A CASE STUDY ON THE APPLICATION OF 0-1 GOAL PROGRAMMING:
NURSE SCHEDULING

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UNIVERSITI TEKNOLOGI MALAYSIA
A CASE STUDY ON THE APPLICATION OF 0-1 GOAL PROGRAMMING:
NURSE SCHEDULING

MUNIRAH ROSSDY

A dissertation submitted in partial fulfilment of the requirement for the award of the degree of Master of Science (Mathematics)

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To my beloved

ayah, Hj. Rosdy Hj. Dalhani
ibu, Hjh. Siti Aminah Hj. Ibrahim
akak, Shantini Hj. Rosdy
abang, Hj. Ahmad Yasir Hj. Rosdy
&
little niece, Auni Dalili

Hold fast to dreams
For if dreams die
Life is a broken-winged bird
That cannot fly.

Hold fast to dreams
For when dreams go
Life is a barren field
Frozen with snow.
ACKNOWLEDGEMENT

Assalamualaikum warahmatullahi wabarakatuh…

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ABSTRACT

The continuous pattern of working 24 hours a day, 7 days a week, needs a working shift environment that could affect the working conditions of the nurses. This involves social life and nurses’ level of health. Therefore the development of a nurse scheduling model that can be accepted well by all parties is necessary to enable it to be applied in the nurse scheduling system. This nurse scheduling considers policy imposed by the hospital and demand from the nurses so that there is more balance, quality and fairness in the production of the nurse scheduling model. Hence, in this research, 0-1 goal programming approach is applied in the development of nurse scheduling model because of its ability to produce a model with multiple objectives. Approach to the problem was illustrated on the Maternity Ward 2, Hospital Tawau, Sabah involving U29 and U19 nurses. The result obtained by LINGO software version 10.0 shows that the developed model of nurse scheduling using 0-1 goal programming approach performs better than the manual method. This is because it was successful in meeting the hospital policy and nurses’ preferences.
Corak bekerja yang berterusan iaitu selama 24 jam sehari 7 hari seminggu, memerlukan waktu kerja mengikut syif yang boleh memberi kesan yang mendalam ke atas keadaan kerja jururawat. Ini melibatkan kehidupan sosial dan tahap penjagaan kesihatan jururawat. Oleh itu pembangunan sebuah model penjadualan jururawat yang dapat diterima baik oleh semua pihak adalah perlu bagi membolehkan ia digunapakai dalam sistem penjadualan jururawat. Penjadualan jururawat ini mempertimbangkan polisi yang dikenakan oleh pihak hospital dan permintaan daripada jururawat agar model penjadualan jururawat yang dihasilkan lebih adil, berkualiti dan seimbang. Justeru, dalam kajian ini, pendekatan pengaturcaraan gol 0-1 diaplikasikan di dalam pembangunan model penjadualan jururawat ini kerana keupayaannya menghasilkan sebuah model dengan pelbagai matlamat. Pendekatan ke atas masalah ini diilustrasikan ke atas jururawat di Maternity Ward 2, Hospital Tawau, Sabah yang melibatkan jururawat terlatih U29 dan jururawat masyarakat U19. Daripada hasil penyelesaian menggunakan perisian LINGO versi 10.0, didapati model penjadualan jururawat secara pengaturcaraan gol 0-1 adalah lebih baik berbanding kaedah secara manual. Ini kerana ia berjaya memenuhi polisi pihak hospital dan permintaan jururawat.
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<td>MIGP</td>
<td>Mix Integer Goal Programming</td>
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<td>ME</td>
<td>Marketing executive</td>
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<tr>
<td>GP</td>
<td>Goal programming</td>
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<td>LGP</td>
<td>Linear goal programming</td>
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<td>NP</td>
<td>Non-deterministic polynomial-time</td>
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LIST OF SYMBOLS

$G_i$ - $i$th goal

$w_i$ - $i$th weight

$\rho_i$ - $i$th priority

$G$ - general objective function
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CHAPTER 1

INTRODUCTION

1.1 Introduction

Operational Research involves the application of scientific principles to decision making. Its development as a formal discipline can be traced to World War II when these techniques were used by the British military in order to determine how best to use radar devices (Cohen, 1984). The name “Operational Research” was introduced because scientists were used to study operational problems. The allied forces also used operational research for strategic bombing, anti submarine and mining operations.

The growth of operational research since World War II has been due primarily to the development of the digital computer. Many of the techniques that were developed during the war also could be applied to industry problems after the war. Production, inventory, maintenance and scheduling techniques were readily transferable. New models eventually were developed for applications in budgeting, capital, marketing and other areas. Today, operational research is being used in almost every field where complex decisions must be made. It is used not only by industries, but also by local and federal governments for public health, regional planning, transportation, education, meteorology and countless other areas.
The analysis of a problem involves many steps. The formulation phase is the most crucial, because if the problem is not set up correctly, the solution found may be the correct answer to the wrong problem. An operational research model usually consists of a system of mathematical equations that contains all information that is relevant to the decision. Computational algorithms have been developed that will solve the system equations and find the satisfying solution.

The environment in which decision makers operate has become increasingly complex. To deal with the vast amount of data that needs to be assimilated and many objectives that must be considered, managers have called upon mathematical modeling to help them make the best decisions. In many instances the use of these models is the only way that a person can hope to attain the best solution.

The decision maker is further limited by a lack of information, limited resources, and an inability to analyze the decision environment accurately. When a decision is reached, it may not be the absolute optimum, the point where all goals have been achieved. Usually, only a “satisfying” solution can be attained, not every goal has been completely achieved, but the firm has come as close as possible. Modern decision analysis introduces a scientific approach that aids the decision maker in achieving the best non optimum, satisfying value.

Decisions are limited by many constraints that are placed upon them. There are two types of constraints which limit the options of decision makers. System constraints are imposed by the decision environment. These include limits on time, manpower, the production capacity of equipment, government regulations, and collective bargaining agreements. Decision constraints are imposed by the organizational goal structure and can change as new policies are adopted. If these goals are ranked and weights are placed upon each one according to its importance, the decision analysis will indicate the best decision. Possible goals include sales goals, profit goals, pollution control,
labor stabilization and goals external growth. A good model will take all of these factors into consideration.

One of the discipline in operational research is multi-criteria decision analysis (MCDA), which sometimes called as multi-criteria decision making (MCDM). It is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations. MCDA aims at highlighting these conflicts and deriving a way to come to a compromise in a transparent process. Unlike methods that assume the availability of measurements, measurements in MCDA are derived or interpreted subjectively as indicators of the strength of various preferences. Preferences differ from decision maker to decision maker, so the outcome depends on who is making the decision and what their goals and preferences are. (Andrew, et al., 2008). Since MCDA involves a certain element of subjectiveness, the morals and ethics of the researcher implementing MCDA play a significant part in the accuracy and fairness of MCDA's conclusions. The ethical point is very important when one is making a decision that seriously impacts on other people, as opposed to a personal decision. Some of the MCDA methods are analytic hierarchy process, analytic network process, inner product of vectors, multi-attributte value theory, data envelopment analysis, dominance-based rough set approach, aggregated indices randomnization method and goal programming. The choice of which model is most appropriate depends on the problem at hand and may be to some extent dependent on which model the decision maker is most comfortable with.

1.2 Background of the problem

Linear programming (LP) is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear equations.
More formally, linear programming is a technique for the optimization of a linear objective function, subject to linear equality and linear inequality constraints. Given a polyhedron a real-valued affine function defined on this polyhedron, a linear programming method will find a point on the polyhedron where this function has the smallest (or largest) value if such point exists, by searching through the polyhedron vertices.

Linear programs are problems that can be expressed in canonical form:

Maximize $c^T x$
Subject to $Ax \leq b$

where $x$ represents the vector of variables (to be determined), $c$ and $b$ are vectors of (known) coefficients and $A$ is a (known) matrix of coefficients. The expression to be maximized or minimized is called the objective function ($c^T x$ in this case). The equations $Ax \leq b$ are the constraints which specify a convex polytope over which the objective function is to be optimized.

Linear programming can be applied to various fields of study. It is used most extensively in business and economics, but can also be utilized for some engineering problems. Industries that use linear programming models include transportation, energy, telecommunications, and manufacturing. It has proved useful in modeling diverse types of problems in planning, routing, scheduling, assignment, and design.

In linear programming problems there is a single objective function to be maximized or minimized (subject to constraints). In some problems there may be more than one competing objective (or goal) and we need to trade-off objectives against each other.
One way of handling problems with multiple objectives is to choose one of the goals as the supreme goal and to treat the others as constraints to ensure that some minimal ‘satisficing’ level of the other goals is achieved. However, goal programming provides a more satisfactory treatment where in many cases problems can still be solved using standard linear programming algorithms.

In a linear programming problem, there is a single objective and constraints are absolutely binding. While in a goal programming problem, there are multiple objectives (with trade-offs) and deviations from constraints are penalized.

Goal programming is a form of linear programming that considers multiple goals that are often in conflict with each other. With multiple goals, all goals usually cannot be realized exactly. For example, the twin goals of an investor who desires investments with maximum return and with minimum risk are generally incompatible and therefore unachievable. Other examples of multiple conflicting objectives can be found in organizations that want to: (1) maximize profits and increase wages; (2) upgrade product quality and reduce product cost; (3) pay larger dividends to stockholders and retain earnings for growth; and (4) reduce credit losses and increase sales. Goal programming does not attempt to maximize or minimize a single objective function as does the linear programming model. Rather, it seeks to minimize the deviations among the desired goals and the actual results according to the priorities assigned. The objective function of a goal programming model is expressed in terms of the deviations from the target goals.

As goal programming is a branch of multi-criteria decision analysis (MCDA), also known as multiple-criteria decision making (MCDM), which in turn it is known as a branch of multi objective optimization. This is an optimization program. It is an extension or generalization of linear programming to handle multiple, normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimized in
an achievement function. This can be a vector or a weighted sum dependent on the goal programming variant used.

Goal programming has been applied to multi objective decision problems in nonprofit organizations, business firms, and government agencies. The most popular application areas of goal programming have been functional management problems, policy analysis, scheduling, resource allocation, and planning. Applications of goal programming include financial planning, resource allocation for environmental problem, municipal economic planning, transportation logistics, advertising media planning, manpower planning, aggregate production planning, capital budgeting, portfolio selection, marketing planning, academic resource planning, and hospital administration.

Goal programming problems can be categorized according to the types of mathematical programming models such as linear programming and nonlinear programming. In this dissertation, the application of goal programming that will be explored is scheduling using the linear goal programming model. This is goal programming problems that fit linear programming where each objective function is linear.

Scheduling is the process by which we plan our use of time. By scheduling effectively, we can reduce stress and maximize our effectiveness. This makes it one of the most important time management skills we can use. It is also a form of planning selects and sequences activities such that they achieve one or more goals. Nurse scheduling is part of a general scheduling problem, which deals with the satisfactory allocation of resources over time to achieve an organization’s tasks. A hospital in general unavoidably will have many scheduling problems in its operations. They need to minimize unnecessary conflicts in the proper and efficient use of its limited resources.
Nursing costs account for 50 percent of total hospital costs (Kiranmai et al., 2000), in other words, the manner on which nurses are deployed has a significant impact on a hospital’s operating budget and quality of work life for employees. Moreover, scheduling is a key to effectiveness and efficiency. An effective scheduling of nursing personal is directly affects the quality of patient care. Hence, in this research, we will focus on scheduling problems which dealing with the nurse shifting activity of Maternity Ward 2, Hospital Tawau, Sabah.

Nurse scheduling has been addressed by operations researchers and computer scientists for more than 40 years (Burke et al., 2004). The scheduling of hospital personnel is particularly challenging because of different staffing needs on different days and shifts. Unlike many other organizations, healthcare institutions work around the clock. Irregular shift work has an effect on the nurses’ well being and job satisfaction (Muelle et al., 1990). The extent to which the staff roster satisfies the staff can impact upon the working environment.

The nurse rerostering problem occurs when one or more nurses cannot work in shifts that were previously assigned to her or them. If no pool of reserve nurses exists to replace those absent, then the current roster must be rebuilt. This new roster must comply with the labour rules and institutional constraints. Moreover, it must be as similar as possible to the current one.

The problem is further complicated by such factors as, variation in patient demand, nurse qualification and specialization, acuity of patient illnesses, organizational characteristics (e.g. minimum required coverage and days off policies), unpredictable absenteeism, and personal requests for vacations, work stretch, and work pattern. Moreover, some of these considerations may conflict with others, such as employee requests versus the need to balance workload.
Nursing skills are in short supply and retaining qualified people is important (Ozkaharan, 1989). Job satisfaction, turnover and absenteeism have all been related to personnel scheduling flexibility. Some individuals might prefer longer but fewer days while others might prefer shorter days. Some nurses would choose part time work if available. Some people, irrespective of shift, would like to start earlier while others would opt for a later start time. No fixed personnel scheduling policy can satisfy all interests and flexible alternatives are needed to increase satisfaction and retention. Besides, the demand for care varies more on the morning and evening shift than on night shift.

One major disadvantage of these various alternative flexible scheduling patterns was the increased complexity of management control. As long as a nursing shortage exists, nursing administrators must either accept the added complexity of work schedules or find themselves paying more for nursing and accepting reduced quality of nursing care.

Oldenkamp and Simons (1995) have suggested five factors for assessing a schedule quality. These factors are given below:

1. **Optimality**: represents the degree in which nursing expertise is distributed over the different shifts.

2. **Completeness**: represents the degree in which the quantitative demands for occupation per shift are met.

3. **Proportionality**: represents the degree in which each nurse has been given about the same amount of working days (morning, evening and night shifts).

4. **Healthiness**: represents the degree in which it has been taken care of the welfare and health of the nurses.
5. Continuity factor: represents the degree in which there is continuity in the nursing crew during the different shifts.

1.3 Statement of the problem

In order to develop a model of scheduling, this study will embark on the application of 0-1 linear goal programming particularly in nurse scheduling based on identified constraints.

Nurse scheduling is a difficult and time consuming task. The schedule should determine the day to day shift assignments of each nurse for a specified horizon of time in a way that satisfies the given requirements. The schedule should also be fair enough to everyone and not disruptive to nurses’ health, families or social lives.

The problems in nurse scheduling are including developing a systematic procedure for allocating nurses to work shifts and workdays in a way to ensure a continuous and appropriate service of patient care and satisfying organizational scheduling policies, such as specific work requirements while using minimum staffing to avoid wasted manpower.

There are few research questions to be answered throughout this research which are:

1. What is the importance of linear goal programming in multi objectives problem?

2. How can 0-1 linear goal programming be applied in nurse scheduling problem?
3. How effective is the linear goal programming approach in solving scheduling problem?

1.4 Objectives of the study

The goal of this research is to apply 0-1 linear goal programming in nurse scheduling for Maternity Ward 2, Hospital Tawau, Sabah.

The objectives of this study are:

- To highlight the importance of linear goal programming in multi objectives problem
- To apply 0-1 linear goal programming approach in nurse scheduling system
- To investigate the effectiveness of linear goal programming approach and its contribution in improving scheduling system

1.5 Scope of the study

The scope of this study is to apply 0-1 linear goal programming approach in nurse scheduling with the aid of LINGO software. Data is gathered from Maternity Ward 2, Hospital Tawau, Sabah which consists of nurses’ preferences and nurses’ roster. Respondents involve are U29 nurses and U19 nurses from Maternity Ward 2.
1.6 Significance of the study

The need for quick, reliable and manageable scheduling system is often encountered in any organization. This study is an introduction of scientific approach in making decision. The result from this study is practical for other organizations as a guide in scheduling especially that involves in working shift time. Scheduling nursing personnel in hospitals is very complex because of the variety of conflicting interests and objectives. Also, demand varies 24-hours a day 7-days a week, needs specific skills to build up the schedule. In the face of this complexity, the needed of a good approach is important in order to satisfy all the constraints and requirements in nurse scheduling models. Thus, application of 0-1 linear goal programming using LINGO software is the main purpose of this study to see whether this approach is good enough for helping to improve the scheduling problems in the hospital.

1.7 Dissertation Organization

The contents of this dissertation have been arranged to be read chapter by chapter. The contents of each chapter are as follows:

**Chapter 1**: This chapter outline a general introduction, background of the problem, statement of the problem, objectives of the study, scope of the study and significance of the study.

**Chapter 2**: This chapter looks at the literature review involving scheduling, nurse scheduling and goal programming.

**Chapter 3**: This chapter describes the methodology for using linear goal programming to solve nurse scheduling problem.
Chapter 4: This chapter presents the implementation of 0-1 linear goal programming in nurse scheduling problem.

