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Scheduling Elective Surgeries in Operation Room with Optimization of Post-Surgery Recovery Unit Capacity

Navneetkumar Rameshbhai Rafaliya
University of Windsor

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By

Navneetkumar Rameshbhai Rafaliya

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Navneetkumar Rameshbhai Rafaliya

APPROVED BY:

____
Dr. Maher El-Masri
Faculty of Nursing

____
Dr. Walid Abdul-Kader
Industrial & Manufacturing Systems Engineering

____
Dr. Mohammed Fazle Baki, Advisor
Industrial & Manufacturing Systems Engineering

____
Dr. Ben A Chaouch, Chair of Defense
Odette School of Business

24 January 2013

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ABSTRACT

Scheduling of surgeries in the Operation rooms with limited available resources is a very complex process. Patients of different specialties are operated by surgery teams in operation rooms and sent to recovery units. In this thesis, we develop a model to help Operation room scheduling management to schedule elective patients based on the availability of surgeons and operation rooms with three phase hierarchical approach of scheduling. A linear integer goal programming method is used to solve problem. The model tries to minimize number of patients waiting for service, underutilization of operating room hours and maximum number of patients in the recovery units. Windsor Regional Hospital help is taken to understand the surgery booking procedure. Lexicographic goal programming method and weighted goal programming is employed and various combinations of priorities are solved to schedule Operating rooms. The focus of the study is to develop mathematical model for scheduling.

DEDICATION

कायेन वाचा मनसेंद्रियैर्वा , बुध्ध्यात्मनावा प्रकृते स्वभावात् |

करोमि यद्यत्सकलं परस्मै, नारायणायेति समर्पयामि ||

(Whatever I do with my mind, body, speech or with other senses of my body, or with my intellect or with my innate natural tendencies, I offer everything to the Lord!)

Dedicated to

To my respected Teachers

To my loving Family

To my caring Friends

ACKNOWLEDGEMENTS

“Tell me and I’ll forget; show me and I may remember; involve me and I’ll understand.” - Confucius

I take this opportunity to thank my supervisor Dr. Mohammed Fazle Baki, for believing in me when I was not sure of myself. Without his patience this work would have not been possible. Thanks for teaching me lessons of modesty and hard work by your actions. How can I forget to remember my thesis committee member who encouraged me for my work with their constructive reviews: Thank you very much Dr. Walid Abdul-Kader and Dr. Maher El-Masri.

I am indebted to my guru HDH Pramukh swami maharaj for being moral support with me since my adolescent age. Today, I remember my parents who has always believed in me and never let me think smaller in my life. I am very much grateful to my brother, sister and my sister in law for guidance and love.

Here, I remember Mehul Lathiya, Dewang Tivar, Shailesh Balar, Devendra Patel, Parth and all my friends who are great support in Canada.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AMPL	A Mathematical Programming Language
CI	Continuous improvement
CIHI	Canadian Institute for Health Information
FMEA	Failure Mode and Effect Analysis
GDP	Gross Domestic Product
ICU	Intensive Care Unit
IIE	Institute of Industrial Engineers
LGP	Linear Goal Programming
LOS	Length of Stay
MILP	Mixed Integer Linear Programming
MSS	Master Surgical Schedule
OR	Operation Room
QFD	Quality Function Deployment
SPC	Statistical Process Control
VSM	Value Stream Mapping
WRH	Windsor Regional Hospital

CHAPTER 1: INTRODUCTION

1.1 Healthcare system

Canadian Health care system is public funded and developed to serve based on the need of services regardless of the ability to pay. Canadian government encourages healthcare professionals and healthcare agencies to provide equal access to health care to all individuals based on the requirement of health services (Storch, 2005). Canadian government imposes limits on expenditures of the healthcare institutions such as hospitals to control size of a national health-care system (Blake and Donald, 2002).

The healthcare expenditure in the year of 2008 in Canada was 10.7% of the gross domestic production (GDP). In the same year, 70.5% of the total health care services were covered by government(CIHI, 2011a).

The expenditure to provide health services are increasing over previous years' because of the high cost of new technology, the aging of the baby boom generation and paradigm shift in the way health services are delivered in present time (Health Canada,2005). A survey in the U.S. suggested that thirty two percent of health care spending occurs in the last two years of patient's life (Walsh, 2012). Healthcare is free at the point of delivery in many countries including Canada and due to that reason neither patients nor service providers feel the direct cost to health services (Beliën et al., 2009). Moreover, hospitals also play a major role in the amount of care needed for the patients. A study suggested that patients at the end of life at New York University Medical centre spent more days at the hospital along with three times more physician visits compared to similar type of patients at Stanford University medical centre (Wennberg et al., 2004). Healthcare expenses are increasing but it is not necessary that it will result in higher-quality care, reduced mortality rates and better satisfaction as increase in funding was mostly devoted to supply sensitive services (Fisher et al., 2003).

Canadian health-care expenditure is ever increasing since 1975 and expected to cross $200 billion in the year of 2011(latest forecast available for 2011). Figure 1 shows total health expenditure of over last 36 years in current Canadian dollars. Canadian Institute for Health Information (CIHI) suggests that total health expenditure for the year of 2009 in Canada was $182.1 billion. All areas where spending is utilized include Hospitals, the other Institutions such as residential care type facilities for chronically ill or disabled, physicians, other professionals, drugs, capital, public health, administration and other health spending. Other professionals include dentists, chiropractors, optometrists, massage therapists, physiotherapists, osteopaths, private duty nurses and naturopath services. Capital expenditures include construction, machinery, equipment and software costs. Moreover, public health expenses are constituted by food and drug safety, health inspections, community mental health programs, public health nursing and occupational health.

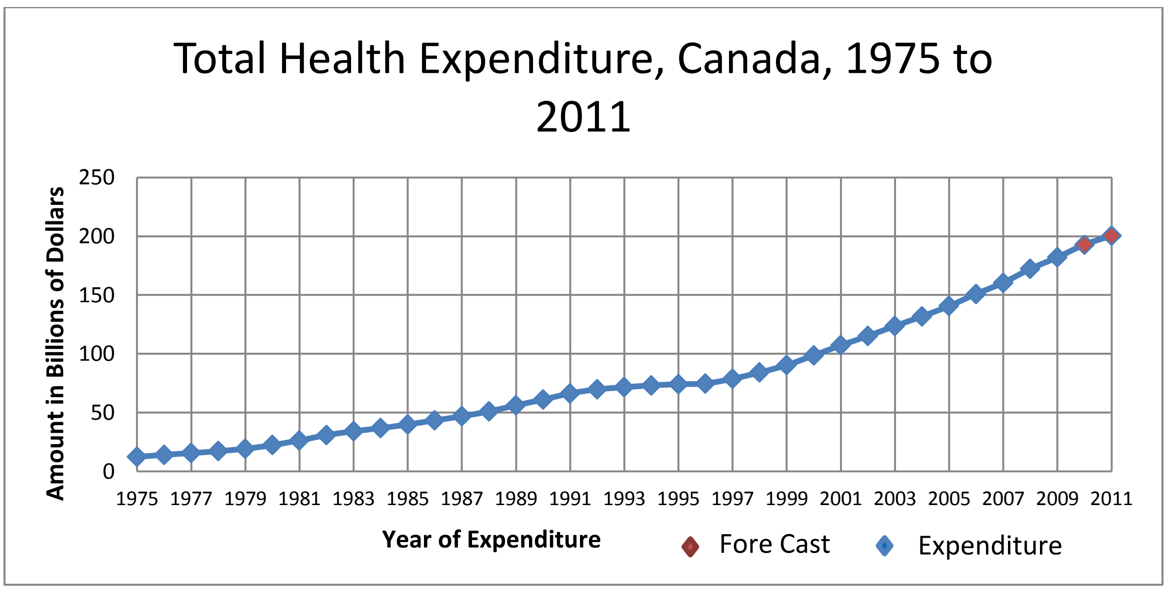

Figure 1 Total health expenditure, Canada (in current dollars) (CIHI, 2011b)

Administration includes long term care programs, hospital operative cost, drug programs and non-insured health services. Other health spending includes health research, medical transportation and hearing aids. Hospitals, drugs, physicians and administrative expenditures are major departments where healthcare expenditure is utilized. The pie chart in Figure 2 shows percentages of expenditures in major areas (CIHI, 2011b).

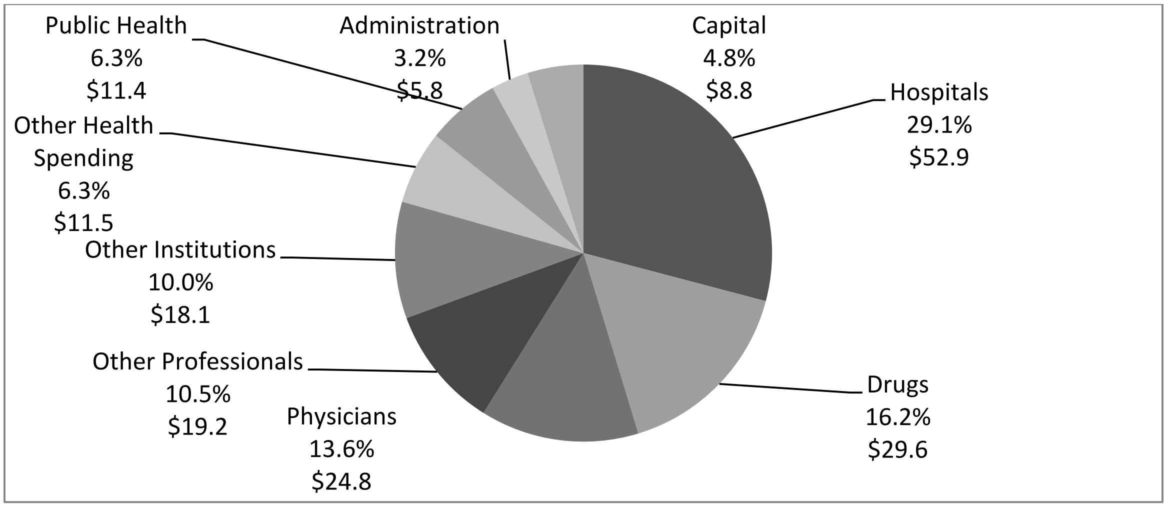

Figure 2 Total health spending by use of funds in 2009, Canada (Percentage of share and Billions of dollars)

Hospitals are defined as institutions where patients are accommodated on the basis of medical need and are provided with continuing medical care and supporting diagnostic and therapeutic services. They are approved by a provincial government or operated by Canadian government. Hospitals consumed around 29% of the Canadian health budget in the year 2009 (Figure 2). Hence, it is clear that hospitals are one of the most important parts of the healthcare system.

1.1.1 Classification of Hospitals

Hospitals are classified according to the number of beds, type of care provided and whether teaching facilities are available. Ministry of Healthcare and long term care has classified hospitals in regulation 964. Hospitals are classified from Group A to Group V (Ministry of Health, 2012). Hospitals are classified as General hospitals, active treatment teaching hospital, and regional rehabilitation hospital as follows:

- **Group A** hospitals are general hospitals having teaching facilities for medical students of any university with which they have affiliations by a written agreement. These hospitals provide post- graduation certification in one or more specialities. These types of hospitals are very large organizations. There are only 20 such hospitals in the province of Ontario.
- **Group B** hospitals are general hospitals with more than 100 beds. These are mostly community hospitals such as Hotel Dieu Grace Hospital and Windsor Regional Hospital (Metropolitan general site, Western hospital centre site and regional children centre) in the region of Windsor-Essex.
- **Group C** type hospitals have fewer than 100 beds. These types of hospitals are aimed to serve very small communities. Leamington District Memorial Hospital in the town of Leamington of Windsor Essex County is categorised as group C hospital.
- **Group D** hospitals treat patients suffering from Cancer and also undertake research for the causes and remedies of cancer with facilities for medical students.

Likewise, group E to group V classification is listed in the regulation 964. In this study, Windsor regional hospital metropolitan campus was contacted for the study. It is a group B hospital.

Hospitals perform various tasks as depicted in the classification above and based on the type of care provided, hospital expenses varies. Hospital consists of various departments based on the type of services and patients they handle. Pharmacy, OR, recovery unit, blood bank, laboratory, and radiology department are very common departments in most hospitals. For example, hospitals performing orthotopic liver transplantation needs a department of organ acquisition for organ storage and supply, ICU to serve critical condition patients before and after transplantation surgery in addition to the departments such as Operation room, Post anesthesia care unit (PACU), preadmission clinic and pharmacy. Relative contribution of different departments on the mean total hospital cost for orthotopic liver transplant of fifty patients at the University of Cincinnati

Medical center is shown in Figure 3 as a percentage of total cost. It clearly indicates that Operation room costs around 10% of the total hospital expenses.

Operating rooms, one of the most important components of the hospitals, are considered bottlenecks along with recovery units (post-surgical unit) (Jebali et al., 2006). Efficient use of operating rooms can be helpful for smooth operation of the hospital. In spite of the substantial research work on operating rooms in literature, it is not fully optimized for the challenges associated with it (Brandeau et al., 2004). ORs need large amount of capital and labour. They require a lot of supplies and sanitization attention. Hospitals' 9-10% revenue is spent on operating rooms, which is one of the most significant source of expenditure (see Gordon et al.1988 and Roland et al. 2010). On the contrary, May et al. (2011) mention OR account to be around 10-30 % of hospital expenditures for different sized hospitals in the United States of America. A study of 100 U.S. hospitals suggest that OR running cost averages $62/min. Range of OR average charges lie between 22/min to 133/min. This figure does not include additional supplies for surgical procedure, surgeon and anesthesia charges (Shippert, 2005).

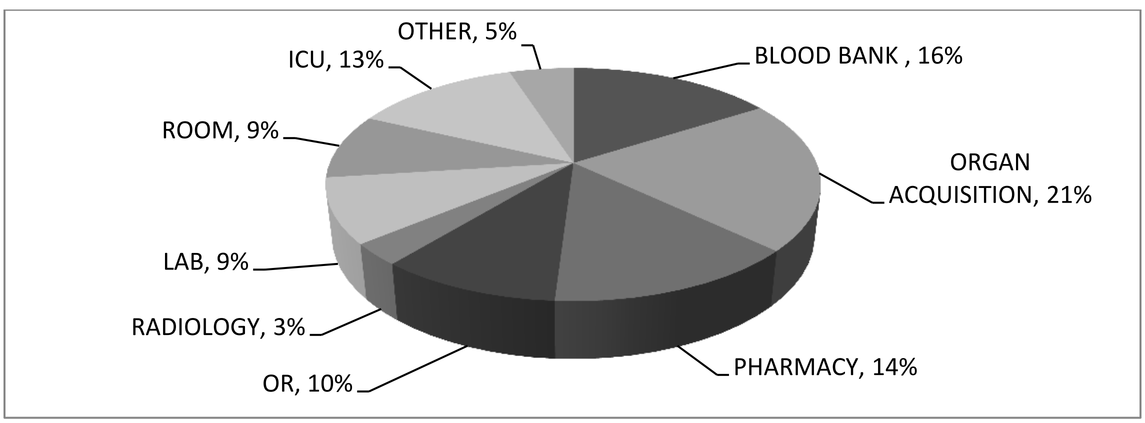

Figure 3 Mean percentage departmental costs of the hospital performing orthotopic liver transplantation (Whiting et al. 1999)

The operating room can be viewed as the Engine of the hospital. Activities of operating room affect a lot to the other departments and almost each activity within the hospital environment.

Well prepared operating room schedule can surely help minimize variability in demand of resources considering elective patients. Variability affects productivity. Therefore, reducing and handling variability is one of the major challenges for health care professionals. Fluctuations in the demand of surgeries make it very difficult to create stable schedule (Brunner et al. 2009). Fluctuation in demand is one of the major differences between manufacturing and service environments. The demand fluctuation can be tackled by reserving several operating rooms for emergency cases. In this thesis, the focus is on the elective patients only. The typical operating room (OR) scheduling involves the assignment of surgeries of different types of patients and surgeons in available ORs. Extensive research has been carried out in the healthcare to schedule surgeries in different conditions in the last decade (Cardeon et al. 2009). The health care systems in developed countries have different setups, but the intention is to serve patients better and faster with the efficient use of available resources. Accurate prediction of the operating room time required for surgery for different surgical speciality and sub specialties and regularity in work are major factors for efficient functioning of the OR. Surgery procedure times are calculated with 10 surgery average of surgeons' previous same kind surgery, pathology of patient and most importantly on surgeons' expertise over procedure (Jebali et al. 2006).

In the health care environment, hospitals need to be responsive to patients as fast as they can. Different types of patients need a different level of attention from hospitals. There can be a number of priorities to schedule surgeries and different priorities (elective patient only, elective and non-elective patient, high demand first, high recovery first) lead to different schedules. Likewise, the resource constraints such as Surgery team availability, OR availability, post-surgical unit capacity, nurses availability, etc. affect a lot to schedule (Tan et al. 2007b) . Most work focus on scheduling OR with various aspects of the hospitals in different regions of the world, but most of them did not consider patient stay duration to create OR schedule. Length of

Patient stay has a strong impact on the overall good performance of the hospital (Adan et al. 2009).

Hospitals are very large institutions which have their own timely developed ways of functioning. There is a strong hierarchy in the hospital which always makes it difficult for new ideas to come in due to disadvantage of someone involved in the process (Brunner et al. 2009). Healthcare industry is facing a financial crisis as resources are limited, but number of patients and type of disease and expenses are growing at a rapid rate. Two types of variability are to be handled by health care management: natural and artificial variability. Natural variability is inherent in nature and cannot be controlled by management, but the later one, artificial variability is controllable as it is caused by poor planning and policies (Beliën et al. 2007). For example, poor planning may cause shortage of bed on Wednesday or Thursday as compared to empty beds on weekends and start of week. This kind of variability can be controlled with the help of well thought scheduling processes. Most important server in the hospital environment, Surgeons, are only service providers and they are not responsible for the cost of medical tests involved while serving patients. There are many more aspects in which healthcare industry is not as ready as manufacturing organizations. Recently, the latest data of health care parameters available is of year 2009. Moreover, it is very hard to measure health in terms of digits. The other most important issue with hospital reporting is to non-admitting attitude of the surgeons when they make a mistake (Carter, 2002).

