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Designing a Decision Support Tool for Nurse Scheduling at Stellenbosch Hospital

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Final year project presented in partial fulfilment of the requirements for the degree of Bachelors of Industrial Engineering at Stellenbosch University.

Study leader: Mrs van Dyk

December 2011

Declaration

I, the undersigned, hereby declare that the work contained in this final year project is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

……………………….. ………………………

Signed:

Sonja Friedrich Date

ECSA Exit level outcomes references

If the document is in English, use this table, otherwise delete it and use the Afrikaans version below. Submit only one table!

Your study leader will help you with the definitions of the exit level outcomes. Refer to ECSA document PE-61-r2.PDF.

The following table includes references to sections in this report where ECSA exit level outcomes are addressed.

Exit level outcome	**Section(s)**	**Page(s)**
1. Problem solving	E.g.: 2.2 2.2 – 4.3	 14-16 14 - 38
2. Application of engineering & scientific knowledge	3.4 4.3	24-32 45-54
5. Engineering methods, skills & tools, incl. IT		
6. Professional & Technical communication		
9. Independent learning ability		
10. Engineering professionalism		

U studieleier sal u help met die definisies van die uittree-vlak uitkomste deur te verwys na ECSA se riglyne in dokument PE-61-r2.PDF.

Die volgende tabel bevat verwysings na afdelings in hierdie verslag waar IRSA uittreevlak-uitkomste aangespreek word.

Uittree-vlak uitkoms	**Afdeling(s)**	**Bladsy(e)**
1. Probleemoplossing	Bv.: 2.2 2.2 – 4.3	 14-16 14 - 38
2. Toepassing van ingenieurs- en wetenskaplike kennis	3.4 4.3	24-32 45-54

5. Ingenieursmetodes, vaardighede en – gereedskap, insluitend IT		
6. Professionele & Tegniese kommunikasie		
9. Onafhanklike leervermoë		
10. Ingenieursprofessionaliteit		

Synopsis

Providing sufficient healthcare to all South African citizens is of significant concern to government. Major problem areas lie in the prevention and control of epidemics, allocation of resources and health systems management. The majority of the government facilitated hospitals in South Africa experience difficulty in attaining health care targets due to these problems. Stellenbosch Hospital, an 85- bed, non-profit public facility that serves a community of 170 000 people, is no exception.

A root cause analysis revealed that an insufficient nurse scheduling process is the underlying cause of numerous problems and that a lack of worker morale is the largest predicament at Stellenbosch Hospital. Different motivational theories are investigated and it is concluded that worker morale at the hospital can be improved by empowering nurses to gain more control over schedules, and that the nurse scheduling process can be enhanced by supporting nurse scheduling with a decision support tool. The purpose of the decision support tool is scoped to deal with day and night scheduling and nurse-to-ward assignments particularly, as this is largest amount of work for the unit managers. Additionally it is decided to involve nurses in the annual day and night schedule as well as the ward preferences, as this has the most significant impact on nurses' work lives. The inputs and expected outcomes of the decision support tool are discussed and the development platform was chosen to be a combination of Visual Basics and Microsoft Excel, as these programs are powerful and freely available.

After careful consideration of different nurse scheduling methods linear programming and a self-developed algorithm were chosen by making use of the Analytical Hierarchy Process. The day and night schedule is solved with an integer programming model, with the drawback being the inflexibility of the fixed quarters which nurses can select, as well as the rigidity of the model and the suboptimal solution which needs rounding. The day and night scheduling results are an input to the self-developed algorithm, which imitates the thought process of the unit managers scheduling process to arrive at a feasible solution. The key to this method is the nurses available over nurses required ratio which drives the algorithm. A flowchart supporting the documentation and understanding of the code has been developed along with a testing table to verify the results of the code.

The user interface is developed and a user friendly output is designed which summarises all results in one sheet. Finally a user validation of the decision support tool at Stellenbosch Hospital confirms its usefulness and effectiveness to support nurse scheduling decision making, enhance nurse utilisation and improve worker morale by including nurses in the scheduling process.

Opsomming

.Die verskaffing van voldoende gesondheidsorg aan alle Suid-Afrikaaners is ' n bekommernis vir die regering. Die meerderheid van Suid Afrikaanse hospitale se struikelblokke om gesondheidsorg teikens te behaal, lê in die voorkoming en beheer van epidemies, die toekenning van hulpbronne en die bestuur van gesondheidstelsels. Stellenbosch Hospitaal, wat sowat 170 000 mense dien is nie 'n uitsondering nie.

n' Oorsaak en gevolg diagram het openbaar dat ' n onvoldoende verpleegsterskeduleringsproses die onderliggende oorsaak van 'n meerderheid van probleme is, en dat 'n gebrek aan werkersmoraal die grootste struikelblok by Stellenbosch Hospitaal is. Verder is verskillende teorieë ondersoek en dit het tot die gevolgtrekking gelei dat die werkermoraal by die hospitaal verbeter kan word word deur die bemagtiging van verpleegkundiges om meer beheer oor hul schedules te verkry, en dat die verpleegkundige skeduleringsproses kan verbeter word deur die ondersteuning van die verpleegsterskedulering met 'n besluitsteuninstrument. Die doel van die besluitondersteunende instrument is bepaal om net dag- en nagskedulering en verpleegstersaalindeling te bevat. Dit is so gekies aangesien dit die grootste hoeveelheid werk vir die eenheidsbestuurders behels. Daarbenewens is besluit om verpleegsters in die jaarlikse dag- en nag kedule sowel as die saalvoorkeure te betrek, aangesien dit die mees beduidende impak op die verpleegsters se werklewens het. Die insette en die verwagte uitkomste van die besluitinstrumentvir ondersteuning word bespreek en die ontwikkelingsplatform is gekies as 'n kombinasie van Visual Basics en Microsoft Excel aangesien hierdie programme kragtig en vryelik beskikbaar is.

Na deeglike oorweging van verskillende verpleegsterskeduleringsmetodes is heelgetalprogrammering en 'n self-ontwikkelde algoritme gekies deur gebruik te maak van die analitiese hiërargie proses. Die dag- en nag skedule is opgelos met 'n heelgetalprogrammersmodel. Die nadeel van die model is sy onbuigsaamheid ten opsigt van die vaste kwartiere wat verpleegsters kan kies, sowel as sy rigiditeit en die sub-optimale oplossing wat afgerond moet word. Die dag- en nagskedulering resultate is 'n inset aan die self ontwikkelde algoritme, wat die gedagte van die eenheidsbestuurder se skeduleringsproses naboots om ‘n haalbare oplossing te bereik. Die sleutel tot hierdie metode is die verpleegsters beskikbaar is oor

verpleegsters vereis verhouding wat die algoritme dryf. 'n Vloeidiagram om die dokumentasie en begrip van die kode te verifieer is ontwikkel saam met' n toetstabel om die resultate van die kode te toets. Die gebruikerskoppelvlak is deeglik ontwikkel en 'n gebruikersvriendelike uitset is ontwerp wat 'n opsomming van al die resultate insluit. Ten slotte is 'n gebruikersvalidering van die instrument by Stellenbosch Hospitaal deurgevoer. Sy bruikbaarheid en effektiwiteit in verpleegsterskedulering en waarde van besluitnemingsondersteuning is bevestig. Verder is die potensieel verbeterde werkermoraal deur die insluiting van die verpleegsters in die skeduleringsproses ook bevestig.

Acknowledgements

Numerous factors contribute towards creating and following through with a large project. Without thorough support and cooperation it is impossible to obtain valuable information and to be able to work in a friendly environment. Having said this, I want to thank SIFE for the exciting project opportunity, Tanya Visser for her patience as well as Liezl van Dyk for her guidance and creative support, Mr B.F. Abrahamse for providing the opportunity to conduct this project at his hospital, and Sister Linders and Sister Skippers for taking time to answer my numerous questions and give valuable input and feedback to the Final Year Project.

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Glossary

AHP	Analytical Hierarchy Process
DSS	Decision Support System
VBA	Visual Basics

1. Introduction

1.1 Background

The provision of healthcare to all South African citizens is of great concern to Government. The Medium Strategic Framework "is a statement of intent identifying the development challenges facing South Africa and outlining the medium-term strategy for improvements in the conditions of life of South Africans and for our enhanced contribution to the cause of building a better world" (The Presidency Republic of South Africa, 2009). This framework was to guide the government's programme in the electoral mandate period from 2009 -2014. One of the goals is to "create a long and healthy life for all South Africans" (The Presidency Republic of South Africa, 2009).

As illustrated in Table 1, the South African health care system faces several challenges that act as a barrier to health care improvement. The central concerns lie in the prevention and control of epidemics, allocation of resources and health systems management. The majority of the government facilitated hospitals in South Africa experience difficulty in attaining strategic goals and improving health care due to these barriers. Stellenbosch Hospital is one of them, founded in 1942 and located in the heart of Stellenbosch in Merriman Avenue. It is an 85- bed, non-profit public facility that serves a community of 170 000 people. Approximately 5000 patients per month are treated, comprising an equal number of outpatients and inpatients. Government subsidises Stellenbosch Hospital with about R95 million to support the goals of the nation.

Prevention and control of epidemics	Allocation of resources	Health systems management
1 Prevention and treatment of HIV/AIDS	4 Distribution of financing & spending	6 Quality of care
2 Prevention of new epidemics	5 Availability of health personnel in the public sector	7 Operational efficiency
3 Prevention of alcohol abuse		8 Devolution of authority
		9 Health worker morale
		10 Leadership & innovation

Table 1 Ten main challenges facing the health sector, 2010 - 2015 adopted from Harrison (2009)

Stellenbosch Hospital is mother to eleven day clinics located in close proximity or within Stellenbosch, and numerous mobile units operating on farms around Stellenbosch. All of these facilities are financed with Stellenbosch Hospital's limited budget. Considering the expenses the hospital has to cover on a daily basis, the funding is insufficient to sustain the hospital, which is exacerbated by the mismanagement of this funding, leading to a multitude of operational problems. The 273 employees of the hospital and clinics receive 53 million of the amount in salaries and in kind, which leaves little for maintenance, medication and development. 80% of the staff at Stellenbosch Hospital is associated with patient care.

SIFE (Students in Free Enterprise) is a group of students that apply their skills acquired at university in conjunction with partners from industry to impact the lives of people in their community by helping them to help themselves. SIFE's mission is to "bring together the top leaders of today and tomorrow to create a better, more sustainable world through the positive power of business" (SIFE, 2011). In October 2010 SIFE was requested by Stellenbosch Hospital deputy manager Mr. Abrahmse, to find a solution to the operational problems that are experienced at the hospital. A cause-and-effect diagram was created to determine the root causes of the problems at Stellenbosch Hospital.

1.2 Root cause analysis

Free primary health care for all patients is the mission of a government hospital and nurses are the provider of this service and its quality (Harrison, 2009). Referring to Figure 1 (cause-and-effect diagram) insufficient quality of health care and nursing services has thus been identified as the main predicament hampering health care at Stellenbosch Hospital. Numerous of the observed problems at Stellenbosch Hospital are consistent with findings in government hospitals generally as identified by Harrison in 2009 and depicted in Table 1. Thus, considering Harrison's (2009) work as well as own findings, the quality of health care and nursing services at Stellenbosch Hospital was determined to be affected by four major causes. These causes are the lack of authority of management (1), low worker morale (2), limited and mismanaged finances and general ineffectiveness (3) and absenteeism (4). Each of these causes represents one bone in Figure 1. In the following passage, each of these areas and root causes relevant to the final year project are expanded on.