Chapter 5: This chapter highlights the result from the implementation of 0-1 linear goal programming in nurse scheduling using LINGO version 10.0 and the discussion as well as the analysis is done and presented using appropriate graphs by the help of Microsoft Office Excel 2007.

Chapter 6: This chapter summarizes and concludes the study. Some conclusions are drawn and finally, some thoughts on possible directions in which future study in this area might be pursued are offered.

1.8 Summary

This chapter, generally discusses on background of the problem, problem statement, research objective, scope and significance of the study. In other word, this chapter gives a general idea of overall situation and the flow of research.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Previous chapter is generally discussed on background of the problem, problem statement, research objective, scope and significance of the study. This chapter will highlight a few literature reviews on scheduling, nurse scheduling and goal programming.

2.2 Scheduling

Scheduling plays a role in a wide variety of situations. It is a decision making process that is used on a regular basis in many manufacturing and services industries. It deals with the allocation of resources to tasks over given time periods and its goal is to optimize one or more objectives. The goal of scheduling can either be satisfaction or optimizing (Draper et al., 1999).

The resources and tasks in an organization can take many different forms. The resources may be machines in a workshop, runways at an airport, crews at a construction site, processing units in a computing environment, and so on. (Michael, 2008) The tasks may be operations in a production process, take-offs and landings at an
airport, stages in a construction project, executions of computer programs, and so on. Each task may have a certain priority level, an earliest possible starting time and a due date. The objectives can also take many different forms. One objective may be the minimization of the completion time of the last task and another may be the minimization of the number of tasks completed after their respective due dates.

Scheduling, as a decision-making process, plays an important role in most manufacturing and production systems as well as in most information processing environments. It is also important in transportation and distribution settings and in other types of service industries.

It may not be immediately clear what impact schedules may have on objectives of interest. Does it make sense to invest time and effort searching for a good schedule rather than just choosing a schedule at random? In practice, it often turns out that the choice of schedule does have a significant impact on the system’s performance and that it does make sense to spend some time and effort searching for a suitable schedule.

Okada (1988) presented heuristic approach to solve nurse scheduling. Heuristic methods begin with one or more initial solutions and employ search strategies that try to avoid local optima. All of these search algorithms can produce high quality solutions but often have a considerable computational cost.

Scheduling can be difficult from a technical as well as from an implementation point of view. The type of difficulties encountered on the technical side is similar to the difficulties encountered in other forms of combinatorial optimization and stochastic modeling. (Michael, 2008) The difficulties on the implementation side are of a completely different kind. They may depend on the accuracy of the model used for the analysis of the actual scheduling problem and on the reliability of the input data that are needed.
The general problem of scheduling has attracted a great deal of interest. Numerous solution procedures have been proposed and tested. Each approach is designed to address certain aspects of the general scheduling problem. Andrew and Collins (1971) suggested a linear programming model, Dyer and Mulvey (1976) proposed a network model in the context of an integrated decision system. Large-scale integer programming models have been developed by Tillet (1975), Breslaw (1976), and McClure and Wells (1984).

Optimization models that address the time component of the scheduling problem have been proposed by Harwood and Lawless (1975), Shih and Sullivan (1977), and Mulvey (1982). The Harwood and Lawless approach uses a mixed integer goal programming model, the Shih and Sullivan method is based on a two-stage optimization of a zero-one integer programming model, and Mulvey (1982) uses a network model. Selim (1982, 1983) presents a linear program for constructing timetables.

### 2.3 Nurse Scheduling Approach

Modeling nurse scheduling is not a new idea. Until the 1960s, scheduling tools consisted only of graphical devices such as Gantt Chart. Howell (1966) outlined the steps necessary to develop a cyclical schedule. Howell’s method is a step-by-step procedure for accommodating the work patterns and individual preferences of nurses. In the early 1970s, scheduling systems began to be based on heuristic models (Smith et al., 1979, Isken and Hancock, 1991). These models were more appropriate because they could theoretically take into account of all scheduling constraints in solving the problem. Maier-Rothe and Wolfe (1973) developed a cyclical scheduling procedure that assigns different types of nurses to each unit based on average patient care requirements, hospital personnel policies, and nursing staff preferences.
In the past, a considerable number of relevant studies on nurse scheduling problem have been found. Smith and Wiggins (1977) divided nurse scheduling modeling into three categories; cyclical scheduling approach, heuristic scheduling approach, and mathematical programming approach. Cyclical scheduling approach sets up shift and vacation arrangement by the head nurse based on the needs of nurse unit, the regulations of hospital, and the number of nursing staffs. Cyclical scheduling approach normally utilizes cyclical scheduling pattern on a fixed time range. For heuristic scheduling approach, the nurse chiefs often construct a decision tree with consideration of nursing staff workforce, nurse service pattern, hospital scheduling policy, and other factors and then utilize the scheduling result on a cyclic basis. Mathematical programming approach is a special mathematical model developed to respond to the scheduling problems for different cases. Normally, it is constructed with objective functions and constraint equations and then utilizes appropriate algorithms to solving for the optimal solutions.

The mentioned three categories of nurse scheduling approaches have their advantages and disadvantages. Cyclical scheduling approach can be conveniently executed. However, a new scheduling must be rearranged in case that some nurses need to change their jobs or shifts. In practice, it is quite common for the nurses changing their jobs or shifts. Thus, cyclical scheduling approach does not provide effective ways to deal with the practical problem. Because the interaction relationship among nursing staffs is very complicated, the decision-making tree, constructed by the heuristic scheduling approach, for the scheduling rule is usually huge. When the constraint conditions are numerous, it will generally be difficult for the heuristic scheduling approach to attain a reasonable solution. As a result, the nurse scheduling activities cannot be easily processed (Harvey and Mona, 1998). Mathematical programming approach shows a substantial level of dependency on the cases addressed. When dealing with different cases, the mathematical scheduling model requires further reformulated.
Nurse scheduling system can be developed and treated in various ways. Ahuja and Sheppard (1975) developed a four-module four-stage interactive cyclical scheduling system, which used the computer to arrange schedules for different nursing staffs. Their system consists of four modules: (1) work pattern selector – it identifies cyclical schedule patterns from the inputted information, different case hospitals may have different work patterns; (2) work schedule assembler – it combines nursing staffs with the work patterns generated by the first module (3) work schedule projector – it displays the work schedules for both the individuals and the organization (4) work prediction and allocation of staffs – it designs a work load index according to the requirements of the nursing staffs and then assigns work to staffs based on this work load index. Smith and Wiggins (1977) developed a batched three-stage cyclical scheduling system to arrange the nurse scheduling, which includes (1) summarizing the requirements of staffs for specified units on weekly bases (2) generating preliminary schedules and evaluating the schedules with the constraint conditions to check if there is any conflict and (3) manually adjusting the preliminary schedule and creating the finalized schedule. Kostreva and Jenning (1991) indicated that a nurse scheduling system should include survey module and scheduler module.

Integer programming, mixed integer programming, goal programming, linear programming, network programming, and constraint programming have been used for solving the nurse scheduling problem. For instance, Miller, Pierskalla, and Rsth (1976) and Ozkarahan and Bailey (1988) utilized the integer programming to search for a schedule with the lowest aversion deviations, whereas Warner (1976b) employed goal programming with multiple-choices to solve nurse scheduling problems. Kostreva, Lescyski, and Passini (1978) and Bell, Hay, and Liang (1986) developed mixed integer programming models to solve nurse scheduling problems, while Arthur and Ravindran (1981) used 0–1 goal programming to solve two-stage cyclical scheduling problems. Azaiez and Al Sharif (2005) also used 0–1 goal programming to solve nurse scheduling problem. Bailey (1985) developed a cyclical scheduling model with integer programming. Brigitte, Semet, and Vovor (1998) utilized linear programming to obtain the solution that can simultaneously minimize the total payment, satisfy the staff

Other techniques have also been found to tackle the nurse scheduling problems. Randhawa and Stiompul (1993) developed a heuristic scheduling decision making support system to handle the multiple goal programming problems with binary variables whereas Aickelin and Dowsland (2000) used genetic algorithms to solve nurse scheduling problems. Dowsland and Thompson (2000) combined tabu search and network programming to establish a non-cyclical scheduling system, while Knjazew (2002) used genetic algorithms to solve cyclical scheduling problems. Aickelin and Li (2006) used Bayesian optimization algorithm to solve nurse scheduling problems.

Several nurse scheduling models were based on linear programming (Ozkaharan, 1989), penalty-point algorithms and mixed-integer programming (Harmeier, 1991). Other optimization techniques have been used in nurse scheduling particularly for the non-cyclical type. These include the assignment problem (Gaetan, Pierri and Brigitte, 1999) integer programming (Ballnski, 1965), stochastic programming (Aberathy et. al., 1973), non-linear programming (Warner, 1976) and goal programming (Ozkaharan, 1989), (Ozkaharan and Bailey, 1988).

Nurses frequently do not know from one day to another whether there will be sufficient work or whether they will be called and told to stay home. (Barbara and Thomas, 2001) Both impacts have serious implications for the professional nursing staff. One major implication is the ability to develop a committed, cohesive working group in the face of uncertain work and uncertain work team members. The constantly shifting work team can result in inefficiencies as staff adjusts daily to the skills and competencies of the other staff with whom they are working, and can potentially affect the quality of nursing care provided.
The nurse scheduling process may be viewed as one of generating a configuration of nurse schedules that specify the number and identities of the nurses working each day of the scheduling period (Holmes, 1976). By specifying nurse identities, one creates a pattern of scheduled days off and on for the individual nurses. These patterns, along with the hospital staffing requirements, define the nurse scheduling problem, how to generate a configuration of nurse schedules fulfilling the hospital staffing requirements while simultaneously satisfying the individual nurse's preferences for various schedule pattern characteristics.

Much of the work relating to nurse scheduling has concerned cyclical scheduling (Morris and O'Conner, 1970, Price, 1970, Howell, 1966) in which each nurse works a cycle of \( n \) weeks, where \( n \) is the length of the scheduling period. Cyclical schedules are easily generated but are characterized by excessive variations in the supply of and demand for nursing services. Two noncyclical scheduling papers of note have been by Rothstein, (1973) and Warner, (1976b). Rothstein's application was to hospital housekeeping operations. He sought to maximize the number of day-off pairs (e.g., Monday-Tuesday) subject to constraints requiring two days off each week and integral assignments. Warner presented a two phase algorithm to solve the nurse scheduling problem. Phase I is involved with finding a feasible solution to various staffing constraints, and Phase II seeks to improve the Phase I solution by maximizing individual preferences for various schedule patterns while maintaining the Phase I solution.

Investigations in health care systems may be classified into four interrelated nursing human resources decisions (Warner, 1976b).

- **Staffing decisions**, which specify the number of full time equivalent nursing personnel of each class of skills to be filled for each nursing unit.
• Scheduling decisions, which specify when each nurse will be on and off duty in the scheduling period and minimum number of nurses of each class of skills required for each shift on each day.

• Allocating decisions, which allocate a pool of available floating nurses to accommodate the fluctuating demand for nursing care and for absenteeism.

• Assignment decisions, which assign nurses to individual shifts.

2.4 Goal Programming

Multiple criteria decision making (MCDM) is a term used to describe a subfield in operations research and management science. Zionts (1992) generally defined MCDM as a means to solving decision problems that involve multiple (sometimes conflicting) objectives. While that definition also applies to goal programming, MCDM is a substantially broader body of methodologies of which goal programming is a small subset.

The various points of origin, methodology and future directions for MCDM can be found in Starr and Zeleny (1977), Hwang, Paidy, and Yoon (1980), Rosenthal (1985), Steuer (1986) and Dyer et. al. (1992). MCDM’s mathematical relationship to goal programming has been substantially described in a variety of publications including Romero (1985a) and Ringuest and Graves (1989).

Goal programming is a multiple-objective decision analysis technique that has applications in both industrial and public decision-making problems. In a goal programming model, the objective is not to optimize one criterion but to achieve multiple objectives. The basic approach is to minimize the deviational variables
through the use of priority factors and different weights. The goal programming methodology was first proposed and identified by A. Charnes and W.W. Cooper in 1962. The technique of goal programming was later extended and refined by Y. Ijiri in 1965. In 1973 and 1983, S.M. Lee had provided one of the comprehensive presentations of the topic. Other writers include James P. Ignizio (1976) and Marc J. Schniederjans (1985).

Goal programming has received many attentions among optimization techniques, as it attempts to optimize a number of objectives simultaneously. These objectives include maximizing utilization of full-time staff, minimizing understaffing and overstaffing costs, minimizing payroll costs, as well as minimizing deviations from desired staffing requirements, nurse preferences, and nurse special requests.

Trivedi (1981) has developed Mix Integer Goal Programming model for expense budgeting in a hospital nursing department. Objectives are based on cost and quality nursing care considerations.

Musa and Saxena (1984) have used a 0-1 goal programming formulation for nurse scheduling in one unit of a hospital. Goals with different priority levels represent hospital policies and nurses preferences.

Berrada, Ferland and Michelon (1996), in their 0-1 goal programming model for nurse scheduling, have used for hard constraints administrative and union contract specifications, while work patterns and nurses preferences have been formulated as soft constraints.

Moores, Garrod and Briggs (1978) have formulated the student nurse allocation problem using also a 0-1 goal programming. The problem was to produce a 3 year
schedule for student nurses to comply with the minimum practical and theoretical standards while being used as part of the hospital work force.

Charles, John and Paul (1984) have used linear programming methods in their study to solve the problem of assigning children to schools. This study uses the more general goal programming approach to analyze the problem of assigning children to secondary schools in Reading, England.

Goal programming model also has been applied by Schniederjans, Kwak and Helmer (1982) to resolve a trucking terminal site location problem. This is accomplished by allowing consideration of quantifiable personal preferences of the individuals who provide and use the truck terminal’s services.

Mathirajan and Ramanathan (2007), addresses the problem of scheduling the tour of a marketing executive (ME) of a large electronics manufacturing company in India using 0-1 goal programming (GP). In this problem, the ME has to visit a number of customers in a given planning period.

2.5 Summary

This chapter reviews some of the literatures relating to scheduling, nurse scheduling and goal programming which have been done by previous researchers. The findings in this chapter will be the basis for discussions in later chapters.
CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In previous chapter the discussion was focus on the literature review involving scheduling, nurse scheduling and goal programming. Whereas, this chapter will discuss on each phase involve in solving the problem, starting from the information collection until writing the report after getting the result based on the implementation.

3.2 Research Procedure

Developing a goal programming model is similar to developing a linear programming model. However, goal programming is a linear programming technique that includes more than one objective in the model. The constraints in goal programming are not absolute as in a linear programming. Consequently, a more realistic model can be constructed because an organization may have goals that are of very high priority but whose non-achievement can be tolerated. The goal programming also allows for the situation in which goals have different priorities. If goals can be enumerated and prioritized then a goal programming model can be formulated.

The model takes input regarding the nurse to be schedule and all the details related to the nurse. The nurse is the allocation of nurses from Maternity Ward 2,
Hospital Tawau. These details then will be analyzed to determine the hard and soft constraints which apply and dealt to the mathematical statement accordingly.

Figure 3.1 below is the flowchart for each step in the research procedure:

![Flowchart](image)

Figure 3.1: The flowchart of the research procedure
3.3 The Phase Involve in Implementing Goal Programming in Nurse Scheduling

There are few phases involve in implementing goal programming at Maternity Ward 2. The phase are 1) general overview and literature review – which will discuss on the general process in determining the problem arise on the chosen scope, 2) collect scheduling information – discuss on general process of data collection, 3) formulate the data into mathematical statement - discuss on which mathematical statement should be formed into hard constraint or soft constraint, 4) implementation - apply 0-1 linear goal programming in the problem 5) result – discuss on analyzing the result produced based on the implementation  6) report – writing the report based on the whole process of the research

3.3.1 Phase 1 : General Overview and Literature Review

In general overview, study the problems arise on the chosen scope. After the decision has been made then, start the process of collecting the information related to the field studies. This phase is the most time consuming parts in this project. Where, it involves the reading process (of related articles as much as possible) in order to understand the concepts, terminology and functionality of the goal programming. Most of the articles are related to goal programming and scheduling problems.