1.1.2 Different methods to prepare Operating room schedules

Kharraja, (2003) discusses about three different approaches to schedule operating rooms which affect the cost and service levels to the patients.

1. Open scheduling approach: In this method, a blank schedule is used for each schedule period. The schedule is filled chronologically on the first come, first serve basis as

surgery teams shows interest in OR slots. Negotiations also take place between two conflicting OR slots. Open scheduling approach is not very common in Canadian Hospitals. This approach is free of constraints.

2. Block scheduling approach: Pre-allocated slots of ORs are used to create the schedule for a time frame of a month. Surgical specialities then assign slots to surgery teams. Surgery teams decide their preferences of slots over the other teams within their speciality. The blocks of uninterrupted time such as whole day or half day are assigned to the surgery teams. In this thesis, we use Block scheduling approach to prepare OR schedule with various constraints.
3. Modified block scheduling approach: This approach is combination of open and blocks scheduling approach. First, blocks are assigned with the block scheduling approach and then reallocation of the unused blocks is done for the other surgical specialities with open scheduling approach.

Block scheduling approach and modified block scheduling are the major approaches used in hospitals. Open scheduling approach is time consuming as well as not an insightful management tool for hospital management.

1.1.3 Definitions

Elective patients (Tan et al. 2007b): Type of patients who do not need emergency medical treatment and can be served on a pre-agreed time. Government has setup surgical target wait times of different surgeries which are calculated from the date of diagnosis to the date of commencement of surgery. They are sub divided in the following categories.

Inpatient: A patient who needs to be admitted for a day or more before surgery in OR is classified as inpatient.

Same day patient: Patients expected to be discharged on the same day of the surgery are also known as the same day patients.

Overnight patient: Patients who are expected to be discharged on the day after surgery are called overnight patients.

Same day admission patient: These types of patients are expected to stay more than one day after surgery in hospital recovery area, but they are admitted in hospital prior to surgery on the surgery day (same day) itself.

Emergency patients: Immediate care is needed for emergency patients. Most hospitals have specially dedicated OR for emergency surgeries. Emergency patients are served just after arrival while urgent patient are served with less priority than that of emergency patients.

OR block: OR functioning time which can be assigned to surgeon on any working day is an OR block. OR block lengths vary as per institutional policies.

Master Surgical Schedule (MSS): It is a cyclic timetable defining type and number of Operating rooms available at a hospital, the operating hours and surgeons who are assigned for the surgical procedures (Blake et al., 2002).

1.2 Industrial Engineering and Healthcare

Industrial Engineering is a branch of engineering dealing with the design, betterment and installation of combined systems of persons, resources, machine tools and energy. It uses specialized knowledge and skills in the mathematics, management, design, services together with principles and techniques of engineering analysis to forecast and run or improve systems under consideration (IIE, 2012). Almost any service industry can be improved with industrial engineering techniques. Improvement is a journey, not a destination. Management tools proven in industry and, successfully used by industrial engineers can be used to improve throughput of patients, provide better services with lesser wait time and reduce wastage of time with proper utilization of available limited resources.

Hospitals are large organizations. Scheduling for surgeons and nurses is done every day. Scheduling without use of software tools consume a lot of time because of large number of people involved. Scheduling for a typical Group B hospital with 10 OR involves around 200 OR blocks for a month for around 65 surgeons. It requires a lot of time and meticulous efforts to prepare such schedules. Hence, industrial engineering techniques help scheduler design priorities and constraints in mathematical equations which can be later solved by computer program very easily. One such mathematical model is discussed in upcoming chapters of this thesis.

Systems engineering tools can be used in numerous types of applications to acquire positive results in efficiency, safety, quality and customer oriented processes in manufacturing and service industry. Health care industry is no exception. Healthcare industry has been very slow in utilizing these benefits. However, a number of organizations are finding these tools useful and started using them with faith and confidence. Tools such as Statistical process control (SPC), quality function deployment (QFD), failure-mode effects analysis (FMEA), systems simulation, system modelling, scheduling and human factors engineering are amongst the most accepted tools to apply in health care delivery by administrators (Reid et al., 2005).

Quality control, regression analysis and design of experiments are other modelling techniques used after meaningful data mining (Kerzner, 2009). Outputs of such methods can be useful in decision making with the help of matrices produced by them.

Lean engineering is used as a tool to do more with less. Lean methodologies originated from Japan and many of them are derived from Toyota manufacturing system. Lean preaches for continuous improvement (CI) which leads to excellent quality product/service with least possible expenses, waste.

- Value stream mapping (VSM) is a technique which graphically defines all steps of a process. Later, non-value adding steps are eliminated and only value added steps are continued. Waste is everything which doesn't create value towards customer needs. VSM gives a chance to view process as a whole like map (Liker, 2004).
- 7 wastes are observed almost in each system before transformation. Waste of overproduction, waiting or idling, transportation, processing, inventory, movement and defective products are the types of waste one has to look for while applying lean tools (Fine et al., 2009).
- Poka-Yoke are techniques which discourage errors in the processing by designing process which will notify worker at the time of mistake and mistake would not be carried forward on to next step (Shimbun, 1988).
- 5s (Sort, Straight, Sweep, Standardize, Sustain) helps to create standardized workplace for same kind of work which encourages interchangeability among nurses and surgery teams. Root cause analysis helps to find root cause of the problem identified and follow up steps are defined and implemented to prevent future accidents or losses (Haggerty et al., 2008).

Table 1 describes tools widely embraced by industrial engineers with its application in manufacturing industry and healthcare industry with similarity and differences among them.

Table 1: Application of Industrial Engineering Techniques in Health care

Tool	**Industrial Engineering Example**	**Healthcare Example**	**Equality/ Differences**
Scheduling	• Creating schedule for production of automobile parts	Preparing schedule for surgery teams, nurses, staff	Similar for the assignment of the time of processing,

	• Schedule of casting products for batch production		Different due to unpredictable nature of human responses compared to predicted responses of nonliving objects
Simulation(Banks et al. 2004)	Simulating manufacturing systems such as product assembly line, warehouse routing patterns for pickers	• Simulation of patient movement for calculation of wait times and average processing times • Assessment of Emergency departments	Very difficult to simulate health care systems due to large range of services and variations in processing time due to unpredictable human response to surgical services
Optimization	Creating efficient network of goods distribution, finding best possible travel route for sales man	Optimizing usage of Operation rooms and recovery units	Similarity in a method of defining objectives to minimize or maximize variables
Project Management(Khurma, 2009)	Managing the construction of an automotive assembly line	Managing a healthcare improvement project for reduced wait times and costs	Similarity in techniques used for keeping the work within time and

			financial limits
Failure mode effect analysis – FMEA (Reid et al. 2005)	• Analysing failure of conveyer belts in food industry • Preventing wrong chemical usage by worker	• Assessing medical centre power failure • Ferromagnetic object found in MRI unit	Similarity in the sense that method is used when accident happens or potential hazard of occurrence in manufacturing industry also used for newly developed products for elimination of potential failures and documentation
Ergonomics(Chen galur et al. 2004)	Designing tool handles for efficient grip and less vibration transmission	Designing better tools for easy transfer of patients, less hazard exposure to nurses	Motive is same in both the systems to provide better work environment to workers who uses machine tools very often.
Quality Control	Keeping size of screw within specified dimensions to encourage interchangeability and standardization	Maintaining sanitization levels of the hospital unit to certain levels to avert infections	It is very difficult to define quality level of patient health which is not the case in the manufacturing

			industry
Lean Engineering tools 1. Value stream mapping (VSM) 2. Poka- Yoke 3. 7 Waste 4. 5 s 5. Root cause analysis	These tools are used for continuous improvement (CI) 1. Mapping the assembly of jet engine to remove non-value added steps 2. Error proofing by using jigs 3. Elimination of excess movements in product assembly 4. Preparing workstation layout for engine assembly such that each tool is within immediate vicinity of the worker 5. Finding root cause for poor welding quality and trying to provide future remedies for the same problem	These tools are used to eliminate errors and waste in the systems 1. Mapping the process of patient going through Emergency 2. Assigning alarms in laboratory equipment 3. Removal of unnecessary steps from service blue print of patient care 4. Assigning standardized locations for tools of surgery in OR 5. Finding root of any mistake occurred in OR and follow up for elimination of mistake	Similarity of application in Industrial engineering and Health care where machine tools are involved but, application varies and can be limited for healthcare where human is involved because of non-linear behaviour of the system

1.3 Engineering Problem

Scheduling of the operating room is an important planning task needed to perform by the surgery department for each planning period. Patients scheduled are operated in assigned OR block and then sent to PACU for anesthetic recovery. Later, they are transferred to recovery unit. Number of patients in the recovery unit varies on different days of the week. Total number of patients adds as week proceeds and on Wednesday, Thursday it reaches to maximum number. Moreover, number is very less on the weekends which lead to high variation in the occupancy of the hospital beds over week span. To overcome this situation, it is possible to prepare a schedule which smartly assigns patients to the schedule based on historical average of recovery time spent in recovery unit. It is possible to manage number of patients thereafter applying such schedule.

This thesis addresses the problem of creating Master surgical schedule (MSS) based on the available number of hours for each surgical group (speciality) as described in Blake and Donald (2002). A 3 step approach is very useful to create MSS. The method extends to scheduling surgeons in such a manner that helps to reduce high mid-week effect. High mid-week effect is an effect caused by inefficient scheduling of patients which are effects of poor planning of surgeries requested by surgeons' offices to hospitals. Linear integer goal programming method is used to solve the problem. Linear goal programming is used to solve multi objective linear programming problem.

1.4 Windsor Regional Hospital – An introduction

Windsor regional hospital is a community serving general hospital of Windsor- Essex county in the province of Ontario, Canada. It has four different campuses in the city of Windsor named - Metropolitan general site, Tayfour campus, Regional children's centre and Windsor regional cancer centre. The metropolitan campus site was contacted for the understanding of practices of OR scheduling.

The metropolitan campus of Windsor Regional Hospital provides acute care services in a general hospital setting classified in group B. It has day surgery, diagnostic imaging, nuclear medicine/MRI, family birthing center, medicine, intensive care, pediatrics, surgery and regional cancer services. It has 11 OR out of them 10 are currently working. The surgical specialties that are handled at the site include: Urology, Orthopedics, Dental, Plastic, Ear nose & throat (ENT), General laparoscopic surgery, and Gynecology. Operating rooms are served by approximately 65 surgeons supported by an administrative staff of 100 personnel. Two booking clerks are assigned to book surgical cases requested from surgeons' offices. The surgical blocks are assigned on week days during 7:30 AM to 3:30 PM(WRH, 2012).

Operating rooms are different because of different equipment and surgery performed. Surgical blocks are assigned as per speciality and surgeon.

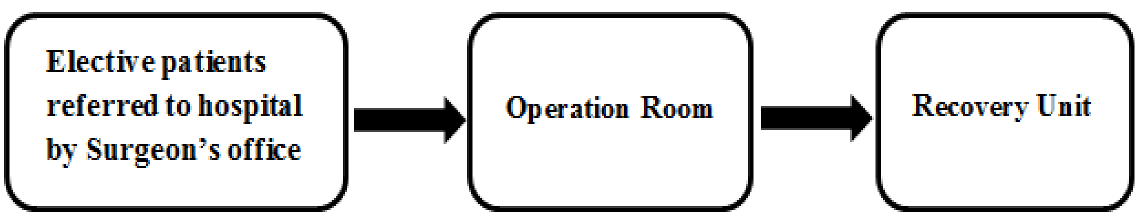

Figure 4 Patient flow at Windsor Regional Hospital Metropolitan Campus

Above figure 4, shows flow of patients in Windsor Regional Hospital.

1.5 Thesis organization

Thesis is organized as follows in next chapters: chapter 2 covers the related review of literature with 3 step hospital operating room schedule. Chapter 3 presents linear goal programming model to solve the problem. The solution of the model with results analysis is covered in chapter 4. Finally, Chapter 5 provides conclusions and recommendations for the future work of the study.

CHAPTER 2 : LITERATURE REVIEW

The importance of operation room (OR) in hospital is analogous to the importance of engine in an automobile (Blake et al., 2002). The hospital OR scheduling process involves scheduling of elective and emergency patients with dedicated and/or mixed OR scheduling approach.

2.1 Three step approach for the OR scheduling

The scheduling of OR can be done in 3 steps from process analysis point of view using hierarchical approach (Blake et al., 2002; Santibáňez et al., 2007; Testi et al., 2007).

Step 1: Sessions Target Planning: Sessions planning determines the number of hours to be assigned to each surgical speciality for the proposed schedule. The number of operation hours available for each speciality is a function of the budget provided by hospital (Blake and Donald, 2002). However the number of hours can also be determined by either following wait list of the patients or following previous schedules (Testi et al., 2007).

Step 2: Master Surgical Scheduling (MSS): It contains clearly defined OR blocks assigned to each surgical team, with time duration. Surgical team decides the number of patients to be operated in each surgery block assigned to them. Schedule is generated to meet the total hours assigned to each speciality achieved in step 1 with least possible difference. MSS are generally created 3 weeks in advance.

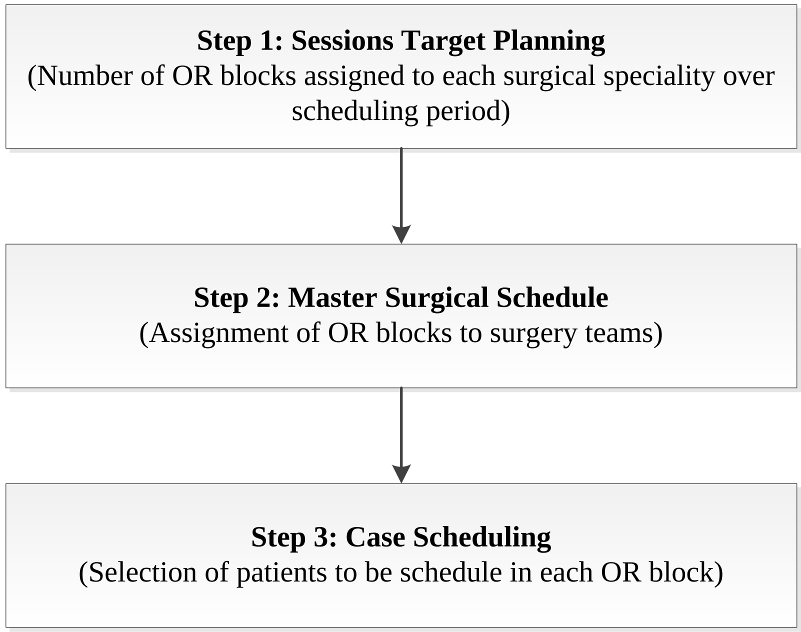

Figure 5 Hierarchical approach to schedule elective patients in the hospital (Testi et al., 2007)

Step 3: Case Scheduling: The purpose of this phase is to prepare detailed daily OR schedule which includes cases to be performed, estimated procedure time, start and finish time of each surgery, type of surgery and names of personnel like nurses and anesthesiologist. This step contains a detailed level of information. Sometimes, this schedule is subjected to change, if any emergent patient needs to be operated (Tan et al.,2007b). Discrete event simulation is a very well-known approach to generate and understand this step (Ogulata and Erol, 2003; Testi et al., 2007).

Figure 5 depicts hierarchical approach to schedule elective patients in Canadian hospitals. Health Science Centre of Winnipeg, Mount Sinai Hospital in Toronto and Windsor Regional Hospital follows above mentioned procedure to prepare schedule of operation rooms.

2.2 Patient flow in the hospital

Emergency patient and elective patients served by hospitals take different routes for health services. As shown in Figure 6., a majority of emergency patients arrive at hospital with the help of emergency medical services. Based on their health condition and available OR time, patients are sent to pre-operative room and then sent to OR. Hospitals schedule elective and emergency surgeries in different ORs in schedule.

However, due to the non-availability of resources, it becomes mandatory to operate emergent patient in the OR scheduled for elective patients (Blake and Donald, 2002; Tan et al., 2007b) . The reason behind separate operation rooms for elective and emergency surgeries is that emergency surgery arrival is non-deterministic (non-predictive). Hence emergency arrivals cannot be pre assumed while in case of elective surgery it is well known in advance about arrival of patient. After surgery, patients are sent to post anesthetic care unit for anesthetic recovery for half an hour to 2 hours. Later, they are transferred to recovery unit for post-surgical recovery and discharged home while they meet discharge criteria. On the other hand, elective patients are booked by surgeon’s office for surgery. Patient is sent to pre-admission clinic for tests pertaining to medical fitness for anesthesia and surgery. On the surgery day, patients get admitted to the hospital and sent to pre-operative unit which is used for anesthetic preparation of the patient. Later, patient is sent to OR for surgery where surgical team consisting of nurses, anesthesiologists, and surgeon operates on patient. Patient is then transferred to the post anesthetic care unit and thereafter taken to the recovery area. Like emergency patient, elective patient is allowed to recover until discharge criteria are satisfied. After discharge, patient is cured by nurse at their home location (Tan et al., 2007b).