1.2.1 Lack of authority of management

The lack of authority of management can be attributed to management's lack of system thinking, and the disregard of the importance of the hospitals nursing staff leads to unconstructive communication and antagonism. Absenteeism undermines management authority as it is an indication of lack of respect for management. An organisational culture change is resisted by employees resulting from a deficiency of trust and management's inability to lead and support its employees. Moreover, management often addresses the symptoms of system inadequacies rather than treating the root causes. For example, management may want to suspend regular absentees, without considering underlying reasons as for example the lack of control that is granted the nurses over the most important part of their working life, their schedule. The complexity of incorporating nurses in the scheduling process has moreover prohibited any effort in that direction as it would place even more strain on unit managers.

1.2.2 Low worker morale

Operational inefficiency causes long waiting time for patients, as patient flow is inefficiently managed. Moreover, ineffective nurse schedules do not provide adequate staff cover to provide enough nurses for patient needs. Due to long waiting times, nurses are verbally abused by irritated patients. No additional nurses can be hired from agencies because of budget constraints, and nurses frequently work in positions they are not trained for. Inexperienced nurses feel insecure and overwhelmed by their job, and busy wards are seldom relieved by extra nurses, as over assigned and dissatisfied nurses stay away from work. This can pose a significant threat to patient health. Furthermore, the unpleasant, dirty and ill equipped work environment is detrimental to the worker morale.

Nurses are generally a scarce resource and all nurses need to be utilised optimally to achieve a schedule that covers all shifts needed. The inadequate work scheduling process causes gaps in the schedule that need to be filled by overtime. Nurses are simply assigned regardless of personal or family commitments. As a result, nurses stay away from work as they have almost no control and ownership over their overtime or general assignment. Absenteeism and understaffing further aggravate overtime and consequently dissatisfaction. This is a vicious circle which negatively affects worker morale. The aspect of worker morale and motivation is further expanded on in a literature study at a later stage.

1.2.3 Limited and mismanaged finances as well as general ineffectiveness

The services a government hospital provides are paid for by government. The time of limited and costly resources like unit managers is utilised inefficiently. Unit managers work out complex schedules by hand which, apart from taking up valuable time, yields questionable results. Badly executed schedules and ineffective utilisation of resources are detrimental to the quality of health care and nursing services.

The largest portion of the hospital's budget is allocated to the staff salaries of 84 nurses. To Stellenbosch Hospital the cost of absenteeism at a rate of 8% per day where nurses are paid on average of R86 per hour for a twelve hour day, four days per week accumulates to roughly R 108 000 per month using a conservative approach. The cost of nurses not coming to work thus amounts to about 5% of the total budget for employee remuneration. These figures are an indicator on how serious the problems at Stellenbosch Hospital are and how important it is to find a way to improve the situation.

1.2.4 Absenteeism

Absenteeism rates influence the quality of health care and nursing services as nurses are over assigned and need to work more over time due to absent employees. Absenteeism rates at Stellenbosch Hospital are as high as 8% (Abrahamse, personal communication, 5 April 2011). Reasons are lack of communication, cases of illness or unexpected leave (Abrahamse, personal communication, 5 April 2011). Low worker morale fuels absenteeism. However, the combination of insufficient control, poor communication and the lack of policies and enforced standards cause absenteeism rates to get out of hand. The possible introduction of documented best practice methods to address these problems would require organisational change. Organisational change in turn, can only be achieved with the cooperation of the nurses. This again requires management to empower nurses, which could be achieved by delegating them more control. However, the complexity of integrating nurses' preferences in schedules would make the scheduling task too complex for unit managers.

In the cause-and-effect diagram in Figure 1 the highlighted root causes in the four major problem areas are all related to the nurse scheduling process. Using industrial engineering tools to improve the nurse scheduling process yields exciting potential opportunities to improve the quality of health care and nursing services. The vision is to improve health care services not only at Stellenbosch Hospital, but using the knowledge obtained at Stellenbosch Hospital as a foundation to attain health care targets on a national level.

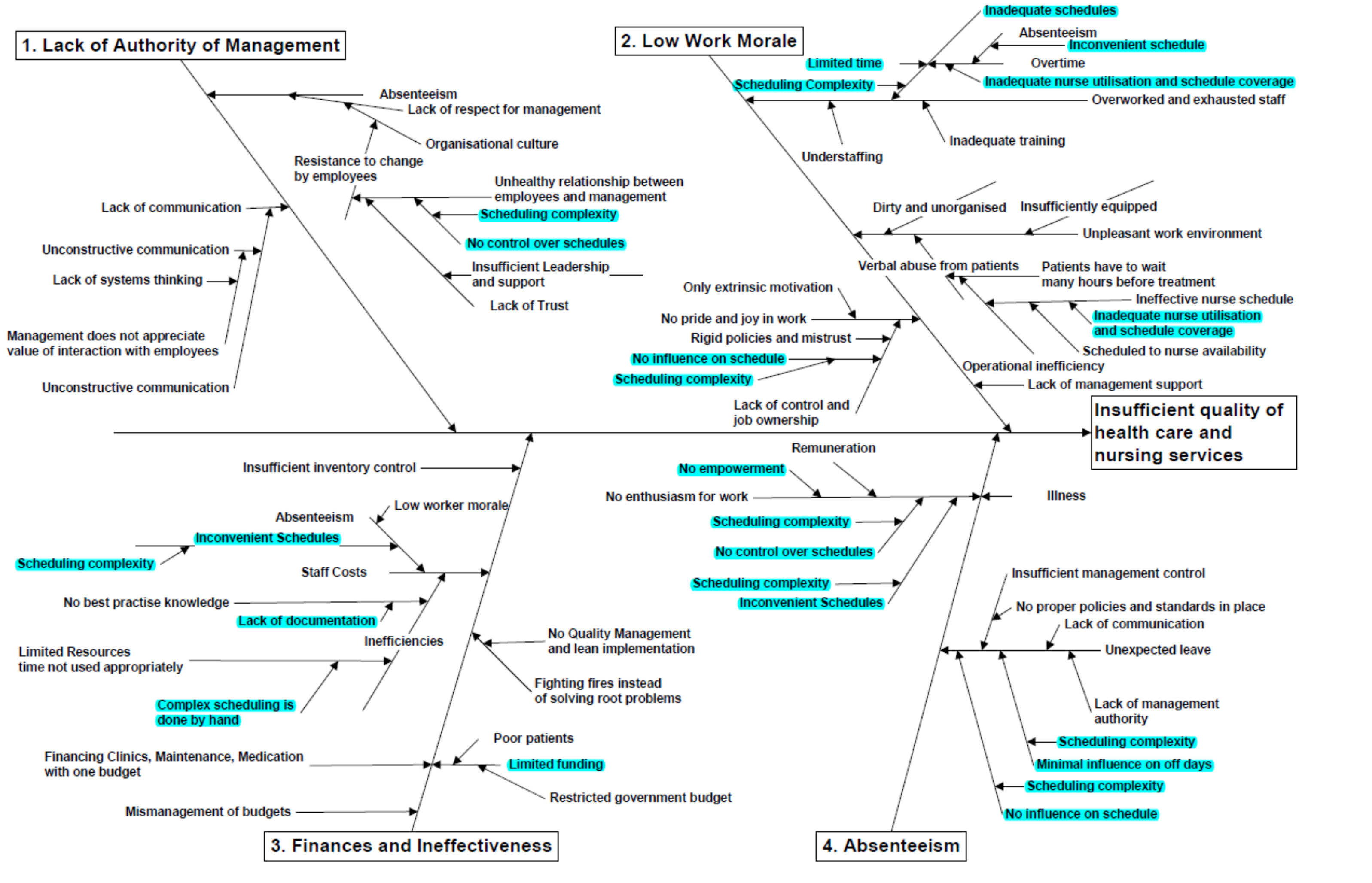


Figure 1 Cause-and-effect diagram

11.2 Problem Statement

In addressing the scheduling process as several root causes highlighted in Figure 1 can be resolved. Among these root causes the most common are the complexity of scheduling and involving nurses' preferences in schedules, inadequate nurse utilisation and shift coverage, and nurses' lack of empowerment and control over schedules. Resolving these root causes ultimately alleviates the main predicament of insufficient quality of health care and nursing services at Stellenbosch Hospital.

1.3 Purpose and objectives

The purpose of this project is to design a user friendly system to support decisions related to the scheduling process of nursing resources at Stellenbosch Hospital on a regular basis.
The following objectives are followed to achieve the purpose:

- Provide decision maker with a tool to support decisions.
- Improve and enhance nurse utilization.
- Involve nurses in scheduling.
- Improve worker morale.

In order to achieve these goals a methodology was designed and integrated in a road map.

1.4 Design and methodology

The following strategy is employed to engage in the final year project in order to reach its purpose and objectives. The design and methodology is a combination of strategies tailor made to fit this project's objectives and purpose. The two strategies used were proposed in "Decision Support Systems and Intelligent Systems" by E .Turban, JE Aronson and TP Liang and in Wayne L. Winston's book "Operations Research Applications and Algorithms".

The methodology is a guidance tool for the reader such that he understands the thought process throughout the development of the decision support tool. It consists of decisions that need to be taken along the way as well as steps that need to be accomplished. Steps are not necessarily followed in sequence and can overlap.

1. Classifying the problem into a standard category

This step is essential in order to know what kind of problem is dealt with and thus to develop a solution that fits the category.

2. Decide on scope of decisions that need to be integrated into the program in order to incorporate the most relevant factors

Due to time constraints, decisions have to be made on the volume of detail to include in the DSS in order to have an impact on the scheduling process, as well as the quality of health care and nursing services.

3. Observing the system and deciding on which data to use

At Stellenbosch Hospital data is an abundant resource. One has to carefully select the data relevant to support the system scoped in the previous step.

4. Decide which development platform to use

Different programs are available to support the task at hand: Matlab, Lindo, Lingo, Excel, VBA and Microsoft Sequel Server and Windows Web Developer. Criteria such as ease of programming and efficiency of user interface are important when deciding on the platform.

5. Choosing an algorithm

A variety of scheduling methods and algorithms has been developed. The most appropriate method needs to be selected in order to satisfy Stellenbosch Hospital's needs.

6. Constructing a mathematical model that describes the real-world problem

This step includes identifying system constraints as well as making valid assumptions to simplify the real world problem.

7. Finding possible solutions to the modelled problem and evaluating them

This step includes verifying and validating the developed solution.

1.5 Road map

There are three main funnel elements illustrated in Figure 2 through which all bulk information has to be filtered before arriving at a solution. The results of the first two funnels feed the third funnel. Concatenating the headings of each element reconstructs the main idea of the project, "designing a decision support tool for Stellenbosch Hospital". Each element is introduced with a short background and literature study and after that, explored in more detail. The process of developing the decision support tool is shown to the left of the framework. Each element is covered in a section as indicated by the arrows before arriving at the final decision support tool which aims to serve people and the system.

