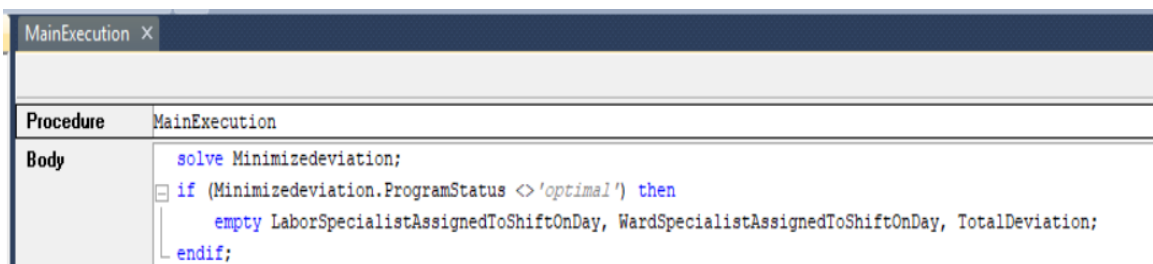

Figure 22. The attribute form of Main-Execution.

8. The figure below shows the execution progress, and as it can be seen the model is solved in 0.38 seconds only.
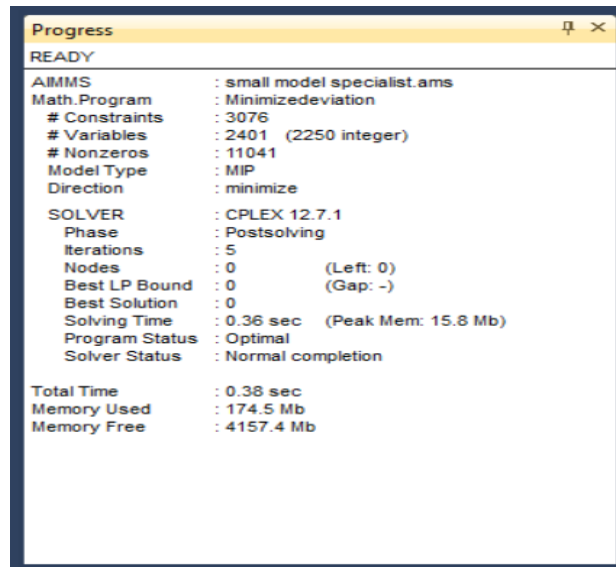


```
Progress                                                    ⚲ ×
READY
AIMMS              : small model specialist.ams
Math.Program       : Minimizedeviation
  # Constraints    : 3076
  # Variables      : 2401   (2250 integer)
  # Nonzeros       : 11041
  Model Type       : MIP
  Direction        : minimize

  SOLVER           : CPLEX 12.7.1
    Phase          : Postsolving
    Iterations     : 5
    Nodes          : 0              (Left: 0)
    Best LP Bound   : 0             (Gap: -)
    Best Solution  : 0
    Solving Time   : 0.36 sec   (Peak Mem: 15.8 Mb)
    Program Status : Optimal
    Solver Status  : Normal completion

Total Time         : 0.38 sec
Memory Used        : 174.5 Mb
Memory Free        : 4157.4 Mb
```

Figure 23. The AIMMS progress window.

It is worth mentioning that, the chief specialist should have access to the AIMMS software, and should have this model which would allow him/her to generate the solution (physicians' schedules). The specialists' schedules can be generated by a single-click from AIMMS software. The chief specialist needs only to open the AIMMS software and load the data case for this model, and then click on execute/run button without the need to make any modifications on it. As a result, the model will be solved in a few seconds, and generates the desired final schedules.

APPENDIX B: The Resulting Specialists' Schedules Using Sensitivity Analysis Technique

This section provides specialists' schedules obtained from conducting the sensitivity analysis on the proposed model,

- The schedule below illustrates the impact of changing the number of labor specialists to 12 labor specialists

d	s	Morning	Evening	Night	free1	free2
Day01	LS01	✔				
	LS02	✔				
	LS03				✔	
	LS04					✔
	LS05				✔	
	LS06		✔			
	LS07			✔		
	LS08					✔
	LS09				✔	
	LS10			✔		
	LS11		✔			
	LS12				✔	
Day02	LS01		✔			
	LS02		✔			
	LS03					✔
	LS04	✔				
	LS05					✔
	LS06			✔		
	LS07				✔	
	LS08	✔				
	LS09					✔
	LS10				✔	
	LS11			✔		
	LS12					✔
Day03	LS01			✔		
	LS02			✔		
	LS03	✔				
	LS04		✔			
	LS06				✔	
	LS07					✔
	LS08		✔			
	LS09	✔				
	LS10					✔
	LS11				✔	
Day04	LS01				✔	
	LS02				✔	
	LS03		✔			
	LS04			✔		
	LS05	✔				
	LS06					✔
	LS08			✔		
	LS09		✔			
	LS10	✔				
	LS11					✔

Continued

Day	LS	1	2	3	4	5
Day05	LS01	☐	☐	☐	☐	☑
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☑	☐	☐	☐
	LS11	☑	☐	☐	☐	☐
	LS12	☑	☐	☐	☐	☐
Day06	LS01	☑	☐	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☑	☐	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☐	☑	☐	☐
	LS11	☐	☑	☐	☐	☐
	LS12	☐	☑	☐	☐	☐
Day07	LS01	☐	☑	☐	☐	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☑	☐	☐	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☐	☐	☑	☐
	LS11	☐	☐	☑	☐	☐
	LS12	☐	☐	☑	☐	☐
Day08	LS01	☐	☐	☑	☐	☐
	LS02	☐	☑	☐	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☐	☐	☑
	LS11	☐	☐	☐	☑	☐
	LS12	☐	☐	☑	☐	☐
Day09	LS01	☐	☐	☐	☑	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☑	☐	☐	☐
Day09	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS09	☐	☑	☐	☐	☐
	LS11	☐	☐	☐	☐	☑
	LS12	☐	☐	☐	☐	☑
Day10	LS01	☐	☐	☐	☐	☑
	LS02	☐	☐	☐	☑	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS12	☑	☐	☐	☐	☐
Day11	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☑	☐	☐	☐	☐
	LS11	☑	☐	☐	☐	☐
	LS12	☐	☑	☐	☐	☐
Day12	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☑	☐	☐	☐
	LS11	☐	☑	☐	☐	☐
	LS12	☐	☐	☑	☐	☐
Day13	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☐	☑
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☑	☐	☐

Continued

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Day	LS	C1	C2	C3	C4	C5
Day13	LS11	☐	☐	☑	☐	☐
	LS12	☐	☐	☐	☑	☐
Day14	LS02	☐	☐	☑	☐	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☐	☑	☐
	LS11	☐	☐	☐	☑	☐
	LS12	☐	☐	☐	☐	☑
Day15	LS01	☑	☐	☐	☐	☐
	LS02	☐	☐	☐	☑	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☐	☐	☐	☑
	LS11	☐	☐	☐	☐	☑
Day16	LS01	☐	☑	☐	☐	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS12	☑	☐	☐	☐	☐
Day17	LS01	☐	☐	☑	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☑	☐	☐	☐	☐
	LS11	☑	☐	☐	☐	☐
	LS12	☐	☑	☐	☐	☐
Day18	LS01	☐	☐	☐	☑	☐
	LS03	☐	☐	☐	☐	☑
Day18	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☑	☐	☐
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☑	☐	☐	☐
	LS11	☐	☑	☐	☐	☐
	LS12	☐	☐	☑	☐	☐
Day19	LS01	☐	☐	☐	☐	☑
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☑	☐	☐
	LS11	☐	☐	☑	☐	☐
	LS12	☐	☐	☐	☑	☐
Day20	LS03	☑	☐	☐	☐	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☐	☐	☑	☐
	LS11	☐	☐	☐	☑	☐
	LS12	☐	☐	☐	☐	☑
Day21	LS01	☑	☐	☐	☐	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☐	☐	☐	☑
	LS11	☐	☐	☐	☐	☑
Day22	LS01	☐	☑	☐	☐	☐
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☑	☐