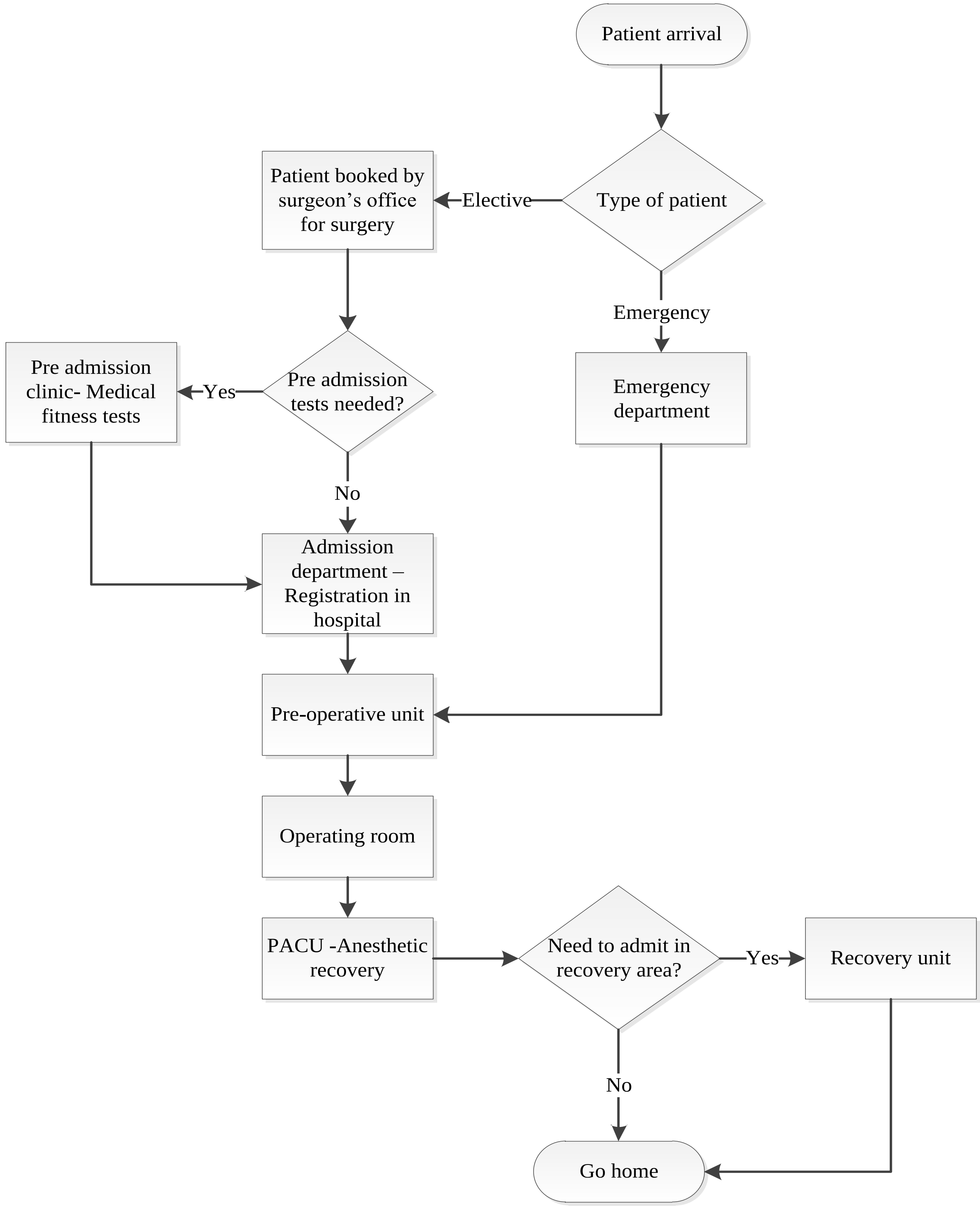

Figure 6 Emergency and elective patient flow in the hospital, adapted and modified from (Tan et al., 2007b)

2.3 Linear Goal Programming (LGP):

Hospitals are institutions with many departments working under one roof. Scheduling involves many demands to be satisfied simultaneously or on priority basis. Hence, it is very natural to have multiple objectives to be accomplished while creating an efficient schedule which satisfies all requirements of booking manager. Sometimes, it is possible to have a conflict of interests between two departments as their objectives are different. Moreover, selection of multi-objective linear programming method largely depends on the information available and distinctive characteristics of the problem. Linear goal programming can be a much useful mathematical programming technique to solve multi objective problem involved with high to low priority levels in objectives. (Rardin, 1998). Linear goal programming (LGP) is a good tool to solve multiple objective linear programming problems. It is used where no trade-off between objectives are allowed. Health care models have very clear and obvious priority levels (Tan et al., 2007a). Several extensions of LGP can be found in literature (Schniederjans, 1984). Scheduling procedure might have several varieties of objective functions, but they are very rare with an equal priority. Preemptive or lexicographic optimization solves multi criteria optimization problems by considering one criterion at a time. The most important criterion is optimized first and later in hierarchical order the other criteria are optimized restricting the first one to its optimal value. The number of linear programs to solve to obtain final solution depends on number of priorities (Anderson et al., 2008) . The objective function value of the first criterion is treated as a constraint while solving less prior objectives. It helps prevent effects of prior objective to be considered in later part of calculations. Limitation of Preemptive optimization is that it focuses with higher intensity for the first objective and later objectives' effects are reduced on the final solution. Alternate method to solve such problems is weighted sum of objectives. In this solution strategy, multiple objective functions are combined into a single combined composite objective with their respective weight expected on the final result. The weights can be decided by management.

2.3.1. Priority assignment of objective functions:

It is very difficult for a novice while deciding the priorities of the objectives. This problem is faced due to fact that the decision maker may not set order of priorities to problem objectives in a fashion which can be directly used in goal programming model. On the contrary, it is most important to design model as per decision makers' perspective. For the solution to this dilemma, it is advised that absolute objectives (objectives which must be satisfied to find feasible solutions) should be assigned at higher priority levels. e.g. In cost minimization problem, it is not advised to prioritize cost minimization before production target. First priority assigned to cost minimization would lead to virtually no products produced as target of the objective would be to keep cost zero.

It is also necessary to keep limit on number of priorities while creating mathematical model for goal programming. Too many priorities are not useful for getting optimal solution. One can create as many priority levels as they want. However, it is not suggested to create more than 5 priority levels for real world problems. It is always preferred to reduce number of priority levels which can reflect problem in true manner (Ignizo, 1976).

Method for Priority rankings suggested by Ignizo, 1976 :

1. Rank each objective function as per decision maker's perspective.
2. Form group of objectives if they lie in the same priority level.
3. Assign weighting factors to the objective functions as per priority levels. Variables which need higher attention should be multiplied with higher weights.
4. Keep absolute objectives in top priority level.

Charnes et al., (2008) suggests the paired comparison method to determine priority over many objectives having unclear priorities. The method suggests comparing all possible combination of objectives in pair. Most preferred objective is given top priority and then 2^{nd} level priority given to the second most preferred objective function and so on.

If objectives are found to be having same number of preferences in comparison, they are grouped together in an objective function. Moreover, if two minute differing priority levels are combined in one objective function, then they should be assigned weights to distinct priority levels within objective.

2.3.2. Objective weighting

Weights assigned to objective functions are positive numbers where weight shows the significance linked with the minimization of a deviation variable assigned to a given objective. Higher the number, higher is the priority of the objective function. Moreover, weights can also reflect judgments such as objective A is 3 times more important than objective B. For example, if the profit attached with the product X is thrice the profit associated with product Y, then the manufacturer would be thrice more concerned for the minimizing the underachievement of target production for product X then product Y. This type of cases can be designed mathematically with the help of objective weighting in the linear goal programming.

2.3.3. Types of Constraints in Linear Goal Programming:

Two types of constraints are used in the LGP are as follow:

Soft Constraints: Constraints having targets of goal, which are desirable to satisfy but may be violated in the feasible solution are soft constraints. They contain decision variables which are maximized or minimized in the objective functions. For example, allocation of hours to a surgical speciality might have defined limit but it might not be possible to achieve it completely. Feasible solution might differ with 1-2% from desired allocated hours.

Hard Constraints: Hard constraints describe limitations of resources. These constraints cannot be violated and hence, they determine feasibility of the solution. The hard constraints allow soft constraints to decide which solution is preferred. For example, OR functioning days are fixed and cannot be changed in any given circumstances. Hence, soft constraints will only look possibility of assigning OR blocks in OR functioning days.

In the next chapter, mathematical model with linear integer goal programming is discussed. Change in priorities gives different schedules. It is usually a choice of scheduler which one to emphasize. However, various combinations of priorities give a better idea of the overall system and an insight over effects of different priorities on one another.

2.4 Relevant papers in literature

In the following section, research papers presenting scheduling approach with different methods and case studies are discussed with their contribution to the field with important topics not included in their respective studies. Cardoen et al. (2009) reviewed all aspect of the literature to cover all studies in the health care which has industrial engineering perspective.

Three step approach

Santibáñez et al.(2007) use 3 step approach to schedule hospital OR, focusing on mathematical model for step 2 to manage wait list and to check possibility of bed utilization improvement under co-operation of several hospitals in the region of a British Columbia health authority, Canada. Santibáñez et al.(2007) suggest keeping schedule repetitive for 6 -12 months. However, the study assumes same demand of the surgeries for one year and prepares schedule without including any change in type of patients for different types of surgeries.

Testi et al. (2007) suggests to use either waiting line or historical demand as a decision factor to obtain number of OR hours for specialties to a public hospital in Genova. Testi et al. (2007) use a 3 step approach in which sessions planning (step 1) considers a weighted sum of waitlist and historical assignment of number of hours assigned to each speciality for determining present allocation of hours between each specialties. The value of weights depends on the decision of scheduling personnel. Step 1 and step 2 are designed with linear programming. However, recovery area is totally neglected while preparing schedule. Moreover, only a week long schedule is aimed from the schedule which is not a common practice in most Canadian hospitals.

Pariente et al. (2009) present two models of case scheduling (step 3) with P-S-OR (patient-surgeon-OR) and P-OR-S (patient-OR-surgeon) policies. P-OR-S policy assigns patient to OR first and then a surgeon is assigned from the surgical speciality. P-S-OR policy assigns patient to surgeon first and then to operation room. They also address target waitlist time for each surgery type to serve patients within deadline of service. It was concluded that P-S-OR is not as flexible as P-OR-S, but on the other hand patients did not preferred P-OR-S policy.

Ogulata and Erol (2003) propose one more step called patient acceptance planning in the beginning of the 3 step scheduling process. The purpose of the added step is to choose patients from the patient list for surgery. The model was designed for group A type of hospitals with large number of patients and services offered.

Linear Goal Programming used for hospital operation room scheduling

Blake and Donald (2002) use goal programming model to meet the expected hourly service targets (defined in step 1) of the surgical specialties each month. The objective function of the linear goal programming model includes penalty to minimize deviation from the targets of the surgical specialities. But, lack of constraints in the study causes additional post processing stage to satisfy need of surgical groups. The method of creating schedule relied upon 3 step approach discussed in section 2.1.

Rohleder et al. (2005) extend the work of Blake and Donald (2002) to schedule ORs for longer period of time including holidays with varying length of surgery block times (8 to 9 hours). The case study of Canada Foothills Medical Center, Calgary proved that goal programming reduces the variability of the patients meeting the goals of surgical services without affecting the total number of patients served compared to previous study. The study does not consider the length of stay of patients in the recovery room to stabilize number of patients in the recovery unit.

Tan et al.(2007a) propose a lexicographic linear integer goal programming programing method which accommodates 4 different type of patients in elective OR scheduling with focus on optimizing 3 different types of post-surgery recovery unit capacity. However, the model assumes length of stay for patients in the recovery area as deterministic number which is not acceptable in real practice as a stochastic length of stay reflects more real picture of the problem. The problem constraints are specifically designed for replication of processes performed at Health science centre, Winnipeg.

Ogulata and Erol (2003) use a hierarchical goal programming to form a schedule for the general surgery department of the Cukurova University Research Hospital, Turkey. Recovery times for surgeries are not considered while assigning OR blocks to surgeons of each speciality.

Zhang et al. (2009) use a mixed integer programming approach for preparing a schedule for ORs. The model determines weekly OR planning which minimizes patients' cost of staying in hospital with different priority of the patients (emergency and elective) subject to conventional constraints of resource allocation. They suggest including a stochastic nature in the mathematical model to tackle issues of uncertainty in the recovery and surgical procedure times.

Arenas et al. (2002) use goal programming to achieve wait list targets and to minimize overtime of OR and referrals to other hospitals in a hospital of the Spanish health authority. They design two different LGP models. The first mode is aimed to reduce wait list within 6 months period and to prevent referrals going out of hospital due to inability of the hospital under study to serve patients in need. The second model is aimed to reduce OR underutilization times and waitlist. The work does not include surgeon's preferences and room constraints while designing schedule. Recovery room is also not considered for resource optimization.

Simulation

Cochran and Bharti (2006) develo{Cochean, 2006 #31}p a methodology that aims on balancing of bed unit utilizations with the help of discrete event simulation. The case study of an obstetrics department of a large regional hospital in Phoenix, Arizona indicates that 38% more patient flow can be achieved with 15% increase in the patient recovery beds. The study uses queuing networks for the assessment of the flow between units of the department.

Marcon, Smolski et al., 2003 provide a simulation model for newly built OR for determining the minimum number of beds necessary in PACU. In addition, they also calculate staff and porters required to make flow smooth of the OR. The scenarios include flow with sufficient staff and the scarcity of staff which resulted in the constant requirement of porters to keep flow uninterrupted most of the time.

It is very important for hospitals to satisfy demands of emergency and elective patients from service and business perspective. Discrete event simulation is useful to determine maximum capacity of the surgical suite OR capacity with performance measures such as number of patients operated for each surgical speciality, time spent by patients in the hospital system, and utilization of OR and nurses (Ballard & Kuhl, 2006).

Marcon and Dexter (2007) use discrete event simulation to understand the occupancy level of PACU from ORs. Scenarios such as long case first, random cases from list are tested which gives results which indicate that long case first causes a large number of patients compared to mix cases.

Ivaldi et al. (2003) develop simulation model to manage waitlist of emergency and elective patients with brick mortar scenarios. Brick mortar scenario is helpful for hospitals which are yet to be erected. Simulation model for 14-bed hospital is defined in the study with first in, first out strategy. The study includes elective and emergency patients which results in need of 3 ORs to satisfy each patient service requirements in waitlist limits. Length of queue, number of admitted patients, and duration of wait for each patient are major performance indices.

Marjamaa et al.(2009) use simulation to optimize workflow of patients in OR out of 5 scenarios describing where and how many nurses should be employed for epidurals in induction rooms. Each scenario is useful in specific situations. The following different cases are analyzed in the study:

- Traditional model where one anesthesiologist is assigned to one operation room
- Four OR with induction rooms and additional nurse
- Circulating induction room where team of anesthesiologist and nurse would give anesthesia to patient prior to surgery
- Centralized induction room
- Four induction teams for 3 surgery teams
- 2 different runs for each scenario which includes long and short cases in the same ORs and in separate ORs.

Linear Integer Programming

Jebali et al. (2006) propose two different Mixed Integer Linear Programming (MILP) models. First model (operation assignments) minimizes costs associated with the operation rooms overtime and under time , hospitalization of patient cost while creating OR cost. Second model (operation sequencing) minimizes overtime and assigns PACU beds and ICU beds, prepared the day before. The model is aimed more on the third step of the three step approach of scheduling.

Brunner et al. (2009) discuss a new modeling approach to schedule surgeons and interns which satisfy a labour agreement with the German hospital. Mixed integer linear programming method is used to solve the problem. The aim of the study is to minimize paid out hours, overtime and visiting physician costs in a German hospital which can be classified as group A hospital. The main constraint is labour agreement hours which needed to be satisfied for each surgeon. On call services are also included while designing the experiment. On the other hand, the model does not take chance to look for operation room constraints while scheduling different specialties.

Cardeon et al. (2009) present a multi criteria decision mathematical model with priorities for sequencing of patients after they are scheduled in the operation room. The priorities include serving urgent patients or children in the start of the block, minimizing capacity of PACU, assigning patients coming from far regions in the later part of the OR block who needs some reports to get completed before surgery. They also determined PACU capacity to sequence patients in order to make flow uninterrupted. The study does not focus on recovery area of the hospital.

Beliën and Demeulemeester, (2007) introduce mean and variance of patients in the recovery room in the objective function with the motive to stabilize patient population. Mixed integer programming approach is used to create MSS. A multi objective model is solved by simulated annealing consisting of the following objectives:

- Levelling of recovery unit beds by minimizing mean and variance of patients in recovery unit
- Assigning same speciality surgery team in same OR with rotation of teams itself to provide ease and comfort of space to users
- Repeating the schedule as long as it is possible

It is known that surgeons prefer fewer rotations in their schedule, but it doesn't keep options open for scheduler to create efficient schedule. Hence, it is advisable to respect surgery team's preferences but not assign those same blocks every schedule due to the dynamic nature of the demands of the surgeries.

Adan et al.(2009) check impact of deterministic length of stay (LOS) over stochastic length of stay in recovery room and Intensive care unit (ICU) by linear integer programming. Furthermore, 4 different important resources (OR time, Intensive care unit beds, Medium care unit beds, Intensive care unit nurses) of the hospital Cardiothoracic department are optimized according to the assigned weight in the mathematical model to achieve target utilization of resources.

Leveling of resources

Beliën et al. (2009) develop a multiple objective decision support system which can help hospital create cyclic master surgery schedule. The study reduces variability in the recovery area by minimizing mean and variance of the number of patients. The study aims to design a master surgical schedule which has least total expected bed shortage in the hospital. Heuristic such as simulated annealing, quadratic programing, and combination of both are tried to reach an optimal solution.

Marcon, Kharraja et al. (2003) distinguished process of OR planning into two phases static and dynamic to stabilize OR utilization time. Static phase, covered by surgical cases, constraints and statistical data of surgery durations, poses no risk of change while preparing schedule. On the other hand, dynamic phase represents up to date use of OR after static phase. The dynamic phase defines percentage of acceptable risk to prepare schedule and leveling. Multiple knapsack problems are used to schedule surgeries in the limited time of OR block.