Chapter 2 focuses on Stellenbosch Hospital which involves a literature study on motivational theories as well as benchmarking Stellenbosch Hospital to the state of the art Medi-Clinic. This is followed by chapter 3 which deals with Decision Support Systems (DSS) and introduces the development of the decision support tool. The nurse scheduling problem is classified and scoped, the system is observed, and finally the development platform is chosen. Chapter 4 addresses nurse scheduling, the selection of appropriate nurse scheduling algorithms as well as their development and validation. Lastly, chapter 5 conducts a user validation and evaluation of the decision support tool.

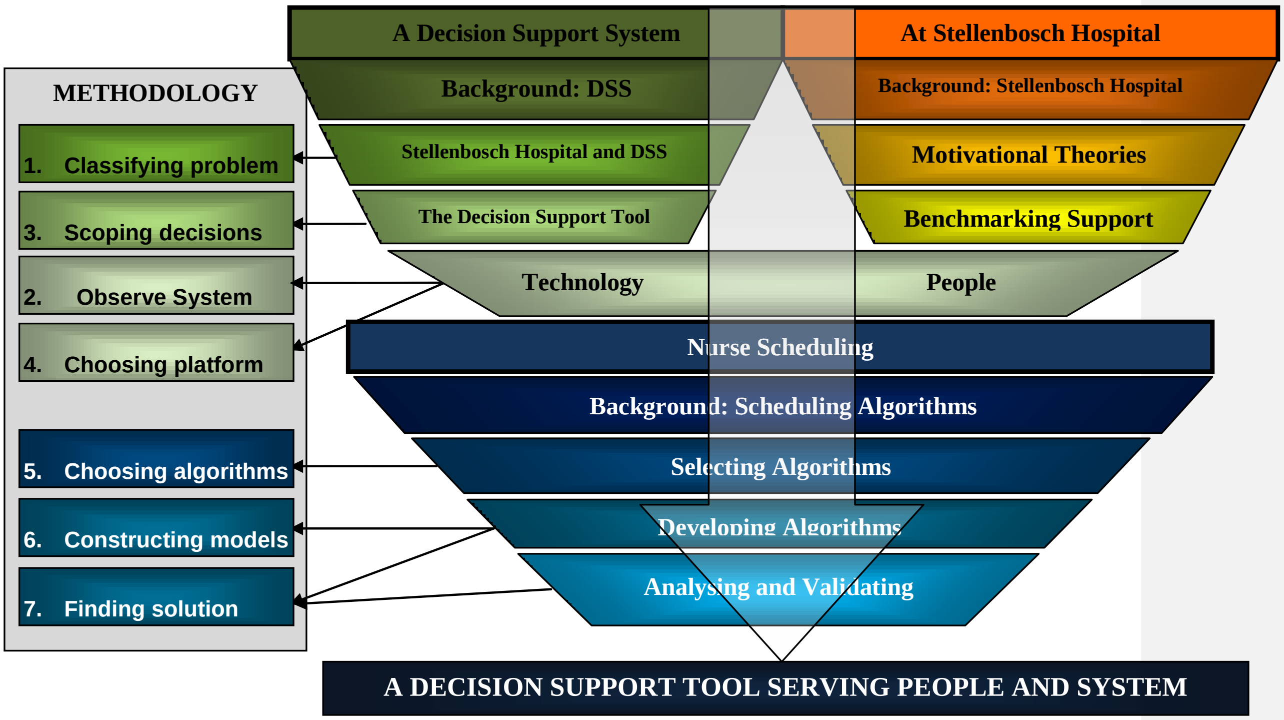


Figure 2 Road Map

2. Stellenbosch Hospital

2.1 Introduction and background to Stellenbosch Hospital

The scope of this chapter is represented by the highlighted area of Figure 3. The hospital is introduced and motivational theories are discussed. Subsequently, Stellenbosch Hospital's problems are benchmarked against the private Medi-Clinic and potential solutions for Stellenbosch Hospital's problems are investigated by adopting ideas from Medi-Clinic's system.

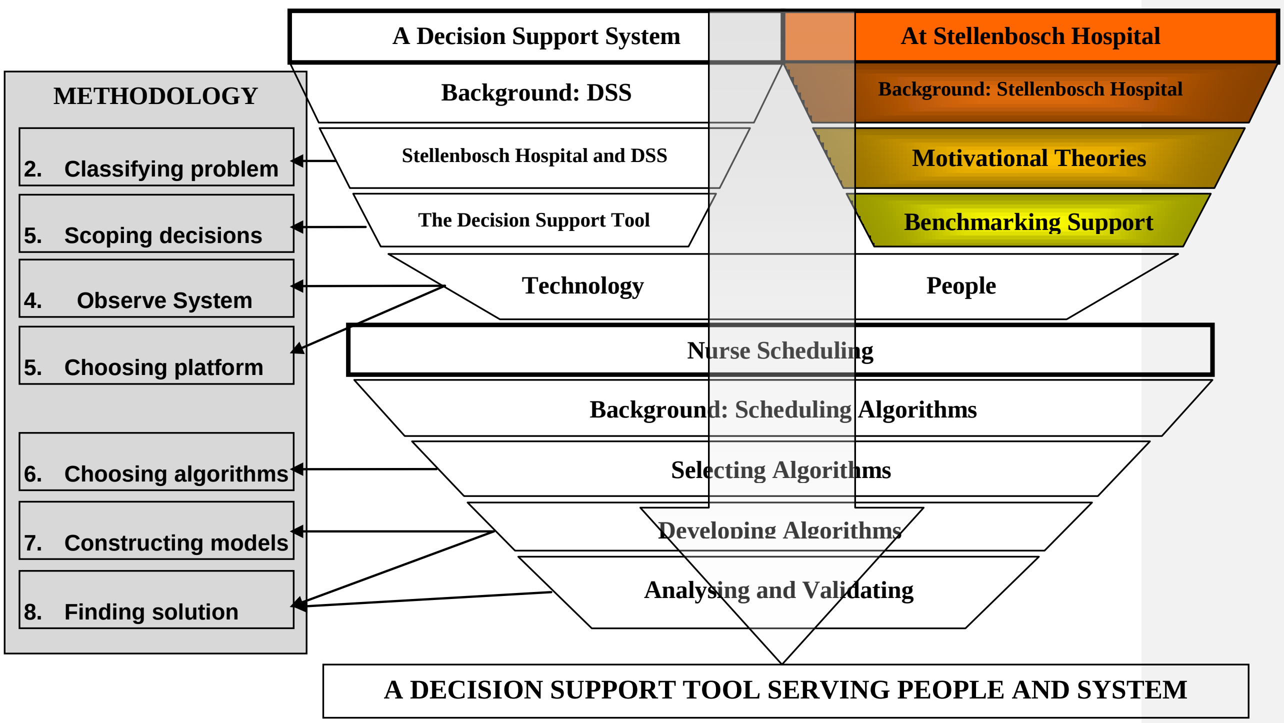


Figure 3 Road map with focus on Stellenbosch Hospital

Worker morale is a central problem area at Stellenbosch Hospital as it can be linked to the lack of respect for management as well as absenteeism and the financial situation of the hospital. Thus, it poses the potentially largest predicament for Stellenbosch Hospital. Alleviating the worker morale problem could alleviate problems of the quality of health care and nursing services at

Stellenbosch Hospital. Thus the concept of worker morale in conjunction with the scheduling process is explored.

2.2 Literature study of motivational theories

As people are the most important part of a system and quality health care and nursing services depends on this, worker morale is an important issue. Segall (1999) quoted by the Harrison (200) states that the "five year review of the public health sector conducted in 1999 found that, with respect to human resources, "the single most consistent finding in our field studies in all parts of the country is that morale among health workers is low, especially among nurses" . Interviews with nurses at Stellenbosch Hospital have revealed that although they were overworked and exhausted, the underlying reason why they were dissatisfied was because they feel that they are being disregarded by management (Linders & Skippers, personal communication, 31 May 2011). "A sense of neglect and lack of support is at the heart of the problem" (Harrison, 2009).

Harrison developed a few strategies in 2009 to improve worker morale which included a campaign to "affirm value of health workers" by monetary incentives, simplifying paper work and providing incentives for further study and personnel development. Althought these actions provide a solution to improve work morale, elaborations in scheduling literature emphasise the improvement of the nurse scheduling process as a more active solution to the worker motivation problem.

Nurses at Stellenbosch Hospital currently have no influence on their schedules and have no autonomy in their jobs. They are rewarded in extrinsic incentives which involve a 13^{th} salary which however, is not sufficient to motivate nurses to come to work more often and to work harder. In Deming's first paradigm it is stated that "people are best inspired by a mix of intrinsic and extrinsic motivation". (Gitlow, Oppenheim, Oppenheim, & Levine, 2005). In order to motivate these workers intrinsically, one has to find a reward that is meaningful to them and which enriches their job (Hitt, Miller, & Colella, 2009).

The nurses' schedule has a crucial impact on the nurses' lives as it controls each of their working days. Having a schedule over which they have no control and which disregards any preferences they have thus affects the nurses attitude towards work negatively. Ozakarahan in 1991 stated that

job satisfaction, turnover as well as absenteeism are related to the nurse schedules. "A high quality roster can lead to a more satisfied and thus more effective workforce" (Burke, De Causmaecker, Berghe, & Van Landeghem, 2004). Their jobs could be enriched by improving the scheduling process and increasing their responsibilities and giving nurses some control over their schedules. First of all the nurses will feel more important and needed. Furthermore, they would believe that management appreciates their work and its importance as their preferences are respected. This can create more pride in their jobs and ulitmately reduce absenteeism and its related costs. Additionally, with an improved relationship to management, organisational change can be brought about which impacts on the quality of health care and nursing services.

In contrast to Stellenbosch Hospital, which is a public health care institution, Medi-Clinic is a privately owned facility which however, serves the same geographical district. The next section benchmarks Stellenbosch Hospital against Medi-Clinic in order to identify aspects which Stellenbosch Hospital can improve to develop the problems stated earlier.

2.3 Benchmarking Stellenbosch Hospital and Medi-Clinic

Table 2 depicts a comparison between Stellenbosch Hospital and Medi-Clinic. The table is expanded on in this section.

Table 2 Overview comparison between Medi- Clinic and Stellenbosch Hospital

	Stellenbosch Hospital	**Medi-Clinic**
Staff work morale	Low – overworked and little pride in job	High – Nurses work with purpose and pride
Staff Availability	Understaffed - No additional nurses can be hired	Enough nurses, can hire additional nurses.
Shifts	12 hour shifts	6 hour shifts – can accumulate to 12 hour shifts
General nurse personal input into schedule	Scarce- have to apply a month ahead for a day off.	Medium – preferences can be handed in and are respected if possible.
Scheduling	Once a month – allocated according to nurses available	Once a moth with two daily assessments and reschedules – nurses allocated according to patient numbers.
Staff work morale	Low – overworked and little pride in job – no goal	High – Nurses work with purpose and pride - diligent
Absenteeism	*High – 8%. Little control*	*Low and well controlled*
Sector Health	*Public*	*Private*

Primary Income Stream	*Government (taxpayer)*	*Health insurers or private*
	Referral system	Direct access to specialist

At Stellenbosch Hospital five unit managers work together for approximately 5 hours once a month to set up a schedule for the following month for 84 nurses with 7 wards to assign them to. Night shifts are assigned every month to cover shifts. Nurses have to work at least three months of night shifts consecutively per year. They currently cannot choose which months would suit them best for night shifts which limits their control on their schedules completely.