Continued

Day	LS	Col1	Col2	Col3	Col4	Col5
Day22	LS07					✔
	LS08	✔				
	LS09					✔
	LS12	✔				
Day23	LS01			✔		
	LS02			✔		
	LS03				✔	
	LS04					✔
	LS05				✔	
	LS06					✔
	LS07	✔				
	LS08		✔			
	LS10	✔				
	LS12		✔			
Day24	LS01				✔	
	LS02				✔	
	LS03					✔
	LS04	✔				
	LS05					✔
	LS06	✔				
	LS07		✔			
	LS08			✔		
	LS10		✔			
	LS12			✔		
Day25	LS01					✔
	LS02					✔
	LS04		✔			
	LS05	✔				
	LS06		✔			
	LS07			✔		
	LS08				✔	
	LS10			✔		
	LS11	✔				
	LS12				✔	
Day26	LS01	✔				
	LS03	✔				
	LS04			✔		
	LS05		✔			
	LS06			✔		
	LS07				✔	
	LS08					✔
	LS10				✔	
	LS11		✔			
	LS12					✔
Day26	LS08					✔
	LS10				✔	
	LS11		✔			
	LS12					✔
Day27	LS01		✔			
	LS02	✔				
	LS03		✔			
	LS04				✔	
	LS05			✔		
	LS06				✔	
	LS07					✔
	LS09	✔				
	LS10					✔
	LS11			✔		
Day28	LS01			✔		
	LS02		✔			
	LS03			✔		
	LS04					✔
	LS05				✔	
	LS06					✔
	LS08	✔				
	LS09		✔			
	LS11				✔	
	LS12	✔				
Day29	LS01				✔	
	LS02			✔		
	LS03				✔	
	LS05					✔
	LS07	✔				
	LS08		✔			
	LS09			✔		
	LS10	✔				
	LS11					✔
	LS12		✔			
Day30	LS01					✔
	LS02				✔	
	LS03					✔
	LS06	✔				
	LS07		✔			
	LS08			✔		
	LS09				✔	
	LS10		✔			
	LS11	✔				
	LS12			✔		

Figure 24. Labor specialists' schedule when the number of labor specialists is increased to 12.

– The schedule below illustrates the impact of changing the number of ward specialists to 6 ward specialists

Day	ws	Morning	Evening	Night	free1	free2
Day01	ws1		✓			
	ws2					✓
	ws3				✓	
	ws4	✓				
	ws5			✓		
	ws6				✓	
Day02	ws1			✓		
	ws2	✓				
	ws3					✓
	ws4		✓			
	ws5				✓	
	ws6					✓
Day03	ws1				✓	
	ws2		✓			
	ws4			✓		
	ws5					✓
	ws6	✓				
Day04	ws1					✓
	ws2			✓		
	ws3	✓				
	ws4				✓	
	ws6		✓			
Day05	ws1	✓				
	ws2				✓	
	ws3		✓			
	ws4					✓
	ws6			✓		
Day06	ws1		✓			
	ws2					✓
	ws3			✓		
	ws5	✓				
	ws6				✓	
Day07	ws1			✓		
	ws2	✓				
	ws3				✓	
	ws5		✓			
	ws6					✓
Day08	ws1				✓	
	ws2		✓			
	ws3					✓
	ws4	✓				
	ws5			✓		
Day09	ws1					✓
	ws2			✓		
Day09	ws3	✓				
	ws4		✓			
	ws5				✓	
Day10	ws2				✓	
	ws3		✓			
	ws4			✓		
	ws5					✓
	ws6	✓				
Day11	ws1	✓				
	ws2					✓
	ws3			✓		
	ws4				✓	
	ws6		✓			
Day12	ws1		✓			
	ws3				✓	
	ws4					✓
	ws5	✓				
	ws6			✓		
Day13	ws1			✓		
	ws3					✓
	ws4	✓				
	ws5		✓			
	ws6				✓	
Day14	ws1				✓	
	ws2	✓				
	ws4		✓			
	ws5			✓		
	ws6					✓
Day15	ws1					✓
	ws2		✓			
	ws3	✓				
	ws4			✓		
	ws5				✓	
Day16	ws1	✓				
	ws2			✓		
	ws3		✓			
	ws4				✓	
	ws5					✓
Day17	ws1		✓			
	ws2				✓	
	ws3			✓		
	ws4					✓
	ws6	✓				
Day18	ws1			✓		

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Figure 25. Ward specialists' schedule when the number of ward specialists is increased to 6.

– The schedule below illustrates the impact of changing the number of work-shifts to 2 work-shifts for labor specialists

d	s	Morning	Night	free1	free2
Day01	LS01	✓			
	LS02				✓
	LS03		✓		
	LS04			✓	
	LS05			✓	
	LS06				✓
	LS07			✓	
	LS08			✓	
	LS09		✓		
	LS10	✓			
Day02	LS01		✓		
	LS02	✓			
	LS03			✓	
	LS04				✓
	LS05				✓
	LS06	✓			
	LS07				✓
	LS08				✓
	LS09			✓	
	LS10		✓		
Day03	LS01			✓	
	LS02		✓		
	LS03				✓
	LS04	✓			
	LS05	✓			
	LS06		✓		
	LS07	✓			
	LS09				✓
	LS10			✓	
Day04	LS01				✓
	LS02			✓	
	LS03	✓			
	LS04		✓		
	LS05		✓		
	LS06			✓	
	LS07		✓		
	LS08	✓			
	LS10				✓
Day05	LS02				✓
	LS03		✓		
	LS04			✓	
	LS05			✓	
	LS06				✓
Day05	LS07			✓	
	LS08		✓		
	LS09	✓			
	LS10	✓			
Day06	LS01	✓			
	LS02	✓			
	LS03			✓	
	LS04				✓
	LS05				✓
	LS07				✓
	LS08			✓	
	LS09		✓		
	LS10		✓		
Day07	LS01		✓		
	LS02		✓		
	LS03				✓
	LS04	✓			
	LS06	✓			
	LS08				✓
	LS09			✓	
	LS10			✓	
Day08	LS01			✓	
	LS02			✓	
	LS04		✓		
	LS05	✓			
	LS06		✓		
	LS08	✓			
	LS09				✓
	LS10				✓
Day09	LS01				✓
	LS02				✓
	LS03	✓			
	LS04			✓	
	LS05		✓		
	LS06			✓	
	LS08		✓		
	LS09	✓			
Day10	LS03		✓		
	LS04				✓
	LS05			✓	
	LS06				✓
	LS07	✓			
	LS08			✓	

Continued

Day	LS	1	2	3	4
Day10	LS09	☐	☑	☐	☐
	LS10	☑	☐	☐	☐
Day11	LS02	☑	☐	☐	☐
	LS03	☐	☐	☑	☐
	LS05	☐	☐	☐	☑
	LS06	☑	☐	☐	☐
	LS07	☐	☑	☐	☐
	LS08	☐	☐	☐	☑
	LS09	☐	☐	☑	☐
	LS10	☐	☑	☐	☐
Day12	LS01	☑	☐	☐	☐
	LS02	☐	☑	☐	☐
	LS03	☐	☐	☐	☑
	LS05	☑	☐	☐	☐
	LS06	☐	☑	☐	☐
	LS07	☐	☐	☑	☐
	LS08	☑	☐	☐	☐
	LS09	☐	☐	☐	☑
	LS10	☐	☐	☑	☐
Day13	LS01	☐	☑	☐	☐
	LS02	☐	☐	☑	☐
	LS04	☑	☐	☐	☐
	LS05	☐	☑	☐	☐
	LS06	☐	☐	☑	☐
	LS07	☐	☐	☐	☑
	LS08	☐	☑	☐	☐
	LS09	☑	☐	☐	☐
	LS10	☐	☐	☐	☑
Day14	LS01	☐	☐	☑	☐
	LS02	☐	☐	☐	☑
	LS03	☑	☐	☐	☐
	LS04	☐	☑	☐	☐
	LS05	☐	☐	☑	☐
	LS06	☐	☐	☐	☑
	LS07	☑	☐	☐	☐
	LS08	☐	☐	☑	☐
	LS09	☐	☑	☐	☐
Day15	LS01	☐	☐	☐	☑
	LS02	☑	☐	☐	☐
	LS03	☐	☑	☐	☐
	LS04	☐	☐	☑	☐
	LS05	☐	☐	☐	☑
	LS07	☐	☑	☐	☐

Day	LS	1	2	3	4
Day15	LS08	☐	☐	☐	☑
	LS09	☐	☐	☑	☐
	LS10	☑	☐	☐	☐
Day16	LS02	☐	☑	☐	☐
	LS03	☐	☐	☑	☐
	LS04	☐	☐	☐	☑
	LS05	☑	☐	☐	☐
	LS07	☐	☐	☑	☐
	LS08	☑	☐	☐	☐
	LS09	☐	☐	☐	☑
	LS10	☐	☑	☐	☐
Day17	LS01	☑	☐	☐	☐
	LS02	☐	☐	☑	☐
	LS03	☐	☐	☐	☑
	LS05	☐	☑	☐	☐
	LS07	☐	☐	☐	☑
	LS08	☐	☑	☐	☐
	LS09	☑	☐	☐	☐
	LS10	☐	☐	☑	☐
Day18	LS01	☐	☑	☐	☐
	LS02	☐	☐	☐	☑
	LS03	☑	☐	☐	☐
	LS05	☐	☐	☑	☐
	LS06	☑	☐	☐	☐
	LS08	☐	☐	☑	☐
	LS09	☐	☑	☐	☐
	LS10	☐	☐	☐	☑
Day19	LS01	☐	☐	☑	☐
	LS03	☐	☑	☐	☐
	LS04	☑	☐	☐	☐
	LS05	☐	☐	☐	☑
	LS06	☐	☑	☐	☐
	LS08	☐	☐	☐	☑
	LS09	☐	☐	☑	☐
	LS10	☑	☐	☐	☐
Day20	LS01	☐	☐	☐	☑
	LS03	☐	☐	☑	☐
	LS04	☐	☑	☐	☐
	LS05	☑	☐	☐	☐
	LS06	☐	☐	☑	☐
	LS07	☑	☐	☐	☐
	LS09	☐	☐	☐	☑
	LS10	☐	☑	☐	☐