Oostrum et al (2008) formulate integer linear programing with min max objective to prepare cyclic schedule for OR for elective procedures which occur quite frequently. The study also notes that 70% of total admissions in the hospital involve contribution of OR and recovery area. Case study of Erasmus Medical Centre, Rotterdam in the Netherlands (group A hospital) states that two phase decomposition method discussed in the work helps in leveling of hospital beds.

Heuristic

Augusto et al. (2010) investigate the impact of a situation where patient starts recovery in the OR due to the non-availability of recovery bed in the recovery unit. They use open scheduling approach, in which patients are scheduled without any surgical constraints. Study concluded that benefit is high when recovery unit utilization rate is high. Each patient data is used to construct OR schedule. Lagrangian relaxation heuristic is used to solve the problem efficiently.

Hongying et al. (2006) utilize column generation procedure to prepare weekly OR schedule and then OR daily schedule is prepared with the help of hybrid genetic algorithm. The constraints of the study are relaxed. For example, there is no limitation on the recovery beds and any room can accommodate any surgical speciality which is not the case in actual practice.

Houdenhoven et al. (2007) use bin packing algorithm to assign OR blocks in MSS. The paper also utilize portfolio technique (technique widely used in the financial stock markets) to reduce non-utilized OR time. The study splits OR blocks in the OR schedule. The recovery area is not considered. The model is validated with a Dutch hospital.

Lamiri et al. (2008) develop stochastic model for OR planning with combination of elective and emergency surgery demands. The model design includes processing time for each possible arrival and cost of underutilization of resources. Monte Carlo convergence algorithm is helpful to solve problem for the emergency patients.

2.5 Contribution of the thesis:

Above discussed papers in the literature addressed hospital Operation room scheduling for different situations and tried to optimize the scheduling process. But, very few papers kept the recovery unit in mind while scheduling surgeons. Moreover, constraints of the mathematical models in the literature were not that of the same kind which is used on hospital floor. Some examples include preferences of surgeons, limitations of operation rooms to accommodate only certain surgical teams.

The thesis contributes to the hospital operation room scheduling problem by developing a mathematical model which aims to reduce a high number of patients during the middle of the week (Wednesday and Thursday). Recovery room over or underutilization is reduced with the help of scheduling approach proposed in the mathematical model. The mathematical model also includes constraints which were not addressed previously in the literature. Windsor regional hospital personnel feedback to understand the process of scheduling is used to design assumptions and constraints. The model is coded in a mathematical programming language (AMPL) and solved with the help of CPLEX solver. This approach is helpful to reduce schedule preparation time.

The model is used to calculate number of beds required for newly commencing hospital as well as the existing hospital with already having recovery rooms. The focus of the model is on community general hospital of group B as discussed in chapter 1. The weighted goal programming objective is tested for several combinations of weights to check best weight selection. The lexicographic goal programming objectives with different priority combinations are also checked to identify effects of different priorities in the final schedule.

CHAPTER 3 : LINEAR INTEGER GOAL PROGRAMMING

The problem focuses on creating MSS(Master Surgical Schedule) based on the available number of hours for each surgical speciality in 3 step approach described by Blake and Donald, 2002 where step 1 is about outlining number of hours to each surgical speciality, step 2 is about creating MSS and step 3 creates micro schedule of OR block with patients and surgery team. The 3 step approach is very useful to create MSS. The method extends to schedule surgery team in such a manner that helps reduce high mid-week effect, which is caused by an inefficient scheduling of patients and a poor planning of surgeries requested by surgeons' offices to hospitals.

3.1 Assumptions

1. We focus elective patients while creating the operation room schedule.
2. Recovery period of the patients is considered from the historical average recovery times.
3. Surgical procedure time is considered to be past performance average for 10 surgeries. Patient is served by the same surgery team by whom s/he was referred to the hospital.
4. Each surgery team specializes on several surgery clusters. Average time for each cluster is calculated from historical data available from hospital.
5. Hospital ORs remain closed on weekends. Only a single shift of 8 hours is considered for scheduling. Hospital management doesn't prefer to operate OR for extended hours.
6. Inpatients, same day patients, overnight patients and same day admission patients are routed to the recovery area for post-surgical recovery.
7. Recovery rooms are open for admission and discharge during the whole week. Number of operational hours assigned to each speciality is a decision of the hospital management committee.
8. Surgery teams and patients are punctual, and they do not cancel the scheduled event.

9. Patients recover from anesthesia in post anesthesia recovery unit and then transferred to the recovery unit. PACU is considered to be excess resource.
10. Single recovery unit holds patients coming out from PACU and are discharged when they meet the discharge criteria.

The probability of the patients staying in the recovery unit for each surgical team is calculated by taking an average of the past recovery durations for patients being operated by such surgery teams. Number of clusters varies for each surgical team based on their experience and expertise. Hence, there are two different levels of sub hierarchy are observed in the mathematical model. Each surgical group has surgery teams and each surgery teams performs several clusters of surgeries on patients in operation room. Average procedure duration for cluster of surgeries for each surgical team is obtained from the historical data of the Windsor Regional Hospital. Frequency of the each cluster helps replenish variable demand of surgeries based on patient health care trends. Frequency is also obtained from past records. It should be always observed to identify trends in demands of the surgeries.

Hospital committee decides number of operation room blocks to be assigned to each surgical speciality. The blocks are distributed among the surgeons based on their seniority and expertise.

An integer decision variable helps decide best suited operation room block. Moreover, number of patients served in the OR block is one of the most important variable, which helps calculate the number of patients staying in the recovery unit and the number of patients leaving the hospital. Although currently neglected, the Inventory of patients in the recovery unit should be taken into consideration when scheduling patients in the ORs.

Deviation variables help keep track of the targets in the calculations. Mostly, deviation variable should be zero in order to achieve targets, but sometimes it is desirable to have positive values of over achievement variables in order to perform with best possible outcome.

Deviation variables d_{1i}^- and d_{1i}^+ are integer target achievement deviation variables. Variable d_{1i}^- should be as small as possible as its positive value indicates patients waiting for the surgery at the end of the time horizon. On the other hand, the desired value of d_{1i}^+ is a non-negative number, but it is mostly zero because the demand usually exceeds capacity.

Deviation variables d_{2ijk}^- and d_{2ijk}^+ are associated with the utilization of operation room. Variable d_{2ijk}^- is a non-integer variable representing idle time in an OR block. It should be as small as possible. Value of d_{2ijk}^+ is always zero as described in the assumptions that overtime is not allowed in the OR blocks.

Deviation variables d_{3r}^- and d_{3r}^+ are associated with the surgical group targets. It is necessary to have both of these variables to zero, so that the exact balance of the number of blocks can be achieved in OR schedule.

3.2 Indices

$i \in (1,2,\dots,m)$	Surgery team
$e \in (1,2,\dots,E_i)$	Clusters of surgery team i
$j \in (1,2,\dots,n)$	Operating Rooms
$k \in (1,2,\dots,T)$	Day of the time horizon
$l \in (0,1,2,\dots,h)$	Length of stay in Hospital
$r \in (1,2,\dots,R)$	Different surgical Specialty

3.3 Parameters

P_{il}	Probability that surgery team i patients stay l nights at recovery unit
h	Maximum number of nights of stay in the recovery unit

v	Length of a OR block for surgery team i
E_i^e	The e^{th} cluster of surgery team i
$D_{i,e}$	Average procedure duration of the e^{th} cluster of surgery team i
$ORF_{i,e}$	OR factor for preparation / cleaning of the e^{th} cluster of surgical team i
	$= \frac{Total\ Duration\ of\ surgery}{skin-skin\ duration}$
$f_{i,e}$	Relative frequency of the e^{th} cluster of surgical team i
N_i	Target number of patients of surgery team i during the planning horizon
T	Number of days in planning horizon
$ROOMNA$	if $(i,j) \in ROOMNA$, then room j is not available for surgery team i
$DAYNA$	if $(i,k) \in DAYNA$, then day k is not available for surgery team i
LOW_i	Minimum number of assignments for Surgery team i in time horizon
$HIGH_i$	Maximum number of assignments for Surgery team i in time horizon
$BLOCK_r$	Surgery team OR blocks allocated to specialty r in time horizon
S_r	Set of surgery teams for surgical specialty r
$Max\_Capacity$	Maximum number of recovery beds available in community hospital

3.4 Decision Variable

x_{ijk}	= 1, if surgery team i is scheduled in OT j on day k;
	= 0, otherwise

3.5 Other Variables

n_{ijk} Number of patients of surgery team i operated in room j on day k

I_k Number of patients in recovery area on day k

$MAX\ I$ Maximum number of patients in recovery unit during whole schedule

$MIN\ I$ Minimum number of patients in recovery unit during whole schedule

H_{jk} Number of hours each operating room j is utilized (out of v hours) on day k

$$H_{jk} = \sum_{i=1}^{m} \sum_{e=1}^{E_i} (D_{i,e} * \ ORF_{i,e} * f_{i,e}) \ n_{ijk}$$

U_{jk} Non-utilized hours of operation room j on day k

$$U_{jk} = v - \ H_{jk}$$

Total Non-Utilized Hours of operation room over time horizon T

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{T} x_{ijk} * v - \sum_{j=1}^{n} \sum_{k=1}^{T} H_{jk}$$

3.6 Deviation Variables:

d_{1i}^{-} Underachievement of the target of surgery team i; the number of patients of Surgery team i waiting at the end of the planning horizon

d_{1i}^{+} Overachievement of the surgery team i

d_{2ijk}^{-} Underutilization of surgery team i in room j on day k

d_{2ijk}^{+} Overutilization of surgery team i in room j on day k

3.7 Constraints:

1: Certain surgery teams can only be assigned to some specific OR as equipment and setup differs with surgical specialties. Moreover, surgery teams have preferences about the working day and time in the OR. E.g., a surgery team may prefer to work in OR # 1 as they have performed numerous surgeries in OR 1 and the whole team is well aware and comfortable with the setup of the OR 1. Based on the equipment unavailability and/or negative preference of the surgical team for given OR, surgery block is not assigned to surgery team i in OR j on any day k of the time horizon.

$$x_{ijk} = 0,$$

$$\forall (i,j) \in ROOMNA, \qquad \forall\, k$$

2: Some surgery teams cannot be assigned to specified day of the time horizon. Surgeons are important members of the surgery teams. They have multiple obligations such as personal clinics, teaching assignments, etc. Surgery teams do not work on weekends and specific days of the time horizon.

$$x_{ijk} = 0,$$

$$(i,k) \in DAYNA, \qquad \forall\, j$$

3: Only one surgery team is scheduled to surgery block. It is observed that hospital and surgery teams both prefer to have each OR block dedicated to a single surgery team as surgeons do not prefer to arrive at hospitals for just 4 hours or less.

$$\sum_{i=1}^{m} x_{ijk} \le 1, \ \ \forall j,k$$

4: Any member of a surgery team is prevented to be assigned in multiple OR during same day. Surgery team i, can be assigned only to one OR during day k. This constraint prevents scheduling one surgery team to multiple OR on same day.

$$\sum_{j=1}^{n} x_{ijk} \leq 1, \quad \forall i, k$$

5: Surgery teams are assigned different number of blocks within surgical speciality blocks assigned in step 1 of the 3 step scheduling approach. Surgery team i must be scheduled for surgery blocks in between LOW_i (lower bound) and $HIGH_i$ (upper bound) during time horizon T days.

$$LOW_i \leq \sum_{j=1}^{n} \sum_{k=1}^{T} x_{ijk} \leq HIGH_i , \quad \forall i$$

6: Targets must be fulfilled by each surgical speciality while scheduling OR. Each surgery team within the same speciality can only use allowed number of blocks in the schedule. Target number of Blocks $BLOCK_r$ of surgical speciality r is one of the main critical factors of acceptable schedule.

$$BLOCK_r = \sum_{i \in S_r} \sum_{j=1}^{n} \sum_{k=1}^{T} x_{ijk} \quad , \forall\, r$$

7: The number of patients operated by surgery team i in all the blocks assigned, plus the number of patients waiting at the end of the planning horizon, less number of patients served more than the target equals the target N_i. This constraint balances the number of patients waiting for the service with patients assigned surgery in current schedule and underachievement of the target.

$$\sum_{j=1}^{n}\sum_{k=1}^{T} n_{ijk} + d_{1i}^{-} - d_{1i}^{+} = N_i, \qquad \forall i$$

8: The number of patients operated for surgery i in OR j on day k plus the underutilization, less over utilization of the OR (in terms of time assigned) equals the capacity of the OR. Here, duration of the clusters e of surgeries for each surgery team i, frequency of the surgery clusters in recent past and Operation room factor altogether determines duration of the surgeries.

$$n_{ijk} + d_{2ijk}^{-} - d_{2ijk}^{+} = x_{ijk} \frac{v}{\sum_{e=1}^{E_i} D_{i,e} \times ORF_{i,e} \times f_{i,e}} \quad , \forall i, j, k$$

9-10: Number of patients in the recovery unit on any day k is the sum of (i): Previous day balance (ii): number of patients operated on day k and subtraction of (iii) number of patients discharged on day k and (iv) patients discharged after end of time horizon are carried forward to the next schedule.

For $2 \leq k \leq T$

$$I_k = I_{k-1} + \sum_{i=1}^{m}\sum_{j=1}^{n} n_{ijk} - \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=0}^{k-1} n_{ij(k-l)} P_{il} - \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{T-k} n_{ij(k+l)} P_{i(T-l)}$$

The schedule is cyclic. For $k = 1$ (the first day of time horizon), previous day inventory (I_{k-1}) is considered to be the last day Inventory (I_T) of the recovery unit.

$$I_1 = I_T + \sum_{i=1}^{m}\sum_{j=1}^{n} n_{ij1} - \sum_{i=1}^{m}\sum_{j=1}^{n} n_{ij1} P_{i0} - \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{T-1} n_{ij(1+l)}\, P_{i(T-l)}$$

11For hospitals which are already in service have definite number of recovery beds. For scheduling of those types of hospitals, it is necessary to limit maximum number of available beds in the hospital. Therefore, this constraint can be only used for community hospitals which have predefined number of rooms.

$$Max\ I \leq Max\_capacity$$

3.8 Objective Function:

3.8.1 Preemptive goal programming objective functions

Objective 1: Minimize number of patients waiting,

$$Min\ d_1^*$$

$where,$

$$d_1^* = \sum_{i=1}^{m} (d_{1i}^- + d_{1i}^+)$$

One possible objective is to reduce underachievement of patients from target for each surgery team's list of patients. This is achieved by assigning each surgery team within their allowed number of slots and their OR room availability. The preferences of surgery teams also make a large difference in choice of blocks for surgeons. The objective leads to choose more little operating time surgeries from possible combinations allowed from constraints. This occurs due to the fact that more small procedural time patients can be served within 8 hour slot compared to large procedural time patients.

Objective 2: Minimize underutilization of operating room,

$$Min\ d_2^*$$

where,

$$d_2^* = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{T}(d_{2ijk}^- + d_{2ijk}^+)$$

Subject to ,

$$\sum_{i=1}^{m}(d_{1i}^- + d_{1i}^+) \le d_1^*$$

The other objective is to minimize underutilization for each surgical time slot available in time horizon for scheduling. The underutilization is wastage of resources and it should be avoided as much as possible by every possible efforts. The objective function tries to utilize every minute possible to be counted for serving towards patients' wellbeing. The objective function assigns as many surgeries as possible which leads to near zero OR underutilization with not focusing on number of patients. Hence, one can observe a good mix of long procedural and short procedural time patients being scheduled on whole time horizon.

Objective 3: Minimize maximum number of patients in the recovery unit:

$$Min\ Max\ I$$

where,

$$I_k \le Max\ I, \forall k$$

Subject to :

$$\sum_{i=1}^{m}(d_{1i}^{-} + d_{1i}^{+}) \leq d_1^*$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{T}(d_{2ijk}^{-} + d_{2ijk}^{+}) \leq d_2^*$$

Minimization of Maximum number of beds in recovery unit can be a good objective to level capacity of recovery unit over period of week. It can help to keep number of patients in the recovery area as low as possible. This objective is usually prioritized in second position. The reason is, as model tries to minimize maximum number of patients it never allows to allocate patients to ORs when recovery time is zero for patients. Hence, if this objective function is prioritized first, then it would not provide an acceptable solution.

Objective 4: Minimize range of Patients in recovery unit

Range = Maximum Number of Patients in recovery – Minimum Number of patients in recovery unit

$$Min\ RANGE$$

Where,

$$Range = Max\ I - Min\ I$$

$$I_k \geq Min\ I, \forall k$$

Subject to

$$\sum_{i=1}^{m}(d_{1i}^{-} + d_{1i}^{+}) \leq d_1^*$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{T}(d_{2ijk}^{-} + d_{2ijk}^{+}) \leq d_2^*$$

$$I_k \leq Max\ I, \forall k$$

Another important objective is to reduce range of patients in recovery unit. The range is defined by the difference between maximum and minimum number of patients in recovery unit during scheduling time. The main idea is to reduce variance for number of patients in recovery unit. This can help to stabilize needs of resources in recovery unit. The main factor causing higher value of variance is due to non-working weekends. Patients' count remains almost stable while weekdays as there is input to compensate output of patients, but on weekends there is only output which leads to very small number of patients in recovery unit on weekends especially on Sundays. The objective helps a lot to assume how many recovery unit beds would be necessary for upcoming weeks and can also be a good brick mortar decision for newly built surgical facilities.

In nutshell, objective function 1 maximizes number of patients served by the hospital and reduces wait list of patients. It is also known from the literature that surgeons prefer to serve as many patients as possible within their allotted OR blocks. Objective function 2 minimizes underutilization and overutilization of OR blocks timing. Objective function 3 minimizes number of maximum patients in the post-operative recovery room. Objective function 4 minimizes range of patients in the recovery unit. Range is calculated by the difference between the maximum and the minimum number of patients in the recovery unit.