At Stellenbosch Hospital nurses have to work a shift of generally 12 hours for approximately four days per week. A cyclical schedule is followed where nurses are 2 days on shift followed by two off days. After that another 3 days of work follow after which 3 days off are assigned. Another nurse is assigned in exactly the opposite way in order to cover the schedule. According to Linders (personal communication, 1 March 2011), this pattern was developed by them only for the simplicity of scheduling. The pattern is arhythmic and completely disregards weekdays, which is often important to the nurses as a weekend off means that they can spend time with family and friends.

At Medi-Clinic every nurse works four days a week. Every second weekend is off. Shifts are generally scheduled in 6 hour patterns. Similar to Stellenbosch Hospital, nurses are scheduled a month in advance to all shifts. However, night shifts are planned ahead considerably longer and nurse preferences are respected as far as possible. In order to reduce strain on nurses and to maximise health care and nursing services, patient levels are assessed twice daily and additional nurses are hired, consented overtime is assigned or nurses are shifted between wards, to satisfy needs. There is close collaboration and cooperation between unit managers and nurses in order to fill all shift needs. In this way busy wards receive extra resources and relieve nurses in charge for that ward. Consequently nurses are not overworked and are motivated through empowerment. Best practise methods are documented and the workforce is well controlled, however on a basis of mutual respect. This creates a comfortable work environment with a motivated workforce.

Nurses higher in the hierarchy can do work of lower sisters, however not the other way around. Thus, no nurses who are not trained for a job are assigned. This prevents situations where nurses would feel overwhelmed and unmotivated. Furthermore, to ensure education and to guide less experienced nurses, differently trained nurses are assigned to different wards and a proportionate number of skilled and unskilled workers must be present. The schedule is relatively flexible and this is essential in a modern hospital, as nurses need to be matched according to patient needs in order to guarantee the best patient care.

According to Deming as introduced in chapter 2.2, training workers continuously, driving out fear as well as empowering employees and enhancing collaboration is conducive for a more motivated workforce that takes pride in their job. In order to achieve this, Medi-Clinic is prepared to input a significant amount of time and resources in setting up the schedules. Although the schedules are set up by hand, best practise methods, collaboration and reviewing leads to schedules that satisfy nurses.

At Medi-Clinc several of the problems shown in the cause-and-effect diagram of Figure 1 are addressed in that nurses are empowered to have an input of personal preference in their schedules. Keeping the cause-and-effect diagram in mind, Stellenbosch Hospital does not have the money, resources and time available to set up such a complex quality schedule and at the same time to keep nurse preferences in mind. Consequently, a tool supporting their efforts and speeding up the scheduling process would aid to solve their problems of an insufficient nurse scheduling process and lack of empowerment of nurses. The nurse scheduling process could be simplified with the aid of a DSS and nurses could be empowered by giving them control over their schedules. This supports the effort of achieving quality health care and nursing services. DSS are introduced in the next chapter.

3. DSS

3.1 Introduction and background to DSS

In this chapter the focus lies on DSS as illustrated in Figure 4. DSS are introduced, the hospital system is classified into a standard category and the decisions are scoped. A decision support tool is identified. The methodology indicates which funnel elements relate to specific processes of the decision support tool development.

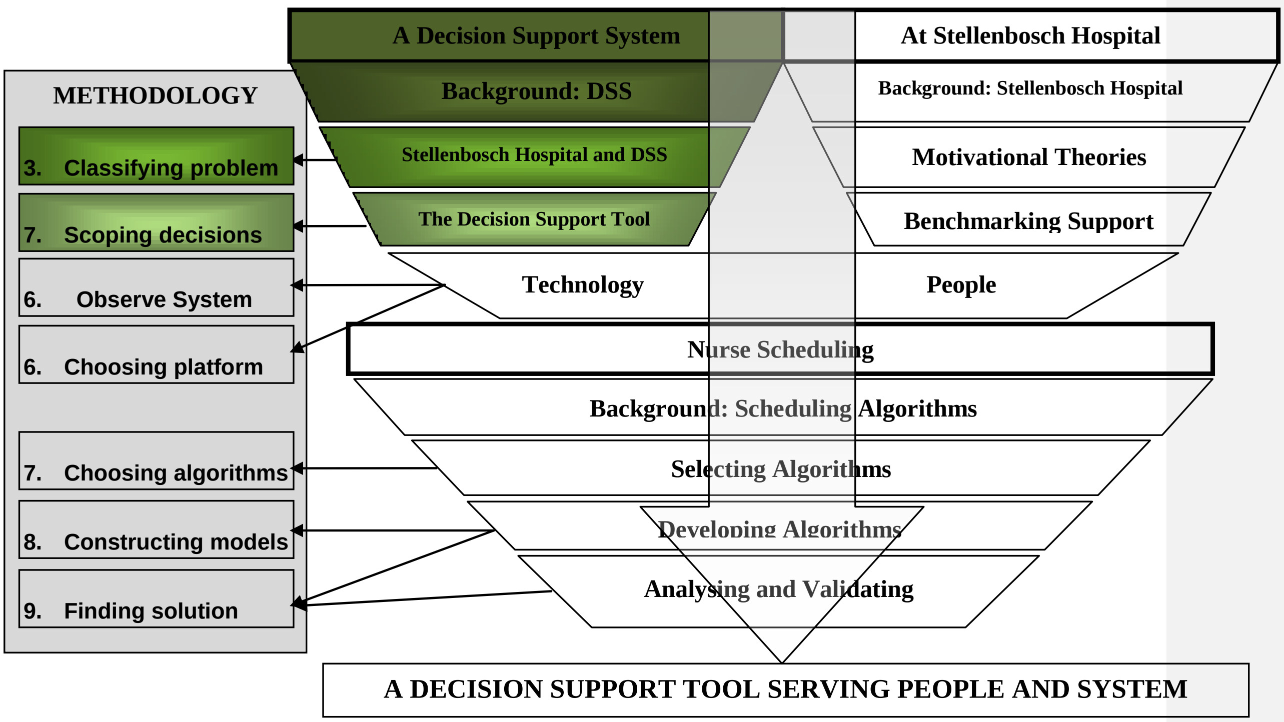


Figure 4 Road Map focusing on the DSS

Over the years modern hospitals in Europe and America have become more and more aware of operational costs and made significant efforts to reduce these. As nursing salaries account for large parts of hospital expenses, DSS have become an integral part of modern hospital systems in order to improve patient care, while at the same time satisfying nurse preferences and reducing scheduling costs as Butters and Eom describe (1992). South Africa is still considerably behind the American and European status, however it is unavoidable that South African health care develops in a similar direction since costs must be reduced in order to sustainably provide health care for all South Africans.

3.2 Defining DSS

DSS “couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions.” “It is a computer-based support system for management decision makers who deal with semi structured problems”. (Turban, Aronson, & Liang, 2005).

The term system can broadly be described by Figure 5. A system is defined by its inputs, processes, outputs, feedback, the system boundary and its environment. A system designer has to take all of these parts into account. Additionally, the “openness” or “closedness” of a system is of importance.

Defining the scheduling problem in conjunction with Figure 5 for Stellenbosch Hospital specifically, the most important inputs for the DSS were identified as the different nurse types (sister, staff nurse, and assistant nurse), nurse’s preferences, nurses’ availability, day or night shift assignment, the nurse requirements and the nurses’ work capabilities. The process would be the scheduling process transforming the input information into a feasible assignment of nurses which would be the output. The decision maker would be the unit managers who ensure the feasibility of the schedule and give comments on how it can be improved. This is transferred to inputs again and an improved schedule is created. Furthermore, the public has no insight into scheduling procedures, thus the hospital scheduling process can be classified a closed system.

The environment of a hospital system would be the factors influencing the whole system, for example HIV/Aids, a poor community, government regulations, nurse availability, work capabilities and skills of nurses and accidents, just to mention a few. The boundary of the system is the scope of a DSS. The boundary is required such that one can single out a problem and solve it while avoiding complexity. For scheduling at Stellenbosch Hospital the environment is scoped to the quality of the health care and nursing services. Thus the environment influencing the quality of health care and nursing services for Stellenbosch Hospital has been identified in the cause-and-effect diagram as the lack of respect for management, absenteeism, low work morale, finances and inefficiencies.

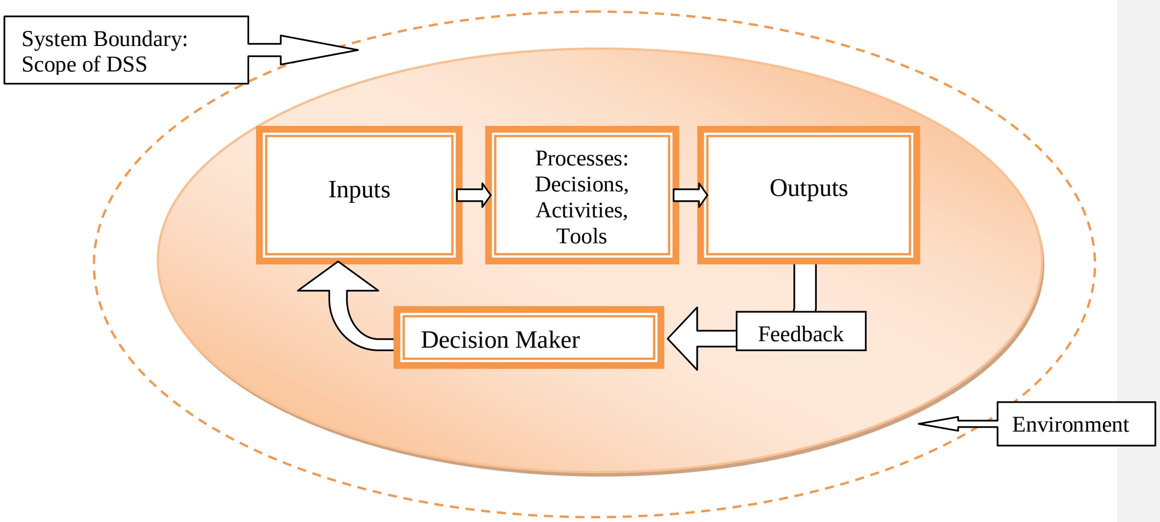


Figure 5 System Definition adopted from Turban, Aronson & Liang (2005)

3.3 Classification of the nurse scheduling problem

The nurse scheduling problem classified in Table 3 is a semi-structured problem as it requires human judgement combined with structured elements such as known variables, for example number of wards or number of beds available. The scheduling problem furthermore supports operational activities (Table 3) which call for regular decision making. Turban et al (2005) proposes that a DSS is one of the solutions to this type of problem.

Table 3 Decision Support Framework adopted from Turban *et al* 2005

	Operational Control	**Managerial Control**	**Strategic Planning**
Structured Problems			
Semi-structured Problems	**Nurse scheduling problem position**		
Unstructured Problems			

"A DSS can improve the quality of the information on which the decision is based by providing not only a single solution but also a range of alternative solutions along with their potential impacts." (Turban *et al*., 2005).

3.4 Scoping decisions of the decision support tool

In the previous section the environment of the DSS was scoped to be the quality of health care and nursing services for Stellenbosch Hospital which is influenced by the lack of respect for management, absenteeism, low work morale, finances and inefficiencies. In this section, scoping the decision support tool to day and night schedules and ward assignments is justified and manifested as a possible input to the work of other authors.