The nurse scheduling problem seemed appropriate because of its complexity and its’ help reducing burden for an important organization, to be specific, hospital.
3.3.1.1 Concept of Literature Review

A literature review is a body of text that aims to review the critical points of current knowledge or methodological approaches on a particular topic. Literature reviews are secondary sources and as such, do not report any new or original experimental work. Most often associated with academic oriented literature, such as thesis, a literature review usually precedes a research proposal and results section. Its ultimate goal is to bring the reader up to date with current literature on a topic and forms the basis for another goal, such as future research that may be needed in the area. A well structured literature review is characterized by a logical flow of ideas, current and relevant references with consistent, appropriate referencing style, proper use of terminology and an unbiased and comprehensive view of the previous research on the topic.

A literature review is a description of the literature relevant to a particular field or topic. It gives an overview of what has been said, who the key writers are, what are the prevailing theories and hypotheses, what questions are being asked, and what methods and methodologies are appropriate and useful. As such, it is not in itself primary research, but rather it reports on other findings.

A literature review may be purely descriptive, as in an annotated bibliography, or it may provide a critical assessment of the literature in a particular field, stating where the weaknesses and gaps are, contrasting the views of particular authors, or raising questions. Such a review will not just be a summary but will also evaluate and show relationships between different materials, so that key themes emerge. Even a descriptive review however should not just list and paraphrase, but should add comment and bring out themes and trends.
3.3.2 Phase 2 : Collect Scheduling Information

This phase is about collecting data regarding the nurse scheduler currently being used at Maternity Ward 2, Hospital Tawau, Sabah. The data consists of interviews and nurse roster from the ward. A meeting has been made with the head nurse that involved in making the roster. This gave an insight into the situation surrounding practical scheduling application. The items in the data are carefully constructed so as to be in line with the purpose of the study. Interviews are conducted in order to gain understanding on nurses’ preferences. Fairness bases are considered both from the interview results and the suggested policies in the literature. Interviews are conducted among the nurses from Maternity Ward 2 in Hospital Tawau, Sabah to get their responses.

3.3.2.1 Interviews

An interview is a conversation between two or more people (the interviewer and the interviewee) where questions are asked by the interviewer to obtain information from the interviewee. There are 3 main types of interviews which are structured, semi structured and depth interview. In this study, the type of interview used was semi structured interview.

Semi structured interviews are conducted with a fairly open framework which allow for focused, conversational and two way communication. They can be used both to give and receive information. Unlike the questionnaire framework, where detailed questions are formulating ahead of time, semi structured interviewing starts with more general questions or topics. Relevant topics are initially identified and the possible relationship between these topics and the issues such as availability, expense, effectiveness become the basis for more specific questions which do not need to be prepared in advance.
Not all questions are designed and phrased ahead of time. The majority of questions are created during the interview, allowing both the interviewer and the person being interviewed the flexibility to probe for details or discuss issues.

The method of semi structured interviews is effective when interviewer collect data from particular individuals by meeting with them only once. During a semi structured interview, an interviewer asks an interviewee questions based on a prepared written list of questions and topics. At the same time, the interviewer encourages the interviewee to freely express ideas and provide information that the interviewee thinks is important. With this flexibility, the researcher can obtain unexpected significant information as well as answers for prepared interview questions. In addition to asking questions, interviewers usually take notes and audio record interviews for later analysis. In order to conduct successful semi structured interviews, interviewers need to make interviewees feel comfortable about talking.

Hence, in this study, the author has met the head nurse and nurses involved to obtain information regarding the policies imposed on hospital and their preferences.

### 3.3.2.2 Nurse Roster

Nurses must be available 24 hours at health care organizations. This means that shift working is an absolute necessity. However, available nurses cannot be arbitrarily rostered to shifts. Nurse roster management must accommodate the constraints on shift allocation, and other kinds of constraints such as nurses' entitlement to vacations and other kinds of absences.

Yet another problem is the skill mix of nurses. Nurses with the right mix of
skills must be present during each shift. Otherwise, the quality of health care will suffer. On the other hand, employing too many staff to accommodate all contingencies will increase costs beyond acceptable levels. It is through effective nurse roster management that an attempt is made to meet both the quality and cost objectives. The roster must be managed in a way that ensures reasonable allocation of duties among nurses. If too much burden is placed on a select few it can have two consequences. One, the quality of healthcare can suffer owing to the heavy and tiring workload on these few. Two, nurses are in high demand, and if they feel aggrieved with the rostering, they can look for other employment opportunities.

24-hour work is typically handled through three shifts, with a single nurse or group being assigned to a single shift. The typical shifts are morning, evening and night shifts. In particular, the night shift is typically very unpopular, and is even considered to cause health problems. Consequently, available nurses must be rotated among different shifts in a way that all of them will be working equal numbers of popular, less popular and unpopular shifts.

The skill sets of the nurses must also be considered while developing the nurse roster. Then there is the problems posed by different kinds of absences, such as weekly off, annual vacations, casual but expected absences and unexpected absences. The nurse roster management system must handle all these requirements and generate rosters that meet the health care needs. As can be visualized, nurse rostering is a complex exercise. We cannot expect to do a good job if we depend on a system of manual rostering, with a human scheduler developing the roster.
3.3.3 Phase 3: Formulate the Problem into Mathematical Statement

Nursing policies will be developed. These policies will be based mainly on the hospital practices. Given that satisfying all preferences while making an effective utilization of nurses seems infeasible, a number of priority levels are considered in developing the scheduling system. Required policies are formulated as model constraints. The remaining policies are modeled as soft constraints with different importance weights and priorities. Hence, these constraints will be formed into mathematical statement.

- The goal constraint will be reformulated into an equation which form the equalities that include deviational variables, $d^-$ and $d^+$.  
- A positive deviational variable ($d^+$) is the amount by which a goal level is exceeded.
- A negative deviational variable ($d^-$) is the amount by which a goal level is underachieved.
- At least one or both deviational variables in a goal constraint must equal zero.
- The objective function in a goal programming model seeks to minimize the deviation from goals in order of the goal priorities.
- Symbol $P_i$, for $i = 1, \ldots, q$ ($q=$number of goals) in the objective function designates as the priority $i$ goal. This means that in goal programming problems with priority levels ($P_1$), they are treated as the first priority goals in an objective function. When this model is solved, the first step will be to minimize the value of deviational variable before any other goal is addressed. Second priority ($P_2$) goals are considered only after the optimal solution has been found using the $P_1$ goals. After the solution with $P_1$ goals is found, an objective function containing $P_2$ goals is then used. The solution is revised under the $P_2$
goal objective function as long as it does not cause a reduction in achievement of the $P_1$ goals. In this extension of goal programming, $P_1$ goals are considered first, then $P_2$ goals, then $P_3$ goals, etc. At each stage a solution revision can be made as long as it causes no reduction in achievement of the higher priority goals.

### 3.3.4 Phase 4: Implementation - Apply 0-1 Linear Goal Programming Approach to the Problem

In this phase, we will discuss more on the general formulation of the goal programming, the characteristics of linear goal programming and 2 different types of methods under goal programming approach which are the preemptive method and weighting method as well as the implementation in the problem.

#### 3.3.4.1 The General Formulation of the Goal Programming

The first application used in business was published by Charnes, Cooper and Neihaus (1975), the model was for manpower planning. Goal programming can be applied to every imaginable area. Some of these include, scheduling of employees, deciding where to locate fire stations, determining the best way to bus students in order to integrate a school district, deciding how much of a product to produce during different time periods, investment of financial portfolios, hospital management, and scheduling of airline flights. In short, there is a use for goal programming in almost any kind of complex decision making process.

The goal program begins with the goal that has been given the highest priority and minimize $d^+$ and $d^-$ as much as possible. That is, the deviation between what the organization would like to achieve and what it is possible to achieve is minimized. The same is then done for the second goal given the constraints which the minimization of
the first goal’ deviational variables has added to the model. Usually the first two or three goals can be completely attained. But eventually lower ranked goals come into conflict with previous goals and cannot be entirely achieved.

The objective function contains constants, deviational variables and “preemptive” priority factors. These priority factors, usually denoted as $P_i$, indicate the relative importance that is being attached to the minimization of each deviational variable. For each $P_i$, $P_i \gg P_{i+1}$, meaning that there is no constant, $s$, for which $sP_{i+1} \gg P_i$.

A generally accepted statement of this type of goal programming model was presented in Charnes and Cooper (1977):

Minimize: $Z = \sum_{i \in m} (d_i^+ + d_i^-)$

Subject to: $\sum_{j=1}^{n} a_{ij}x_j - d_i^+ + d_i^- = b_i$

$d_i^+, d_i^-, x_j \geq 0$, for $i = 1, ..., m$; for $j = 1, ..., n$ (1)

The values $a_i$, represent constants that take values other than 1 if the model requires different weights at the same priority level. The following is the example of general form for a goal programming with two goals, two constraints, and two decision variables:

$$Min \ Z = a_1 P_1 d_1^- + a_2 P_2 d_1^- + a_3 P_1 d_1^+ + a_4 P_2 d_1^+ + a_5 P_1 d_2^- + a_6 P_2 d_2^- + a_7 P_1 d_2^+ + a_8 P_2 d_2^+$$

subject to

$$C_{11} X_1 + C_{12} X_2 + d_1^- - d_1^+ = b_1$$
\[ C_{21}X_1 + C_{22}X_2 + d^-_2 - d^+_2 = b_2 \]

where all variables are real.

Suppose

\[
\begin{align*}
    a_2 &= a_3 = a_4 = a_5 = a_6 = a_7 = 0, \\
    a_1 &= a_8 = 1, \\
    C_{11} &= 1, C_{12} = 0, C_{21} = 2, C_{22} = -1, b_1 = 1, b_2 = 2.
\end{align*}
\]

Then the problem becomes:

\[
    \text{Min } Z = P_1 d^-_1 + P_2 d^+_2
\]

subject to

\[
\begin{align*}
    X_1 + d^-_1 - d^+_1 &= 1 \\
    2X_1 - X_2 + d^-_2 - d^+_2 &= 2
\end{align*}
\]

The top priority is to minimize \( d^-_1 \) and the second priority is to minimize \( d^+_2 \). Since \( d^-_2 \) and \( d^+_1 \) are not in the objective function, the minimization of these variables is not a goal. If one of the deviational variables could not be allowed to be positive, it would be omitted from the constraints.

3.3.4.2 Characteristics of Linear Goal Programming

The characteristics common to all linear goal programming models:
- Each goal appears in a separate constraint with the right hand side value indicating the target value for the goal.

- Deviation variables $d^+_i$ and $d^-_i$ are included for each goal in order to reflect the possible overachievement or underachievement of the goal.

- Other constraints, reflecting resource capacities or other restrictions, are included just as they would be in any linear programming model.

- The objective function requires minimizing the weighted value of the deviation variables. Coefficients (weights) for the deviation variables in the objective function reflect the relative “cost” or “penalty” for each unit deviation from the corresponding goal’s target value. Zero coefficients mean that the corresponding deviations from the target values carry no penalty.

3.3.4.3 Goal Programming Methods

This section presents two methods for solving the goal programming problem. Both methods are based on representing the multiple goals by a single objective function. In the weighted method, a single objective function is formed as the weighted sum of the functions representing the goals of the problem. The preemptive method starts by prioritizing the goals in order of importance. The model is then optimized using one goal at a time, and in such a manner that the optimum value of a higher priority goal is not degraded by a lower priority goal.

The proposed two methods are distinct, in the sense that they will not generally produce the same solution. Neither method, however, can be claimed superior because each technique is designed to satisfy certain decision making preferences.
3.3.4.3.1 The Preemptive Method

In the preemptive method, the \( n \) goals of the problem are ranked in order of importance as judged by the decision maker - that is,

\[
\begin{align*}
\text{Minimize } G_1 &= \rho_1 \quad \text{(Highest priority)} \\
\text{Minimize } G_n &= \rho_n \quad \text{(Lowest priority)}
\end{align*}
\]

The variable \( \rho_i \) is the component of the deviational variables, \( s_i^+ \) or \( s_i^- \), that describes goal \( i \). The solution procedure solves one goal problem at a time, starting with the highest priority goal \( G_1 \) and terminating with the lowest goal \( G_n \). The process is carried out such that the solution obtained from a lower priority goal does not degrade any of the solutions already secured for the higher priority goals. This means that, for all \( i \geq 1 \), if \( z(G_i) \) is the optimum objective value given goal \( G_i \), then the optimization of lower goals \( G_j (j > i) \) cannot produce a solution that will worsen the value of \( z(G_i) \).

The following steps exemplify the approach:

**Step 0:** Identify the goals of the model and rank them in order of priority. 
\( G_1 = \rho_1 > G_2 = \rho_2 > \cdots > G_n = \rho_n \). Set \( i = 1 \).

**Step \( i \):** Solve \( LP_i \) that minimizes \( G_i \) and let \( \rho_i = \rho_i^* \) define the corresponding optimum value of the deviational variable \( \rho_i \). If \( i = n \), stop; \( LP_n \) solves the \( n \)-goal program. Otherwise, augment the constraint \( \rho_i = \rho_i^* \) to the constraints of the \( G_i \) problem to ensure that the value of \( \rho_i \) will not be degraded in future problems. Set \( i = i + 1 \), and repeat step \( i \).
3.3.4.3.2 The Weighting Method

Suppose that the goal programming model has $n$ goals and that the $ith$ goal is given as

Minimize $G_i, i = 1, 2, \ldots, n$

The combined objective function used in the weighting method is then defined as

Minimize $w_1G_1 + w_2G_2 + \cdots + w_nG_n$

where $w_i, i = 1, 2, \ldots, n$, are positive weights that reflect the decision maker’s preferences regarding the relative importance of each goal. For example, if $w_i=1$, for all $i$, signifies that all the goals carry equal weights. The determination of the specific values of these weights is subjective. Indeed, the apparently sophisticated analytic procedures developed in the literature (Cohon, 1978) are still rooted in subjective assessments.

3.3.4.4 Implementation

The nurse scheduling model will attempt to satisfy several goals as well as incorporating nurses’ preferences and establishing fairness bases among nurses. These suggest using a 0-1 linear goal programming (LGP) approach.

Before applying linear goal programming approach, every notation must be correctly introduced.

$n$ : number of days in a schedule ($n=14$).

$m$ : number of nurses available for the unit of interest.
$i$ : index of days, $i=1,2,\ldots,n$.

$k$ : index for nurses, $k=1,2,\ldots,m$.

$M_i$ : staff requirements for morning shift of day $i$, $i=1,2,\ldots,n$.

$E_i$ : staff requirements for evening shift of day $i$, $i=1,2,\ldots,n$.

$N_i$ : staff requirement for night shift of day $i$, $i=1,2,\ldots,n$.

$G_i$ : staff on day off of day $i$, $i=1,2,\ldots,n$.

Table 3.1 below shows the index for each day with respect to the date and Table 3.2 shows the index for each nurse with respect to the assigned nurse.

**Table 3.1 : Index for Days ($i=1,2,\ldots,n$)**

<table>
<thead>
<tr>
<th>Day</th>
<th>$i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/01/10</td>
<td>1</td>
</tr>
<tr>
<td>05/01/10</td>
<td>2</td>
</tr>
<tr>
<td>.............</td>
<td>............</td>
</tr>
<tr>
<td>17/01/10</td>
<td>14</td>
</tr>
</tbody>
</table>

**Table 3.2 : Index for Nurses ($k=1,2,\ldots,m$)**

<table>
<thead>
<tr>
<th>Nurse</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nurse 1</td>
<td>1</td>
</tr>
<tr>
<td>Nurse 2</td>
<td>2</td>
</tr>
<tr>
<td>Nurse 3</td>
<td>3</td>
</tr>
<tr>
<td>.............</td>
<td>.............</td>
</tr>
</tbody>
</table>
3.3.5 Phase 5: Solve Using LINGO Software.

It is not expected however that a feasible solution may be obtained while satisfying all set of constraints. Therefore, these sets are divided into two groups, one group consists of sets of hard constraints that must be satisfied. The other group consists of the remaining sets of constraints that are considered as soft constraints. The model will attempt to satisfy these soft constraints. If not possible, the model will reduce to at least the violations of these soft constraints based on the importance of each set. The scheduling problem will be solved using LINGO software.

When a linear programming package such as LINGO is used for goal programming, the problem is solved sequentially (preemptive method). In this procedure a new problem is formulated and solved for each priority goal in the objective function beginning with the highest priority. The minimization of the deviational variables at the highest priority is the initial objective function. Once a solution for this problem is achieved, the value of the deviational variable in the objective function is added to the model as a constraint and the second-priority goal becomes the new objective function. New solutions are achieved for each new objective function sequentially until all priorities have been exhausted. Sequential solution is generally cumbersome and inefficient approach, however, it is beneficial to show this approach since it coincides identically with the sequential steps used in solving a model graphically.