3.8.2 Weighted sum of objective functions

$$Min\ (\gamma_1 * d_1^* + \gamma_2 * d_2^* + \gamma_3 * Max\ I + \gamma_4 * Range)$$

Where,

γ_1, $\gamma_{2,}$ $\gamma_{3,}$ γ_4 are weights assigned to each variable in weighted sum objective function.

$$d_1^* = \sum_{i=1}^{m} (d_{1i}^- + d_{1i}^+)$$

$$d_2^* = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{T} (d_{2ijk}^- + d_{2ijk}^+)$$

$$I_k \leq Max\ I, \forall k$$

$$Range = Max\ I - Min\ I$$

$$I_k \geq Min\ I, \forall k$$

Weighted goal programming objective reduces multiple objectives into single objective as weights are multiplied with each variable which is needed to be minimized.

CHAPTER 4 : NUMERICAL EXAMPLE

The mathematical model discussed in the previous chapter is programmed in A Mathematical Programming Language (AMPL) and solved with ILOG CPLEX solver. Chapter includes current scenario, proposed model calculations and results with 2 different sets of objective functions and effects of priority level shuffling on performance of the schedule. The same data file is used to compare each case which to provides legit comparison.

4.1 Numbers assigned to objective functions

Objective functions are given numbers to simplify identification in calculations. A priority shuffling gives better mean to compare effectiveness of the OR schedule and indicates which objective should be given priority over the other one.

Table 2 Number assigned to objective functions

Objective Number	Objective Description
1	Minimization of underachievement of patients to be served
2	Minimization of underutilization of OR
3	Minimization of maximum numbers of patients in recovery units
4	Minimize range of patients

Values for weights are chosen such that the weights can give a better comparison over the lexicographic goal programming method. For example, values of $\gamma_1,\ \gamma_{2,}\ \gamma_{3,}\ \gamma_4$ chosen as 100, 20, 10, 5 gives a same representation as priority 1234 in lexicographic programming. Moreover, other combinations of the weights are chosen to check different impacts of the objective functions and its various combinations.

4.2 Current OR scheduling technique and High mid-week effect

The current schedule is obtained from the same data file which is obtained from the literature. Appendix A contains data tables for each parameter necessary to create hospital schedule. Mathematical calculations helps to determine number of patients assigned in the schedule and number of patients in the recovery unit. From figure 7, it is understood that traditional approach to scheduling is leading to peaks in the mid of the week which is also called high mid-week effect. It is observed that number of patients start to pour in from start of the week and as week progresses, it keeps pouring in. As a result, on Wednesday and Thursday number of patients in the recovery area comes to peak of the week. On the later part of the week, the number starts to decline. The reason behind decline is inactivity of operation rooms as they do not operate on weekends. Next week same pattern follows in the recovery room.

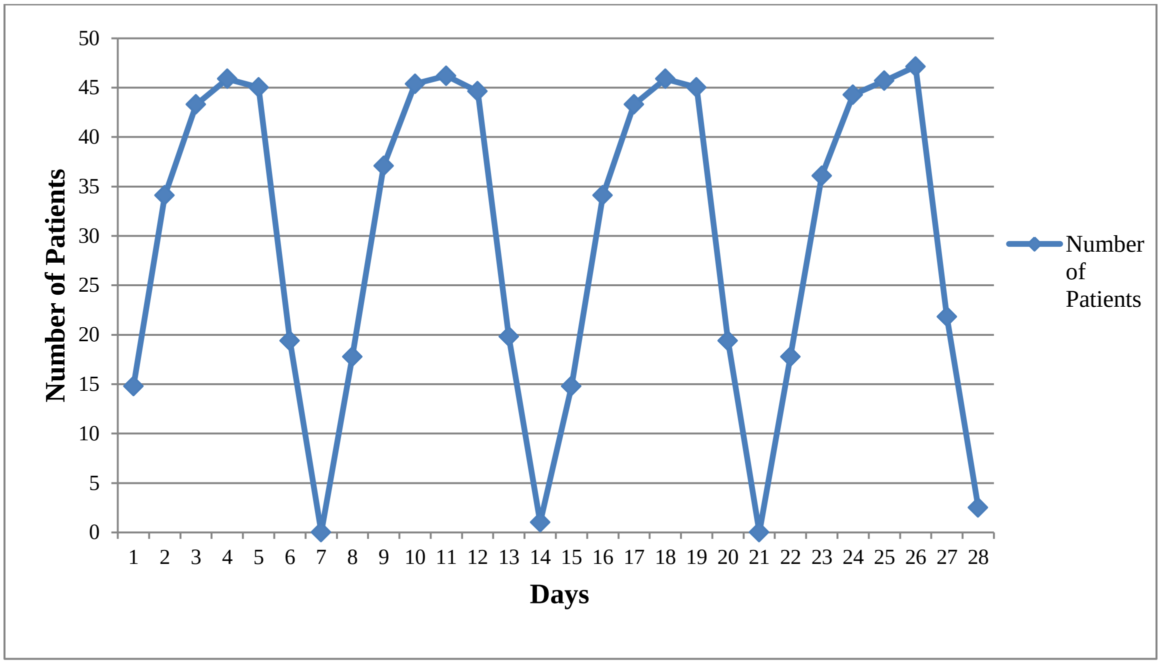

Figure 7 : Traditional scheduling approach's effect on recovery room

It is possible to diminish high mid-week effect and level number of patient in the recovery area. There are two possible cases for doing so:

1. For decision making: The hospital which is yet not built need to calculate number of recovery beds for the proposed volume of patients coming for health care service from hospital. The decision of such type is also called brick mortar decision.

2. For optimization of case scheduling for already in service hospital: Small community hospitals which are already in service have known number of beds and based on that number it is necessary to plan surgeries to avoid congestions in the recovery area.

4.3 Case 1: Brick Mortar decision

The mathematical model with objectives and constraint is discussed in chapter 3. AMPL program

Table 3 : Lexicographic goal programming and weighted goal programing results obtained by CPLEX for Brick mortar decision

Method		Case	Max I	Standard deviation in recovery area	Range in recovery area	Number of blocks assigned	Percentage underutilization of OR time (%)	Number of Patients included in the schedule
Lexicographic goal programming with priorities	1	1234	36	12.0	36.0	219	15.8	729
	2	1243	36	11.8	36.0	219	15.8	729
	3	2134	37	12.0	37.0	219	15.8	729
	4	2143	36	11.7	36.0	219	15.8	729
Weighted goal programming	1	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ - 100,20,10,5	35	11.5	35.0	220	15.8	729
	2	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ - 20,100,10,5	35	11.5	35.0	219	15.8	729
	3	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ - 50,20,10,10	35	11.6	35.0	219	15.8	729
	4	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ -1,1,1,1	36	11.6	36.0	219	16.2	727
	5	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ -1,1,10,10	26	9.4	26	197	26	651
		Current Method	48	16.3	48	220	17	715

of priority 1234 is given in appendix B.1. As priorities change, APML program changes a bit at objective functions. Moreover, same data file is used for all combination of priorities calculations to achieve OR schedule and have an idea of the numbers situation in the recovery area.

Data file used in AMPL for the calculations purpose is given in Appendix B.3. Data obtained and generated is given in Appendix A.

Comparison between current schedule and mathematical model presented in this thesis states that the number of patients served by current schedule is less than patients served by new schedule. Moreover, peak number of patients in the recovery area is also reduced.

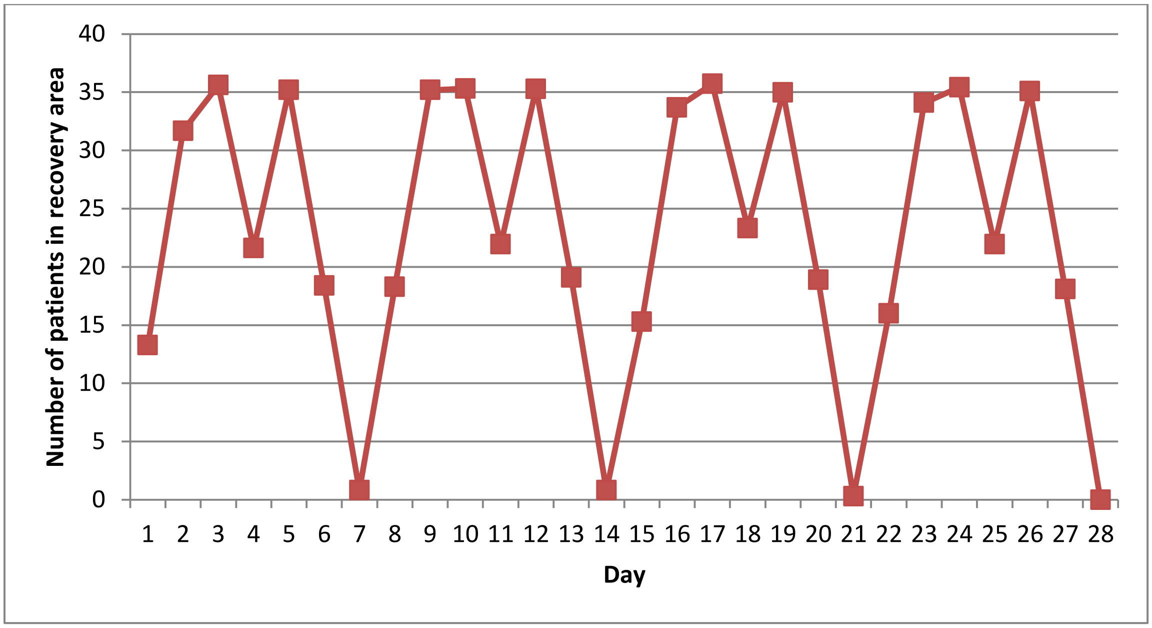

Figure 8 Number of patients in the recovery area for priority 1234 (Case 1 lexicographic method- brick mortar decision)

When one compares figure 7 with figure 8, it can be observed that the new schedule is created smartly such that it is trying to reduce peaks in the mid of the week. The method described here is doing exactly the reverse of the traditional approach. Traditional approach adds patients on Wednesday which aerates highest peak of the weak on Thursday. However, the proposed method prevents such peaks by allocating surgeries which are not having long length of stay in the hospital recovery room and this is how it prevents occurrence of peaks in the schedule. Figure 8 represents number of patients in the recovery area for priorities 1234. In additional comparison, variance of the traditional approach is having higher standard deviation compared to each solution given in table 3. Standard deviation is calculated from the following formula

$$\sqrt{\frac{\sum(x - \bar{x})^2}{n}}$$

Where, $\bar{x}$ is mean of the data population.

Standard deviation gives better idea of the scattering of the data. Lower the standard deviation, more readings near mean value. The concept of standard deviation is helpful in recovery room because lower standard deviation value means stable or near to stable number of patients. These patients also need stable amount of resources. Sometimes demand of nurses rise steeply as high mid-week effect escalates out of proportion.

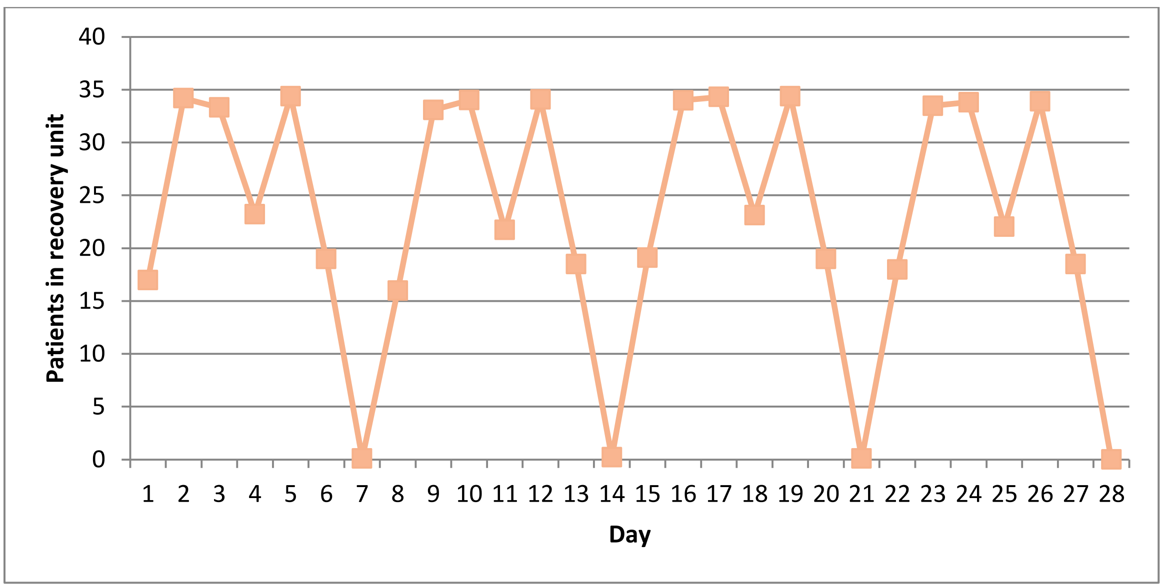

Figure 9 Number of patients in the recovery area for Case 1 weighted goal programming method- brick mortar decision)

In analysis to table 3 readings, it should be noted that lexicographic and weighted goal programming is used to compare and find best suited method to prepare OR schedule.

- Priority 2143 is best amongst lexicographic goal programming cases as it has least standard deviation with highest patient assignment rate.
- OR underutilization is as high as 15 percent because of the restriction on extension of the OR block, hence little time let after last surgery of the day is not accumulated.
- Weighted goal programming is successful to reduce number of patients in the recovery area by 1 more patient compared to lexicographic method cases.
- Case 5 in the weighted goal programming has least standard deviation, but it is not accepted as the number of surgery block allocated is no more that 197 out of 220.
- Figure 9 represents case 1($\gamma_1, \gamma_2, \gamma_3, \gamma_4$- 100, 20, 10, 5) of weighted goal programming which is not much different from figure 8 pattern to keep number of patients in the recovery.

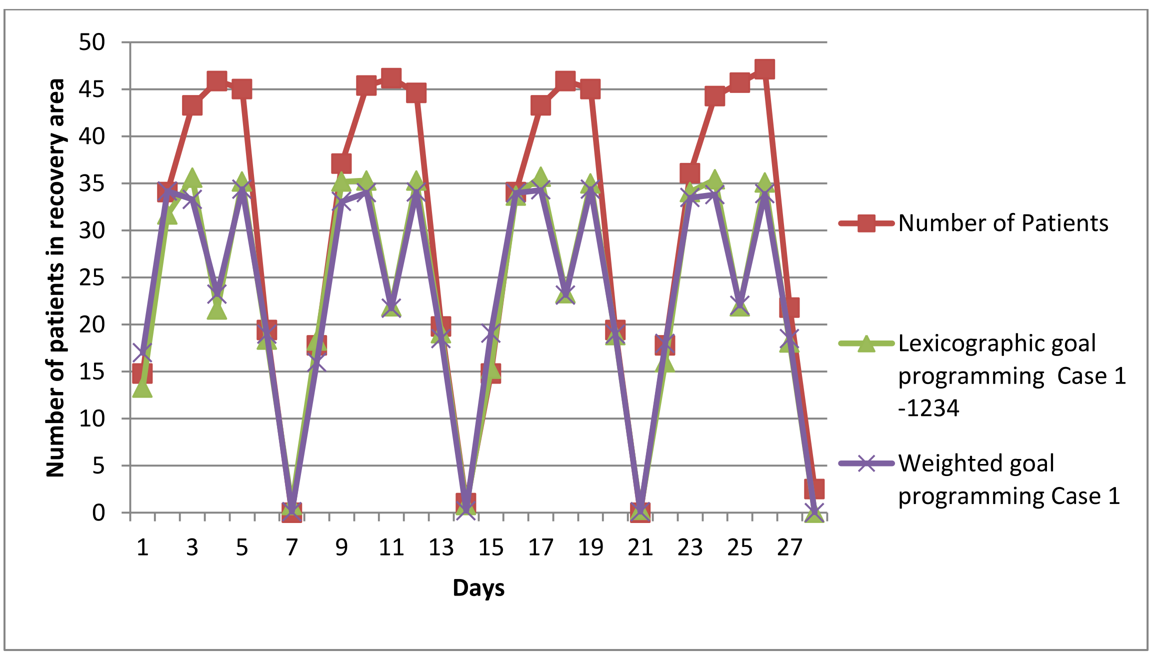

Figure 10 Comparison between conventional approach, lexicographic goal programming method and weighted goal programming method for recovery unit

- Different values of weights (γ) projects variable as more important than the colleague variables in the objective function. For example, in table 3, case 3 for weighted goal programming function has 10 as weights for two variables which provide same importance of both in the solution.
- Figure 10 provides comparison between 3 different cases by means of recovery unit population. Both techniques of goal programming very closely follow each other's path.

The deviation variables responsible for assignment of the surgical blocks to surgery teams were assigned satisfactorily in each case. Hence, there is no need of bartering for number of hours in next schedule which is practice otherwise.

4.4 Case 2: OR schedule for Community hospital already in service

The mathematical model for this case is presented in chapter 3 where constraint 11 is very important. The idea of that constraint is to restrain schedule from specific number of beds. Table 4 represents lexicographic and weighted goal programming methods to obtain OR schedule for community hospital having finite number of beds in recovery area.

Table 4 Lexicographic goal programming and weighted goal programing results obtained by CPLEX for Operative community general hospital

- Comparing lexicographic goal programming case 1 and 2, capacity of the hospital was set to 30 for case 1 and 35 for case 2. Due to lower capacity, 10 blocks could not be assigned and many blocks were partially assigned to cope with the situation in the recovery area. Additionally, underutilization of case 1 is 21% while for case 2 it is reduced to 16.7%. This confirms mathematical model's response to the capacity limits.