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Day	LS	Shift 1	Shift 2	Shift 3	Shift 4
Day21	LS01	✔	☐	☐	☐
	LS03	☐	☐	☐	✔
	LS04	☐	☐	✔	☐
	LS05	☐	✔	☐	☐
	LS06	☐	☐	☐	✔
	LS07	☐	✔	☐	☐
	LS09	✔	☐	☐	☐
	LS10	☐	☐	✔	☐
Day22	LS01	☐	✔	☐	☐
	LS04	☐	☐	☐	✔
	LS05	☐	☐	✔	☐
	LS06	✔	☐	☐	☐
	LS07	☐	☐	✔	☐
	LS08	✔	☐	☐	☐
	LS09	☐	✔	☐	☐
	LS10	☐	☐	☐	✔
Day23	LS01	☐	☐	✔	☐
	LS03	✔	☐	☐	☐
	LS04	✔	☐	☐	☐
	LS05	☐	☐	☐	✔
	LS06	☐	✔	☐	☐
	LS07	☐	☐	☐	✔
	LS08	☐	✔	☐	☐
	LS09	☐	☐	✔	☐
Day24	LS01	☐	☐	☐	✔
	LS03	☐	✔	☐	☐
	LS04	☐	✔	☐	☐
	LS05	✔	☐	☐	☐
	LS06	☐	☐	✔	☐
	LS07	✔	☐	☐	☐
	LS08	☐	☐	✔	☐
	LS09	☐	☐	☐	✔
Day25	LS01	✔	☐	☐	☐
	LS02	✔	☐	☐	☐
	LS03	☐	☐	✔	☐
	LS04	☐	☐	✔	☐
	LS05	☐	✔	☐	☐
	LS06	☐	☐	☐	✔
	LS07	☐	✔	☐	☐
	LS08	☐	☐	☐	✔
Day26	LS01	☐	✔	☐	☐
	LS02	☐	✔	☐	☐
	LS03	☐	☐	☐	✔
	LS04	☐	☐	☐	✔
	LS05	☐	☐	✔	☐
	LS07	☐	☐	✔	☐
	LS08	✔	☐	☐	☐
	LS09	✔	☐	☐	☐
Day27	LS01	☐	☐	✔	☐
	LS02	☐	☐	✔	☐
	LS03	✔	☐	☐	☐
	LS04	✔	☐	☐	☐
	LS05	☐	☐	☐	✔
	LS07	☐	☐	☐	✔
	LS08	☐	✔	☐	☐
	LS09	☐	✔	☐	☐
Day28	LS01	☐	☐	☐	✔
	LS02	☐	☐	☐	✔
	LS03	☐	✔	☐	☐
	LS04	☐	✔	☐	☐
	LS07	✔	☐	☐	☐
	LS08	☐	☐	✔	☐
	LS09	☐	☐	✔	☐
	LS10	✔	☐	☐	☐
Day29	LS02	✔	☐	☐	☐
	LS03	☐	☐	✔	☐
	LS04	☐	☐	✔	☐
	LS06	✔	☐	☐	☐
	LS07	☐	✔	☐	☐
	LS08	☐	☐	☐	✔
	LS09	☐	☐	☐	✔
	LS10	☐	✔	☐	☐
Day30	LS01	✔	☐	☐	☐
	LS02	☐	✔	☐	☐
	LS03	☐	☐	☐	✔
	LS04	☐	☐	☐	✔
	LS06	☐	✔	☐	☐
	LS07	☐	☐	✔	☐
	LS08	✔	☐	☐	☐
	LS10	☐	☐	✔	☐

Figure 26. Labor specialists' schedule when the number of work-shifts is reduced to 2 work-shifts.

– The schedule below illustrates the impact of changing the number of work-shifts to 2 work-shifts for ward specialists

Day	ws	Morning	Night	free1	free2
Day01	ws1				✔
	ws2		✔		
	ws3	✔			
	ws4			✔	
	ws5			✔	
Day02	ws1	✔			
	ws2			✔	
	ws3		✔		
	ws4				✔
	ws5				✔
Day03	ws1		✔		
	ws2				✔
	ws3			✔	
	ws4	✔			
Day04	ws1			✔	
	ws3				✔
	ws4		✔		
	ws5	✔			
Day05	ws1				✔
	ws3	✔			
	ws4			✔	
	ws5		✔		
Day06	ws2	✔			
	ws3		✔		
	ws4				✔
	ws5			✔	
Day07	ws2		✔		
	ws3			✔	
	ws4	✔			
	ws5				✔
Day08	ws1	✔			
	ws2			✔	
	ws3				✔
	ws4		✔		
	ws5	✔			
Day09	ws1		✔		
	ws2				✔
	ws3	✔			
	ws4			✔	
	ws5		✔		
Day10	ws1			✔	
	ws2	✔			
	ws3		✔		
	ws4				✔
Day10	ws5			✔	
Day11	ws1				✔
	ws2		✔		
	ws3			✔	
	ws4	✔			
	ws5				✔
Day12	ws2			✔	
	ws3				✔
	ws4		✔		
	ws5	✔			
Day13	ws2				✔
	ws3	✔			
	ws4			✔	
	ws5		✔		
Day14	ws2	✔			
	ws3		✔		
	ws4				✔
	ws5			✔	
Day15	ws1	✔			
	ws2		✔		
	ws3			✔	
	ws5				✔
Day16	ws1		✔		
	ws2			✔	
	ws3				✔
	ws5	✔			
Day17	ws1			✔	
	ws2				✔
	ws4	✔			
	ws5		✔		
Day18	ws1				✔
	ws2	✔			
	ws4		✔		
	ws5			✔	
Day19	ws1	✔			
	ws2		✔		
	ws4			✔	
	ws5				✔
Day20	ws1		✔		
	ws2			✔	
	ws4				✔
	ws5	✔			
Day21	ws1			✔	
	ws2				✔

Continued

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Day	WS	Col1	Col2	Col3	Col4
Day21	ws1	☐	☐	☑	☐
	ws2	☐	☐	☐	☑
	ws4	☑	☐	☐	☐
	ws5	☐	☑	☐	☐
Day22	ws1	☐	☐	☐	☑
	ws3	☑	☐	☐	☐
	ws4	☐	☑	☐	☐
	ws5	☐	☐	☑	☐
Day23	ws2	☑	☐	☐	☐
	ws3	☐	☑	☐	☐
	ws4	☐	☐	☑	☐
	ws5	☐	☐	☐	☑
Day24	ws1	☑	☐	☐	☐
	ws2	☐	☑	☐	☐
	ws3	☐	☐	☑	☐
	ws4	☐	☐	☐	☑
Day25	ws1	☐	☑	☐	☐
	ws2	☐	☐	☑	☐
	ws3	☐	☐	☐	☑
	ws4	☑	☐	☐	☐
Day26	ws1	☐	☐	☑	☐
	ws2	☐	☐	☐	☑
	ws3	☑	☐	☐	☐
	ws4	☐	☑	☐	☐
Day27	ws1	☐	☐	☐	☑
	ws2	☑	☐	☐	☐
	ws3	☐	☑	☐	☐
	ws4	☐	☐	☑	☐
Day28	ws1	☑	☐	☐	☐
	ws2	☐	☑	☐	☐
	ws3	☐	☐	☑	☐
	ws4	☐	☐	☐	☑
Day29	ws1	☐	☑	☐	☐
	ws2	☐	☐	☑	☐
	ws3	☐	☐	☐	☑
	ws5	☑	☐	☐	☐
Day30	ws1	☐	☐	☑	☐
	ws2	☐	☐	☐	☑
	ws4	☑	☐	☐	☐
	ws5	☐	☑	☐	☐

Figure 27. Ward specialists' schedule when the number of work-shifts is reduced to 2 work-shifts.