3.3.5.1 LINGO Software

LINGO is a comprehensive tool designed to make building and solving linear, nonlinear and integer optimization models faster, easier and more efficient. One of LINGO's most powerful features is its mathematical modeling language. LINGO's
modeling language lets us express our problems in a natural manner very similar to standard mathematical notation. LINGO allows us to do things such as quickly express a series of similar constraints in a single compact statement. Our models are compact and easy to read.

When building models, we typically find there is one or more sets of related objects (e.g., sets of factories, customers, vehicles, or employees). Often if a constraint applies to one member of a set, then a constraint of the same form also applies to each of the other set members. Rather than requiring that we express an individual constraint for each set member, LINGO allows us to express the entire group of constraints in one concise statement. Taking advantage of sets is the foundation of LINGO's modeling language, the fundamental building block of the program's most powerful capabilities. LINGO even allows us to express common sets implicitly, such as days of the week or months of the year.

LINGO's modeling language can help drastically cut our model development time. Very large models can often be efficiently expressed with LINGO. The modeling language's similarity to standard mathematical notation makes it very easy to read. Models are easier for the developer to maintain and for colleagues to read and understand.

Using LINGO, we can easily make our model "scalable". This means the dimensions of our model can change without requiring changes to our expression of the problem. For example, suppose we are finding the cheapest way to supply a product from several different warehouses to several different customers. If the number of warehouses or customers changes, many modeling packages would require significant changes to the problem's formulation. However, with LINGO, our problem formulation needs no modification. We can simply change the size of our data files and LINGO takes care of the rest.
3.3.5.2 Procedure in LINGO

In order to solve the problem in the developed mathematical model using LINGO, a set of coding has been established and coding should conform to the characteristics set out in LINGO.

**Figure 3.2**: LINGO software

Figure 3.2 above shows the example of LINGO software. While Figure 3.3, shows the example of window containing the coding of mathematical model that has been completed.
Then, press the Solve button (as shown in Figure 3.4) to find the solution. Only a few seconds (sometimes several minutes) required to obtain the optimal solution in LINGO.

**Figure 3.3 : LINGO code**

**Figure 3.4 : Solve button**
As can be seen in Figure 3.5 above, when the Lingo managed to get the optimal solution, it will show the window for the solution report and solver status. Solver status indicates the extent to which the optimum solution is achieved. If the objective value is zero, then it is the best optimum solution. Through the solver status, we can find the infeasibility of a solution, the solver type, number of iterations needed to achieve the global optimum solution, number of variables, number of constraints and the running time. Meanwhile, in the solution report, it shows the value of each deviational variable and the scheduling result based on the 0-1 linear goal programming.
3.3.6 Phase 6 : Analyze the Result

If the result is acceptable, we stop. Then, result is discussed and analyzed. Otherwise, repeat steps 3.2.3 - 3.2.6. Result sometimes is not acceptable due to some errors in formulation of mathematical statement or missing some important information. If this occurs, author has to look back at the model and resolve using LINGO until getting a valid optimization result.

3.3.7 Phase 7 : Writing the Report

The report was written based on the whole process of the research. It is included every single important fact about the project from the phase one – which is information collection until result phase.

3.4 Summary

This chapter, generally discusses the methodology used in applying 0-1 linear goal programming in Maternity Ward 2 starting from the process of gaining information on the related field until finding the result based on the implementation and the process of documentation of the research.
CHAPTER 4

IMPLEMENTATIONS

4.1 Introduction

The previous chapter generally discusses the methodology used in applying linear goal programming for Maternity Ward 2 – which was described in seven phases. Whereby, this chapter will focus on the implementation of the methodology.

4.2 Nursing Policies

Nurse scheduling problem deals with the jobs, vacations, and shifts arrangement for the nursing staffs in hospital’s daily operation. Many factors need to be considered while the head nurse arrange the nurse scheduling activities, for instance, the hospital management policies, the government regulations, and the fairness among nurses. Cheang, Li, Lim, and Rodrigues (2003) added nursing staffs’ preference into the scheduling factors. Bard and Purnomo (2007) considered factors such as nurse workforce, hospital work and hospital scheduling regulation to establish a schedule making decision tree. The constraint conditions to nurse scheduling are broad and they may differ from case to case. Some of the constraint conditions even conflict with each other. For instance, the shift preference of nursing staffs may violate the requirement for shift fairness. In practice, the head nurses arrange the nurse scheduling based on their subjective experience. To meet the complicated situations with ever increasing
patient demands and limited nurse workforce, the head nurse may require spending more effort than ever to deal with the nurse scheduling but may still fail to be fair to all nurses. Nurses are influential in shaping the future of health care because optimal nursing care means improved health care and healthier people.

Nursing policies will be developed. These policies will be based mainly on current hospital practices that the head nurses consider as implicit requirements, the results of the interviews, and published policies. The importance in incorporating some of the published policies relies on accounting for ergonomic considerations. In fact, the human being has various physical limitations and the lack of ergonomic consideration causes frustration and reduces productivity quantitatively and qualitatively.

This nurse scheduling study is carried out in Hospital Tawau, Sabah to develop a system of work scheduling regular nurse on duty for a period of 2 weeks. 0-1 linear goal programming model will be implemented in Maternity Ward 2 with a number of 6 U29 nurses and 7 U19 nurses. There are 3 shifts implemented, namely the morning shift from 7 am until 2 pm for 7 hours on duty, the evening shift began at 2 pm until 9 pm also served for 7 hours and night shift hours starting from 9 pm until 7 am which took over 10 hours working time. The minimum number of nurses for morning shift are at least 2 nurses (1 U29 nurse and 1 U19 nurse), as well as evening and night shift.

Nurse scheduling system that will be developed takes into consideration the objectives and requirements of hospital nurses to maximize their satisfaction that the quality of services can be improved. Because of the large number of constraints that the schedule attempts to satisfy, it is possible that no feasible solutions to such a nurse scheduling problem would exist. For this reason, the constraints are divided into two classes, hard constraints that must be satisfied and soft constraints that may be violated. Hospital policies will be considered as hard constraints while nurses’ preferences will be considered as soft constraints. However, the model will minimize these violations by reducing the deviations in the soft constraints from their respective targets. The
schedule will extend over a 2 week period. The set of all constraints combined is given as follows:

### 4.2.1 Assumption

The schedule is assumed to start on the first day (Monday) of a week. A working day starts from 7:00 am to 7:00 am of the next day (three shifts per 24 hours). The length of a schedule is 14 days (2 weeks).

### 4.2.2 Hospital Policies

1) The unit is covered by three shifts with 7 hours morning shift (7 am – 2 pm), 7 hours evening shift (2 pm – 9 pm) and 10 hours night shift (9 pm – 7 am) for duration 24 hours a day and 7 days a week.

2) For each day, there should be at least 1 U29 nurse and 1 U19 nurse working in the morning shift, evening shift and night shift, respectively.

3) Minimum staff level requirements must be satisfied.

4) Each nurse is required to work only one shift per day (morning, evening or night shift).

5) Avoid any isolated days on (off-on-off).

6) A nurse who works the night shift for 3 consecutive days must have off day for the next 3 consecutive days.

7) A nurse who works the night shift for 2 consecutive days must have off day for the next 2 consecutive days.
8) The regular working days are between 8 to 10 days per schedule in 2 weeks.

9) No nurse can work for more than 6 consecutive working days.

10) Request on days off should be considered.

11) A nurse who works a night shift is not allowed to work the morning shift or the evening shift of the following day.

4.2.3 Nurses Preferences

1) All nurses should have the same amount of working days which are 9 days per schedule.

2) Combination of morning and evening shifts should exceed night shift for each nurse in the schedule.

3) Avoid evening shift followed by morning shift or night shift of the following day.

4) Avoid morning shift followed by evening shift or night shift of the following day.

4.2.4 Problems Faced by Head Nurse

The problem that we are concerned with in this study is the application of 0-1 linear goal programming in nurse scheduling problem. It is to be solved based on nurses’ personal preferences in which each slot of roster has to be divided fairly among 6 U29 nurses and 7 U19 nurses.
The overall process of manual roster runs as follows. Early of each week, head nurse of Maternity Ward 2 will draft the roster for each nurse. The process of producing the roster begins with the collection of information from each nurse, which consist of their preference of day offs and shifts. However, there are few problems faces by the head nurse during production of the roster which are:

a) They need to reproduce drafts until nurses with adequate skills and experiences are equally mixed in each shift.

b) When new nurses need to attend training/courses, the workload of these leaving nurses has to be equally distributed. Therefore the roster needs to be reshuffled.

c) When certain nurses have to be transferred to other wards for a few weeks because their expertise is needed, the roster also needs to be reshuffled.

It is inefficient for the head nurse to spend so much time and effort to arrange the schedule. Moreover, the task is difficult for the head nurse because of few reasons stated above. Because of these problems, we need one solution that will create a good scheduler while solving these problems.

4.3 Development of the 0-1 Linear Goal Programming Model

Here, we will discuss more on the concept of 0-1 linear goal programming itself, hard and soft constraints, as well as the formulation of hard and soft constraints.
4.3.1 0-1 Linear Goal Programming

0-1 linear goal programming is based on linear goal programming method that uses the approach of integer 0 and 1 only. It is like a "yes" and "no" method. For example, when nurse $k$ is required to work in the morning shift on day $i$, for $i = 1, 2, ..., n$ and $k = 1, 2, ..., m$, the value of morning shift for her is 1, otherwise it will be zero. The same concept also applies to the value for the evening shift, night shift and days off. For the development of the model formulation, each formulation of constraint that must satisfy the hard and soft constraints are resulting from the value of 0 and 1 only.

4.3.2 Modeling Hard and Soft Constraints

The problem consists of scheduling 6 U29 nurses and 7 U19 nurses for a 2 week period in a cyclical way for Maternity Ward 2, while satisfying minimum staffing requirements, along with other constraints. The nurse scheduling model will also attempt to satisfy several goals including reducing overstaffing (and hence overtime cost) as well as incorporating nurses’ preferences and establishing fairness among nurses. These suggest using a 0-1 linear goal programming (LGP) approach.

The scheduling problem contains a total of 14 scheduling sets of constraints. It is not expected however that a feasible solution may be obtained while satisfying all sets of constraints. Therefore, these sets are divided into two groups, one group consists of sets of hard constraints that must be satisfied. The other group consists of the remaining sets of constraints that are considered as soft constraints. The model will attempt to satisfy these soft constraints. If not possible, the model will reduce to a least violations of these soft constraints based on the importance of each set. Classifying constraints into hard and soft constraints as well as assigning importance priority and weight have been made through consulting the head nurse that is in charge of nurse scheduling. The sets of hard and soft constraints are given below.
4.3.2.1 Hard Constraints

1) The first set of constraints ensures that the request on days off should be approved. This model will always be changed according to application of day off per schedule.

2) The second set of constraints ensures that the daily minimum staff level is met because the daily requirements may differ from one day to another. The model will allow the user to insert the daily minimum requirement for each morning, evening and night shift.

3) The third set of constraints ensures that each nurse is only allowed to work a shift each day. Constraints also do not allow nurses working night shift followed by morning or evening shift the next day.

4) The fourth set of constraints attempts to avoid isolated days on (off-on-off patterns).

5) The fifth set of constraints ensures that nurses who work night shift 3 days continuously, are obliged for day off 3 days continuously on the following day.

6) The sixth set of constraints ensures that nurses who work night shift 2 days continuously, are obliged for day off 2 days continuously on the following day.

7) The seventh set of constraints ensures that each nurse is assigned 8 days on and at most 10 days on per 2 weeks schedule.

8) The eighth set of constraints ensures that no nurse is assigned more than 6 consecutive days on.
9) The ninth set of constraints ensures that no nurse can work for more than 3 consecutive night shifts.

10) The tenth set of constraints attempts that each nurse must work in 3 shifts (morning, evening and night) for the 2 weeks period.

4.3.2.2 **Soft Constraints**

1) The first set of soft constraints attempts to assign to each nurse a total of 9 days as per schedule. This will create balance in the workload of the different nurses.

2) The second set of soft constraints attempts to have in the schedule more combination of morning and evening than night shifts. Each nurse is preferred to get average working days for morning and evening shift higher than night shift because they feel more comfortable working in the morning and evening shift compared to the night duty that requires a longer period and somewhat tired (working outside the normal hours). Besides, most of the main activities are done in the morning (and evening) shift which require more nurses.

3) The third set of soft constraints attempts to avoid assigning an evening shift followed by a morning or night shift on the next day.

4) The fourth set of soft constraints attempts to avoid assigning a morning shift followed by an evening or night shift on the next day. This would help nurses adjust their time to sleep. This policy is also recommended in the literature. (Tucker, Smith and Folkard, 1999)
4.3.3 Notations and Assumptions

The schedule is assumed to start on the first day (Monday) of a week. A working day starts from 7:00 am to 2:00 pm (morning shift), 2:00 pm to 9:00 pm (evening shift) and 9:00 pm to 7:00 am (night shift), (three shifts per 24 hour). The length of a schedule is 14 days (2 weeks). The following set of notations is introduced.

\( n \) : number of days in a schedule \((n=14)\).

\( m \) : number of nurses available for the unit of interest. \((m=6 \text{ for U29 nurses}, m=7 \text{ for U19 nurses})\)

\( i \) : index of days, \(i=1,2,\ldots,n\).

\( k \) : index for nurses, \(k=1,2,\ldots,m\).

\( bM_i \) : staff required for morning shift of day \(i, i=1,2,\ldots,n\).

\( bE_i \) : staff required for evening shift of day \(i, i=1,2,\ldots,n\).

\( bN_i \) : staff required for night shift of day \(i, i=1,2,\ldots,n\).

\( M_i \) : minimum staff requirements for morning shift of day \(i, i=1,2,\ldots,n\).

\( E_i \) : minimum staff requirement for evening shift of day \(i, i=1,2,\ldots,n\).

\( N_i \) : minimum staff requirements for night shift of day \(i, i=1,2,\ldots,n\).

\( C_i \) : staff on day off of day \(i, i=1,2,\ldots,n\).
4.3.4 Decision Variable

Below are the variables which given the value for each decision. For example, if the first nurse on the first day has duty on the evening shift, value $bE_{1,1} = 1$, otherwise $bE_{1,1} = 0$

$$bM_{i,k} = \begin{cases} 1 & \text{if nurse } k \text{ is assigned a morning shift for day } i, \ i=1,2,\ldots,n, \ k=1,2,\ldots,m \\ 0 & \text{otherwise} \end{cases}$$

$$bE_{i,k} = \begin{cases} 1 & \text{if nurse } k \text{ is assigned an evening shift for day } i, \ i=1,2,\ldots,n, \ k=1,2,\ldots,m \\ 0 & \text{otherwise} \end{cases}$$

$$bN_{i,k} = \begin{cases} 1 & \text{if nurse } k \text{ is assigned a night shift for day } i, \ i=1,2,\ldots,n, \ k=1,2,\ldots,m \\ 0 & \text{otherwise} \end{cases}$$

$$c_{i,k} = \begin{cases} 1 & \text{if nurse } k \text{ is on day off for day } i, \ i=1,2,\ldots,n, \ k=1,2,\ldots,m \\ 0 & \text{otherwise} \end{cases}$$
4.3.5 Formulating Model Constraints

In this section, each of formulation for hard and soft constraints is shown in more detail.