Different models like the NURODSS, developed by Bester *et al* in 2007 where a DSS is developed for Stikland Hospital, Western Cape as well as the "Integrated days off and shift

personnel scheduling" written by Bailey in 1985, have been developed. These models focus mainly on the day to day scheduling. This involves work patterns, off days, weighing nurse preference or dissatisfaction against cost (overstaffing or patient inconvenience) and taking different constraints, for example maximum working days per week allowed, and various others, into account. These models take the day and night assignments as well as the different nurse types assigned to different wards as a given input.

Ozkarahan in 1991 wrote his article "Disaggregation Model of a Flexible Nurse Scheduling Support System" which uses elements from Bailey's (1985) work and expands on it. He "allocates optimum work patterns to individual nurses based on their desires and compatibilities" (Ozkarahan, 1991). In contrast to Bailey's work, in Ozkarahan's model the ward/unit allocations are taken into account in his day to day scheduling system. His model assigns a nurse to a specific work pattern in a specific ward. Aickelin and Dowsland (2004) and Aickelin and Dowsland (2000) as referred to by Burke *et al* (2004) on the other hand take day and night scheduling into account, but ignore nurse type and applicable ward assignments.

Summing up, most models either assume day and night shifts as well as ward assignments as set or given values. Other models only cater for day and night scheduling and again other models model ward assignments but ignore day and night scheduling. It is difficult to incorporate all factors in one algorithm as the problem becomes too complex. Consequently in this final year project the decision support tool caters for these neglected, however important scheduling areas that could be used as a possible input to the other models described.

The scope of the tool was discussed, descriptions of the proposed model, its exact inputs and outputs as well as the development platform that is used for the tool, are discussed in the following section.

3.5 A decision support tool considering people and technology

In Figure 6 the roadmap emphasises the integration of people and technology. This section observes the nurse scheduling system and illustrates the inputs and outputs of the decision support tool with a data flow diagram. A development platform is chosen in order to provide a technological tool supporting the people in the hospital.

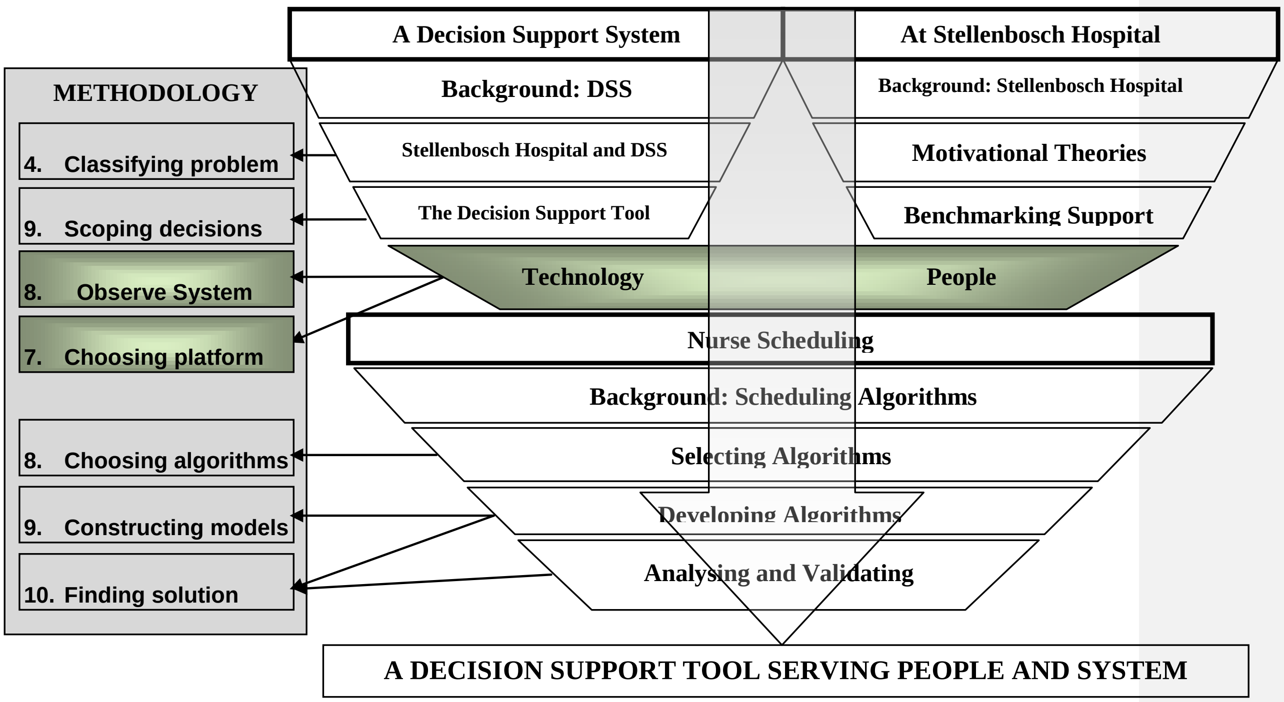


Figure 6 Road Map with focus on the areas technology and people

3.5.1 Observing the system and input data

In Figure 7 a conceptual data flow diagram was used to model a summary of the input data for the decision support tool. This model is relevant to the day and night scheduling of the nurses as well as the ward assignment of the nurses and the output of the process. Each input and output is elaborated on in the following text. The process body and its constituting parts are discussed later in the report.

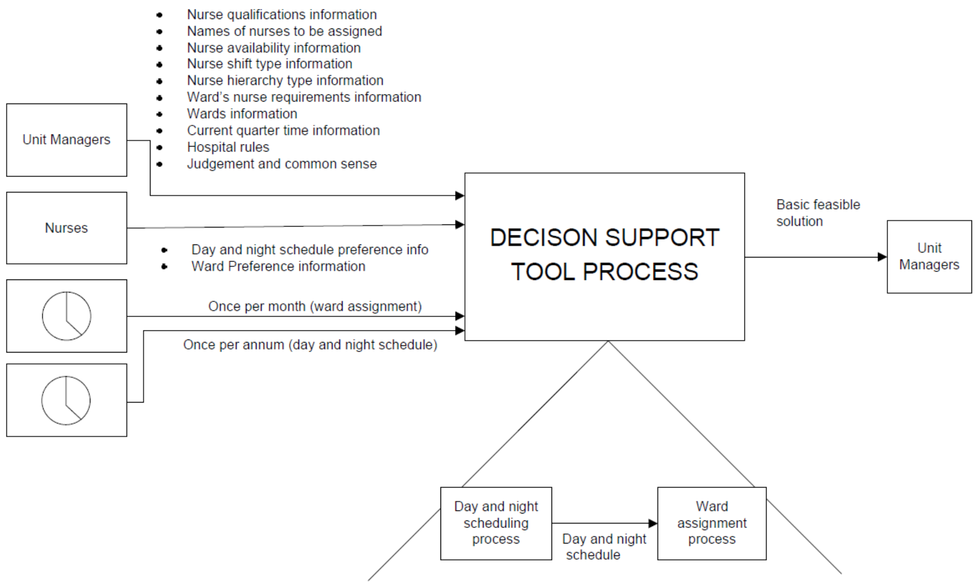


Figure 7 Data flow diagram of the decision support tool

In the current scheduling system, unit managers sit together once a month to decide on day and night assignments as well as ward assignments of different nurses, with diverse capabilities to seven wards. This is the bulk of the work. After this nurses are written into the shift book according to the fixed three on, three off, two on, two off days shift pattern. One shift is 12 hours from 7pm -7am or from 7am to 7pm. Nurses are always paired such that the second nurse has a pattern of three off, three on, two off, and two on days. The unit managers call this the "wissel"-shift. They have developed the pattern. According to unit manager Linders (personal communication, 1 March 2011), there is no specific reason for this specific pattern except that it reduces complexity of scheduling. The five unit managers themselves and some of the assistant nurses follow a stretch shift which is a normal working day shift from 7am to 4pm from Monday to Friday. The unit managers input the shift type for each nurse.

Day and night shift assignments are currently done each month and each nurse has to work three months night shifts consecutively according to Linders (personal communication, 1 March 2011). These are part of the hospital rules. Currently, no input from nurses is taken and nurses do not know when they have to commence night shifts. In the decision support tool day and night shift assignments are assigned on an annual basis (as indicated by the time trigger in Figure 7). As the day and night schedule have a crucial impact on the nurses working lives, their preference is used as an input when making this schedule. Nurses are be able to select specific quarters of the year they to work night shifts. In the monthly ward assignments unit managers input the specific quarter they are currently in.

In Figure 8 the nurse hierarchy can be observed. It is taken as a set input to the decision support tool. Unit managers' enter the names of the nurses to be assigned as well as the hierarchy state of each nurse. The hierarchy consists of four levels where at the highest level unit managers oversee the patient care staff, attend to administration and sometimes help out with nursing tasks. However, as their shifts are set and as they are not specific to any ward, they are not be included in the scheduling tool. Sisters are responsible for administering of medication and instructing assistant nurses and staff nurses on patient care. Staff nurses are mainly to support the work of sisters, they for example make sure patients get correct medication and that they take it regularly. Assistant nurses would handle patients, wash them and see to their general well being. The nurses are ranked and promoted according to training and experience. Currently the hospital has 24 sisters, 37 assistant nurses and 23 staff nurses with different capabilities and availability that changes over time. Up to ten nurses more per type are able to be added per nurse type making the model moderately variable. For Stellenbosch Hospital nurse numbers are not likely to increase more due to the restricted budget. In the scheduling tool, the number of sisters, staff nurses as well as assistant nurses essential per ward and their capabilities are taken as a variable input by unit managers.

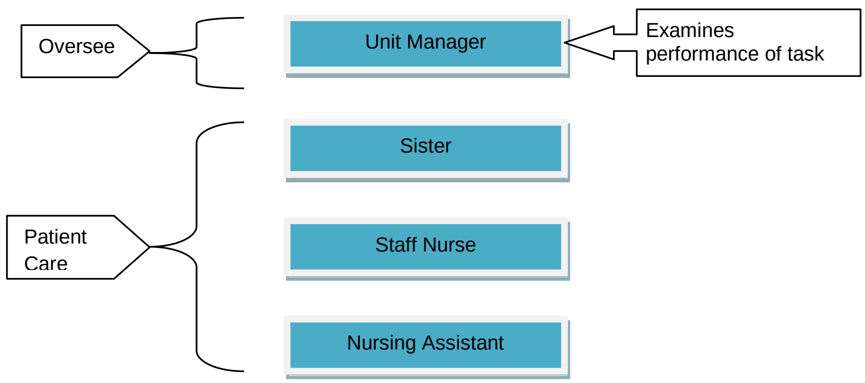


Figure 8 Nursing hierarchy at Stellenbosch Hospital

Ward assignments are done once a month as indicated by the time trigger in Figure 7. Nurses have the option to give a preferred ward assignment input. The Hospital has seven wards: Paediatric ward, Ward A (chronic patients), Ward B (women), Ward C (men), Theatre, Trauma/Accidents ward and Maternity ward. Each of these wards needs a mix of sisters, assistant nurses and staff nurses as specified by the unit managers. The mix is taken as a variable input to the support tool. Additionally, for the support tool the wards are a set input as it is unlikely that another ward is added.