– The schedule below illustrates the impact of changing the number of days to 28 days for labor specialists

Continued

196

Day	LS					
Day09	LS07			✔		
	LS08					✔
	LS09		✔			
	LS10	✔				
Day10	LS01					✔
	LS02					✔
	LS03	✔				
	LS04				✔	
	LS05		✔			
	LS06			✔		
	LS07				✔	
	LS08	✔				
	LS09			✔		
	LS10		✔			
Day11	LS01	✔				
	LS02	✔				
	LS03		✔			
	LS04					✔
	LS05			✔		
	LS06				✔	
	LS07					✔
	LS08		✔			
	LS09				✔	
	LS10			✔		
Day12	LS01		✔			
	LS02		✔			
	LS03			✔		
	LS04	✔				
	LS05				✔	
	LS06					✔
	LS07	✔				
	LS08			✔		
	LS09					✔
	LS10				✔	
Day13	LS01			✔		
	LS02			✔		
	LS03				✔	
	LS04		✔			
	LS05					✔
	LS06	✔				
	LS07		✔			
	LS08				✔	
	LS09	✔				
Day13	LS10					✔
Day14	LS01				✔	
	LS02				✔	
	LS03					✔
	LS04			✔		
	LS05	✔				
	LS06		✔			
	LS07			✔		
	LS08					✔
	LS09		✔			
	LS10	✔				
Day15	LS01					✔
	LS02					✔
	LS03	✔				
	LS04				✔	
	LS05		✔			
	LS06			✔		
	LS07				✔	
	LS08	✔				
	LS09			✔		
	LS10		✔			
Day16	LS01	✔				
	LS02	✔				
	LS03		✔			
	LS04					✔
	LS05			✔		
	LS06				✔	
	LS07					✔
	LS08		✔			
	LS09				✔	
	LS10			✔		
Day17	LS01		✔			
	LS02		✔			
	LS03			✔		
	LS04	✔				
	LS05				✔	
	LS06					✔
	LS07	✔				
	LS08			✔		
	LS09					✔
	LS10				✔	
Day18	LS01			✔		
	LS02			✔		

Continued

197

Day	LS	1	2	3	4	5
Day18	LS03	☐	☐	☐	✔	☐
	LS04	☐	✔	☐	☐	☐
	LS05	☐	☐	☐	☐	✔
	LS06	✔	☐	☐	☐	☐
	LS07	☐	✔	☐	☐	☐
	LS08	☐	☐	☐	✔	☐
	LS09	✔	☐	☐	☐	☐
	LS10	☐	☐	☐	☐	✔
Day19	LS01	☐	☐	☐	✔	☐
	LS02	☐	☐	☐	✔	☐
	LS03	☐	☐	☐	☐	✔
	LS04	☐	☐	✔	☐	☐
	LS05	✔	☐	☐	☐	☐
	LS06	☐	✔	☐	☐	☐
	LS07	☐	☐	✔	☐	☐
	LS08	☐	☐	☐	☐	✔
	LS09	☐	✔	☐	☐	☐
	LS10	✔	☐	☐	☐	☐
Day20	LS01	☐	☐	☐	☐	✔
	LS02	☐	☐	☐	☐	✔
	LS03	✔	☐	☐	☐	☐
	LS04	☐	☐	☐	✔	☐
	LS05	☐	✔	☐	☐	☐
	LS06	☐	☐	✔	☐	☐
	LS07	☐	☐	☐	✔	☐
	LS08	✔	☐	☐	☐	☐
	LS09	☐	☐	✔	☐	☐
	LS10	☐	✔	☐	☐	☐
Day21	LS01	✔	☐	☐	☐	☐
	LS02	✔	☐	☐	☐	☐
	LS03	☐	✔	☐	☐	☐
	LS04	☐	☐	☐	☐	✔
	LS05	☐	☐	✔	☐	☐
	LS06	☐	☐	☐	✔	☐
	LS07	☐	☐	☐	☐	✔
	LS08	☐	✔	☐	☐	☐
	LS09	☐	☐	☐	✔	☐
	LS10	☐	☐	✔	☐	☐
Day22	LS01	☐	✔	☐	☐	☐
	LS02	☐	✔	☐	☐	☐
	LS03	☐	☐	✔	☐	☐
	LS04	✔	☐	☐	☐	☐
	LS05	☐	☐	☐	✔	☐
Day22	LS06	☐	☐	☐	☐	✔
	LS07	✔	☐	☐	☐	☐
	LS08	☐	☐	✔	☐	☐
	LS09	☐	☐	☐	☐	✔
	LS10	☐	☐	☐	✔	☐
Day23	LS01	☐	☐	✔	☐	☐
	LS02	☐	☐	✔	☐	☐
	LS03	☐	☐	☐	✔	☐
	LS04	☐	✔	☐	☐	☐
	LS05	☐	☐	☐	☐	✔
	LS06	✔	☐	☐	☐	☐
	LS07	☐	✔	☐	☐	☐
	LS08	☐	☐	☐	✔	☐
	LS09	✔	☐	☐	☐	☐
	LS10	☐	☐	☐	☐	✔
Day24	LS01	☐	☐	☐	✔	☐
	LS02	☐	☐	☐	✔	☐
	LS03	☐	☐	☐	☐	✔
	LS04	☐	☐	✔	☐	☐
	LS05	✔	☐	☐	☐	☐
	LS06	☐	✔	☐	☐	☐
	LS07	☐	☐	✔	☐	☐
	LS08	☐	☐	☐	☐	✔
	LS09	☐	✔	☐	☐	☐
	LS10	✔	☐	☐	☐	☐
Day25	LS01	☐	☐	☐	☐	✔
	LS02	☐	☐	☐	☐	✔
	LS03	✔	☐	☐	☐	☐
	LS04	☐	☐	☐	✔	☐
	LS05	☐	✔	☐	☐	☐
	LS06	☐	☐	✔	☐	☐
	LS07	☐	☐	☐	✔	☐
	LS08	✔	☐	☐	☐	☐
	LS09	☐	☐	✔	☐	☐
	LS10	☐	✔	☐	☐	☐
Day26	LS01	✔	☐	☐	☐	☐
	LS02	✔	☐	☐	☐	☐
	LS03	☐	✔	☐	☐	☐
	LS04	☐	☐	☐	☐	✔
	LS05	☐	☐	✔	☐	☐
	LS06	☐	☐	☐	✔	☐
	LS07	☐	☐	☐	☐	✔
	LS08	☐	✔	☐	☐	☐

Continued

Day	LS	1	2	3	4	5
Day26	LS01	☑	☐	☐	☐	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☐	☑	☐	☐
Day27	LS01	☐	☑	☐	☐	☐
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☑	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☑	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☐	☐	☑	☐
Day28	LS01	☐	☐	☑	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☐	☐	☑

Figure 28. Labor specialists' schedule when the number of days is reduced to 28 days.

– The schedule below illustrates the impact of changing the number of days to 28 days for ward specialists

d	ws	Morning	Evening	Night	free1	free2
Day01	ws1		✓			
	ws2	✓				
	ws3				✓	
	ws4					✓
	ws5			✓		
Day02	ws1			✓		
	ws2		✓			
	ws3					✓
	ws4	✓				
	ws5				✓	
Day03	ws1				✓	
	ws2			✓		
	ws3	✓				
	ws4		✓			
	ws5					✓
Day04	ws1					✓
	ws2				✓	
	ws3		✓			
	ws4			✓		
	ws5	✓				
Day05	ws1	✓				
	ws2					✓
	ws3			✓		
	ws4				✓	
	ws5		✓			
Day06	ws1		✓			
	ws2	✓				
	ws3				✓	
	ws4					✓
	ws5			✓		
Day07	ws1			✓		
	ws2		✓			
	ws3					✓
	ws4	✓				
	ws5				✓	
Day08	ws1				✓	
	ws2			✓		
	ws3	✓				
	ws4		✓			
	ws5					✓
Day09	ws1					✓
	ws2				✓	
	ws3		✓			
	ws4			✓		
Day09	ws5	✓				
Day10	ws1	✓				
	ws2					✓
	ws3			✓		
	ws4				✓	
	ws5		✓			
Day11	ws1		✓			
	ws2	✓				
	ws3				✓	
	ws4					✓
	ws5			✓		
Day12	ws1			✓		
	ws2		✓			
	ws3					✓
	ws4	✓				
	ws5				✓	
Day13	ws1				✓	
	ws2			✓		
	ws3	✓				
	ws4		✓			
	ws5					✓
Day14	ws1					✓
	ws2				✓	
	ws3		✓			
	ws4			✓		
	ws5	✓				
Day15	ws1	✓				
	ws2					✓
	ws3			✓		
	ws4				✓	
	ws5		✓			
Day16	ws1		✓			
	ws2	✓				
	ws3				✓	
	ws4					✓
	ws5			✓		
Day17	ws1			✓		
	ws2		✓			
	ws3					✓
	ws4	✓				
	ws5				✓	
Day18	ws1				✓	
	ws2			✓		
	ws3	✓				