4.3.5.1 Hard Constraints

(1) Ensures that request on days off should be approved. This model will always be changed according to application of day off per schedule:

\[
U_{29} \text{ nurses }\]

\[C_{i,k} + C_{i+1,k} = 2\]

for \(i=1\) and \(k=2\) \hspace{1cm} (4.1)

\[C_{i,k} + C_{i+1,k} = 2\]

for \(i=12\) and \(k=6\) \hspace{1cm} (4.2)

\[
U_{19} \text{ nurses }\]

\[C_{i,k} + C_{i+1,k} = 2\]

for \(i=1\) and \(k=1\) \hspace{1cm} (4.3)

\[C_{i,k} + C_{i+1,k} + C_{i+2,k} + C_{i+3,k} + C_{i+4,k} = 5\]

for \(i=9\) and \(k=2\) \hspace{1cm} (4.4)
(2) Satisfy daily staff requirements for each shift:

\[\sum_{k=1}^{m} bM_{i,k} \geq M_i, \text{ for all } i=1,2,\ldots,n. \tag{4.5}\]

\[\sum_{k=1}^{m} bE_{i,k} \geq E_i, \text{ for all } i=1,2,\ldots,n. \tag{4.6}\]

\[\sum_{k=1}^{m} bN_{i,k} \geq N_i, \text{ for all } i=1,2,\ldots,n. \tag{4.7}\]

(3) Each nurse is only allowed to work one shift per day and avoid a nurse who works on night shift to work morning or evening shift on the following day.

\[bM_{i,k} + bE_{i,k} + bN_{i,k} + C_{i,k} = 1, \text{ for all } i=1,2,\ldots,n \text{ and } k=1,2,\ldots,m \tag{4.8}\]

\[bN_{i,k} + bM_{i+1,k} + bE_{i+1,k} \leq 1, \text{ for all } i=1,2,\ldots,n-1 \text{ and } k=1,2,\ldots,m \tag{4.9}\]

(4) Avoid any isolated days on (off-on-off).

\[C_{i,k} + bM_{i+1,k} + bE_{i+1,k} + bN_{i+1,k} + C_{i+2,k} \leq 2, \]

for all \(i=1,2,\ldots,n-2\) and \(k=1,2,\ldots,m\) \tag{4.10}\]

(5) A nurse who works the night shift for 3 consecutive days must have off day for the next 3 consecutive days.
\[ bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6 \]

for \( i=1 \) and \( k=1 \) \hspace{1cm} (4.11)

\[ bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6 \]

for \( i=4 \) and \( k=2 \) \hspace{1cm} (4.12)

\[ bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6 \]

for \( i=7 \) and \( k=3 \) \hspace{1cm} (4.13)

\[ bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} = 5 \]

for \( i=10 \) and \( k=4 \) \hspace{1cm} (4.14)

\[ bN_{i,k} + bN_{i+1,k} = 2 \]

for \( i=13 \) and \( k=5 \) \hspace{1cm} (4.15)

(6) A nurse who works the night shift for 2 consecutive days must have

off day for the next 2 consecutive days.

( U29 nurses )

\[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]

for \( i=1,13 \) and \( k=1 \) \hspace{1cm} (4.16)

\[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]
for $i=3$ and $k=2$  

(4.17) \[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]

for $i=5$ and $k=3$  

(4.18) \[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]

for $i=7$ and $k=4$  

(4.19) \[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]

for $i=9$ and $k=5$  

(4.20) \[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]

for $i=11$ and $k=6$  

(4.21) \[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]

( for U19 nurses )

for $i=1$ and $k=1$  

(4.22) \[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]

for $i=3$ and $k=2$  

(4.23) \[ bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \]
for \( i=5 \) and \( k=3 \) \hspace{1cm} (4.24)

\[
bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4
\]

for \( i=7 \) and \( k=4 \) \hspace{1cm} (4.25)

\[
bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4
\]

for \( i=9 \) and \( k=5 \) \hspace{1cm} (4.26)

\[
bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4
\]

for \( i=11 \) and \( k=6 \) \hspace{1cm} (4.27)

\[
bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4
\]

for \( i=13 \) and \( k=7 \) \hspace{1cm} (4.28)

(7) Ensure the working days are between 8 to 10 days per schedule in 2 weeks.

\[
\sum_{i=1}^{n} (bM_{i,k} + bE_{i,k} + bN_{i,k}) \geq 8, \text{ for all } k=1,2,\ldots,m \hspace{1cm} (4.29)
\]

\[
\sum_{i=1}^{n} (bM_{i,k} + bE_{i,k} + bN_{i,k}) \leq 10, \text{ for all } k=1,2,\ldots,m \hspace{1cm} (4.30)
\]

(8) No nurse can work for more than 6 consecutive working days.

\[
C_{i,k} + C_{i+1,k} + C_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} + C_{i+6,k} \geq 1,
\]
for all $i=1,2,…,n-6$ and $k=1,2,…,m$ \hspace{1cm} (4.31)

(9) No nurse can work for more than 3 consecutive night shifts.

$$bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + bN_{i+3,k} \leq 3,$$

for all $i=1,2,…,n-3$ and $k=1,2,…,m$ \hspace{1cm} (4.32)

(10) Each nurse must work in 3 shifts for the 2 weeks period.

$$\sum_{i=1}^{n} bM_{i,k} \geq 1, \text{ for all } i=1,2,…,n \text{ and } k=1,2,…,m$$ \hspace{1cm} (4.33)

$$\sum_{i=1}^{n} bE_{i,k} \geq 1, \text{ for all } i=1,2,…,n \text{ and } k=1,2,…,m$$ \hspace{1cm} (4.34)

$$\sum_{i=1}^{n} bN_{i,k} \geq 1, \text{ for all } i=1,2,…,n \text{ and } k=1,2,…,m$$ \hspace{1cm} (4.35)

---

**Figure 4.1**: Part of the coding of hard constraints in LINGO
4.3.5.2 Soft Constraints

(1) All nurses have the same amount of working days which are 9 days per schedule. (14 days)

\[
\sum_{i=1}^{n} (bM_{i,k} + bE_{i,k} + bN_{i,k}) = 9,
\]

\[
\sum_{i=1}^{n} (bM_{i,k} + bE_{i,k} + bN_{i,k}) + s1_{k}^{-} - s1_{k}^{+} = 9,
\]

for all \( k = 1, 2, \ldots, m \) \hspace{1cm} (4.36)

(2) Attempts to have in the schedule more morning and evening than night shifts.

\[
(\sum_{i=1}^{n} bM_{i,k} + s2_{k}^{-} - s2_{k}^{+} + \sum_{i=1}^{n} bE_{i,k} + s3_{k}^{-} - s3_{k}^{+}) - \\
(\sum_{i=1}^{n} bN_{i,k} + s4_{k}^{-} - s4_{k}^{+}) = 1,
\]

for all \( i = 1, 2, \ldots, n \) \hspace{1cm} (4.37)

(3) Avoid evening shift followed by morning shift or night shift of the following day.

\[
bE_{i,k} + bM_{i+1,k} + bN_{i+1,k} \leq 1,
\]

\[
bE_{i,k} + bM_{i+1,k} + bN_{i+1,k} + s5_{i,k}^{-} - s5_{i,k}^{+} = 1,
\]

for all \( i = 1, 2, \ldots, n-1 \) and \( k = 1, 2, \ldots, m \) \hspace{1cm} (4.38)
Avoid morning shift followed by evening shift or night shift of the following day.

\[ bM_{i,k} + bE_{i+1,k} + bN_{i+1,k} \leq 1, \]

\[ bM_{i,k} + bE_{i+1,k} + bN_{i+1,k} + s^{2-}_{i,k} - s^{2+}_{i,k} = 1, \]

for all \( i=1,2,\ldots,n-1 \) and \( k=1,2,\ldots,m \) \hspace{1cm} (4.39)

\[ \text{Figure 4.2} \text{ : Coding of soft constraints in LINGO} \]

4.3.6 Formulating Goals

In order to incorporate the soft constraints into the scheduling model, we will include the following goals, which are consistent respectively with the above soft constraints. The problem has therefore four goals as follows:
4.3.6.1 Goal 1

This goal ensures that all nurses are scheduled to have exactly 9 days as possible in the 2 weeks schedule.

\[ \sum_{i=1}^{n} (bM_{i,k} + bE_{i,k} + bN_{i,k}) + s1_k^- - s1_k^+ = 9, \]

for all \( k = 1, 2, \ldots, m \)

Here, \( s1_k^- \) (respectively \( s1_k^+ \)) is the amount of negative (respectively positive) deviation from goal 1 for nurse \( k \). Since the goal tries to get the value of 9, any overachievement and underachievement is to be avoided. Hence, both deviations (positive and negative) are penalized.

4.3.6.2 Goal 2

It ensures to have in the schedule more morning and evening than night shifts.

\[ (\sum_{i=1}^{n} bM_{i,k} + s2_k^- - s2_k^+ + \sum_{i=1}^{n} bE_{i,k} + s3_k^- - s3_k^+) - \]
\[ (\sum_{i=1}^{n} bN_{i,k} + s4_k^- - s4_k^+) = 1, \]

for all \( k = 1, 2, \ldots, m \)

Here, \( s2_k^- \), \( s3_k^- \) and \( s4_k^- \) (respectively \( s2_k^+ \), \( s3_k^+ \) and \( s4_k^+ \)) is the amount of negative (respectively positive) deviation from goal 2 for nurse \( k \). Negative deviations for morning and evening shift are penalized to avoid underachievement and positive deviation for night shift is penalized to avoid overachievement.
4.3.6.3 Goal 3

It avoids assigning a nurse to work an evening shift followed by morning or night shift of the following day.

\[ bE_{i,k} + bM_{i+1,k} + bN_{i+1,k} + s5^-_{i,k} - s5^+_{i,k} = 1, \]

for all \( i=1,2,\ldots,n-1 \) and \( k=1,2,\ldots,m \)

Here, \( s5^-_{i,k} \) (respectively \( s5^+_{i,k} \)) is the amount of negative (respectively positive) deviation from goal 3 for day \( i \) and nurse \( k \). Only positive deviations are penalized to avoid overachievement.

4.3.6.4 Goal 4

It avoids assigning a nurse to work a morning shift followed by evening or night shift of the following day.

\[ bM_{i,k} + bE_{i+1,k} + bN_{i+1,k} + s6^-_{i,k} - s6^+_{i,k} = 1, \]

for all \( i=1,2,\ldots,n-1 \) and \( k=1,2,\ldots,m \)

Here, \( s6^-_{i,k} \) (respectively \( s6^+_{i,k} \)) is the amount of negative (respectively positive) deviation from goal 4 for day \( i \) and nurse \( k \). Only positive deviations are penalized to avoid overachievement.
4.3.7 Preemptive Method

Here, the features and characteristics of preemptive method for this problem will be discussed further.

4.3.7.1 Assigning Level of Priorities

Levels of priorities are assigned to each goal reflecting the priority of that goal compared to the others. These levels are denoted respectively by $\rho_1, \rho_2, \rho_3,$ and $\rho_4$. The goals of the problem are ranked in order of priority. Since this is a sequential method, the solution procedure solves one goal problem at a time, starting with the highest priority goal $\rho_1$ and terminating with the lowest goal $\rho_4$.

4.3.7.2 Objective Function

The following is the objective function. The objective function is formed to minimize a function subject to the constraints. Hence, the goal is formulated based on the sets of soft constraints sorted by their level of priorities as in Equations (4.36) to (4.39).

**Priority goal 1, $\rho_1$**
Minimize $G_1 = \rho_1 \sum_{k=1}^{m} (s_{1k}^- + s_{1k}^+)$

**Priority goal 2, $\rho_2$**
Minimize $G_2 = \rho_2 \sum_{k=1}^{m} (s_{2k}^- + s_{3k}^- + s_{4k}^+)$

**Priority goal 3, $\rho_3$**
Minimize $G_3 = \rho_3 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_{5i}^+$
Priority goal $4, \rho_4$

Minimize $G_4 = \rho_4 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_{i,k}^+$

Minimize

\[
G = \rho_1 \sum_{k=1}^{m} (s_{1,k}^- + s_{1,k}^+) + \rho_2 \sum_{k=1}^{m} (s_{2,k}^- + s_{3,k}^- + s_{4,k}^+) + \\
\rho_3 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_{5,i,k}^+ + \rho_4 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_{6,i,k}^+
\]

(Objective Function)

4.3.8 Weighting Method

Whereas, for this section, the characteristic and features of weighting method for this problem will be discussed further.

4.3.8.1 Assigning Importance Weights

Importance weights are assigned to each goal reflecting the relative importance of that goal compared to the others. These weights are denoted respectively by $w_1, w_2, w_3$, and $w_4$. For the sake of the application of Hospital Tawau, each goal has different weight where $w_1 = 4, w_2 = 3, w_3 = 2$, and $w_4 = 1$.

4.3.8.2 Objective Function

The following is the objective function. The objective function consists of minimizing the sum of the weighted deviations from the corresponding goals as in Equations (4.36) to (4.39). Note that all goals are being minimized in particular the
unnecessary achievement and therefore the corresponding cost. The expression of the objective function is given by:

Minimize \[
G = w_1 \sum_{k=1}^{m} (s_1^- k + s_1^+ k) + w_2 \sum_{k=1}^{m} (s_2^- k + s_3^- k + s_4^+ k) + \\
w_3 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_5^+ i,k + w_4 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_6^+ i,k
\]

(Objective Function)

where \(w_1 = 4, w_2 = 3, w_3 = 2, w_4 = 1\) (for Hospital Tawau)

### 4.3.9 Problem Formulation for Preemptive and Weighting Method

For this section, the objective function and constraints for each method and group will be shown.

#### 4.3.9.1 Preemptive Method for U29 Nurses

Below is the objective function for Preemptive Method and constraints associated to it.

Minimize \[
G = \rho_1 \sum_{k=1}^{m} (s_1^- k + s_1^+ k) + \rho_2 \sum_{k=1}^{m} (s_2^- k + s_3^- k + s_4^+ k) + \\
\rho_3 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_5^+ i,k + \rho_4 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s_6^+ i,k
\]

(Objective Function)
subject to

\[ C_{i,k} + C_{i+1,k} = 2, \text{ for } i=1 \text{ and } k=2 \]  \hspace{1cm} (4.1)

\[ C_{i,k} + C_{i+1,k} = 2, \text{ for } i=12 \text{ and } k=6 \]  \hspace{1cm} (4.2)

\[ \sum_{k=1}^{m} b M_{i,k} \geq M_i, \text{ for all } i=1,2,\ldots,n. \]  \hspace{1cm} (4.3)

\[ \sum_{k=1}^{m} b E_{i,k} \geq E_i, \text{ for all } i=1,2,\ldots,n. \]  \hspace{1cm} (4.4)

\[ \sum_{k=1}^{m} b N_{i,k} \geq N_i, \text{ for all } i=1,2,\ldots,n. \]  \hspace{1cm} (4.5)

\[ b M_{i,k} + b E_{i,k} + b N_{i,k} + C_{i,k} = 1, \text{ for all } i=1,2,\ldots,n \text{ and } k=1,2,\ldots,m \]  \hspace{1cm} (4.6)

\[ b N_{i,k} + b M_{i+1,k} + b E_{i+1,k} \leq 1, \text{ for all } i=1,2,\ldots,n-1 \text{ and } k=1,2,\ldots,m \]  \hspace{1cm} (4.7)

\[ C_{i,k} + b M_{i+1,k} + b E_{i+1,k} + b N_{i+1,k} + C_{i+2,k} \leq 2, \]

\[ \text{ for all } i=1,2,\ldots,n-2 \text{ and } k=1,2,\ldots,m \]  \hspace{1cm} (4.8)

\[ b N_{i,k} + b N_{i+1,k} + b N_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6 \]

\[ \text{ for } i=1 \text{ and } k=1 \]  \hspace{1cm} (4.9)

\[ b N_{i,k} + b N_{i+1,k} + b N_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6 \]

\[ \text{ for } i=4 \text{ and } k=2 \]  \hspace{1cm} (4.10)
\begin{align*}
&\text{for } i=7 \text{ and } k=3 \quad (4.11) \\
&bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} = 5 \\
&\text{for } i=10 \text{ and } k=4 \quad (4.12) \\
&bN_{i,k} + bN_{i+1,k} = 2 \\
&\text{for } i=13 \text{ and } k=5 \quad (4.13) \\
&bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \\
&\text{for } i=1,13 \text{ and } k=1 \quad (4.14) \\
&bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \\
&\text{for } i=3 \text{ and } k=2 \quad (4.15) \\
&bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \\
&\text{for } i=5 \text{ and } k=3 \quad (4.16) \\
&bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \\
&\text{for } i=7 \text{ and } k=4 \quad (4.17) \\
&bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4 \\
&\text{for } i=9 \text{ and } k=5 \quad (4.18) \\
&bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4
\end{align*}
for $i=11$ and $k=6$  

\[
\sum_{i=1}^{n}(bM_{i,k} + bE_{i,k} + bN_{i,k}) \geq 8, \text{ for all } k=1,2,\ldots,m
\]  

(4.19)

\[
\sum_{i=1}^{n}(bM_{i,k} + bE_{i,k} + bN_{i,k}) \leq 10, \text{ for all } k=1,2,\ldots,m
\]  

(4.20)

\[
C_{i,k} + C_{i+1,k} + C_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} + C_{i+6,k} \geq 1,
\]  

for all $i=1,2,\ldots,n-6$ and $k=1,2,\ldots,m$  

(4.21)

\[
bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + bN_{i+3,k} \leq 3,
\]  

for all $i=1,2,\ldots,n-3$ and $k=1,2,\ldots,m$  

(4.22)

\[
\sum_{i=1}^{n}bM_{i,k} \geq 1, \text{ for all } k=1,2,\ldots,m
\]  