Nurses' availability is an input from unit managers. Nurses who are on study leave, normal leave, maternity leave or sick leave during a scheduling month are entered by the unit managers.

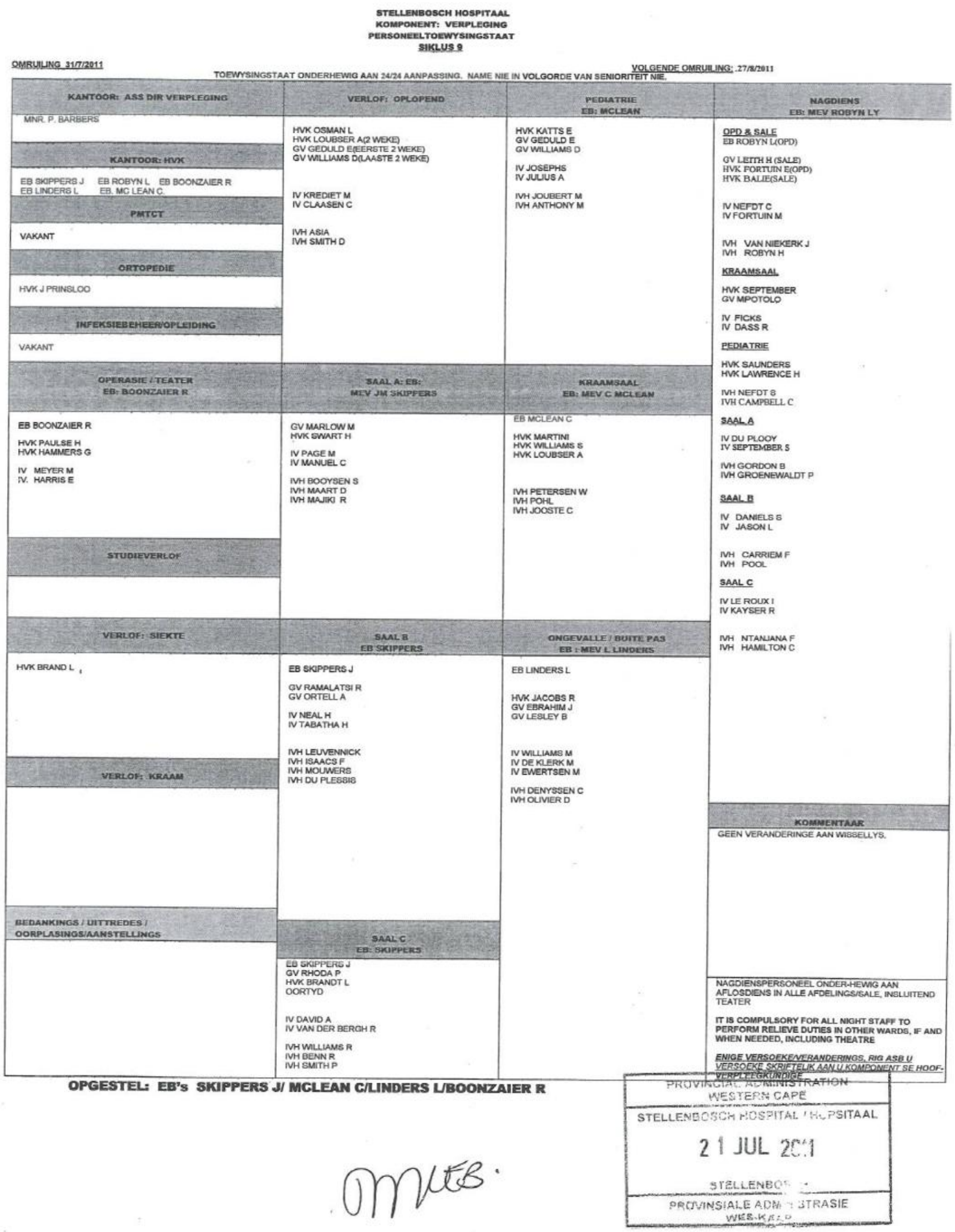
Nursing costs per shift is not be taken as an input, because all the nurses are usually assigned and as indicated in the cause-and-effect diagram high nursing costs are a result of insufficient schedules, absenteeism and resulting overtime. Thus the tool's objective is to improve schedules and involve nurses and as a result possibly reduce costs due to a more efficient approach and solution.

Patient admission data is not directly be incorporated in the tool. Patient admissions follow clear trends which the experienced unit managers are well aware of. For example, admissions increase at the end of the month after people have received their salaries and admissions increase on

Friday nights (Linders & Skippers, personal communication, 31 May 2011). Unit managers manually adjust the nurses required per month per ward and assign extra nurses on daily shifts as required.

3.5.2 Output

The basic feasible solution in Figure 7 is similar to the current output of the manual nurse scheduling process such that the unit managers adapt more comfortably to the new method. An example of the current output can be seen in Figure 9. Before publishing the final output, nurses use their judgement and common sense to adjust the computer made ward assignment such that a good basic feasible solution can be obtained. The output sheet includes the different ward assignments, day and night assignments and indicates nurses who are not available for periods of the month. Unit managers manually document in the output sheet for which reasons nurses are not available. Furthermore, nurse pool sections are added which indicate the nurses that have not been assigned for various reasons. From this point of departure unit managers use the output sheet and create an optimal assignment sheet for the month. The developed output sheet is displayed later in the report.



STELLENBOSCH HOSPITAAL
KOMPONENT: VERPLEGING
PERSONEELTOEWYSINGSTAAT
SIKLUS 9

OMRUILING 31/7/2011

VOLGENDE OMRUILING: 27/8/2011

TOEWYSINGSTAAT ONDERHEWIG AAN 24/24 AANPASSING. NAME NIE IN VOLGORDE VAN SENIORITEIT NIE.

KANTOOR: ASS DIR VERPLEGING
MNR. P. BARBERS

KANTOOR: HVK
EB SKIPPERS J EB ROBYN L EB BOONZAIER R
EB LINDERS L EB. MC LEAN C.

PMTCT
VAKANT

ORTOPEDIE
HVK J PRINSLOO

INFEKSIEBEHEER/OPLEIDING
VAKANT

VERLOF: OPLOPEND
HVK OSMAN L
HVK LOUBSER A(2 WEKE)
GV GEDULD E(EERSTE 2 WEKE)
GV WILLIAMS D(LAASTE 2 WEKE)
IV KREDIET M
IV CLAASEN C
IVH ASIA
IVH SMITH D

PEDIATRIE
EB: MCLEAN
HVK KATTS E
GV GEDULD E
GV WILLIAMS D
IV JOSEPHS
IV JULIUS A
IVH JOUBERT M
IVH ANTHONY M

NAGDIENS
EB: MEV ROBYN LY
OPD & SALE
EB ROBYN L(OPD)
GV LEITH H (SALE)
HVK FORTUIN E(OPD)
HVK BALIE(SALE)
IV NEFDT C
IV FORTUIN M
IVH VAN NIEKERK J
IVH ROBYN H
KRAAMSAAL
HVK SEPTEMBER
GV MPOTOLO
IV FICKS
IV DASS R
PEDIATRIE
HVK SAUNDERS
HVK LAWRENCE H
IVH NEFDT S
IVH CAMPBELL C
SAAL A
IV DU PLOOY
IV SEPTEMBER S
IVH GORDON B
IVH GROENEWALDT P
SAAL B
IV DANIELS S
IV JASON L
IVH CARRIEM F
IVH POOL
SAAL C
IV LE ROUX I
IV KAYSER R
IVH NTANJANA F
IVH HAMILTON C

OPERASIE / TEATER
EB: BOONZAIER R
EB BOONZAIER R
HVK PAULSE H
HVK HAMMERS G
IV MEYER M
IV. HARRIS E

SAAL A: EB:
MEV JM SKIPPERS
GV MARLOW M
HVK SWART H
IV PAGE M
IV MANUEL C
IVH BOOYSEN S
IVH MAART D
IVH MAJIKI R

KRAAMSAAL
EB: MEV C MCLEAN
EB MCLEAN C
HVK MARTINI
HVK WILLIAMS S
HVK LOUBSER A
IVH PETERSEN W
IVH POHL
IVH JOOSTE C

STUDIEVERLOF

VERLOF: SIEKTE
HVK BRAND L

SAAL B
EB SKIPPERS
EB SKIPPERS J
GV RAMALATSI R
GV ORTELL A
IV NEAL H
IV TABATHA H
IVH LEUVENNICK
IVH ISAACS F
IVH MOUWERS
IVH DU PLESSIS

ONGEVALLE / BUITE PAS
EB : MEV L LINDERS
EB LINDERS L
HVK JACOBS R
GV EBRAHIM J
GV LESLEY B
IV WILLIAMS M
IV DE KLERK M
IV EWERTSEN M
IVH DENYSSEN C
IVH OLIVIER D

VERLOF: KRAAM

KOMMENTAAR
GEEN VERANDERINGE AAN WISSELLYS.

BEDANKINGS / UITTREDES / OORPLASINGS/AANSTELLINGS

SAAL C
EB: SKIPPERS
EB SKIPPERS J
GV RHODA P
HVK BRANDT L
OORTYD
IV DAVID A
IV VAN DER BERGH R
IVH WILLIAMS R
IVH BENN R
IVH SMITH P

NAGDIENSPERSONEEL ONDER-HEWIG AAN AFLOSDIENS IN ALLE AFDELINGS/SALE, INSLUITEND TEATER

IT IS COMPULSORY FOR ALL NIGHT STAFF TO PERFORM RELIEVE DUTIES IN OTHER WARDS, IF AND WHEN NEEDED, INCLUDING THEATRE

ENIGE VERSOEKE/VERANDERINGS, RIG ASB U VERSOEKE SKRIFTELIK AAN U KOMPONENT SE HOOF-VERPLEEGKUNDIGE

OPGESTEL: EB's SKIPPERS J/ MCLEAN C/LINDERS L/BOONZAIER R

WESTERN CAPE
STELLENBOSCH HOSPITAL
21 JUL
PROVINSIALE ADM
STRASIE

Figure 9 Nurse Scheduling Output Sheet

3.5.3 Decide which development platform to use

The inputs and outputs of the decision support tool have been discussed. This section investigates a possible development platform for it.

~~(Wiederholung!)~~Microsoft Sequel Server Express 2005

This programme comes together with the Microsoft package. However, it is mainly effective for applications where a significant amount of data processing is involved. This program would for example be effective if patient admission data would have been used as an input to the decision support tool. As the staff set up is fixed, no patient admission forecasting needs to be made for schedules and consequently no large database is necessary, which makes Microsoft Sequel Server unsuitable. It could however be used in a future project to create an information system for the hospital.

Matlab

It is a powerful programme capable of solving complex mathematical programs and models. However, the problem to be solved at Stellenbosch Hospital is not complex enough to justify such a program. Furthermore, the program is expensive and Stellenbosch Hospital does not have the financial possibilities to purchase an expensive software package for the purposes of implementing the Final Year Project. Although a user interface can be made, the add-in for that feature needs to be bought additionally. Consequently, Matlab is not an option for the Final Year Project.

Lingo and Lindo

These programs would be appropriate to use in order to find solutions to linear programming models; however they do not have a convenient user interface which makes it difficult to use these programs for Stellenbosch Hospital. Moreover, the only free version of Lindo/Lingo is a student version which cannot process large numbers of variables. The real versions again, are too expensive to be bought for a Final Year Project.