Continued

200

Day	WS	S1	S2	S3	S4	S5
Day18	ws4	☐	✔	☐	☐	☐
	ws5	☐	☐	☐	☐	✔
Day19	ws1	☐	☐	☐	☐	✔
	ws2	☐	☐	☐	✔	☐
	ws3	☐	✔	☐	☐	☐
	ws4	☐	☐	✔	☐	☐
	ws5	✔	☐	☐	☐	☐
Day20	ws1	✔	☐	☐	☐	☐
	ws2	☐	☐	☐	☐	✔
	ws3	☐	☐	✔	☐	☐
	ws4	☐	☐	☐	✔	☐
	ws5	☐	✔	☐	☐	☐
Day21	ws1	☐	✔	☐	☐	☐
	ws2	✔	☐	☐	☐	☐
	ws3	☐	☐	☐	✔	☐
	ws4	☐	☐	☐	☐	✔
	ws5	☐	☐	✔	☐	☐
Day22	ws1	☐	☐	✔	☐	☐
	ws2	☐	✔	☐	☐	☐
	ws3	☐	☐	☐	☐	✔
	ws4	✔	☐	☐	☐	☐
	ws5	☐	☐	☐	✔	☐
Day23	ws1	☐	☐	☐	✔	☐
	ws2	☐	☐	✔	☐	☐
	ws3	✔	☐	☐	☐	☐
	ws4	☐	✔	☐	☐	☐
	ws5	☐	☐	☐	☐	✔
Day24	ws1	☐	☐	☐	☐	✔
	ws2	☐	☐	☐	✔	☐
	ws3	☐	✔	☐	☐	☐
	ws4	☐	☐	✔	☐	☐
	ws5	✔	☐	☐	☐	☐
Day25	ws1	✔	☐	☐	☐	☐
	ws2	☐	☐	☐	☐	✔
	ws3	☐	☐	✔	☐	☐
	ws4	☐	☐	☐	✔	☐
	ws5	☐	✔	☐	☐	☐
Day26	ws1	☐	✔	☐	☐	☐
	ws2	✔	☐	☐	☐	☐
	ws3	☐	☐	☐	✔	☐
	ws4	☐	☐	☐	☐	✔
	ws5	☐	☐	✔	☐	☐
Day27	ws1	☐	☐	✔	☐	☐
	ws2	☐	✔	☐	☐	☐
	ws3	☐	☐	☐	☐	✔
	ws4	✔	☐	☐	☐	☐
	ws5	☐	☐	☐	✔	☐
Day28	ws1	☐	☐	☐	✔	☐
	ws2	☐	☐	✔	☐	☐
	ws3	✔	☐	☐	☐	☐
	ws4	☐	✔	☐	☐	☐
	ws5	☐	☐	☐	☐	✔

Figure 29. Ward specialists' schedule when the number of days is reduced to 28 days.

The schedule below illustrates the impact of changing the number of days to 31 days for labor specialists

Day	s	Morning	Evening	Night	free1	free2
Day01	LS01	✔				
	LS02		✔			
	LS03		✔			
	LS04	✔				
	LS05					✔
	LS06				✔	
	LS07					✔
	LS08			✔		
	LS09				✔	
	LS10			✔		
Day02	LS01		✔			
	LS02			✔		
	LS03			✔		
	LS04		✔			
	LS05	✔				
	LS06					✔
	LS07	✔				
	LS08				✔	
	LS09					✔
	LS10				✔	
Day03	LS01			✔		
	LS02				✔	
	LS03				✔	
	LS04			✔		
	LS05		✔			
	LS06	✔				
	LS07		✔			
	LS08					✔
	LS09	✔				
	LS10					✔
Day04	LS01				✔	
	LS02					✔
	LS03					✔
	LS04				✔	
	LS05			✔		
	LS06		✔			
	LS07			✔		
	LS08	✔				
	LS09		✔			
	LS10	✔				
Day05	LS01					✔
	LS02	✔				
	LS03	✔				
Day05	LS04					✔
	LS05				✔	
	LS06			✔		
	LS07				✔	
	LS08		✔			
	LS09			✔		
	LS10		✔			
Day06	LS01	✔				
	LS02		✔			
	LS03		✔			
	LS04	✔				
	LS05					✔
	LS06				✔	
	LS07					✔
	LS08			✔		
	LS09				✔	
	LS10			✔		
Day07	LS01		✔			
	LS02			✔		
	LS03			✔		
	LS04		✔			
	LS05	✔				
	LS06					✔
	LS07	✔				
	LS08				✔	
	LS09					✔
	LS10				✔	
Day08	LS01			✔		
	LS02				✔	
	LS03				✔	
	LS04			✔		
	LS05		✔			
	LS06	✔				
	LS07		✔			
	LS08					✔
	LS09	✔				
	LS10					✔
Day09	LS01				✔	
	LS02					✔
	LS03					✔
	LS04				✔	
	LS05			✔		
	LS06		✔			

Continued

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Day	LS	C1	C2	C3	C4	C5
Day09	LS07			✔		
	LS08	✔				
	LS09		✔			
	LS10	✔				
Day10	LS01					✔
	LS02	✔				
	LS03	✔				
	LS04					✔
	LS05				✔	
	LS06			✔		
	LS07				✔	
	LS08		✔			
	LS09			✔		
	LS10		✔			
Day11	LS01	✔				
	LS02		✔			
	LS03		✔			
	LS04	✔				
	LS05					✔
	LS06				✔	
	LS07					✔
	LS08			✔		
	LS09				✔	
	LS10			✔		
Day12	LS01		✔			
	LS02			✔		
	LS03			✔		
	LS04		✔			
	LS05	✔				
	LS06					✔
	LS07	✔				
	LS08				✔	
	LS09					✔
	LS10				✔	
Day13	LS01			✔		
	LS02				✔	
	LS03				✔	
	LS04			✔		
	LS05		✔			
	LS06	✔				
	LS07		✔			
	LS08					✔
	LS09	✔				
Day13	LS10					✔
Day14	LS01				✔	
	LS02					✔
	LS03					✔
	LS04				✔	
	LS05			✔		
	LS06		✔			
	LS07			✔		
	LS08	✔				
	LS09		✔			
	LS10	✔				
Day15	LS01					✔
	LS02	✔				
	LS03	✔				
	LS04					✔
	LS05				✔	
	LS06			✔		
	LS07				✔	
	LS08		✔			
	LS09			✔		
	LS10		✔			
Day16	LS01	✔				
	LS02		✔			
	LS03		✔			
	LS04	✔				
	LS05					✔
	LS06				✔	
	LS07					✔
	LS08			✔		
	LS09				✔	
	LS10			✔		
Day17	LS01		✔			
	LS02			✔		
	LS03			✔		
	LS04		✔			
	LS05	✔				
	LS06					✔
	LS07	✔				
	LS08				✔	
	LS09					✔
	LS10				✔	
Day18	LS01			✔		
	LS02				✔	

Continued

Day	LS	C1	C2	C3	C4	C5
Day18	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☐	☐	☑
Day19	LS01	☐	☐	☐	☑	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☐	☐	☑
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☑	☐	☐	☐	☐
Day20	LS01	☐	☐	☐	☐	☑
	LS02	☑	☐	☐	☐	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☑	☐	☐	☐
Day21	LS01	☑	☐	☐	☐	☐
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☐	☑	☐	☐
Day22	LS01	☐	☑	☐	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☐	☐	☑	☐	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☑	☐	☐	☐	☐
Day22	LS06	☐	☐	☐	☐	☑
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☐	☐	☑	☐
Day23	LS01	☐	☐	☑	☐	☐
	LS02	☐	☐	☐	☑	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☐	☐	☑
Day24	LS01	☐	☐	☐	☑	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☐	☐	☐	☑
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☑	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☑	☐	☐	☐	☐
Day25	LS01	☐	☐	☐	☐	☑
	LS02	☑	☐	☐	☐	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☐	☑	☐	☐	☐
Day26	LS01	☑	☐	☐	☐	☐
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☑	☐	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☑	☐	☐

Continued

Figure 30. Labor specialists' schedule when the number of days is increased to 31 days.