(4.23)

\[
\sum_{i=1}^{n}bE_{i,k} \geq 1, \text{ for all } k=1,2,\ldots,m
\]  

(4.24)

\[
\sum_{i=1}^{n}bN_{i,k} \geq 1, \text{ for all } k=1,2,\ldots,m
\]  

(4.25)

\[
\sum_{i=1}^{n}(bM_{i,k} + bE_{i,k} + bN_{i,k}) + s1_k^- - s1_k^+ = 9,
\]  

for all $k=1,2,\ldots,m$  

(4.26)

\[
\left((\sum_{i=1}^{n}bM_{i,k} + s2_k^- - s2_k^+) + \left(\sum_{i=1}^{n}bE_{i,k} + s3_k^- - s3_k^+\right)\right) - (\sum_{i=1}^{n}bN_{i,k} + s4_k^- - s4_k^+) = 1,
\]  

for all $k=1,2,\ldots,m$  

(4.27)

\[
bE_{i,k} + bM_{i+1,k} + bN_{i+1,k} + s5_{i,k}^- - s5_{i,k}^+ = 1,
\]  

(4.28)
\[ bM_{i,k} + bE_{i+1,k} + bN_{i+1,k} + s6^\cdot_{i,k} - s6^\uparrow_{i,k} = 1, \]
for all \( i=1,2,\ldots,n-1 \) and \( k=1,2,\ldots,m \) \hspace{1cm} (4.29)

\[ \text{for all } i=1,2,\ldots,n-1 \text{ and } k=1,2,\ldots,m \] \hspace{1cm} (4.30)

4.3.9.2 Weighting Method for U29 Nurses

Below is the objective function for Weighting Method and constraints associated to it

\[
\text{Minimize} \quad G = w_1 \sum_{k=1}^{m} (s1^\cdot_k + s1^\uparrow_k) + w_2 \sum_{k=1}^{m} (s2^\cdot_k + s3^\cdot_k + s4^\uparrow_k) + \\
w_3 \sum_{l=1}^{n-1} \sum_{k=1}^{m} s5^\cdot_{l,k} + w_4 \sum_{l=1}^{n-1} \sum_{k=1}^{m} s6^\cdot_{l,k} \\
\text{(Objective Function)}
\]

where \( w_1 = 4, w_2 = 3, w_3 = 2, w_4 = 1 \) (for Hospital Tawau)

subject to

Similar constraints as the above which are from (4.1) – (4.30)

4.3.9.3 Preemptive Method for U19 Nurses

Below is the objective function for Preemptive Method and constraints associated to it
Minimize\[ G = \rho_1 \sum_{k=1}^{m} (s1_k^- + s1_k^+) + \rho_2 \sum_{k=1}^{m} (s2_k^- + s3_k^- + s4_k^+) + \rho_3 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s5_{i,k}^+ + \rho_4 \sum_{i=1}^{n-1} \sum_{k=1}^{m} s6_{i,k}^+ \]

(Objective Function for Preemptive Method)

subject to

\[ C_{i,k} + C_{i+1,k} = 2, \text{ for } i=1 \text{ and } k=1 \]  \hspace{1cm} (4.1)

\[ C_{i,k} + C_{i+1,k} + C_{i+2,k} + C_{i+3,k} + C_{i+4,k} = 5, \text{ for } i=9 \text{ and } k=2 \]  \hspace{1cm} (4.2)

\[ \sum_{k=1}^{m} bM_{i,k} \geq M_i, \text{ for all } i=1,2,...,n. \]  \hspace{1cm} (4.3)

\[ \sum_{k=1}^{m} bE_{i,k} \geq E_i, \text{ for all } i=1,2,...,n. \]  \hspace{1cm} (4.4)

\[ \sum_{k=1}^{m} bN_{i,k} \geq N_i, \text{ for all } i=1,2,...,n. \]  \hspace{1cm} (4.5)

\[ bM_{i,k} + bE_{i,k} + bN_{i,k} + C_{i,k} = 1, \text{ for all } i=1,2,...,n \text{ and } k=1,2,...,m \]  \hspace{1cm} (4.6)

\[ bN_{i,k} + bM_{i+1,k} + bE_{i+1,k} \leq 1, \text{ for all } i=1,2,...,n-1 \text{ and } k=1,2,...,m \]  \hspace{1cm} (4.7)

\[ C_{i,k} + bM_{i+1,k} + bE_{i+1,k} + bN_{i+1,k} + C_{i+2,k} \leq 2, \text{ for all } i=1,2,...,n-2 \text{ and } k=1,2,...,m \]  \hspace{1cm} (4.8)

\[ bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6 \]  \hspace{1cm} (4.9)

\[ bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6 \]
for $i=4$ and $k=2$  

$$bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} = 6$$  

(4.10)

for $i=7$ and $k=3$  

$$bN_{i,k} + bN_{i+1,k} + bN_{i+2,k} + C_{i+3,k} + C_{i+4,k} = 5$$  

(4.11)

for $i=10$ and $k=4$  

$$bN_{i,k} + bN_{i+1,k} = 2$$  

(4.12)

for $i=13$ and $k=5$  

$$bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4$$  

(4.13)

for $i=1$ and $k=1$  

$$bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4$$  

(4.14)

for $i=3$ and $k=2$  

$$bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4$$  

(4.15)

for $i=5$ and $k=3$  

$$bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4$$  

(4.16)

for $i=7$ and $k=4$  

$$bN_{i,k} + bN_{i+1,k} + C_{i+2,k} + C_{i+3,k} = 4$$  

(4.17)
\[ b_{N_{i,k}} + b_{N_{i+1,k}} + C_{i+2,k} + C_{i+3,k} = 4 \]

for \( i=9 \) and \( k=5 \) \hfill (4.18)

\[ b_{N_{i,k}} + b_{N_{i+1,k}} + C_{i+2,k} + C_{i+3,k} = 4 \]

for \( i=11 \) and \( k=6 \) \hfill (4.19)

\[ b_{N_{i,k}} + b_{N_{i+1,k}} + C_{i+2,k} + C_{i+3,k} = 4 \]

for \( i=13 \) and \( k=7 \) \hfill (4.20)

\[ \sum_{i=1}^{n} (b_{M_{i,k}} + b_{E_{i,k}} + b_{N_{i,k}}) \geq 8, \text{ for all } k=1,2,\ldots,m \] \hfill (4.21)

\[ \sum_{i=1}^{n} (b_{M_{i,k}} + b_{E_{i,k}} + b_{N_{i,k}}) \leq 10, \text{ for all } k=1,2,\ldots,m \] \hfill (4.22)

\[ C_{i,k} + C_{i+1,k} + C_{i+2,k} + C_{i+3,k} + C_{i+4,k} + C_{i+5,k} + C_{i+6,k} \geq 1, \]

for all \( i=1,2,\ldots,n-6 \) and \( k=1,2,\ldots,m \) \hfill (4.23)

\[ b_{N_{i,k}} + b_{N_{i+1,k}} + b_{N_{i+2,k}} + b_{N_{i+3,k}} \leq 3, \]

for all \( i=1,2,\ldots,n-3 \) and \( k=1,2,\ldots,m \) \hfill (4.24)

\[ \sum_{i=1}^{n} b_{M_{i,k}} \geq 1, \text{ for all } k=1,2,\ldots,m \] \hfill (4.25)

\[ \sum_{i=1}^{n} b_{E_{i,k}} \geq 1, \text{ for all } k=1,2,\ldots,m \] \hfill (4.26)

\[ \sum_{i=1}^{n} b_{N_{i,k}} \geq 1, \text{ for all } k=1,2,\ldots,m \] \hfill (4.27)
\[
\sum_{i=1}^{n} (bM_{i,k} + bE_{i,k} + bN_{i,k}) + s1_{k}^{1} - s1_{k}^{1} = 9,
\]
for all \(k=1,2,\ldots,m\) \hspace{1cm} (4.28)

\[
\left( \sum_{i=1}^{n} bM_{i,k} + s2_{k}^{1} - s2_{k}^{1} \right) + \left( \sum_{i=1}^{n} bE_{i,k} + s3_{k}^{1} - s3_{k}^{1} \right) - \left( \sum_{i=1}^{n} bN_{i,k} + s4_{k}^{1} - s4_{k}^{1} \right) = 1,
\]
for all \(k=1,2,\ldots,m\) \hspace{1cm} (4.29)

\[
bE_{i,k} + bM_{i+1,k} + bN_{i+1,k} + s5_{i,k}^{1} - s5_{i,k}^{1} = 1,
\]
for all \(i=1,2,\ldots,n-1\) and \(k=1,2,\ldots,m\) \hspace{1cm} (4.30)

\[
bM_{i,k} + bE_{i+1,k} + bN_{i+1,k} + s6_{i,k}^{1} - s6_{i,k}^{1} = 1,
\]
for all \(i=1,2,\ldots,n-1\) and \(k=1,2,\ldots,m\) \hspace{1cm} (4.31)

### 4.3.9.4 Weighting Method for U19 Nurses

Below is the objective function for Weighting Method and constraints associated to it

Minimize \( G = w_{1} \sum_{k=1}^{m} (s1_{k}^{1} + s1_{k}^{1}) + w_{2} \sum_{k=1}^{m} (s2_{k}^{1} + s3_{k}^{1} + s4_{k}^{1}) + \)

\[
\left\{ w_{3} \sum_{i=1}^{n-1} \sum_{k=1}^{m} s5_{i,k}^{1} + w_{4} \sum_{i=1}^{n-1} \sum_{k=1}^{m} s6_{i,k}^{1} \right\}
\]

(Objective Function for Weighting Method)

where \( w_{1} = 4, w_{2} = 3, w_{3} = 2, w_{4} = 1 \) (for Hospital Tawau)
subject to

Similar constraints as the above which are from (4.1) – (4.31)

4.4 Summary

This chapter attempted to implement 0-1 linear goal programming in nurse scheduling. Hard constraints (based on hospital policies) and soft constraints (based on nurses’ preferences) are formulated. Finally, the formulation of the model constraints is developed using the weighting method and preemptive method.
CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

The previous chapter generally discusses the implementation of 0-1 linear goal programming in nurse scheduling for Maternity Ward 2, Hospital Tawau. Consequently, this chapter will discuss the result produced by the implementation of the approach – scheduling using 0-1 linear goal programming on Maternity Ward 2 nurse shift. The result produced will be analyzed and compared with the current schedule which was manually produced.

5.2 Underlying Linear Goal Programming Model

The linear goal programming model consists of minimizing the objective function under the hard and soft constraints (4.1) – (4.31) and (4.35) - (4.39), respectively.
5.3 **Issues on Model Implementation**

Some issues regarding the model implementation will be discussed in the next sub topic.

5.3.1 **Introduction**

The Maternity Ward 2 is selected for this study. In this unit, there are a total of 16 nurses (1 head nurse, 2 staff U29 nurses (not in shift working hours), 6 staff U29 nurses and 7 U19 nurses). Figure 5.1 shows manual schedule made by the head nurse. The schedule accounts for 6 U29 nurses and 7 U19 nurses. The minimum requirement of nurses per shift is 1 U29 nurse and 1 U19 nurse for all morning, evening and night shifts and for all days including weekends/public holidays.

5.3.2 **Subgrouping**

Huarng (1997) proposes for NP hard scheduling problems the approach of subgrouping by splitting nurses and workloads into several subgroups, so that each subgroup will be of manageable size. By aggregating these subgroups, all the hard constraints must be satisfied. According to the computational experience in Huarng (1997), the solutions obtained by such an approach are very satisfactory. Hence, in this study the sub grouping will be categorized into the level of nurses respectively. There were two subgroups that are split out, the first subgroup is U29 nurse and the second subgroup is U19 nurse. However, this approach is model dependent.

Sub grouping is opted to solve the scheduling problem at the Maternity Ward 2 using LINGO. The total computational time required to determine the optimal solution
for a schedule with 13 nurses is found to be few minutes using an Intel Pentium Dual CPU 1.8GHz. We select 2 subgroups of respectively 6 and 7 nurses for the 13 nurses Maternity Ward 2. Subgroup 1 consists of 6 U29 nurses and Subgroup 2 consists of 7 U19 nurses. At every shift, at least one nurse from each subgroup will be assigned. This guarantees that the aggregate minimum requirement is met, including the types of nurses per shift. Figure 5.1 below shows the manual made nurse scheduling for subgroups 1 and 2.

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<tr>
<th>Nurse (U29)</th>
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<td>5 1 4 10</td>
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| Morning | 2 1 1 1 1 1 2 2 2 1 1 1 1 | 19 |
| Evening | 2 2 1 1 1 1 1 1 1 1 1 1 | 16 |
| Night | 2 2 2 2 1 1 1 2 2 1 1 1 | 21 |
### TOTAL ON DUTY

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<th>Evening</th>
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![Figure 5.1](image-url): Manual made nurse roster for U29 and U19 nurses

### 5.3.3 Application

Before running the model, a computer code has been developed and has interfaced with LINGO to avoid violations. The serious types of violations that may occur are to assign to a given nurse a night shift at the last day of one schedule and a morning shift on the first day of the next schedule leading to a continuous shift. A second type of violation would be to assign for a nurse say the last 3 days of a schedule and the first 4 days of the following one resulting into 7 consecutive days on, which violated the *no more than 6 consecutive days on* rule. Thus, to avoid (or reduce) the violations, the new periodic nurse schedule will be redeveloped (considering nurses’ day off) every 2 weeks and keeps record of the last days of the schedule for each nurse and adds additional constraints (hard and soft when appropriate).

In preemptive method, out of the 8 runs, optimality (i.e., zero objective value) has been obtained in 6 occasions. In the remaining cases, same as weighted method, soft constraints violations have occurred for the fourth priority of soft constraint for U29 nurses and first priority of soft constraint for U19 nurses. The largest running time was of about 31 minutes 51 seconds obtained for the soft constraint (fourth priority level of U19 nurses) and the rest just took few seconds to complete.
While in weighting method, out of the 2 runs, zero objective value has not been obtained for both runs. Soft constraints violations have occurred for the fourth goal of soft constraint for U29 nurses and first goal of soft constraint for U19 nurses. The running time obtained was 46 seconds for U29 nurses case and 11 seconds for U19 nurses.

5.4 Discussion on the Results From Preemptive Method

Figure 5.2 shows the 2 weeks scheduling result using 0-1 linear goal programming approach (preemptive method) for 3 shifts (morning, evening and night shift). Each shift is 7 hours long for morning and evening, respectively while night shift is 10 hours.

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**Figure 5.2**: Result of the scheduling using 0-1 linear goal programming (the preemptive method)
5.4.1 Discussion on Soft Constraint Priority 1

As we can see in Figure 5.3 and 5.4, the 0-1 linear goal programming scheduling (preemptive method) produced a balance shift result compared to scheduler which is generated manually. There are differences in terms of total number of working days in 2 weeks period between nurse rosters manually made with 0-1 linear goal programming approach (preemptive method). For manual made U29 nurse roster, the number of working days which should be between 8 to 10 days (based on hospital policy) is not satisfied. This is because there are nurses who worked more than 10 days (nurse with code number 4 has to work 11 days), and nurse with code number 6, the working days are less than 8 (7 days). This has created inequality in terms of number of working days in the nurse roster throughout the period of 2 weeks. Meanwhile, the schedule for U29 nurses which based on 0-1 linear goal programming (preemptive method) is much more balanced as each nurse has total 9 days, respectively. It is clearly shown that the segregation of the shift for roster generate using 0-1 linear goal programming is equally distributed compared to roster which is manually generated. Hence, it certainly creates a sense of satisfaction among nurses as there is fairness performed in distribution of number of working days between them. As a result, nurse will be more diligent and enthusiastic in performing their duties.