Microsoft Excel Solver

Excel and Excel Solver are available on every standard computer with Mircrosoft Office installed and consequently Excel solver is a less costly option. Nonetheless, it is a powerful tool and can

solve complex problems. Even though it is not completely easy to use and one has to exactly understand the Excel sheet and the problem Solver should solve, one could train nurses on using Excel Solver as a tool.

Excel & VBA

VBA standalone is programming intensive and thus requires good programming skills. It has an acceptable user interface and like Excel Solver, VBA is an inexpensive option which is compatible with almost every computer running Microsoft Office. VBA can be powerful in the hands of a skilled programmer. Excel standalone, although a powerful programme is too slow to execute complex calculations. Long formulas typed into single cells do not allow for a dynamically solving programme. Consequently using VBA in conjunction with Excel is the most effective way of creating a decision support tool. Basic programming skills are sufficient and working steps can be simplified by using Excel functions, whose results can be read into VBA to perform calculations or iterations. Data can be validated in Excel for nurses to only input certain values and not tamper with formulas. An acceptable user interface can be created.

Considering all the different options Excel Solver as well as Excel in conjunction with VBA seem to be the best technology development platforms for the decision support tool subject to the mentioned constraints.

In this section the decision support tool and its human inputs was elaborated on as well as its output and the technological development platform was chosen. In the next section the process of the decision support tool as depicted in Figure 7, is described.

4. Nurse scheduling

4.1 Introduction and background to nurse scheduling

In this chapter a background on nurse scheduling algorithms and models is provided and a suitable scheduling algorithm/model is selected. The algorithm/model is developed, described, verified and validated.

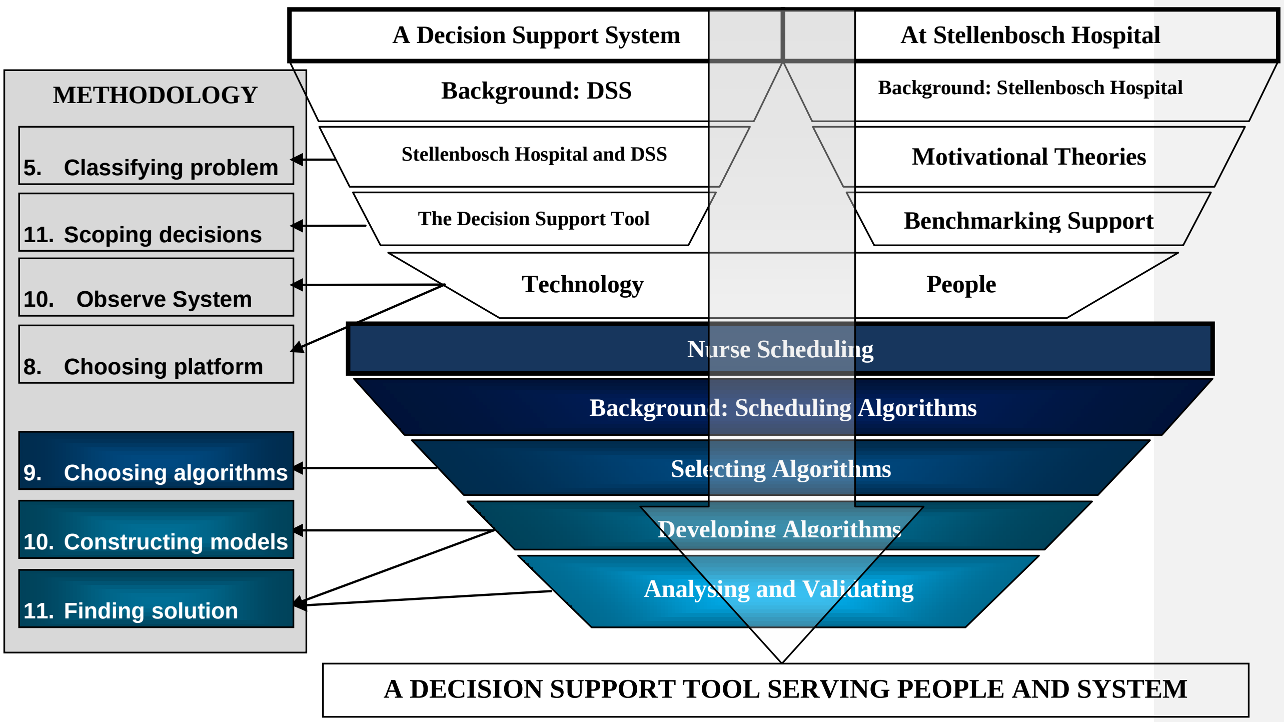


Figure 10 Road Map with focus on nurse scheduling

Nurse scheduling affects nurses all over the world on a daily basis. Numerous minds have thought up different algorithms of simplifying the cumbersome, time consuming task of setting these schedules up. Although nurse scheduling problems are similar to other scheduling approaches, they are more intricate because of different staffing needs, nurse preferences and different shift times. The following text introduces different scheduling algorithms.

Burke et al have summarised a number of algorithms in the text "The State of the Art of Nurse Rostering" in 2004. The collection is expanded with more details from the original articles. An overview of the described algorithms/models is depicted in Figure 11. In the following text each approach is concisely introduced. Examples from the literature are mentioned and interesting features which would be relevant for the scheduling of nurses at Stellenbosch Hospital from different journals are highlighted. Finally, advantages and disadvantages of each method are stated.

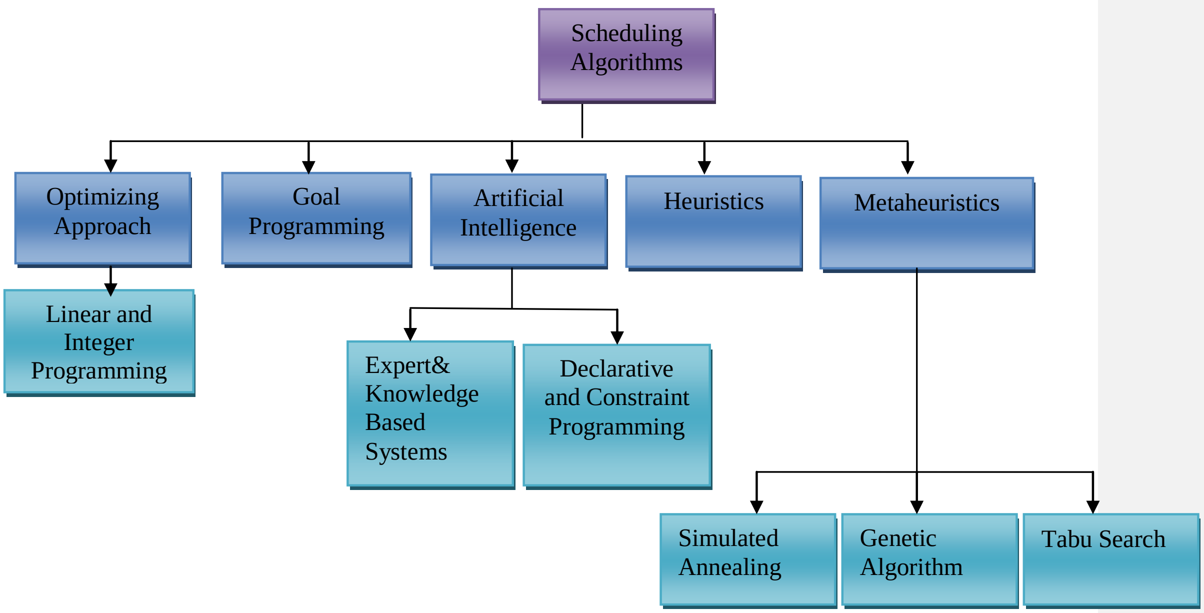


Figure 11 Algorithm Overview

4.2 Optimising approaches: mathematical programming

4.2.1 Linear programming and integer programming models

Although Baily (1985) does not work with day and night scheduling, elements from his modelling and output approach are interesting. He takes into account different scheduling patterns and the start time of each work day. The objective of the method is to minimize overtime costs and customer inconvenience due to overstaffing or understaffing. An integrated linear programming method is used to meet fluctuating customer demand. Slack and surplus variables are introduced to determine overstaffing or understaffing and the result is displayed in a matrix with ones indicating shifts and zeros indicating off-days. The one and zero matrix is interesting for the Stellenbosch Hospital problem, because it is easy to understand and seems easy to implement. It could be a comprehensive output from a scheduling algorithm or an easy input method which can be easily grasped by the nurses. The one and zero outcome is achieved with integer programming to force all outcomes to either one or zero.

Numerous other authors have addressed nurse scheduling with linear and integer programming and have found intricate solutions to day to day scheduling problems. For example Moz and Pato (2004) referred to by Burke *et al* (2004), introduce solutions for the re-rostering of nurse schedules by looking for replacement nurses within the wards instead of using nurses that are on stand-by. Miller, Perskalla, and Rath (1976) referred to by Burke *et al* (2004) formulate nursing requirements in terms of “minimum and preferred number of personnel per day without specifying shifts”. The solutions obtained are nearly optimal.

Advantages of linear/integer programming

Models yield near optimal solutions and modelling is simple. Additionally these problems are easy to solve and the author has thorough knowledge on how to set up and develop a linear programming problem.

Disadvantages of linear/integer programming

Linear programming often requires simplifications which make the real world problem unrealistic. The linear programming models are static thus no change of variables with time is taken into account. Also, due to its linearity problems with higher power exponents cannot be solved. Moreover, if the problem becomes intricate, it can become over constrained and solving large problems can cause computations to take long. Burke *et al* (2004) emphasizes that in practice the size and complexity of rostering problems and the lack of structure of most prevents the application of exact optimisation methods. Furthermore, he stated that mathematical programming methods are often not flexible enough to implement the relative importance of various goals. Thus he created a goal programming model described in the next section.

4.3 Goal programming

Winston in 2004 expanded that a decision maker may face situations where there may be no feasible solution to satisfy all objectives. Consequently in goal programming each coefficient in the objective function receives a weighting, such as to rank the importance of the objective. This ensures that a solution is found where the most important objectives are met first and where possible, less important objectives are respected.

Musa and Saxena (1984) referred to by Burke *et al* make use of goal programming by creating an interactive heuristic procedure where users can change relative weights of goals during scheduling processes such that special temporal conditions can be taken into account. This idea is interesting as it provides for more flexibility which is important for nurse scheduling.

Ozkarahan in 1991 proposes a DSS with a goal programming approach. He states that job satisfaction, turnover and absenteeism have all been found to be related to personnel scheduling flexibility. However, no scheduling policy is able to satisfy all needs, thus one has to find flexible alternatives in order to maximise satisfaction. In his approach he tries to minimise over- and understaffing and minimises several personnel costs. Furthermore, his solution provides for nurses' preferences. However, it is generally more for a small scale problem. Ozkarahan's (1991) theories on worker motivation in connection with nurse scheduling are attractive to the Stellenbosch Hospital problem and were already chosen to be implemented.

Advantages of goal programming

Goal programming can ensure that more than one objective can be met with differences in importance. Models are more flexible than linear programming problems.