– The schedule below illustrates the impact of changing the number of days to 31 days for ward specialists

Continued

Day	WS	1	2	3	4	5
Day18	ws4			✔		
	ws5					✔
Day19	ws1					✔
	ws2		✔			
	ws3			✔		
	ws4				✔	
	ws5	✔				
Day20	ws1	✔				
	ws2			✔		
	ws3				✔	
	ws4					✔
	ws5		✔			
Day21	ws1		✔			
	ws2				✔	
	ws3					✔
	ws4	✔				
	ws5			✔		
Day22	ws1			✔		
	ws2					✔
	ws3	✔				
	ws4		✔			
	ws5				✔	
Day23	ws1				✔	
	ws2	✔				
	ws3		✔			
	ws4			✔		
	ws5					✔
Day24	ws1					✔
	ws2		✔			
	ws3			✔		
	ws4				✔	
	ws5	✔				
Day25	ws1	✔				
	ws2			✔		
	ws3				✔	
	ws4					✔
	ws5		✔			
Day26	ws1		✔			
	ws2				✔	
	ws3					✔
	ws4	✔				
	ws5			✔		
Day27	ws1			✔		
	ws2					✔
	ws3	✔				
	ws4		✔			
	ws5				✔	
Day28	ws1				✔	
	ws2	✔				
	ws3		✔			
	ws4			✔		
	ws5					✔
Day29	ws1					✔
	ws2		✔			
	ws3			✔		
	ws4				✔	
	ws5	✔				
Day30	ws1	✔				
	ws2			✔		
	ws3				✔	
	ws4					✔
	ws5		✔			
Day31	ws1		✔			
	ws2				✔	
	ws3					✔
	ws4	✔				
	ws5			✔		

Figure 31. Ward specialists' schedule when the number of days is increased to 31 days.

–   The schedule below illustrates the impact of changing the number of days to 60 days (2-months) for labor specialists

d	s	Morning	Evening	Night	free1	free2
Day01	LS01			✓		
	LS02					✓
	LS03		✓			
	LS04					✓
	LS05				✓	
	LS06	✓				
	LS07				✓	
	LS08		✓			
	LS09			✓		
	LS10	✓				
Day02	LS01				✓	
	LS02	✓				
	LS03			✓		
	LS04	✓				
	LS05					✓
	LS06		✓			
	LS07					✓
	LS08			✓		
	LS09				✓	
	LS10		✓			
Day03	LS01					✓
	LS02		✓			
	LS03				✓	
	LS04		✓			
	LS05	✓				
	LS06			✓		
	LS07	✓				
	LS08				✓	
	LS09					✓
	LS10			✓		
Day04	LS01	✓				
	LS02			✓		
	LS03					✓
	LS04			✓		
	LS05		✓			
	LS06				✓	
	LS07		✓			
	LS08					✓
	LS09	✓				
	LS10				✓	
Day05	LS01		✓			
	LS02				✓	
	LS03	✓				
Day05	LS04				✓	
	LS05			✓		
	LS06					✓
	LS07			✓		
	LS08	✓				
	LS09		✓			
	LS10					✓
Day06	LS01			✓		
	LS02					✓
	LS03		✓			
	LS04					✓
	LS05				✓	
	LS06	✓				
	LS07				✓	
	LS08		✓			
	LS09			✓		
	LS10	✓				
Day07	LS01				✓	
	LS02	✓				
	LS03			✓		
	LS04	✓				
	LS05					✓
	LS06		✓			
	LS07					✓
	LS08			✓		
	LS09				✓	
	LS10		✓			
Day08	LS01					✓
	LS02		✓			
	LS03				✓	
	LS04		✓			
	LS05	✓				
	LS06			✓		
	LS07	✓				
	LS08				✓	
	LS09					✓
	LS10			✓		
Day09	LS01	✓				
	LS02			✓		
	LS03					✓
	LS04			✓		
	LS05		✓			
	LS06				✓	

Continued

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Day	LS	C1	C2	C3	C4	C5
Day09	LS07		✔			
	LS08					✔
	LS09	✔				
	LS10				✔	
Day10	LS01		✔			
	LS02				✔	
	LS03	✔				
	LS04				✔	
	LS05			✔		
	LS06					✔
	LS07			✔		
	LS08	✔				
	LS09		✔			
	LS10					✔
Day11	LS01			✔		
	LS02					✔
	LS03		✔			
	LS04					✔
	LS05				✔	
	LS06	✔				
	LS07				✔	
	LS08		✔			
	LS09			✔		
	LS10	✔				
Day12	LS01				✔	
	LS02	✔				
	LS03			✔		
	LS04	✔				
	LS05					✔
	LS06		✔			
	LS07					✔
	LS08			✔		
	LS09				✔	
	LS10		✔			
Day13	LS01					✔
	LS02		✔			
	LS03				✔	
	LS04		✔			
	LS05	✔				
	LS06			✔		
	LS07	✔				
	LS08				✔	
	LS09					✔
Day13	LS10			✔		
Day14	LS01	✔				
	LS02			✔		
	LS03					✔
	LS04			✔		
	LS05		✔			
	LS06				✔	
	LS07		✔			
	LS08					✔
	LS09	✔				
	LS10				✔	
Day15	LS01		✔			
	LS02				✔	
	LS03	✔				
	LS04				✔	
	LS05			✔		
	LS06					✔
	LS07			✔		
	LS08	✔	✔			
	LS09		✔			
	LS10					✔
Day16	LS01			✔		
	LS02					✔
	LS03		✔			
	LS04					✔
	LS05				✔	
	LS06	✔				
	LS07				✔	
	LS08		✔			
	LS09			✔		
	LS10	✔				
Day17	LS01				✔	
	LS02	✔				
	LS03			✔		
	LS04	✔				
	LS05					✔
	LS06		✔			
	LS07					✔
	LS08			✔		
	LS09				✔	
	LS10		✔			
Day18	LS01					✔
	LS02		✔			

Continued

Day	LS	C1	C2	C3	C4	C5
Day18	LS03				✓	
	LS04		✓			
	LS05	✓				
	LS06			✓		
	LS07	✓				
	LS08				✓	
	LS09					✓
	LS10			✓		
Day19	LS01	✓				
	LS02			✓		
	LS03					✓
	LS04			✓		
	LS05		✓			
	LS06				✓	
	LS07		✓			
	LS08					✓
	LS09	✓				
	LS10				✓	
Day20	LS01		✓			
	LS02				✓	
	LS03	✓				
	LS04				✓	
	LS05			✓		
	LS06					✓
	LS07			✓		
	LS08	✓				
	LS09		✓			
	LS10					✓
Day21	LS01			✓		
	LS02					✓
	LS03		✓			
	LS04					✓
	LS05				✓	
	LS06	✓				
	LS07				✓	
	LS08		✓			
	LS09			✓		
	LS10	✓				
Day22	LS01				✓	
	LS02	✓				
	LS03			✓		
	LS04	✓				
	LS05					✓
Day22	LS06		✓			
	LS07					✓
	LS08			✓		
	LS09				✓	
	LS10		✓			
Day23	LS01					✓
	LS02		✓			
	LS03				✓	
	LS04		✓			
	LS05	✓				
	LS06			✓		
	LS07	✓				
	LS08				✓	
	LS09					✓
	LS10			✓		
Day24	LS01	✓				
	LS02			✓		
	LS03					✓
	LS04			✓		
	LS05		✓			
	LS06				✓	
	LS07		✓			
	LS08					✓
	LS09	✓				
	LS10				✓	
Day25	LS01		✓			
	LS02				✓	
	LS03	✓				
	LS04				✓	
	LS05			✓		
	LS06					✓
	LS07			✓		
	LS08	✓				
	LS09		✓			
	LS10					✓
Day26	LS01			✓		
	LS02					✓
	LS03		✓			
	LS04					✓
	LS05				✓	
	LS06	✓				
	LS07				✓	
	LS08		✓			

Continued

210

Day	LS	1	2	3	4	5
Day26	LS09	☐	☐	☑	☐	☐
	LS10	☑	☐	☐	☐	☐
Day27	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☑	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☑	☐	☐	☐
Day28	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☐	☑	☐	☐
Day29	LS01	☑	☐	☐	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☐	☑	☐
Day30	LS01	☐	☑	☐	☐	☐
	LS02	☐	☐	☐	☑	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☐	☐	☑	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☐	☐	☑
Day31	LS01	☐	☐	☑	☐	☐

Day	LS	1	2	3	4	5
Day31	LS02	☐	☐	☐	☐	☑
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☑	☐	☐	☐	☐
Day32	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☑	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☑	☐	☐	☐
Day33	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☐	☑	☐	☐
Day34	LS01	☑	☐	☐	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☑	☐	☐	☐
	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☐	☑	☐
Day35	LS01	☐	☑	☐	☐	☐
	LS02	☐	☐	☐	☑	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☐	☐	☑	☐

Continued

Day	LS	C1	C2	C3	C4	C5
Day35	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☐	☐	☑	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☐	☐	☑
Day36	LS01	☐	☐	☑	☐	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☑	☐	☐	☐	☐
Day37	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☑	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☑	☐	☐	☐
Day38	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☐	☑	☐	☐
Day39	LS01	☑	☐	☐	☐	☐
	LS02	☐	☐	☑	☐	☐
	LS03	☐	☐	☐	☐	☑
	LS04	☐	☐	☑	☐	☐
	LS05	☐	☑	☐	☐	☐
	LS06	☐	☐	☐	☑	☐
	LS07	☐	☑	☐	☐	☐