Since LINGO result for the first soft constraint was able to get the best minimum value as referred to Figure 5.5 (the global optimum is 0), thus the objective of the first soft constraint has been successfully met. This explains why each nurse manages to get the same total working days for the 2 weeks period under 0-1 linear goal programming approach.
**Figure 5.3**: Number of days distribution for U29 nurses (manually generated)

**Figure 5.4**: Number of days distribution for U29 nurses (for 0-1 linear GP scheduling – preemptive method)
Similarly, U19 nurses roster which carried out manually, there are nurses who do not meet hospital policy to work between 8 to 10 days (Figure 5.6). For instance, nurse with code number 2 and 3, total duty are respectively 5 and 6 days. Imbalanced of working days among U19 nurses cause more burden task imposed on other nurses such as sixth and seventh nurse as they have to work 10 days, respectively. This will cause fatigue and quality of performance will decrease. However, the distribution of work among U19 nurses with implementation of 0-1 linear goal programming preemptive method (Figure 5.7) is more balanced and fair as 5 out of 7 nurses receive 9 numbers of working days, while only 2 nurses namely 1st and 2nd nurse receive total working days of 8.
Based on Figure 5.8, implementation to all U19 nurses receives the same number of working days in 0-1 linear goal programming cannot be fully met as the global optimum is 1 (which should be zero to get the most optimal value). This is the reason why there are 2 nurses worked 8 days and the remaining 9 days. However, overall it still satisfies the hard constraints.

**Figure 5.6**: Number of days distribution for U19 nurses (manually generated)

**Figure 5.7**: Number of days distribution for U19 nurses (for 0-1 linear GP scheduling – preemptive method)
Figure 5.8: Result for the first priority level – preemptive method (U19 nurses)
5.4.2 Discussion on Soft Constraint Priority 2

Each nurse is preferred to get average working days for morning and evening shift higher than night shift. They feel more comfortable working in the morning and evening shift compared to the night duty that requires a longer period and somewhat tired (working outside the normal hours). As at night there is not a lot of main activities performed, the required number of nurses on duty is not many. If viewed in terms of the distribution of working hours for U29 nurses schedule established manually (Figure 5.9) and 0-1 linear goal programming preemptive method (Figure 5.10), both are successful in achieving the objectives which is each nurse received a combination of duties for morning and evening shifts higher than night. This is proved through successful results using LINGO software, as the global optimum is zero (Figure 5.11).

![Graph showing work shift distribution for U29 nurses](image)

**Figure 5.9**: Work shift distribution for U29 nurses (manually generated)
Figure 5.10: Work shift distribution for U29 nurses (for 0-1 linear GP scheduling – preemptive method)

Figure 5.11: Result for the second priority level – preemptive method (U29 nurse)
Based on manual made U19 nurses work shift distribution, there are nurses work night shifts more than combination of morning and evening shifts (Figure 5.12). This happens to nurse number 3 who has to work 4 night shifts while morning and evening shift is only 1 shift, respectively. However, the result is different for 0-1 goal programming approach preemptive method (Figure 5.13) where all U19 nurses have successfully met the objective of soft constraint priority 2, as each nurse received a combination of working days for morning and evening shift higher than night shift. It is line with the optimum result obtained in LINGO (i.e., zero objective value) as referred to Figure 5.14.

Figure 5.12 : Work shift distribution for U19 nurse (manually generated)
Figure 5.13: Work shift distribution for U19 nurses (for 0-1 linear GP scheduling – preemptive method)

Figure 5.14: Result for the second priority level (U19 nurse)
5.4.3 Discussion on Soft Constraint Priority 3

Each nurse prefers to have more consistent working hours in terms of shifts distribution. For example, if today they are on duty in the evening, possibly the next day also working in the evening to enable them manage their time sleeping with more organization. Similarly, this is also applicable to morning and night shift. If they work in the morning and night on the following day, they will have less time to rest and will affect the quality level of their health. Hence, based on Figure 5.15, can be seen, manually made nurse schedule does not distribute the shifts orderly as what is desired by the nurses. Almost all nurses (1st to 5th nurse) have duty time in evening shift followed by morning shift the next day. It certainly will cause dissatisfaction among nurses. However, different result for 0-1 linear goal programming preemptive method schedule (Figure 5.16), no person is required on duty in evening shift followed by morning shift on the following day. It can be seen from the result achieved in Figure 5.17 where optimality has been obtained (zero objective value)

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<td>Saerah Wahab</td>
<td>E  M  E  E  M  N  N  E  E  M  M</td>
<td></td>
</tr>
<tr>
<td>Haliza Kasau</td>
<td>M  M  E  M  M  M  N  N</td>
<td></td>
</tr>
<tr>
<td>Rosmah M. Yusuf</td>
<td>M  M  M  E  E  N  N  C  C</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.15: Schedule shows any occurrence of evening shift followed by morning/night shift of the following day for U29 nurses (manually generated)
<table>
<thead>
<tr>
<th>Nurse (U29)</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>04/01/2010-17/01/2010</td>
</tr>
<tr>
<td></td>
<td>Name</td>
</tr>
<tr>
<td>1 Faridah Ahmad</td>
<td>N</td>
</tr>
<tr>
<td>2 Sabturani Patomdang</td>
<td>C</td>
</tr>
<tr>
<td>3 Arbaya Lalunga</td>
<td>E</td>
</tr>
<tr>
<td>4 Saerah Wahab</td>
<td>E</td>
</tr>
<tr>
<td>5 Haliza Kasau</td>
<td>M</td>
</tr>
<tr>
<td>6 Rosmah M. Yusuf</td>
<td>M</td>
</tr>
</tbody>
</table>

**Figure 5.16**: Schedule shows any occurrence of evening shift followed by morning/night shift of the following day for U29 nurses (for 0-1 linear GP scheduling – preemptive method).

**Figure 5.17**: Result for the third priority level – preemptive method (U29 nurses)
As has been mentioned in the section in the discussion of U29 nurses, the same result occurred to nurse scheduling for U19 nurses. All nurses in manual made schedule have to work in evening shift followed by morning shift the next day (Figure 5.18). However, none of the nurses are required to work in morning shift the following day with schedule established by 0-1 linear goal programming preemptive method (Figure 5.19). It is in line with the results obtained by LINGO where the global optimum is zero (Figure 5.20).

<table>
<thead>
<tr>
<th>Nurse (U19)</th>
<th>Hospital Tawau</th>
<th>Maternity Ward 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
<td>04/01/2010-17/01/2010</td>
</tr>
<tr>
<td>Days</td>
<td>Name</td>
<td>1    2    3    4    5    6    7    8    9    10   11   12   13   14</td>
</tr>
<tr>
<td>1 Dg Rohani Ag. Masri</td>
<td>C   C   M   M   N   N   E   E   M   M</td>
<td></td>
</tr>
<tr>
<td>2 A. Arina A. Panyuki</td>
<td>M   N   N   E   M   C   C   C   C   C</td>
<td></td>
</tr>
<tr>
<td>3 Hamizah Maning</td>
<td>N   N   E   M   N   N   E   E   M   M   M   M   N   N   E</td>
<td></td>
</tr>
<tr>
<td>4 Marinawati</td>
<td>N   E   E   M   M   M   N   N   E   E   M   M   M   M   N   N   E</td>
<td></td>
</tr>
<tr>
<td>5 Fitriana Sjafei</td>
<td>E   E   E   N   N   E   E   E   E   E   E   E   E   E   E   E   E   E</td>
<td></td>
</tr>
<tr>
<td>6 Watinah Duram</td>
<td>E   E   M   N   N   E   M   M   N   N   N   N   N   N   N   N   N   N</td>
<td></td>
</tr>
<tr>
<td>7 Wendalean Wendy</td>
<td>M   M   N   N   E   M   M   M   N   N   N   N   N   N   N   N   N   N</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.18**: Schedule shows any occurrence of evening shift followed by morning/night shift of the following day for U19 nurses (manually generated)
<table>
<thead>
<tr>
<th>Nurse (U19)</th>
<th>Hospital Tawau</th>
<th>Maternity Ward 2</th>
<th>04/01/2010-17/01/2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Dg Rohani Ag. Masri</td>
<td>1   C</td>
<td>2   C</td>
<td>3   N</td>
</tr>
<tr>
<td>2 A. Arina A. Panyuki</td>
<td>2   E</td>
<td>3   E</td>
<td>4   E</td>
</tr>
<tr>
<td>3 Hamizah Maning</td>
<td>3   M</td>
<td>4   M</td>
<td>5   M</td>
</tr>
<tr>
<td>4 Marlinaawati</td>
<td>4   E</td>
<td>5   E</td>
<td>6   E</td>
</tr>
<tr>
<td>5 Fitriana Sjafei</td>
<td>5   M</td>
<td>6   E</td>
<td>7   E</td>
</tr>
<tr>
<td>6 Watinah Duram</td>
<td>6   N</td>
<td>7   N</td>
<td>8   E</td>
</tr>
<tr>
<td>7 Wendalean Wendy</td>
<td>7   N</td>
<td>8   N</td>
<td>9   N</td>
</tr>
</tbody>
</table>

**Figure 5.19**: Schedule shows any occurrence of evening shift followed by morning/night shift of the following day for U19 nurses (for 0-1 linear GP scheduling – preemptive method)

**Figure 5.20**: Result for the third priority level – preemptive method (U19 nurses)
5.4.4 Discussion on Soft Constraint Priority 4

Based on the Figure 5.21, it can be seen that nurse schedule established manually for U29 nurses still does not emphasize on nurses preferences not to have different shift on the following day. All nurses who worked in the morning shift are required to work evening shift on the next day (some night shift). Meanwhile, the distribution of working shift in Figure 5.22 (carried out by 0-1 linear goal programming - preemptive method) is more concerned on nurses’ preferences. However, only nurse number of 2 does not satisfy the objective as she has to work on night shift after the morning shift. As referred to Figure 5.23, 0-1 goal programming is not able to completely achieve the goal for fourth priority of soft constraint as the global optimum obtained by LINGO is 1 (i.e., does not achieve zero objective value).

<table>
<thead>
<tr>
<th>Nurse (U29)</th>
<th>Hospital Tawau</th>
<th>Maternity Ward 2</th>
<th>04/01/2010-17/01/2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>Name</td>
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<td>2</td>
</tr>
<tr>
<td>1 Faridah Ahmad</td>
<td>E M M N N N</td>
<td>E M M E E</td>
<td></td>
</tr>
<tr>
<td>2 Sabturani Patomdang</td>
<td>C C N N</td>
<td>E E M M E M</td>
<td></td>
</tr>
<tr>
<td>3 Arbaya Lalunga</td>
<td>N N E M E M M N</td>
<td>N N</td>
<td></td>
</tr>
<tr>
<td>4 Saerah Wahab</td>
<td>E M E E M</td>
<td>N N E E M M</td>
<td></td>
</tr>
<tr>
<td>5 Haliza Kasau</td>
<td>M M E M M M N</td>
<td>N N</td>
<td></td>
</tr>
<tr>
<td>6 Rosmah M. Yusuf</td>
<td>M M E E</td>
<td>N N C C</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.21 : Schedule shows any occurrence of morning shift followed by evening/night shift of the following day for U29 nurses (manually generated)
**Figure 5.22**: Schedule shows any occurrence of morning shift followed by evening/night shift of the following day for U29 nurses (for 0-1 linear GP scheduling – preemptive method)

**Figure 5.23**: Result for the fourth priority level – preemptive method (U29 nurses)
Similarly with U19 nurses’ schedule established manually, all nurses who worked in the morning shift are required to have duty on night shift the next day (Figure 5.24). However, none of U19 nurses is required to work on night or evening shift after morning shift with 0-1 linear goal programming preemptive method made schedule (Figure 5.25) Based on Figure 5.26, this has successfully achieved since the global optimum obtained in LINGO is zero.

![Table](image.png)

**Figure 5.24**: Schedule shows any occurrence of morning shift followed by evening/night shift of the following day for U19 nurses (manually generated)
Figure 5.25: Schedule shows any occurrence of morning shift followed by evening/night shift of the following day for U19 nurses (for 0-1 linear GP scheduling – preemptive method)

Figure 5.26: Result for the fourth priority level – preemptive method (U19 nurses)
### 5.5 Discussion on The Results From Weighting Method

Figure 5.27 shows the 2 weeks scheduling result using 0-1 linear goal programming approach (weighting method) for 3 shifts (morning, evening and night shift). Each shift is 7 hours long for morning and evening, respectively while night shift is 10 hours.

<table>
<thead>
<tr>
<th>Nurse (U29)</th>
<th>Hospital Tawau</th>
<th>Maternity Ward 2</th>
<th>04/01/2010-17/01/2010</th>
<th>Morning</th>
<th>Evening</th>
<th>Night</th>
<th>Total</th>
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<tbody>
<tr>
<td>Name</td>
<td>Days</td>
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<tr>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Saerah Wahab</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Haliza Kasau</td>
<td>E E M M M M N N</td>
<td>4 3 2 9</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rosmah M. Yusuf</td>
<td>M M M E E E E</td>
<td>C C N 4 4 1 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Days</td>
<td>Morning</td>
<td>Evening</td>
<td>Night</td>
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<td>Night</td>
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<td>16</td>
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<table>
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<th>Nurse (U19)</th>
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<th>Morning</th>
<th>Evening</th>
<th>Night</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Days</td>
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<tr>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Marinawati</td>
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<td>1 5 3 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitriana Sjafei</td>
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<td>3 2 4 9</td>
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<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>2 5 2 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Days</td>
<td>Morning</td>
<td>Evening</td>
<td>Night</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>20</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Evening</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night</td>
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<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**TOTAL ON DUTY**

|       | 2 | 2 | 4 | 4 | 3 | 2 | 4 | 4 | 2 | 2 | 3 | 2 | 2 | 2 |  | 38 |
|-------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Morning |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Evening | 4 | 3 | 3 | 3 | 2 | 3 | 4 | 4 | 2 | 3 | 3 | 3 | 3 | 3 | 5 |   | 45 |
| Night   | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 4 |   |   | 33 |

**Figure 5.27**: Result of the scheduling using 0-1 linear goal programming (the weighting method)

### 5.5.1 Discussion on U29 Nurses

In this section, we will discuss the result obtained from goal programming approach under weighting method (referred to Figure 5.28, 5.29, 5.30 and 5.31). Different weights were used for all soft constraints based on the level of priority assigned where goal 1 has the highest value of weight and following with goal 4 as the lowest one. Hence, this method is trying to achieve all soft constraints goals at the same time with different weights assigned to them, respectively. However, the objective function is 1 where it did not succeed to get the best optimum value (i.e zero objective value). As we can see from Figure 5.31, only the fourth soft constraint is violated (avoid morning shift followed by evening shift or night shift of the following day). It occurs to 2\textsuperscript{nd} nurse, day 3, where after morning shift, she has to work night shift the following day. Based on Figure 5.32, the global optimum obtained is not the best value (not achieving 0).
Figure 5.28: Number of days distribution for U29 nurses (for 0-1 linear GP scheduling – weighting method)

Figure 5.29: Work shift distribution for U29 nurses (for 0-1 linear GP scheduling – weighting method)
<table>
<thead>
<tr>
<th>Nurse (U29)</th>
<th>Hospital Tawau</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maternity Ward 2</td>
</tr>
<tr>
<td></td>
<td>04/01/2010-17/01/2010</td>
</tr>
<tr>
<td>Days</td>
<td></td>
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<tr>
<td>Name</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Sabturani Patomdang</td>
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</tr>
<tr>
<td>Arbaya Lalunga</td>
<td>N</td>
</tr>
<tr>
<td>Saerah Wahab</td>
<td>E</td>
</tr>
<tr>
<td>Haliza Kasau</td>
<td>E</td>
</tr>
<tr>
<td>Rosmah M. Yusuf</td>
<td>M</td>
</tr>
</tbody>
</table>

**Figure 5.30**: Schedule shows any occurrence of evening shift followed by morning/night shift of the following day for U29 nurses (for 0-1 linear GP scheduling – weighting method)

<table>
<thead>
<tr>
<th>Nurse (U29)</th>
<th>Hospital Tawau</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maternity Ward 2</td>
</tr>
<tr>
<td></td>
<td>04/01/2010-17/01/2010</td>
</tr>
<tr>
<td>Days</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>1</td>
</tr>
<tr>
<td>Faridah Ahmad</td>
<td>N</td>
</tr>
<tr>
<td>Sabturani Patomdang</td>
<td>C</td>
</tr>
<tr>
<td>Arbaya Lalunga</td>
<td>N</td>
</tr>
<tr>
<td>Saerah Wahab</td>
<td>E</td>
</tr>
<tr>
<td>Haliza Kasau</td>
<td>E</td>
</tr>
<tr>
<td>Rosmah M. Yusuf</td>
<td>M</td>
</tr>
</tbody>
</table>

**Figure 5.31**: Schedule shows any occurrence of morning shift followed by evening/night shift of the following day for U29 nurses (for 0-1 linear GP scheduling – weighting method)
Figure 5.32: Result of the objective function – weighting method (U29 nurses)