	Case No.	Case priority	Max I	Standard deviation of recovery area	Number of OR blocks assigned	Percentage underutilization of OR time (%)	Patients assigned
Lexicographic goal programming with priorities	1	1234	30	10.4	210	21	690
	2	1234_1	35	11.7	220	16.7	721
	3	1243	30	10.6	212	21	690
	4	2134	30	10.3	209	21	692
	5	2143	30	10.3	208	21	692
Weighted goal programming	1	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ – (50,20,10,10)	35	11.7	220	16.7	721
	2	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ - (1,1,1,1)	30	10.5	210	21	692
	3	$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ – (1,1,10,10)	27	9.7	201	23	668

Insights in the mathematical model and its responses:

- Standard deviation for case 2 is little bit higher because of the difference of 5 between maximum number of patients in recovery area for case 1 and case 2.
- Figure 11 is showing similar pattern where high mid-week effect is not very much arose because of the lexicographic objectives.30 is the recovery area capacity, hence number of patients is not increasing over 30 at any day of the horizon.

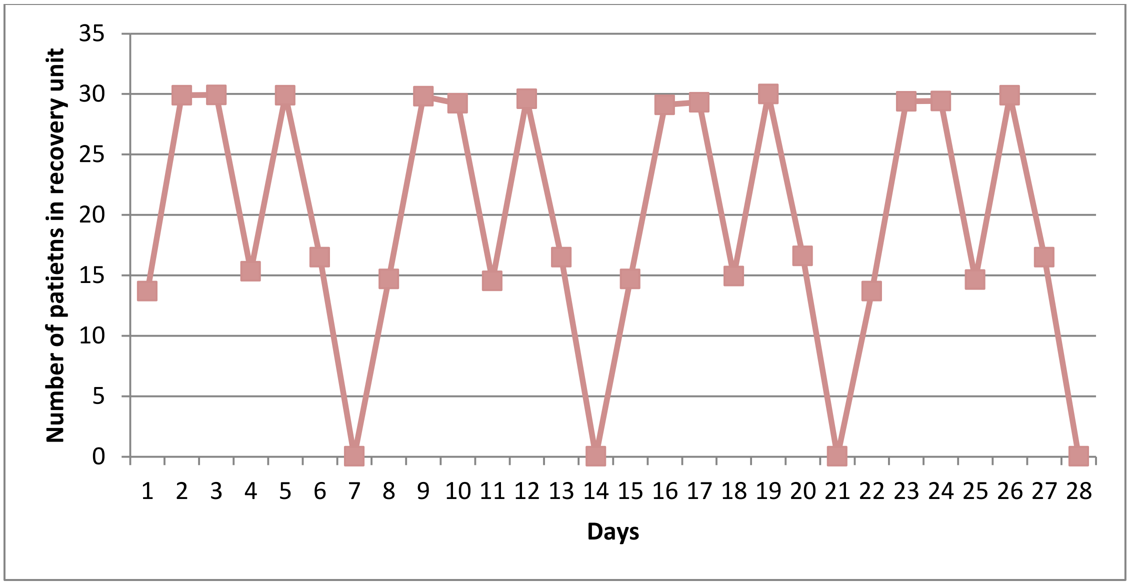

Figure 11 Patients in the recovery unit obtained from priority 2143 (Lexicographic case 5-Community hospital)

4.5 Number of variables and constraints in the problem and calculation time

4.5.1 Number of variables and constraints

Table 5 depicts number of variables in for the both cases discussed above. It should be noted that as size of the problem changes, number of variable and constraint changes dramatically. In the calculations, problem size is 54 surgery teams to be scheduled in 11 operation room in prescribed 28 day time period for 9 surgical specialties.

Table 5 Number of variables and constraints for Brick mortar decision and community hospital

Type of Problem	Parameters of Problem	Variables				Constraints
		Integer	Non Integer	Deviational	Total	
Determination of recovery beds for new hospital	54 Surgery teams, 11 ORs,28 days, 9 Surgical Specialties	16632	16973	16704	50309	20809
Community hospital already in service	54 Surgery teams, 11 ORs,28 days, 9 Surgical Specialties	16632	16973	16704	50309	20810

For the both type of problems discussed, number of variables remains same where as one additional constraint (constraint 11 in chapter 3) is necessary for community hospital. Hence, counter of constraint for community hospital is one more than that of the brick mortar decision.

4.5.2 Calculation time

Table 6 and table 7 represents calculation times to solve problem, the size of it is discussed in section 4.5.1. AMPL software is used to program mathematical model. AMPL uses CPLEX as solver. Intel core i5 processor 2.3 GHz, 8gb ram and windows 7 operating system computer was sued to solve the problem.

It is evident that the problem is huge and there for it takes a while to solve the problem, but sometimes it takes hours to reach near optimal solution. Optimality gap is the distance from optimal solution. For some of the cases below, it is very hard to reach optimal solution within very short time. The most time consumed was 780 seconds for case 3 of weighted goal programming problem. However, it is possible to find a near optimal solution by heuristic methods such as simulated annealing, ant colony optimization.

Table 6 Calculation time and optimality gap for different cases of Brick Mortar decision

	Case number	Scenario	Optimality Gap	Calculation time
Lexicographic goal programming with priorities	Case 1	1234	3	201 sec
	Case 2	1243	3	91 sec
	Case 3	2134	8	132 sec
	Case 4	2143	8	205 sec
Weighted goal programming	Case 1	Weight1 (100,20,10,5)	9	181sec
	Case 2	Weight2 (20,100,10,5)	9	79 sec
	Case 3	Weight3 (50,20,10,10)	12	780 sec
	Case 4	Weight4(1,1,1,1)	8	84sec
	Case 5	weight5(1,1,10,10)	8	87sec

Table 7 Calculation time and optimality gap for different cases of Community hospital

	Case number	Scenario	Optimality Gap	Calculation time
Lexicographic goal programming with priorities	Case 1	1234_1	9	7 sec
	Case 2	1234_2	9	25sec
	Case 3	1243	9	6 sec
	Case 4	2134	8	50 sec
	Case 5	2143	9	62 sec
Weighted goal programming	Case 1	weight3 (50,20,10,10)	12	45 sec
	Case 2	weight4(1,1,1,1)	12	603 sec
	Case 3	weight5(1,1,10,10)	8	102 sec

4.6 Sample Master surgical schedule

Table 8 is master surgical schedule for one week. It states Surgery team number and time with day and Operation room number. It is obtained from the priorities 1234 as discussed in case 1 of brick mortar decision.

Table 8 Master surgical schedule created from the solution of priorities 1234 by lexicographic goal programming

Master Surgical Schedule Week 1 (11 Operation rooms - Elective cases only)

	OR 1	OR 2	OR 3	OR 4	OR 5	OR 6	OR 7	OR 8	OR 9	OR 10	OR 11
Mon	Team 9 08:00-16:00	Team 33 09:00-17:00	Team 15 08:00-16:00	Team 12 08:00-16:00	Team 11 08:00-16:00	Team 16 08:00-16:00	Team 19 08:00-16:00	Team 10 08:00-16:00	Team 42 08:00-16:00	Team 28 08:00-16:00	Team 05 09:00-17:00
Tues	Team 30 08:00-16:00	Team 53 09:00-17:00	Team 43 08:00-16:00	Team 51 08:00-16:00	Team 06 08:00-16:00	Team 41 08:00-16:00	Team 21 08:00-16:00	Team 14 08:00-16:00	Team 44 08:00-16:00	Team 42 08:00-16:00	Team 39 09:00-17:00
Wed	Team 15 08:00-16:00	Team 51 09:00-17:00	Team 52 08:00-16:00	Team 54 08:00-16:00	Team 04 08:00-16:00	Team 01 08:00-16:00	Team 05 08:00-16:00	Team 50 08:00-16:00	Team 49 08:00-16:00	Team 45 08:00-16:00	Team 02 09:00-17:00
Thur	Team 16 08:00-16:00	Team 35 09:00-17:00	Team 36 08:00-16:00	Team 50 08:00-16:00	Team 47 08:00-16:00	Team 48 08:00-16:00	Team 06 08:00-16:00	Team 29 08:00-16:00	Team 38 08:00-16:00	Team 37 08:00-16:00	Team 34 09:00-17:00
Fri	Team 23 08:00-16:00	Team 31 09:00-17:00	Team 18 08:00-16:00	Team 13 08:00-16:00	Team 21 08:00-16:00	Team 12 08:00-16:00	Team 24 08:00-16:00	Team 26 08:00-16:00	Team 25 08:00-16:00	Team 27 08:00-16:00	Team 45 09:00-17:00

4.7 Variability in the mathematical model

The mathematical model utilizes many parameters ($P_{il}, ORF_{i,e}, f_{i,e}, D_{i,e}$) aggregate values. The usual period for the schedule shown in table is 4 weeks which is fairly long span of time to cover the variability of the model. The model which deals with patients as an individual can provide accurate basis to diminish variability in the study. However, individual patients are not at scope of the current study.

CHAPTER 5 : CONCLUSION AND FUTURE WORKS

5.1 Conclusion

In this thesis, hospital operation room is scheduled for a definite period of time with the help of 3 step approach given in the literature. The study focuses on stabilizing resources in the recovery room. The proposed method reduces high mid-week effect observed on Wednesday and Thursday. Decision maker can solve several combinations of priorities to check effect of each of them before finalizing the schedule. Constraints such as surgery team working preference, operation room preference are designed in this study which reduces post processing of the schedule.

Linear integer goal programming is a very good method to schedule operation room with recovery room capacity optimization. The method is developed for two different situations. First, estimate future requirement of recovery beds in the hospital being built. Second, creating OR schedule such that recovery unit would not be overflowed with patients in currently working hospital. Current method of scheduling is compared with newly generated schedule and its effects are observed in performance indicators. Data such as surgery times, frequency of arrival of different type of surgeries, operation room factor, and population of patients is obtained from previous studies.

The lexicographic goal programing method takes less calculation times, but weighted goal programming method also provides better solutions for same problems with equal optimality gap(Table 3,4,6,7). Moreover, flexibility of assigning same weight to two different objective functions is an added advantage to weighted goal programming.

Hospital OR schedule involves many stakeholders and surgeons are most important of them. There should be a mechanisms to micro manage OR schedule. Guidelines based on the mathematical model can be very helpful to optimize recovery area. Currently, surgeons book as many patients as they can irrespective of the length of stay of patient in the hospital.

The thesis would be helpful to OR managers who creates OR schedule on daily basis. It is on manager to decide which objective function needs to be prioritized or weighed more over the other ones.

5.2 Future Work

The wait list is a major service criterion which is not involved in this thesis. Ontario government has set targets to fulfill the operational requirements within specified period of time. The future extension of the thesis can be on the treating patients individually with their specific surgery time. Moreover, the optimality is very time consuming or not feasible for more than 24 hours or so. Hence, heuristic for solution of finding optimal solution can be helpful to solve problem quickly and efficiently. Extension of the mathematical model can be done to allow certain amount of time to check weather over time is justified by the healthcare provided to patients. Moreover, PACU is also a major critical area of the hospital where patients arrive to recover form anesthesia. PACU can be a part of the flow where patient passes through always after surgery.

Weighted goal programming has shown very promising results for scheduling problem. Systematic procedure to determine value of each weight can provide better control over objective function.

In future, the mathematical model presented in the thesis can be applied to hospital schedule to generate a set of guidelines for the surgeons while booking patients in the OR block.

APPENDICES

Appendix A

A.1 Different surgery clusters for surgery teams and duration

Average procedure times for each surgical cluster are obtained from Houdenhoven et al. 2007. Average procedure times and frequency of occurrence of surgeries was obtained from Erasmus surgical hospital, Rotterdam, the Netherlands. The data is retrieved from more than 180,000 surgical cases. Total 9 surgical specialties were observed which is shown in table 9 below. Category one represents the average of the surgical cases for which very solid prediction of the surgical duration was not available. Here, most frequently occurring surgeries are then considered in category 2 to 8.

Table 9 Mean surgical procedural time ($D_{i,e}$) of clusters for different surgical departments in Erasmus Medical Centre

		Surgical procedure mean time (Hours)							
	Category →	1	2	3	4	5	6	7	8
Surgical Speciality	General	2.50	1.12	1.67	2.25	2.85	3.55	2.00	3.35
	Gynecology	1.33	0.87	1.22	1.63	2.08	2.60	3.55	
	Plastic	1.98	1.05	1.37	1.87	2.32	3.12	1.50	
	ENT	1.70	0.67	1.08	1.70	2.12	3.03	2.98	3.33
	Orthopedic	1.78	1.02	1.38	1.82	2.67	3.32	3.00	
	Urology	2.02	0.98	1.23	1.70	2.53	3.83	2.20	2.10
	Oral Surgery	1.62	1.45	2.17	1.50				
	Ophthalmology	1.38	0.77	1.00	1.58	2.12			
	Trauma	1.67	1.03	1.35	2.03	2.93			

A.2 Operation room factor for the surgical clusters for different surgery rooms

The operation room factor is ratio between total times of the surgery to skin to skin duration. It is usually 10 to 15 minutes varying upon the surgery type, swiftness of surgery team, uninterrupted flow of patients to and fro OR. OR factor shown below are calculated from the data available in appendix A.1. Table 10 shows ORF for each surgical specialty with different set of surgical operations.

Table 10 Operation room factor ($ORF_{i,e}$) for each surgery team for different type of surgeries

		Operation Room factor							
		1	2	3	4	5	6	7	8
Surgical Speciality	General	1.08	1.22	1.15	1.11	1.09	1.07	1.06	1.04
	Gynecology	1.19	1.29	1.21	1.15	1.12	1.10	1.07	
	Plastic	1.13	1.24	1.18	1.13	1.11	1.08	1.06	
	ENT	1.15	1.38	1.23	1.15	1.12	1.08	1.08	1.08
	Orthopedic	1.14	1.25	1.18	1.14	1.09	1.08	1.05	
	Urology	1.12	1.25	1.20	1.15	1.10	1.07	1.06	1.12
	Oral Surgery	1.15	1.17	1.12	1.06				
	Ophthalmology	1.18	1.33	1.25	1.16	1.12			
	Trauma	1.15	1.24	1.19	1.12	1.09			

A.3 Frequency of surgeries requested by surgeons to the hospital

Each surgery performed by surgical teams is shown in table 11 with the percentage of frequency of occurrence.

Table 11 Frequency in percentage ($f_{i,e}$) for each surgery type in Erasmus Medical Centre

		Frequency for different surgery types (%)							
		1	2	3	4	5	6	7	8
Surgical Speciality	General	8	3	12	19	21	3	25	9
	Gynecology	2	14	19	25	32	2	6	
	Plastic	5	14	17	21	22	11	10	
	ENT	4	32	19	12	14	8	5	6
	Orthopedic	9	10	18	21	21	16	5	
	Urology	3	6	30	15	17	19	5	5
	Oral Surgery	1	44	44	11				
	Ophthalmology	1	35	43	17	4			
	Trauma	7	22	32	20	19			

Enough number of patients is provided to each surgeon to make sure that starvation of patients doesn't occur. Hence, randomly generated number of patients was assigned to surgery teams. Total of 1362 patients were waiting for service.

A.4 Probability of Length of stay in recovery area

The values of the length of stay are generated randomly. The distribution for each of them is shown in table 13.

Table 12 : Probability of stay in the recovery area for different surgical speciality

		Surgical Specialties and probabilities of staying in recovery area								
		General	Gynecology	Oral	Trauma	ENT	Urology	Orthopedics	Ophthalmology	Plastic surgery
Length of stay in recovery unit	0	0.2	0	0	1	0.3	0	0	1	0.2
	1	0.4	0.1	0.2	0	0.2	0.1	0.2	0	0.3
	2	0.4	0.4	0.3	0	0.12	0.2	0.3	0	0.3
	3	0	0.4	0.4	0	0.38	0.3	0.5	0	0.2
	4	0	0.1	0.1	0	0	0.4	0	0	0
	5	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0
	21	0	0	0	0	0	0	0	0	0
	22	0	0	0	0	0	0	0	0	0
	23	0	0	0	0	0	0	0	0	0
	24	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0
	26	0	0	0	0	0	0	0	0	0
	27	0	0	0	0	0	0	0	0	0

The value of the Mean and standard deviation is calculated based on 7 day as a population of the sample. 95% confidence interval (CI) was found for each of the distribution for length of stay. The parameters and standards deviation was obtained with the help of Minitab 15.0.