Day	LS	C1	C2	C3	C4	C5
Day39	LS08	☐	☐	☐	☐	☑
	LS09	☑	☐	☐	☐	☐
	LS10	☐	☐	☐	☑	☐
Day40	LS01	☐	☑	☐	☐	☐
	LS02	☐	☐	☐	☑	☐
	LS03	☑	☐	☐	☐	☐
	LS04	☐	☐	☐	☑	☐
	LS05	☐	☐	☑	☐	☐
	LS06	☐	☐	☐	☐	☑
	LS07	☐	☐	☑	☐	☐
	LS08	☑	☐	☐	☐	☐
	LS09	☐	☑	☐	☐	☐
	LS10	☐	☐	☐	☐	☑
Day41	LS01	☐	☐	☑	☐	☐
	LS02	☐	☐	☐	☐	☑
	LS03	☐	☑	☐	☐	☐
	LS04	☐	☐	☐	☐	☑
	LS05	☐	☐	☐	☑	☐
	LS06	☑	☐	☐	☐	☐
	LS07	☐	☐	☐	☑	☐
	LS08	☐	☑	☐	☐	☐
	LS09	☐	☐	☑	☐	☐
	LS10	☑	☐	☐	☐	☐
Day42	LS01	☐	☐	☐	☑	☐
	LS02	☑	☐	☐	☐	☐
	LS03	☐	☐	☑	☐	☐
	LS04	☑	☐	☐	☐	☐
	LS05	☐	☐	☐	☐	☑
	LS06	☐	☑	☐	☐	☐
	LS07	☐	☐	☐	☐	☑
	LS08	☐	☐	☑	☐	☐
	LS09	☐	☐	☐	☑	☐
	LS10	☐	☑	☐	☐	☐
Day43	LS01	☐	☐	☐	☐	☑
	LS02	☐	☑	☐	☐	☐
	LS03	☐	☐	☐	☑	☐
	LS04	☐	☑	☐	☐	☐
	LS05	☑	☐	☐	☐	☐
	LS06	☐	☐	☑	☐	☐
	LS07	☑	☐	☐	☐	☐
	LS08	☐	☐	☐	☑	☐
	LS09	☐	☐	☐	☐	☑
	LS10	☐	☐	☑	☐	☐

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Day	LS	C1	C2	C3	C4	C5
Day44	LS01	✔				
	LS02			✔		
	LS03					✔
	LS04			✔		
	LS05		✔			
	LS06				✔	
	LS07		✔			
	LS08					✔
	LS09	✔				
	LS10				✔	
Day45	LS01		✔			
	LS02				✔	
	LS03	✔				
	LS04				✔	
	LS05			✔		
	LS06					✔
	LS07			✔		
	LS08	✔				
	LS09		✔			
	LS10					✔
Day46	LS01			✔		
	LS02					✔
	LS03		✔			
	LS04					✔
	LS05				✔	
	LS06	✔				
	LS07				✔	
	LS08		✔			
	LS09			✔		
	LS10	✔				
Day47	LS01				✔	
	LS02	✔				
	LS03			✔		
	LS04	✔				
	LS05					✔
	LS06		✔			
	LS07					✔
	LS08			✔		
	LS09				✔	
	LS10		✔			
Day48	LS01					✔
	LS02		✔			
	LS03				✔	
Day48	LS04		✔			
	LS05	✔				
	LS06			✔		
	LS07	✔				
	LS08				✔	
	LS09					✔
	LS10			✔		
Day49	LS01	✔				
	LS02			✔		
	LS03					✔
	LS04			✔		
	LS05		✔			
	LS06				✔	
	LS07		✔			
	LS08					✔
	LS09	✔				
	LS10				✔	
Day50	LS01		✔			
	LS02				✔	
	LS03	✔				
	LS04				✔	
	LS05			✔		
	LS06					✔
	LS07			✔		
	LS08	✔				
	LS09		✔			
	LS10					✔
Day51	LS01			✔		
	LS02					✔
	LS03		✔			
	LS04					✔
	LS05				✔	
	LS06	✔				
	LS07				✔	
	LS08		✔			
	LS09			✔		
	LS10	✔				
Day52	LS01				✔	
	LS02	✔				
	LS03			✔		
	LS04	✔				
	LS05					✔
	LS06		✔			

Continued

Day	LS	1	2	3	4	5
Day52	LS07					✓
	LS08			✓		
	LS09				✓	
	LS10		✓			
Day53	LS01					✓
	LS02		✓			
	LS03				✓	
	LS04		✓			
	LS05	✓				
	LS06			✓		
	LS07	✓				
	LS08				✓	
	LS09					✓
	LS10			✓		
Day54	LS01	✓				
	LS02			✓		
	LS03					✓
	LS04			✓		
	LS05		✓			
	LS06				✓	
	LS07		✓			
	LS08					✓
	LS09	✓				
	LS10				✓	
Day55	LS01		✓			
	LS02				✓	
	LS03	✓				
	LS04				✓	
	LS05			✓		
	LS06					✓
	LS07			✓		
	LS08	✓				
	LS09		✓			
	LS10					✓
Day56	LS01			✓		
	LS02					✓
	LS03		✓			
	LS04					✓
	LS05				✓	
	LS06	✓				
	LS07				✓	
	LS08		✓			
	LS09			✓		
Day56	LS09			✓		
	LS10	✓				
Day57	LS01				✓	
	LS02	✓				
	LS03			✓		
	LS04	✓				
	LS05					✓
	LS06		✓			
	LS07					✓
	LS08			✓		
	LS09				✓	
	LS10		✓			
Day58	LS01					✓
	LS02		✓			
	LS03				✓	
	LS04		✓			
	LS05	✓				
	LS06			✓		
	LS07	✓				
	LS08				✓	
	LS09					✓
	LS10			✓		
Day59	LS01	✓				
	LS02				✓	
	LS03					✓
	LS04			✓		
	LS05		✓			
	LS06				✓	
	LS07		✓			
	LS08					✓
	LS09	✓				
	LS10				✓	
Day60	LS01		✓			
	LS02				✓	
	LS03	✓				
	LS04				✓	
	LS05			✓		
	LS06					✓
	LS07			✓		
	LS08	✓				
	LS09		✓			
	LS10					✓

Figure 32. Labor specialists' schedule for 2-months period (60 days).

The schedule below illustrates the impact of changing the number of days to 60 days (2-months) for ward specialists

d	ws	Morning	Evening	Night	free1	free2
Day01	ws1					✔
	ws2		✔			
	ws3	✔				
	ws4			✔		
	ws5				✔	
Day02	ws1	✔				
	ws2			✔		
	ws3		✔			
	ws4				✔	
	ws5					✔
Day03	ws1		✔			
	ws2				✔	
	ws3			✔		
	ws4					✔
	ws5	✔				
Day04	ws1			✔		
	ws2					✔
	ws3				✔	
	ws4	✔				
	ws5		✔			
Day05	ws1				✔	
	ws2	✔				
	ws3					✔
	ws4		✔			
	ws5			✔		
Day06	ws1					✔
	ws2		✔			
	ws3	✔				
	ws4			✔		
	ws5				✔	
Day07	ws1	✔				
	ws2			✔		
	ws3		✔			
	ws4				✔	
	ws5					✔
Day08	ws1		✔			
	ws2				✔	
	ws3			✔		
	ws4					✔
	ws5	✔				
Day09	ws1			✔		
	ws2					✔
	ws3				✔	
	ws4	✔				
Day09	ws5		✔			
Day10	ws1				✔	
	ws2	✔				
	ws3					✔
	ws4		✔			
	ws5			✔		
Day11	ws1					✔
	ws2		✔			
	ws3	✔				
	ws4			✔		
	ws5				✔	
Day12	ws1	✔				
	ws2			✔		
	ws3		✔			
	ws4				✔	
	ws5					✔
Day13	ws1		✔			
	ws2				✔	
	ws3			✔		
	ws4					✔
	ws5	✔				
Day14	ws1			✔		
	ws2					✔
	ws3				✔	
	ws4	✔				
	ws5		✔			
Day15	ws1				✔	
	ws2	✔				
	ws3					✔
	ws4		✔			
	ws5			✔		
Day16	ws1					✔
	ws2		✔			
	ws3	✔				
	ws4			✔		
	ws5				✔	
Day17	ws1	✔				
	ws2			✔		
	ws3		✔			
	ws4				✔	
	ws5					✔
Day18	ws1		✔			
	ws2				✔	
	ws3			✔		