5.5.2 Discussion on U19 Nurses

The same result also occurred to U19 nurses problem where it did not manage to get the best optimum value (e.g. zero objective value). This can be shown through Figure 5.37. Similar like in the preemptive method, the only violated soft constraint is the first one as referred to Figure 5.33. However, in weighting method the result is better compared to preemptive method since only one nurse has violated the goal. Whereas, second, third and fourth soft constraints have successfully met the needed criteria (Figure 5.34, 5.35 and 5.36).
Figure 5.33: Number of days distribution for U19 nurses (for 0-1 linear GP scheduling – weighting method)

Figure 5.34: Work shift distribution for U19 nurses (for 0-1 linear GP scheduling – weighting method)
Figure 5.35: Schedule shows any occurrence of evening shift followed by morning/night shift of the following day for U19 nurses (for 0-1 linear GP scheduling – weighting method)

<table>
<thead>
<tr>
<th>Nurse (U19)</th>
<th>Hospital Tawau</th>
<th>Maternity Ward 2</th>
<th>04/01/2010-17/01/2010</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
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<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1 Dg Rohani Ag. Masri</td>
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<td>C</td>
<td>N</td>
</tr>
<tr>
<td>2 A. Arina A. Panyuki</td>
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<td>E</td>
<td>M</td>
</tr>
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<td>M</td>
<td>M</td>
</tr>
<tr>
<td>4 Marlinawati</td>
<td>M</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>5 Fitriana Sjafie</td>
<td>E</td>
<td>E</td>
<td>N</td>
</tr>
<tr>
<td>6 Watinah Duram</td>
<td>M</td>
<td>M</td>
<td>N</td>
</tr>
<tr>
<td>7 Wendalean Wendy</td>
<td>N</td>
<td>N</td>
<td>E</td>
</tr>
</tbody>
</table>

Figure 5.36: Schedule shows any occurrence of morning shift followed by evening/night shift of the following day for U19 nurses (for 0-1 linear GP scheduling – weighting method)

<table>
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<th>Maternity Ward 2</th>
<th>04/01/2010-17/01/2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
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<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1 Dg Rohani Ag. Masri</td>
<td>C</td>
<td>C</td>
<td>N</td>
</tr>
<tr>
<td>2 A. Arina A. Panyuki</td>
<td>E</td>
<td>E</td>
<td>M</td>
</tr>
<tr>
<td>3 Hamizah Maning</td>
<td>E</td>
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<td>M</td>
</tr>
<tr>
<td>4 Marlinawati</td>
<td>M</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>5 Fitriana Sjafie</td>
<td>E</td>
<td>E</td>
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</tr>
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<td>M</td>
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</tr>
<tr>
<td>7 Wendalean Wendy</td>
<td>N</td>
<td>N</td>
<td>E</td>
</tr>
</tbody>
</table>
5.6 Advantages

1. Automated scheduling – where the roster is generated by the system.

2. It is fair for the nurses because the computer built the roster – this avoids the favoritism disease occurred between the head nurses and the nurses.

3. The problems in finding the nurses to work based on their preferences can be reduced – The system will automatically generate the roster based on the hard constraint and soft constraint identified.
5.7 Disadvantages

1. Difficulties in developing the system. This applied in coding and interface with LINGO in order to generate the fair roster, which fulfill the rules and yet satisfies nurse’s need.

2. Specifically design for Maternity Ward 2, Hospital Tawau cases, which cannot be applied to other ward situation.

5.8 Summary

This chapter generally discusses the results achieved in the implementation of 0-1 linear goal programming to the nurse scheduling in the Maternity Ward 2, Hospital Tawau, Sabah. Both preemptive and weighting method has been applied and compared with manually generated schedule.
6.1 Introduction

This chapter summarized the results and findings obtained in Chapter 5. From these observations, conclusion is drawn. Finally, some recommendations for future research in this area which might be pursued are offered.

6.2 Discussion

The solution obtained for the entire unit is almost optimal for preemptive method since almost all goals are met (objective function is zero). For weighting method, both cases (U29 and U19 nurses) are not achieving the best optimum value (ie. zero objective value) since both objective function gives value of 1, respectively. The total computational time is about less than 45 minutes. In this computerized schedule, for preemptive method, almost all nurses (U29 and U19) work for 9 days, as recommended by the first soft constraint with only 2 times are violated. Similar thing happen to schedule generated by weighting method where this soft constraint is violated. However, it is better since only 1 violation occurred (1 U19 nurse work for 8 days). This is not the case for the manual-made schedule. The manual-made schedule is
very unbalanced with respect to total number of days working. In addition, the number of working days to be between 8 and 10 days (considered in the model as a hard constraint) is violated 4 times in the manual schedule (working days 6\textsuperscript{th} U29 nurse, 2\textsuperscript{nd} U19 nurse and 3\textsuperscript{rd} U19 nurse are less than 8 while 4\textsuperscript{th} U29 nurse is greater than 10). Moreover, the soft constraint of avoiding an evening shift followed by morning or night shift in the next day is violated 10 times in the manual schedule for U29 nurses and 8 times for U19 nurses. However, none of the third priority soft constraint is violated in 0-1 goal programming (preemptive method and weighting method) schedule for both nurses’ level. For the soft constraint of avoiding a morning shift followed by evening or night shift on the next day, violation has occurred 6 times in the manual schedule for U29 nurses and 7 times for U19 nurses. In 0-1 goal programming, the fourth priority of soft constraint is violated 1 time for both methods (preemptive and weighting) on 2\textsuperscript{nd} U29 nurse, respectively.

From the observations, there is the possibility to see the reasons that cause violation of the soft constraints. Given the violation occurs only on the 2\textsuperscript{nd} nurse of U29 group, 1\textsuperscript{st} and 2\textsuperscript{nd} nurse of U19 group, it is probably closely related to the application of leave days by the nurses which resulting in a limited space on the schedule to distribute the shifts randomly (based on LINGO) for each nurse involved. Since the leave application is a hard constraint, then it must be followed and included in the tabulation. In the meantime, for the weighting method, as only 1 nurse has to work for 8 days compared with the preemptive method which the nurses involved was 2, the high weight imposed on the first goal has helped to reduce the violation. This explains why only 1 nurse involved in weighting method rather than in preemptive method, 2 nurses involved.

From the implementation, it shows that 0-1 linear goal programming can help in producing a good scheduler. It is clearly shown that the scheduling using 0-1 linear goal programming can produce better result than manual generated roster because:
a) Almost all of number of working days are equally distributed among the nurses involved (refer Figure 5.4, 5.7, 5.28 and 5.33) compared to manually generated schedule.

b) It is also shown that, the distribution of the combination of morning and evening shift are more than night shift – can be seen clearly from the Figure 5.10, 5.13, 5.29 and 5.34. Compared to manual roster, there is a situation where a nurse (2\textsuperscript{nd} U19 nurse) has combination of morning and evening less than night shift. This will affect the distribution of the nurse on the other two shifts – which is also important especially morning and evening shifts because most of the main activities are done at the morning (and evening) shift.

c) Almost all nurses from manually generated schedule (U29 and U19) have morning or night shift after evening shift but none case from 0-1 goal programming for both methods (preemptive and weighting). Avoiding morning and night shift after evening shift would help nurses adjust their time to sleep.

d) The same also shows in the last priority of soft constraint as almost all nurses (U29 and U19) in manual schedule, have evening and night shift after morning shift. However, only 2 cases (2\textsuperscript{nd} U29 nurse) occurred in 0-1 linear goal programming generated schedule for both methods (preemptive and weighting).

Looking at the results for both methods, it can be concluded that weighting method gives better result than preemptive method. Even though both methods have violation in the same soft constraint but there is a difference in terms of number of the violation occurs. This can be seen from the first soft constraint under U19 group, where in preemptive method, 2 nurses have 8 working days while only 1 nurse has working days of 8 in weighting method. Hence, overall weighting method gives better result than preemptive method.
6.3 Conclusion

Solution obtained from the 0-1 linear goal programming model has been implemented with the Lingo software. Several models have been developed and modified to obtain the best solution. Nevertheless, the model described here is the best by demonstrating similarities and differences compared with the work pattern working manually. Currently, the head nurse at each unit/department/ward makes a manual schedule through a trial and error approach. This approach is not only costly, but also inefficient in producing satisfactory schedules. These manual schedules do not satisfy a number of important criteria for efficient scheduling. These include balanced schedules, fairness considerations, and nurses’ preferences, in addition to ergonomic considerations, and staffing requirements both in quality and size. The developed model provides important improvements in this regard besides the fact that it offers a practical computerized tool.

The developed model considers nurses’ preferences. Other sources used in building scheduling policies are the current applied policies in the hospital, as well as recommended policies displayed in the literature and that account for ergonomic factors. Satisfying simultaneously all the suggested policies need not be feasible. Consequently, some of these policies are taken as hard constraints that must be satisfied. Hard constraints are selected based on feedback from head nurse. The rest of the constraints are taken as soft constraints. Also, the priority levels and weights assigned are assessed based on the judgment of the head nurse.

As has been mentioned before, for measuring a schedule quality, Oldenkamp and Simons (1995) develop five factors as specified below.

1. *Optimality*: *represents the degree in which nursing expertise is distributed over the different shifts.* The way sub grouping is made in the developed 0-1 goal programming accounts for this factor.
2. Completeness: represents the degree in which the quantitative demands for occupation per shift are met. In the 0-1 goal programming model, this is formulated as hard constraint and is always satisfied.

3. Proportionality: represents the degree in which each nurse has been given about the same amount of working days (morning, evening and night shifts). This is amply satisfied in the developed 0-1 goal programming model as shown in Chapter 5.

4. Healthiness: represents the degree in which it has been taken care of the welfare and health of the nurses. This is also largely considered in the model by incorporating several related factors as hard and soft constraints.

5. Continuity factor: represents the degree in which there is continuity in the nursing crew during the different shifts. This is also satisfied in the developed model.

Therefore, the developed model performs quite well based on the quality criteria. The model has been found not only to satisfy hospital’s objectives but also, and to a larger extent, nurses’ preferences (proportionality, days off, isolated days on and off, etc.).

Results comparison between 0-1 linear goal programming approach (preemptive and weighting method) with existing methods shows that the use of 0-1 goal programming method can help the administration make a working schedule that meets the objectives of the hospital and demand of nurses. Even though nurse schedule that is produced through 0-1 goal programming has weaknesses, but it is still better than manually produced. The new schedule will be developed every 2 weeks.
This study yields many good results. The approach of 0-1 linear goal programming in rostering environment has proven useful and powerful.

### 6.4 Recommendation for Future Work

Due to the time constraint of this research work, the study is done in Maternity Ward 2 only and specifically in 0-1 linear goal programming approach. There is actually quite a lot of further work possible in this area. The following recommendations are suggested for the future research in this study:

1. Research can be expanded to develop a 0-1 linear goal programming model for all units/departments/wards in Hospital Tawau, and as well as other hospitals too.

2. Future work may focus on building a user-friendly computer package. There is also a need to improve the system, therefore the head nurse can regenerate the system if unexpected occurrence occurred (no feasible solution).

3. 0-1 linear goal programming can be hybrid with other approach such as Simulated Annealing, Genetic Algorithm, Neural Network, Tabu Search, etc. for improvement.

4. If the number of days off request becomes fairly high by several nurses, then some rules can be developed (such as priority for assigning days off, first requested first accepted with a maximum number of requested days) to keep the schedule feasible.
5. Long vacations are incorporated by taking out the corresponding nurses from the schedules or from a number of weeks in the schedules. However, other rules are taken under considerations to ensure that the nurses, after taking vacations, would have a balanced remaining schedule.
REFERENCES


Andrew, G. M. and R. Collins (1971). Matching Faculty to Courses. College and University. 46, 2, 83-89 (Winter)


# APPENDIX A

## MANUAL-MADE NURSE ROSTER FOR U29 AND U19 NURSES

(04/01/10-10/01/10)

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**TOTAL ON DUTY**


**Descakal Oleh**

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Jawatan: 
Tarih: 31/10/10
APPENDIX B

MANUAL MADE NURSE ROSTER FOR U29 AND U19 NURSES
(11/01/10-17/01/10)

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TARikh DARi : 11/01/2010-17/01/2010

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SH. SABAATON SY. OSMAN
Jawatan:
B 1.2.09

Disinggalkan Oleh:
RITA. JOKININ
Jawatan:
Panyelia, Jumu'at
Tarih:
11/1/2010
APPENDIX C

LINGO SOFTWARE VERSION 10.0
APPENDIX D

PART OF THE CODING OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – PREEMPTIVE METHOD (U29 NURSES)
APPENDIX E

PART OF THE SOLUTION OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – PREEMPTIVE METHOD (U29 NURSES)
APPENDIX F

PART OF THE CODING OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – PREEMPTIVE METHOD (U19 NURSES)
APPENDIX G

PART OF THE SOLUTION OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – PREEMPTIVE METHOD (U19 NURSES)

| BM | 1, 1 | 0.000000 | 0.000000 |
| BM | 1, 2 | 0.000000 | 0.000000 |
| BM | 1, 3 | 1.000000 | 0.000000 |
| BM | 1, 4 | 0.000000 | 0.000000 |
| BM | 1, 5 | 1.000000 | 0.000000 |
| BM | 1, 6 | 0.000000 | 0.000000 |
| BM | 1, 7 | 0.000000 | 0.000000 |
| BM | 2, 1 | 0.000000 | 0.000000 |
| BM | 2, 2 | 0.000000 | 0.000000 |
| BM | 2, 3 | 1.000000 | 0.000000 |
| BM | 2, 4 | 0.000000 | 0.000000 |
| BM | 2, 5 | 0.000000 | 0.000000 |
| BM | 2, 6 | 0.000000 | 0.000000 |
| BM | 2, 7 | 0.000000 | 0.000000 |
| BM | 3, 1 | 0.000000 | 0.000000 |
| BM | 3, 2 | 0.000000 | 0.000000 |
| BM | 3, 3 | 0.000000 | 0.000000 |
| BM | 3, 4 | 1.000000 | 0.000000 |
| BM | 3, 5 | 0.000000 | 0.000000 |
| BM | 3, 6 | 0.000000 | 0.000000 |
| BM | 3, 7 | 0.000000 | 0.000000 |
| BM | 4, 1 | 0.000000 | 0.000000 |
| BM | 4, 2 | 0.000000 | 0.000000 |
| BM | 4, 3 | 1.000000 | 0.000000 |
| BM | 4, 4 | 1.000000 | 0.000000 |
| BM | 4, 5 | 0.000000 | 0.000000 |
| BM | 4, 6 | 0.000000 | 0.000000 |
APPENDIX H

PART OF THE CODING OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – WEIGHTING METHOD (U29 NURSES)

MODEL:

SETS:

DAYS /1..14/;
NURSES /1..6/: N01, N02, N03, N04, N05, N06;
LINKS(DAYS, NURSES): hN, hE, eN, eE, N05, N06;
ENDSETS

OBJECTIVE FUNCTION;

all nurses have the same amount of working days. 9 days per schedule, weight=4.0;
! attempts to have in the schedule more morning and evening than night shifts, weight=3.0;
! avoid evening shift following with morning shift or night shift of the following day, weight=1.0;
! avoid morning shift following with evening shift or night shift of the following day, weight=1.0;

MIN: 4*SUM((NURSES: P01+N01)+4*SUM((NURSES: N02+N03)+2*SUM(LINKS: PO5)+4*SUM(LINKS: PO6));

HARD CONSTRAINT;

!1. days off to be approved (this model will always be changed according to application of day off per schedule);

@FOR(NURSES: N01) @FOR(N01): C(1, N01)=C(11, N01)=2;
@FOR(NURSES: N02) @FOR(N02): C(12, N02)=C(13, N02)=2;
APPENDIX I

PART OF THE SOLUTION OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – WEIGHTING METHOD (U29 NURSES)
PART OF THE CODING OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – WEIGHTING METHOD (U19 NURSES)
### APPENDIX K

**PART OF THE SOLUTION OF NURSE SCHEDULING BASED ON 0-1 GOAL PROGRAMMING APPROACH – WEIGHTING METHOD (U19 NURSES)**

<table>
<thead>
<tr>
<th></th>
<th>C (1, 5)</th>
<th>C (1, 6)</th>
<th>C (1, 7)</th>
<th>C (2, 1)</th>
<th>C (2, 2)</th>
<th>C (2, 3)</th>
<th>C (2, 4)</th>
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<th>C (3, 7)</th>
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<th>C (4, 4)</th>
<th>C (4, 5)</th>
<th>C (4, 6)</th>
<th>C (4, 7)</th>
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