Table 13: Probability distributions for the LOS

Speciality number	Speciality	Name of distribution	Parameters		Mean	Std. Deviation
			AD	P-Value		
1	General	Normal Distribution (95% CI)	0.872	0.012	0.143	0.19
2	Gynecology	Normal Distribution (95% CI)	0.805	0.018	0.143	0.18
3	Oral	Normal Distribution (95% CI)	0.438	0.203	0.143	0.161
4	Trauma	Normal Distribution (95% CI)	2	<0.005	0.143	0.377
5	ENT	Normal Distribution (95% CI)	0.422	0.226	0.143	0.155
6	Urology	Normal Distribution (95% CI)	0.438	0.203	0.143	0.161
7	Orthopedics	Normal Distribution (95% CI)	0.727	0.031	0.143	0.199
8	Ophthalmology	Normal Distribution (95% CI)	2	<0.005	0.143	0.377
9	Plastic surgery	Normal Distribution (95% CI)	0.727	0.031	0.143	0.199

Appendix B

AMPL Program for Mathematical model and variants:

B.1 : Lexicographic linear integer goal programming model

Following AMPL program is representing priorities 1234.

```
reset;

option solver cplex;

option cplex_options 'absmipgap=2';

set surgery;

set room ;

set day;

set ROOMNA within { surgery, room };

set DAYNA within  { surgery, day } ;

set speciality;


param m > 0;

param n > 0;

param T > 0;

param R > 0;

param h >= 0;

param E { i in 1..m} > 0;

param ORF { i in 1..m, e in 1..E[i] } >= 0;

param D { i in 1..m, e in 1..E[i] } >= 0;

param f { i in 1..m, e in 1..E[i] } >= 0;
```

```
param N { i in 1..m } > 0;

param v > 0;

param P { i in 1..m, l in 0..h} >=0, <= 1  ;

param shat {i in 1..m} > 0;

param B { r in 1..R} > 0;

param F { r in 1..R} > 0;


param HIGH {i in 1..m} >= 0;

param LOW {i in 1..m} >= 0;

param BLOCK { r in 1..R} >=0;


data finallarge.dat;


var O{ i in 1..m, j in 1..n, k in 1..T } integer >= 0;

var x { i in 1..m, j in 1..n, k in 1..T } binary;

var I {k in 1..T } >= 0;

var I_max >= 0;

var I_min >= 0;

var d1n { i in 1..m } >= 0;

var d1p { i in 1..m } >= 0;

var d2n { i in 1..m, j in 1..n, k in 1..T } >= 0;

var d2p { i in 1..m, j in 1..n, k in 1..T } >= 0;

var H { j in 1..n, k in 1..T } >= 0;

var U { j in 1..n, k in 1..T } >= 0;

var range >= 0;
```

```
var d1star >= 0;

var d2star >= 0;


minimize P1 : d1star ;


subject to eq1 { k in 1..T, (i,j) in ROOMNA} :

x[i,j,k] = 0 ; # surgery teams can be assigned to equipped rooms for specific surgery types


subject to eq2 { j in 1..n, (i,k) in DAYNA} :

x[i,j,k] = 0 ; # surgery teams can be assigned to only preferred days of surgery teams


subject to eq3 { j in 1..n, k in 1..T } :

sum {i in 1..m} x[i,j,k] <= 1; # single surgery team assignment constraint in a OR block


subject to eq4 { i in 1..m, k in 1..T } :

sum {j in 1..n} x[i,j,k] <= 1; # prevention of multiple assignment of same surgery team in same day OR blocks


subject to eq5 {i in 1..m}:

LOW[i] <= (sum {j in 1..n, k in 1..T} x[i,j,k]) <= HIGH[i];# Constraint to limit number of assignments for each doctor in time  horizon


subject to eq6 {r in 1..R}:
```

```
BLOCK[r] = (sum {i in B[r]..F[r], j in 1..n, k in 1..T} x[i,j,k])  ;#
Assignment of OR blocks to surgical specialties


subject to eq8 { i in 1..m} :

sum{j in 1..n} sum{k in 1..T} O[i,j,k] + d1n[i]= N[i]; #target constraint


subject to eq9 { i in 1..m, j in 1..n, k in 1..T} :

O[i,j,k] + d2n[i,j,k] = x[i,j,k] * v * (1/ sum { e in 1..E[i]}  D[i,e] *
ORF[i,e] *  f[i,e]) ; #capacity constraint


subject to EQ10_1 { k in 2..T} :

I[k] = I[k-1] + ( sum {i in 1..m} sum {j in 1..n} O[i,j,k]) - (sum {i in
1..m} sum {j in 1..n} sum {l in 0..k-1} O[i,j,k-l]*P[i,l]) - (sum {i in 1..m}
sum {j in 1..n}


sum {l in 1..T-k} O[i,j,k+l]*P[i,T-l]); #Number of patients in recovery area


subject to EQ10_2 { k in 1..1} :

I[k] =I[T] + ( sum {i in 1..m} sum {j in 1..n} O[i,j,k]) - (sum {i in 1..m}
sum {j in 1..n} sum {l in 0..k-1} O[i,j,k-l]*P[i,l]) - (sum {i in 1..m} sum {j
in 1..n} sum {l in 1..T-k} O[i,j,k+l]*P[i,T-l]);


subject to eq12 {j in 1..n, k in 1..T}:

H[j,k] = sum { i in 1..m, e in 1..E[i]} D[i,e] * ORF[i,e] * f[i,e] * O[i,j,k]
;# number of hours each OR utilized


subject to eq13 {j in 1..n, k in 1..T }: U[j,k] = v - H[j,k] ; # number of
hours each OR not utilized
```

```
subject to eq14 :
d1star = sum {i in 1..m} d1n[i] ;
solve;

drop P1;
minimize P2: d2star;
subject to eq15 :
d2star = sum {i in 1..m, j in 1..n, k in 1..T} d2n[i,j,k]  ;
fix d1star;
solve;

drop P2;
minimize P3: I_max;
subject to eq16 {k in 1..T} :
I_max >= I[k];
fix d1star;
fix d2star;
solve;
drop P2;

minimize P4: range;
subject to eq17 {k in 1..T} :
I_min <= I[k];
subject to eq18 :
```

```
range = I_max - I_min ;

fix d1star;

fix d2star;

fix I_max ;

solve;


display range;


display (sum {i in 1..m, j in 1..n, k in 1..T} x[i,j,k] * v) - sum {j in 1..n,
k in 1..T} H[j,k];# Total Underutilized hours of Operation Room

display 5*T*n/7;

display sum{ i in 1..m, j in 1..n, k in 1..T} x[i,j,k];# Number of assigned
Surgery blocks in Schedule

display sum{ i in 1..m, j in 1..n, k in 1..T} O[i,j,k];#number of assigned
surgeries in schedule

display sum {i in 1..m} N[i];# sum of total elective surgeries requested

display ((sum {i in 1..m, j in 1..n, k in 1..T} x[i,j,k] * v) - sum {j in
1..n, k in 1..T} H[j,k])*100/(sum{ i in 1..m, j in 1..n, k in 1..T}
x[i,j,k]*v) ;# Percentage of Underutilized hours of operating room (sum of
underutilized hours * 100/ total hours assigned to surgery block)

display  {i in 1..m} : sum {j in 1..n, k in 1..T} O[i,j,k]; #Number of
surgeries assigned to each  doctors in time horizon

display sum {i in 1..m, j in 1..n,k in 1..T} O[i,j,k];# Total surgeries
assigned in the schedule

display {j in 1..n, k in 1..T : U[j,k]= 0} U[j,k];#non assigned surgery blocks
# control omit_zreo_rows option for this command as it has duty to display
zero elements only


display N,  I, I_max ;
```

```
option omit_zero_rows 1;
display x, O, d2n ;
option omit_zero_columns 1;

display {j in 1..n, k in 1..T} U[j,k];
display {j in 1..n, k in 1..T} H[j,k];
```

B.2 Weighted goal programming objectives

```
reset;
option solver cplex;
option cplex_options 'absmipgap=3';
set surgery;
set room ;
set day;
set ROOMNA within { surgery, room };
set DAYNA within  { surgery, day } ;
set speciality;


param m > 0;
param n > 0;
param T > 0;
param R > 0;
param h >= 0;
param g1 > 0;
param g2 > 0;
param g3 > 0;
```

```
param g4 > 0;

param E { i in 1..m} > 0;

param ORF { i in 1..m, e in 1..E[i] } >= 0;

param D { i in 1..m, e in 1..E[i] } >= 0;

param f { i in 1..m, e in 1..E[i] } >= 0;

param N { i in 1..m } > 0;

param v > 0;

param P { i in 1..m, l in 0..h} >=0, <= 1  ;

param shat {i in 1..m} > 0;

param B { r in 1..R} > 0;

param F { r in 1..R} > 0;


param HIGH {i in 1..m} >= 0;

param LOW {i in 1..m} >= 0;

param BLOCK { r in 1..R} >=0;


data Weightedobjective.dat;

var O{ i in 1..m, j in 1..n, k in 1..T } integer >= 0;

var x { i in 1..m, j in 1..n, k in 1..T } binary;

var I {k in 1..T } >= 0;

var I_max >= 0;

var I_min >= 0;

var d1n { i in 1..m } >= 0;

var d1p { i in 1..m } >= 0;

var d2n { i in 1..m, j in 1..n, k in 1..T } >= 0;
```

```
var d2p { i in 1..m, j in 1..n, k in 1..T } >= 0;

var H { j in 1..n, k in 1..T } >= 0;

var U { j in 1..n, k in 1..T } >= 0;

var range >= 0;

var d1star >= 0;

var d2star >= 0;


minimize P1 : (g1*d1star + g2*d2star + g3*I_max + g4*range) ;


subject to eq1 { k in 1..T, (i,j) in ROOMNA} :

x[i,j,k] = 0 ;


subject to eq2 { j in 1..n, (i,k) in DAYNA} :

x[i,j,k] = 0 ;


subject to eq3 { j in 1..n, k in 1..T } :

sum {i in 1..m} x[i,j,k] <= 1;


subject to eq4 { i in 1..m, k in 1..T } :

sum {j in 1..n} x[i,j,k] <= 1;


subject to eq5 {i in 1..m}:

LOW[i] <= (sum {j in 1..n, k in 1..T} x[i,j,k]) <= HIGH[i];# Constraint to
limit number of assignments for each doctor in time  horizon
```

```
subject to eq6 {r in 1..R}:

BLOCK[r] = (sum {i in B[r]..F[r], j in 1..n, k in 1..T} x[i,j,k])  ;


subject to eq8 { i in 1..m} :

sum{j in 1..n} sum{k in 1..T} O[i,j,k] + d1n[i]= N[i];


subject to eq9 { i in 1..m, j in 1..n, k in 1..T} :

O[i,j,k] + d2n[i,j,k] = x[i,j,k] * v * (1/ sum { e in 1..E[i]}  D[i,e] *
ORF[i,e] *  f[i,e]) ;


subject to EQ10 { k in 2..T} :

I[k] = I[k-1] + ( sum {i in 1..m} sum {j in 1..n} O[i,j,k]) - (sum {i in
1..m} sum {j in 1..n} sum {l in


0..k-1} O[i,j,k-l]*P[i,l]) - (sum {i in 1..m} sum {j in 1..n} sum {l in 1..T-
k} O[i,j,k+l]*P[i,T-l]);


subject to EQ11 { k in 1..1} :

I[k] =I[T] + ( sum {i in 1..m} sum {j in 1..n} O[i,j,k]) - (sum {i in 1..m}
sum {j in 1..n} sum {l in


0..k-1} O[i,j,k-l]*P[i,l]) - (sum {i in 1..m} sum {j in 1..n} sum {l in 1..T-
k} O[i,j,k+l]*P[i,T-l]);


subject to eq12 {j in 1..n, k in 1..T}:

H[j,k] = sum { i in 1..m, e in 1..E[i]} D[i,e] * ORF[i,e] * f[i,e] * O[i,j,k];
```

```
subject to eq13 {j in 1..n, k in 1..T }: U[j,k] = v - H[j,k] ;

subject to eq14 : d1star = sum {i in 1..m} d1n[i] ;

subject to eq15 :
d2star = sum {i in 1..m, j in 1..n, k in 1..T} d2n[i,j,k]  ;

subject to eq16 {k in 1..T} :
I_max >= I[k];

subject to eq17 {k in 1..T} :
I_min <= I[k];
subject to eq18 :
range = I_max - I_min ;
solve;
```

B.3 Data file for Lexicographic goal programming model

```
param m = 54;

param n = 11;

param T = 28;

param h = 28;

param v = 8;

param R = 9;
```

```
set surgery:=       1      2      3      4      5      6      7      8      9
       10     11     12     13     14     15     16     17     18     19     20
       21     22     23     24     25     26     27     28     29     30     31
       32     33     34     35     36     37     38     39     40     41     42
       43     44     45     46     47     48     49     50     51     52     53
       54;


set room:=    1      2      3      4      5      6      7      8      9      10
       11;

set day:=     1      2      3      4      5      6      7      8      9      10
       11     12     13     14     15     16     17     18     19     20     21
       22     23     24     25     26     27     28;



set speciality:=    1      2      3      4      5      6      7      8      9;



param :

       N      E      shat   HIGH   LOW:=

1      23     8      1      8      3
2      26     8      1      8      3
3      18     8      1      8      3
4      14     8      1      8      3
5      20     8      1      8      3
6      25     8      2      9      2
7      23     8      2      9      2
```

8	31	8	2	9	2
9	24	8	2	9	2
10	28	8	2	9	2
11	28	8	2	9	2
12	20	8	2	9	2
13	12	8	2	9	2
14	23	8	2	9	2
15	27	8	2	9	2
16	37	8	2	9	2
17	32	8	2	9	2
18	18	8	3	11	3
19	20	8	3	11	3
20	18	8	3	11	3
21	22	8	3	11	3
22	17	8	3	11	3
23	18	8	3	11	3
24	17	8	3	11	3
25	19	8	3	11	3
26	20	8	3	11	3
27	21	8	3	11	3
28	24	8	3	11	3
29	28	8	4	4	3
30	30	8	5	10	3
31	32	8	5	10	3
32	28	8	5	10	3
33	30	8	5	10	3
34	16	8	6	10	3
35	20	8	6	10	3
36	22	8	6	10	3

```
37      23      8       6       10      3
38      22      8       6       10      3
39      35      8       7       8       2
40      37      8       7       8       2
41      23      8       7       8       2
42      25      8       7       8       2
43      23      8       7       8       2
44      22      8       7       8       2
45      20      8       7       8       2
46      30      8       8       7       3
47      35      8       8       7       3
48      38      8       8       7       3
49      39      8       8       7       3
50      40      8       8       7       3
51      30      8       9       5       3
52      25      8       9       5       3
53      32      8       9       5       3
54      32      8       9       5       3;

param:
        B       F       BLOCK:=
1       1       5       20
2       6       17      49
3       18      28      45
4       29      29      4
5       30      33      16
6       34      38      20
7       39      45      29
8       46      50      20
```

```
9     51    54    16;

set ROOMNA:
      1     2     3     4     5     6     7     8     9     10    11:=
1     -     -     -     -     -     -     -     -     -     +     -
2     -     -     -     -     -     -     -     -     -     +     -
3     -     -     -     -     -     -     -     -     -     +     -
4     -     -     -     -     -     -     -     -     -     +     -
5     -     -     -     -     -     -     -     -     -     +     -
6     -     +     -     -     -     -     -     -     +     +     +
7     -     +     -     -     -     -     -     -     +     +     +
8     -     +     -     -     -     -     -     -     +     +     +
9     -     +     -     -     -     -     -     -     +     +     +
10    -     +     -     -     -     -     -     -     +     +     +
11    -     +     -     -     -     -     -     -     +     +     +
12    -     +     -     -     -     -     -     -     +     +     +
13    -     +     -     -     -     -     -     -     +     +     +
14    -     +     -     -     -     -     -     -     +     +     +
15    -     +     -     -     -     -     -     -     +     +     +
16    -     +     -     -     -     -     -     -     +     +     +
17    -     +     -     -     -     -     -     -     +     +     +
18    -     +     -     -     -     -     -     -     -     -     +
19    -     +     -     -     -     -     -     -     -     -     +
20    -     +     -     -     -     -     -     -     -     -     +
21    -     +     -     -     -     -     -     -     -     -     +
22    -     +     -     -     -     -     -     -     -     -     +
23    -     +     -     -     -     -     -     -     -     -     +
24    -     +     -     -     -     -     -     -     -     -     +
25    -     +     -     -     -     -     -     -     -     -     +
```

26	-	+	-	-	-	-	-	-	-	-	+
27	-	+	-	-	-	-	-	-	-	-	+
28	-	+	-	-	-	-	-	-	-	-	+
29	+	+	+	-	+	+	-	-	-	+	+
30	-	-	-	+	-	-	+	+	+	+	+
31	-	-	-	+	-	-	+	+	+	+	+
32	-	-	-	+	-	-	+	+	+	+	+
33	-	-	-	+	-	-	+	+	+	+	+
34	-	-	-	-	-	+	-	+	-	-	-
35	-	-	-	-	-	+	-	+	-	-	-
36	-	-	-	-	-	+	-	+	-	-	-
37	-	-	-	-	-	+	-	+	-	-	-
38	-	-	-	-	-	+	-	+	-	-	-
39	+	+	-	+	-	-	+	-	-	-	-
40	+	+	-	+	-	-	+	-	-	-	-
41	+	+	-	+	-	-	+	-	-	-	-
42	+	+	-	+	-	-	+	-	-	-	-
43	+	+	-	+	-	-	+	-	-	-	-
44	+	+	-	+	-	-	+	-	-	-	-
45	+	+	-	+	-	-	+	-	-	-	-
46	+	+	-	-	-	-	-	-	-	+	-
47	+	+	-	-	-	-	-	-	-	+	-
48	+	+	-	-	-	-	-	-	-	+	-
49	+	+	-	-	-	-	-	-	-	+	-
50	+	+	-	-	-	-	-	-	-	+	-
51	-	-	-	-	-	+	+	-	+	+	+
52	-	-	-	-	-	+	+	-	+	+	+
53	-	-	-	-	-	+	+	-	+	+	+
54	-	-	-	-	-	+	+	-	+	+	+;

```
set DAYNA :
          1    2    3    4    5    6    7    8    9    10
     11   12   13   14   15   16   17   18   19   20   21
     22   23   24   25   26   27   28 :=
1    +    -    -    -    -    +    +    +    -    -    -
     -    +    +    +    -    -    -    -    +    +    +
     -    -    -    -    +    +
2    -    +    -    -    -    +    +    -    +    -    -
     -    +    +    -    +    -    -    -    +    +    -
     +    -    -    -    +    +
3    -    -    +    -    -    +    +    -    -    +    -
     -    +    +    -    -    +    -    -    +    +    -
     -    +    -    -    +    +
4    -    -    -    +    -    +    +    -    -    -    +
     -    +    +    -    -    -    +    -    +    +    -
     -    -    +    -    +    +
5    -    -    -    -    +    +    +    -    -    -    -
     +    +    +    -    -    -    -    +    +    +    -
     -    -    -    +    +    +
6    +    -    -    -    -    +    +    +    -    -    -
     -    +    +    +    -    -    -    -    +    +    +
     -    -    -    -    +    +
7    -    +    -    -    -    +    +    -    +    -    -
     -    +    +    -    +    -    -    -    +    +    -
     +    -    -    -    +    +
8    -    -    +    -    -    +    +    -    -    +    -
     -    +    +    -    -    +    -    -    +    +    -
     -    +    -    -    +    +
```