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Day	ws	1	2	3	4	5
Day18	ws4	☐	☐	☐	☐	☑
	ws5	☑	☐	☐	☐	☐
Day19	ws1	☐	☐	☑	☐	☐
	ws2	☐	☐	☐	☐	☑
	ws3	☐	☐	☐	☑	☐
	ws4	☑	☐	☐	☐	☐
	ws5	☐	☑	☐	☐	☐
Day20	ws1	☐	☐	☐	☑	☐
	ws2	☑	☐	☐	☐	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☑	☐	☐	☐
	ws5	☐	☐	☑	☐	☐
Day21	ws1	☐	☐	☐	☐	☑
	ws2	☐	☑	☐	☐	☐
	ws3	☑	☐	☐	☐	☐
	ws4	☐	☐	☑	☐	☐
	ws5	☐	☐	☐	☑	☐
Day22	ws1	☑	☐	☐	☐	☐
	ws2	☐	☐	☑	☐	☐
	ws3	☐	☑	☐	☐	☐
	ws4	☐	☐	☐	☑	☐
	ws5	☐	☐	☐	☐	☑
Day23	ws1	☐	☑	☐	☐	☐
	ws2	☐	☐	☐	☑	☐
	ws3	☐	☐	☑	☐	☐
	ws4	☐	☐	☐	☐	☑
	ws5	☑	☐	☐	☐	☐
Day24	ws1	☐	☐	☑	☐	☐
	ws2	☐	☐	☐	☐	☑
	ws3	☐	☐	☐	☑	☐
	ws4	☑	☐	☐	☐	☐
	ws5	☐	☑	☐	☐	☐
Day25	ws1	☐	☐	☐	☑	☐
	ws2	☑	☐	☐	☐	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☑	☐	☐	☐
	ws5	☐	☐	☑	☐	☐
Day26	ws1	☐	☐	☐	☐	☑
	ws2	☐	☑	☐	☐	☐
	ws3	☑	☐	☐	☐	☐
	ws4	☐	☐	☑	☐	☐
	ws5	☐	☐	☐	☑	☐
Day27	ws1	☑	☐	☐	☐	☐
	ws2	☐	☐	☑	☐	☐
Day27	ws3	☐	☑	☐	☐	☐
	ws4	☐	☐	☐	☑	☐
	ws5	☐	☐	☐	☐	☑
Day28	ws1	☐	☑	☐	☐	☐
	ws2	☐	☐	☐	☑	☐
	ws3	☐	☐	☑	☐	☐
	ws4	☐	☐	☐	☐	☑
	ws5	☑	☐	☐	☐	☐
Day29	ws1	☐	☐	☑	☐	☐
	ws2	☐	☐	☐	☐	☑
	ws3	☐	☐	☐	☑	☐
	ws4	☑	☐	☐	☐	☐
	ws5	☐	☑	☐	☐	☐
Day30	ws1	☐	☐	☐	☑	☐
	ws2	☑	☐	☐	☐	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☑	☐	☐	☐
	ws5	☐	☐	☑	☐	☐
Day31	ws1	☐	☐	☐	☐	☑
	ws2	☐	☑	☐	☐	☐
	ws3	☑	☐	☐	☐	☐
	ws4	☐	☐	☑	☐	☐
	ws5	☐	☐	☐	☑	☐
Day32	ws1	☑	☐	☐	☐	☐
	ws2	☐	☐	☑	☐	☐
	ws3	☐	☑	☐	☐	☐
	ws4	☐	☐	☐	☑	☐
	ws5	☐	☐	☐	☐	☑
Day33	ws1	☐	☑	☐	☐	☐
	ws2	☐	☐	☐	☑	☐
	ws3	☐	☐	☑	☐	☐
	ws4	☐	☐	☐	☐	☑
	ws5	☑	☐	☐	☐	☐
Day34	ws1	☐	☐	☑	☐	☐
	ws2	☐	☐	☐	☐	☑
	ws3	☐	☐	☐	☑	☐
	ws4	☑	☐	☐	☐	☐
	ws5	☐	☑	☐	☐	☐
Day35	ws1	☐	☐	☐	☑	☐
	ws2	☑	☐	☐	☐	☐
	ws3	☐	☐	☐	☐	☑
	ws4	☐	☑	☐	☐	☐
	ws5	☐	☐	☑	☐	☐
Day36	ws1	☐	☐	☐	☐	☑

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Day	ws	C1	C2	C3	C4	C5
Day36	ws2	☐	✔	☐	☐	☐
	ws3	✔	☐	☐	☐	☐
	ws4	☐	☐	✔	☐	☐
	ws5	☐	☐	☐	✔	☐
Day37	ws1	✔	☐	☐	☐	☐
	ws2	☐	☐	✔	☐	☐
	ws3	☐	✔	☐	☐	☐
	ws4	☐	☐	☐	✔	☐
	ws5	☐	☐	☐	☐	✔
Day38	ws1	☐	✔	☐	☐	☐
	ws2	☐	☐	☐	✔	☐
	ws3	☐	☐	✔	☐	☐
	ws4	☐	☐	☐	☐	✔
	ws5	✔	☐	☐	☐	☐
Day39	ws1	☐	☐	✔	☐	☐
	ws2	☐	☐	☐	☐	✔
	ws3	☐	☐	☐	✔	☐
	ws4	✔	☐	☐	☐	☐
	ws5	☐	✔	☐	☐	☐
Day40	ws1	☐	☐	☐	✔	☐
	ws2	✔	☐	☐	☐	☐
	ws3	☐	☐	☐	☐	✔
	ws4	☐	✔	☐	☐	☐
	ws5	☐	☐	✔	☐	☐
Day41	ws1	☐	☐	☐	☐	✔
	ws2	☐	✔	☐	☐	☐
	ws3	✔	☐	☐	☐	☐
	ws4	☐	☐	✔	☐	☐
	ws5	☐	☐	☐	✔	☐
Day42	ws1	✔	☐	☐	☐	☐
	ws2	☐	☐	✔	☐	☐
	ws3	☐	✔	☐	☐	☐
	ws4	☐	☐	☐	✔	☐
	ws5	☐	☐	☐	☐	✔
Day43	ws1	☐	✔	☐	☐	☐
	ws2	☐	☐	☐	✔	☐
	ws3	☐	☐	✔	☐	☐
	ws4	☐	☐	☐	☐	✔
	ws5	✔	☐	☐	☐	☐
Day44	ws1	☐	☐	✔	☐	☐
	ws2	☐	☐	☐	☐	✔
	ws3	☐	☐	☐	✔	☐
	ws4	✔	☐	☐	☐	☐
	ws5	☐	✔	☐	☐	☐
Day45	ws1	☐	☐	☐	✔	☐
	ws2	✔	☐	☐	☐	☐
	ws3	☐	☐	☐	☐	✔
	ws4	☐	✔	☐	☐	☐
	ws5	☐	☐	✔	☐	☐
Day46	ws1	☐	☐	☐	☐	✔
	ws2	☐	✔	☐	☐	☐
	ws3	✔	☐	☐	☐	☐
	ws4	☐	☐	✔	☐	☐
	ws5	☐	☐	☐	✔	☐
Day47	ws1	✔	☐	☐	☐	☐
	ws2	☐	☐	✔	☐	☐
	ws3	☐	✔	☐	☐	☐
	ws4	☐	☐	☐	✔	☐
	ws5	☐	☐	☐	☐	✔
Day48	ws1	☐	✔	☐	☐	☐
	ws2	☐	☐	☐	✔	☐
	ws3	☐	☐	✔	☐	☐
	ws4	☐	☐	☐	☐	✔
	ws5	✔	☐	☐	☐	☐
Day49	ws1	☐	☐	✔	☐	☐
	ws2	☐	☐	☐	☐	✔
	ws3	☐	☐	☐	✔	☐
	ws4	✔	☐	☐	☐	☐
	ws5	☐	✔	☐	☐	☐
Day50	ws1	☐	☐	☐	✔	☐
	ws2	✔	☐	☐	☐	☐
	ws3	☐	☐	☐	☐	✔
	ws4	☐	✔	☐	☐	☐
	ws5	☐	☐	✔	☐	☐
Day51	ws1	☐	☐	☐	☐	✔
	ws2	☐	✔	☐	☐	☐
	ws3	✔	☐	☐	☐	☐
	ws4	☐	☐	✔	☐	☐
	ws5	☐	☐	☐	✔	☐
Day52	ws1	✔	☐	☐	☐	☐
	ws2	☐	☐	✔	☐	☐
	ws3	☐	✔	☐	☐	☐
	ws4	☐	☐	☐	✔	☐
	ws5	☐	☐	☐	☐	✔
Day53	ws1	☐	✔	☐	☐	☐
	ws2	☐	☐	☐	✔	☐
	ws3	☐	☐	✔	☐	☐
	ws4	☐	☐	☐	☐	✔

Continued

Figure 33. Ward specialists' schedule for 2 months period (60 days).