9	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					
10	-	-	-	-	+	+	+	-	-	-	-
	+	+	+	-	-	-	-	+	+	+	-
	-	-	-	+	+	+					
11	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					
12	-	-	+	-	-	+	+	-	-	+	-
	-	+	+	-	-	+	-	-	+	+	-
	-	+	-	-	+	+					
13	-	+	-	-	-	+	+	-	+	-	-
	-	+	+	-	+	-	-	-	+	+	-
	+	-	-	-	+	+					
14	+	-	-	-	-	+	+	+	-	-	-
	-	+	+	+	-	-	-	-	+	+	+
	-	-	-	-	+	+					
15	-	+	-	-	-	+	+	-	+	-	-
	-	+	+	-	+	-	-	-	+	+	-
	+	-	-	-	+	+					
16	-	-	+	-	-	+	+	-	-	+	-
	-	+	+	-	-	+	-	-	+	+	-
	-	+	-	-	+	+					
17	-	-	-	+	+	+	+	-	-	-	+
	+	+	+	-	-	-	+	+	+	+	-
	-	-	+	+	+	+					

18	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					
19	-	-	-	-	+	+	+	-	-	-	-
	+	+	+	-	-	-	-	+	+	+	-
	-	-	-	+	+	+					
20	-	-	-	-	+	+	+	-	-	-	-
	+	+	+	-	-	-	-	+	+	+	-
	-	-	-	+	+	+					
21	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					
22	-	-	+	-	-	+	+	-	-	+	-
	-	+	+	-	-	+	-	-	+	+	-
	-	+	-	-	+	+					
23	-	+	-	-	-	+	+	-	+	-	-
	-	+	+	-	+	-	-	-	+	+	-
	+	-	-	-	+	+					
24	+	-	-	-	-	+	+	+	-	-	-
	-	+	+	+	-	-	-	-	+	+	+
	-	-	-	-	+	+					
25	-	+	-	-	-	+	+	-	+	-	-
	-	+	+	-	+	-	-	-	+	+	-
	+	-	-	-	+	+					
26	-	-	+	-	-	+	+	-	-	+	-
	-	+	+	-	-	+	-	-	+	+	-
	-	+	-	-	+	+					

27	–	–	–	+	–	+	+	–	–	–	+
	–	+	+	–	–	–	+	–	+	+	–
	–	–	+	–	+	+					
28	–	–	–	–	+	+	+	–	–	–	–
	+	+	+	–	–	–	–	+	+	+	–
	–	–	–	+	+	+					
29	–	–	+	–	–	+	+	–	–	+	–
	–	+	+	–	–	+	–	–	+	+	–
	–	+	–	–	+	+					
30	+	–	–	–	–	+	+	+	–	–	–
	–	+	+	+	–	–	–	–	+	+	+
	–	–	–	–	+	+					
31	–	+	–	–	–	+	+	–	+	–	–
	–	+	+	–	+	–	–	–	+	+	–
	+	–	–	–	+	+					
32	–	–	+	–	–	+	+	–	–	+	–
	–	+	+	–	–	+	–	–	+	+	–
	–	+	–	–	+	+					
33	–	+	–	+	+	+	+	–	+	–	+
	+	+	+	–	+	–	+	+	+	+	–
	+	–	+	+	+	+					
34	–	–	–	–	–	+	+	–	–	–	–
	–	+	+	–	–	–	–	–	+	+	–
	–	–	–	–	+	+					
35	–	–	–	–	–	+	+	–	–	–	–
	–	+	+	–	–	–	–	–	+	+	–
	–	–	–	–	+	+					

36	-	-	-	-	-	+	+	-	-	-	-
	-	+	+	-	-	-	-	-	+	+	-
	-	-	-	-	+	+					
37	-	-	-	-	-	+	+	-	-	-	-
	-	+	+	-	-	-	-	-	+	+	-
	-	-	-	-	+	+					
38	-	-	-	-	-	+	+	-	-	-	-
	-	+	+	-	-	-	-	-	+	+	-
	-	-	-	-	+	+					
39	+	-	-	-	-	+	+	+	-	-	-
	-	+	+	+	-	-	-	-	+	+	+
	-	-	-	-	+	+					
40	-	+	-	-	-	+	+	-	+	-	-
	-	+	+	-	+	-	-	-	+	+	-
	+	-	-	-	+	+					
41	-	-	+	-	-	+	+	-	-	+	-
	-	+	+	-	-	+	-	-	+	+	-
	-	+	-	-	+	+					
42	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					
43	-	-	-	-	+	+	+	-	-	-	-
	+	+	+	-	-	-	-	+	+	+	-
	-	-	-	+	+	+					
44	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					

45	-	+	-	-	-	+	+	-	+	-	-
	-	+	+	-	+	-	-	-	+	+	-
	+	-	-	-	+	+					
46	+	-	-	-	-	+	+	+	-	-	-
	-	+	+	+	-	-	-	-	+	+	+
	-	-	-	-	+	+					
47	-	+	-	-	-	+	+	-	+	-	-
	-	+	+	-	+	-	-	-	+	+	-
	+	-	-	-	+	+					
48	-	-	+	-	-	+	+	-	-	+	-
	-	+	+	-	-	+	-	-	+	+	-
	-	+	-	-	+	+					
49	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					
50	-	-	-	-	+	+	+	-	-	-	-
	+	+	+	-	-	-	-	+	+	+	-
	-	-	-	+	+	+					
51	-	-	-	-	+	+	+	-	-	-	-
	+	+	+	-	-	-	-	+	+	+	-
	-	-	-	+	+	+					
52	-	-	-	+	-	+	+	-	-	-	+
	-	+	+	-	-	-	+	-	+	+	-
	-	-	+	-	+	+					
53	-	-	+	-	-	+	+	-	-	+	-
	-	+	+	-	-	+	-	-	+	+	-
	-	+	-	-	+	+					

```
54    -    +    -    -    -    +    +    -    +    -    -
      -    +    +    -    +    -    -    -    +    +    -
      +    -    -    -    +    +;

param P :
      0    1    2    3    4    5    6    7    8    9    10
      11   12   13   14   15   16   17   18   19   20   21
      22   23   24   25   26   27:=
1     0.2  0.4  0.4  0    0    0    0    0    0    0    0
      0    0    0    0    0    0    0    0    0    0    0
      0    0    0    0    0    0
2     0.2  0.4  0.4  0    0    0    0    0    0    0    0
      0    0    0    0    0    0    0    0    0    0    0
      0    0    0    0    0    0
3     0.2  0.4  0.4  0    0    0    0    0    0    0    0
      0    0    0    0    0    0    0    0    0    0    0
      0    0    0    0    0    0
4     0.2  0.4  0.4  0    0    0    0    0    0    0    0
      0    0    0    0    0    0    0    0    0    0    0
      0    0    0    0    0    0
5     0.2  0.4  0.4  0    0    0    0    0    0    0    0
      0    0    0    0    0    0    0    0    0    0    0
      0    0    0    0    0    0
6     0    0.1  0.4  0.4  0.1  0    0    0    0    0    0
      0    0    0    0    0    0    0    0    0    0    0
      0    0    0    0    0    0
7     0    0.1  0.4  0.4  0.1  0    0    0    0    0    0
      0    0    0    0    0    0    0    0    0    0    0
      0    0    0    0    0    0
```

8	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
9	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
10	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
11	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
12	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
13	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
14	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
15	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
16	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					

17	0	0.1	0.4	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
18	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
19	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
20	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
21	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
22	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
23	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
24	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
25	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					

26	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
27	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
28	0	0.2	0.3	0.4	0.1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
29	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
30	0.3	0.2	0.12	0.38	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
31	0.3	0.2	0.12	0.38	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
32	0.3	0.2	0.12	0.38	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
33	0.3	0.2	0.12	0.38	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
34	0	0.1	0.2	0.3	0.4	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					

35	0	0.1	0.2	0.3	0.4	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
36	0	0.1	0.2	0.3	0.4	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
37	0	0.1	0.2	0.3	0.4	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
38	0	0.1	0.2	0.3	0.4	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
39	0	0.2	0.3	0.5	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
40	0	0.2	0.3	0.5	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
41	0	0.2	0.3	0.5	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
42	0	0.2	0.3	0.5	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
43	0	0.2	0.3	0.5	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					

44	0	0.2	0.3	0.5	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
45	0	0.2	0.3	0.5	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
46	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
47	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
48	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
49	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
50	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
51	0.2	0.3	0.3	0.2	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					
52	0.2	0.3	0.3	0.2	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0					

```
53      0.2     0.3     0.3     0.2     0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0       0
54      0.2     0.3     0.3     0.2     0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0       0;

param D:
        1       2       3       4       5       6       7       8:=
1       2.5     1.1     1.7     2.3     2.9     3.6     2.0     3.4
2       2.5     1.1     1.7     2.3     2.9     3.6     2.0     3.4
3       2.5     1.1     1.7     2.3     2.9     3.6     2.0     3.4
4       2.5     1.1     1.7     2.3     2.9     3.6     2.0     3.4
5       2.5     1.1     1.7     2.3     2.9     3.6     2.0     3.4
6       1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
7       1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
8       1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
9       1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
10      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
11      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
12      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
13      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
14      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
15      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
16      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
17      1.3     0.9     1.2     1.6     2.1     2.6     3.6     0
18      1.6     1.5     2.2     1.5     0.0     0.0     0.0     0
19      1.6     1.5     2.2     1.5     0.0     0.0     0.0     0
20      1.6     1.5     2.2     1.5     0.0     0.0     0.0     0
```

21	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
22	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
23	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
24	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
25	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
26	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
27	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
28	1.6	1.5	2.2	1.5	0.0	0.0	0.0	0
29	1.7	1.0	1.4	2.0	2.9	0.0	0.0	0
30	1.7	0.7	1.1	1.7	2.1	3.0	3.0	3.3
31	1.7	0.7	1.1	1.7	2.1	3.0	3.0	3.3
32	1.7	0.7	1.1	1.7	2.1	3.0	3.0	3.3
33	1.7	0.7	1.1	1.7	2.1	3.0	3.0	3.3
34	2.0	1.0	1.2	1.7	2.5	3.8	2.2	2.1
35	2.0	1.0	1.2	1.7	2.5	3.8	2.2	2.1
36	2.0	1.0	1.2	1.7	2.5	3.8	2.2	2.1
37	2.0	1.0	1.2	1.7	2.5	3.8	2.2	2.1
38	2.0	1.0	1.2	1.7	2.5	3.8	2.2	2.1
39	1.8	1.0	1.4	1.8	2.7	3.3	3.0	0
40	1.8	1.0	1.4	1.8	2.7	3.3	3.0	0
41	1.8	1.0	1.4	1.8	2.7	3.3	3.0	0
42	1.8	1.0	1.4	1.8	2.7	3.3	3.0	0
43	1.8	1.0	1.4	1.8	2.7	3.3	3.0	0
44	1.8	1.0	1.4	1.8	2.7	3.3	3.0	0
45	1.8	1.0	1.4	1.8	2.7	3.3	3.0	0
46	1.4	0.8	1.0	1.6	2.1	0.0	0.0	0
47	1.4	0.8	1.0	1.6	2.1	0.0	0.0	0
48	1.4	0.8	1.0	1.6	2.1	0.0	0.0	0
49	1.4	0.8	1.0	1.6	2.1	0.0	0.0	0

```
50      1.4     0.8     1.0     1.6     2.1     0.0     0.0     0
51      2.0     1.1     1.4     1.9     2.3     3.1     1.5     0
52      2.0     1.1     1.4     1.9     2.3     3.1     1.5     0
53      2.0     1.1     1.4     1.9     2.3     3.1     1.5     0
54      2.0     1.1     1.4     1.9     2.3     3.1     1.5     0;


param ORF:
        1       2       3       4       5       6       7       8:=
1       1.1     1.2     1.2     1.1     1.1     1.1     1.1     1.0
2       1.1     1.2     1.2     1.1     1.1     1.1     1.1     1.0
3       1.1     1.2     1.2     1.1     1.1     1.1     1.1     1.0
4       1.1     1.2     1.2     1.1     1.1     1.1     1.1     1.0
5       1.1     1.2     1.2     1.1     1.1     1.1     1.1     1.0
6       1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
7       1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
8       1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
9       1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
10      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
11      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
12      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
13      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
14      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
15      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
16      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
17      1.2     1.3     1.2     1.2     1.1     1.1     1.1     0.0
18      1.2     1.2     1.1     1.1     0.0     0.0     0.0     0.0
19      1.2     1.2     1.1     1.1     0.0     0.0     0.0     0.0
20      1.2     1.2     1.1     1.1     0.0     0.0     0.0     0.0
```

21	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
22	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
23	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
24	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
25	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
26	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
27	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
28	1.2	1.2	1.1	1.1	0.0	0.0	0.0	0.0
29	1.2	1.2	1.2	1.1	1.1	0.0	0.0	0.0
30	1.1	1.4	1.2	1.1	1.1	1.1	1.1	1.1
31	1.1	1.4	1.2	1.1	1.1	1.1	1.1	1.1
32	1.1	1.4	1.2	1.1	1.1	1.1	1.1	1.1
33	1.1	1.4	1.2	1.1	1.1	1.1	1.1	1.1
34	1.1	1.3	1.2	1.1	1.1	1.1	1.1	1.1
35	1.1	1.3	1.2	1.1	1.1	1.1	1.1	1.1
36	1.1	1.3	1.2	1.1	1.1	1.1	1.1	1.1
37	1.1	1.3	1.2	1.1	1.1	1.1	1.1	1.1
38	1.1	1.3	1.2	1.1	1.1	1.1	1.1	1.1
39	1.1	1.2	1.2	1.1	1.1	1.1	1.1	0.0
40	1.1	1.2	1.2	1.1	1.1	1.1	1.1	0.0
41	1.1	1.2	1.2	1.1	1.1	1.1	1.1	0.0
42	1.1	1.2	1.2	1.1	1.1	1.1	1.1	0.0
43	1.1	1.2	1.2	1.1	1.1	1.1	1.1	0.0
44	1.1	1.2	1.2	1.1	1.1	1.1	1.1	0.0
45	1.1	1.2	1.2	1.1	1.1	1.1	1.1	0.0
46	1.2	1.3	1.3	1.2	1.1	0.0	0.0	0.0
47	1.2	1.3	1.3	1.2	1.1	0.0	0.0	0.0
48	1.2	1.3	1.3	1.2	1.1	0.0	0.0	0.0
49	1.2	1.3	1.3	1.2	1.1	0.0	0.0	0.0

```
50    1.2   1.3   1.3   1.2   1.1   0.0   0.0   0.0
51    1.1   1.2   1.2   1.1   1.1   1.1   1.1   0.0
52    1.1   1.2   1.2   1.1   1.1   1.1   1.1   0.0
53    1.1   1.2   1.2   1.1   1.1   1.1   1.1   0.0
54    1.1   1.2   1.2   1.1   1.1   1.1   1.1   0;

param f:
      1     2     3     4     5     6     7     8:=
1     0.1   0.0   0.1   0.2   0.2   0.0   0.3   0.1
2     0.1   0.0   0.1   0.2   0.2   0.0   0.3   0.1
3     0.1   0.0   0.1   0.2   0.2   0.0   0.3   0.1
4     0.1   0.0   0.1   0.2   0.2   0.0   0.3   0.1
5     0.1   0.0   0.1   0.2   0.2   0.0   0.3   0.1
6     0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
7     0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
8     0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
9     0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
10    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
11    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
12    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
13    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
14    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
15    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
16    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
17    0.0   0.1   0.2   0.3   0.3   0.0   0.1   0.0
18    0.0   0.4   0.4   0.1   0.0   0.0   0.0   0.0
19    0.0   0.4   0.4   0.1   0.0   0.0   0.0   0.0
20    0.0   0.4   0.4   0.1   0.0   0.0   0.0   0.0
21    0.0   0.4   0.4   0.1   0.0   0.0   0.0   0.0
```

22	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0
23	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0
24	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0
25	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0
26	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0
27	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0
28	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0
29	0.1	0.2	0.3	0.2	0.2	0.0	0.0	0.0
30	0.0	0.3	0.2	0.1	0.1	0.1	0.1	0.1
31	0.0	0.3	0.2	0.1	0.1	0.1	0.1	0.1
32	0.0	0.3	0.2	0.1	0.1	0.1	0.1	0.1
33	0.0	0.3	0.2	0.1	0.1	0.1	0.1	0.1
34	0.0	0.1	0.3	0.2	0.2	0.2	0.1	0.1
35	0.0	0.1	0.3	0.2	0.2	0.2	0.1	0.1
36	0.0	0.1	0.3	0.2	0.2	0.2	0.1	0.1
37	0.0	0.1	0.3	0.2	0.2	0.2	0.1	0.1
38	0.0	0.1	0.3	0.2	0.2	0.2	0.1	0.1
39	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0
40	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0
41	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0
42	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0
43	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0
44	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0
45	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0
46	0.0	0.4	0.4	0.2	0.0	0.0	0.0	0.0
47	0.0	0.4	0.4	0.2	0.0	0.0	0.0	0.0
48	0.0	0.4	0.4	0.2	0.0	0.0	0.0	0.0
49	0.0	0.4	0.4	0.2	0.0	0.0	0.0	0.0
50	0.0	0.4	0.4	0.2	0.0	0.0	0.0	0.0

51	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.0
52	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.0
53	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.0
54	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0;

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VITA AUCTORIS

NAME:	Navneetkumar Rameshbhai Rafaliya
PLACE OF BIRTH:	Damarala, Gujarat, India
YEAR OF BIRTH:	1988
EDUCATION:	Axay High School, Ahmedabad, India, 2005
	Gujarat University, B.E., Ahmedabad, India, 2009
	University of Windsor, M.A.Sc., Windsor, ON, 2013