Disadvantages of goal programming

In Ozkarahan's (1991) opinion the major criticisms of goal programming are the difficulty of choosing goals that represent the decision-makers true aspirations, the possibility of generating dominated solutions as well as preoccupations with pre-emptive weighting: one cannot always specify whether one criterion is more important than another or even give specific weights associated with that. Solving goal programming problems poses the same problem as with linear programming problems: complex problems can be time-consuming to solve.

4.4 Artificial intelligence methods

4.4.1 Declarative and constraint programming

Okada and Okada (1988) referred to by Burke *et al* (2004) presented a method in Prolog which assisted in nurse scheduling. The significance of requirements can change during planning period and not all of the constraints need to be satisfied. Okada (1991) had an original approach: his program was generated through an interview with the user. Constraints are presented as grammar and individual preferences are constraints on strings. The model is depicted in transition graphs. Darmoni *et al* (1995) referred to by Burke *et al* (2004) uses a system called Horoplan for scheduling in a large scale hospital. The system imitates the way head nurses would create their schedules manually. This idea is original and is intriguing. In this way the nurses' experience is used in a system and the wheel is not reinvented by creating a completely new algorithm.

4.4.2 Expert systems and knowledge based systems

Expert systems are fed with human knowledge and can apply it to solve complex problems. Moreover, as described by Nutt (1984) in Burke *et al* (2004) paper, they provide the possibility to develop user–interactive DSS for nurse scheduling problems. Smith, Bird and Wiggins mentioned by Burke *et al* (2004) developed a "what-if" DSS for various sets of weights. Similar to earlier mentioned Musa and Saxena (1984), the weights to different objectives can be adjusted by the user which provides for an interactive system.

Advantages of artificial intelligence methods

These systems use already available human knowledge and experience and build on that. Users understand the modelling approach, because it models their thought process and thus take on more rapidly to the new model. In addition to human knowledge, mathematical programming can be incorporated to provide an excellent and at the same time flexible solution. The systems can be a combination of any of the described methods modelled together with human knowledge.

Disadvantages of artificial intelligence methods

The systems developed in the literature make use of expensive programs to build the models and systems. Models/Systems are less generic if applied to a specific hospital.

4.5 Heuristics

In heuristics a manual process with specific rules and formulas is followed for scheduling. A number of steps are outlined to create a schedule with respect to its constraints. Heuristics often have been applied in real world hospital systems in an acceptable computation time. At Stellenbosch Hospital unit managers make use of a semi-developed heuristic to schedule nurses, it however takes a long time and best practise methods have not been documented to execute this process. A clear formulation of the requirements as well as a method to quantify the quality of the schedules is essential. Smith (1976) as referred to by Burke *et al* (2004) created an interactive algorithm which supports the scheduler to create a cyclical schedule in his heuristic coverage constraints, and days off are of importance.

Advantages of heuristics

Unit managers control the process and understand what they are doing, thus they understand the resulting schedule well and can repeat the process.

Disadvantages of heuristics

Heuristics can be time consuming and in Stellenbosch Hospital where time is a constrained resource, chances of a badly executed heuristic are good. Additionally, a heuristic must be well thought through and documented. Errors in documentation can cause schedules of low coverage and quality. Finally, heuristics stop searching after they find a feasible solution. They find a local maximum, which might be only a sub optimal solution, while neighbouring solutions could be superior as is described by Luke (2010).

4.6 Metaheuristic scheduling

Burke *et al* (2004) proposes that metaheuristics are generally better suited to solving scheduling problems than any other approach. This is simply because finding optimal solutions is complicated with a large constraint load and in today's practice it is usually necessary for computer systems to cope with infeasibilities.

In his book "Essentials of Metaheuristics" Luke (2010) describes metaheuristics as algorithms with a degree of randomness that come up with a variety of solutions to a problem. Solutions can be tested by iteratively producing new answers until you reach a maximum. The neighbours of a state are solutions modified in some way. Simulated Annealing, Genetic Algorithm and Tabu Search are three ways to do that. For example in the scheduling problem, the solution to a schedule can be minimally manipulated by modifying some shifts. This action is called “move”. By moving through to neighbouring solutions a global maximum can be found.

4.6.1 Simulated Annealing

The simulated annealing “move” process can be fundamentally explained with the analogy of metal annealing. The algorithm considers a broad solution space, and as the “temperature” which is a specific probability of selecting a neighbouring solution cools down, the algorithm becomes more selective. Isken and Hancock (1991) and Brusco and Jacobs (1995) as referred to by Burke *et al* (2004) used this approach to solve flexible and complex scheduling problems.

4.6.2 Tabu search

In Tabu search “move” operations, finding new solution spaces “are forbidden (tabu) unless they result in a new minimum.” “The incumbent is always replaced by its best non-tabu neighbour even if it is inferior.” (Alfares, 2004). This method prevents that the algorithm gets stuck on a local minimum. After an extensive market research a nurse rostering software called “Plane” which is a software programme was implemented in Belgium hospitals in 1995 in order to solve the over constrained nurse scheduling problem. It was found that nurses prefer an “ad-hoc schedule in which they can express their personal wishes and priorities” (Burke, De Causmaecker, & Vanden Berghe, 1999). The product was developed by companies called Impact N.V. and GET (General Engineering and Technology). The programme is ever evolving trying to accommodate new and more real world problems.

4.6.3 Genetic algorithm

In a genetic algorithm the analogy of reproduction is used as a model. A population of chromosomes evolves. This happens from an initial population over several generations. In each generation the fitness of each individual chromosome is evaluated and measured with a fitness function. Weak chromosomes are eliminated and some of the children mutate. The sum of all new strong individuals forms the new population (the new solution). The algorithm runs until a maximum number of generations or until a satisfactory solution has been reached.

Aickelin and Dowsland (2000) as referred to by Burke *et al* (2004) approached staff scheduling at a major UK hospital in this article. They divided their problem into different sub problems where for example the day and night scheduling is handled as a separate sub problem. This is interesting for this final year project as two problems, namely the day and night scheduling as well as wards assignments, are addressed. Separating this into two sub problems simplifies the model significantly.

Advantages of metaheuristics

Instead of only finding a local maximum with a basic feasible solution the best, global feasible solution can be determined.

Disadvantages of metaheuristics

In his article Burke *et al* (2004) states that implementing constraints into a genetic algorithm is not pre-defined which is a potential drawback. Developing a metaheuristic is a time consuming and intricate process. Excellent programming skills are necessary as well as a deep understanding of the problem in conjunction with a metaheuristic. No optimal solution can be guaranteed to found with a metaheuristic.

4.7 Selecting algorithm

In the previous section different methods and algorithms for nurse scheduling were introduced. Each one has advantages and disadvantages. The most appropriate one according to Stellenbosch Hospital's needs and the final year project is selected in this section by making use of the Analytical Hierarchy Process (AHP). This process ensures that different decision variables can be respected all at once and ranks the outputs from best to worst option. In the following section the basic working of the AHP and its results is discussed.

4.7.1 AHP

The following scheduling methods were chosen for the AHP on the basis of the applicability to Stellenbosch Hospital, the literature available and their familiarity to the author: linear programming, goal programming, artificial intelligence, heuristics which involves nurses' experience, metaheuristics as well as a self-developed algorithm with a basic feasible solution. After having selected six different scheduling methodologies, the preeminent ones are determined.

The different objectives each scheduling method should meet are the following:

- Reduce Cost – Reduce resources time spent on scheduling.
- Involve nurses – Nurses preferences should be included in the scheduling algorithm.
- Software Availability – The algorithm used must be translatable to a software programme that is readily available and easy to use.
- Speed – Time it takes for the algorithm to compute a solution.
- Accuracy and Repeatability – This determines the quality and stability of the scheduling method. It determines whether the scheduling method yields satisfactory results with different inputs.
- Skills – This is the personal familiarity with the algorithm and confidence in working with it. This is an important factor for the success of the algorithm.

In the first step of the AHP the importance of these objectives are ranked relative to each other in a matrix depicted in Figure 12. In this matrix, for example, involving nurses is twice as important as reducing cost and nine times more important than speed according to the decision maker. The matrix is normalised and the average of each row yields the weighting of each objective. The weighted matrix w is displayed in Figure 13. The figures are in terms of percentages that sum to 100. It can be seen that "Involving Nurses" is the most important objective due to its weighting. This ranking is consistent with the purpose of the project, as involving nurses is one of the main objectives of the project and thus should be ranked accordingly.

A =

	Reduce Cost	Involve Nurses	Software Availability	Speed	Accuracy and Repeatability	Skills
Reduce Cost	1.0	0.5	3.0	7.0	5.0	2.0
Involve Nurses	2.0	1.0	5.0	9.0	7.0	3.0
Software Availability	0.3	0.2	1.0	3.0	2.0	0.5
Speed	0.1	0.1	0.3	1.0	0.5	0.2
Accuracy and Repeatability	0.2	0.1	0.5	2.0	1.0	0.2
Skills	0.5	0.3	3.0	5.0	3.0	1.0

Figure 12 Matrix x A with ranked objectives

w =

Reduce Cost	25.2
Involve Nurses	40.9
Software Availability	8.9
Speed	3.4
Accuracy and Repeatability	5.1
Skills	16.5

Figure 13 Weighted matrix

In order to ensure consistency in the ranking, a consistency calculation was performed as follows: multiplying the transpose of matrix w with matrix A and using the product (Aw^T) in Formula 1, where n is the number of rows or columns of the matrix and the matrix must be square. Computing, Formula 1 yields a value of 6.1.

$$\frac{1}{n} * \sum \frac{i_{th}\_entry\_in\_Aw^T}{i_{th}\_entry\_in\_w^T} \qquad \text{....1}$$

The Consistency Index (CI) value can be computed using the result from Formula 1 as:

$$CI = \frac{(result\_from\_formula\_1) - n}{n-1} \qquad \text{....2}$$

This generates a CI of 0.0717. Dividing the CI value with the value of the Random Index as read off in a table from Winston (2003) from the AHP process, yields a value of 0.01377. This value is smaller than the proposed 0.1 border. Thus the decisions were indeed consistent according to Winston (2003).

For each of the six objectives a matrix similar to matrix w in Figure 12 was set up and the different scheduling methods were ranked according to the specific objective relative to each other. The results are displayed in Figure 14. Subsequently, each matrix was normalised and the average of the rows was taken to obtain each objective's weighted matrix similar to the one in Figure 13.

Reduce Cost						
	Linear Programming	Own Development	Artificial Intelligence	Heuristics	Metaheuristics	Goal Programming
Liner Programming	1.0	3.0	5.0	4.0	3.0	7.0
Own Development	0.3	1.0	4.0	2.0	3.0	5.0
Artificial Intelligence	0.2	0.3	1.0	0.3	0.5	2.0
Heuristics	0.3	0.5	3.0	1.0	2.0	4.0
Metaheuristics	0.2	0.3	2.0	0.5	1.0	3.0
Goal Programming	0.1	0.2	0.5	0.3	0.3	1.0

Accuracy and Repeatability						
	Linear Programming	Own Development	Artificial Intelligence	Heuristics	Metaheuristics	Goal Programming
Liner Programming	1.0	2.0	7.0	5.0	3.0	9.0
Own Development	0.5	1.0	5.0	4.0	2.0	7.0
Artificial Intelligence	0.1	0.2	1.0	0.5	0.3	2.0
Heuristics	0.2	0.3	2.0	1.0	0.5	3.0
Metaheuristics	0.3	0.5	3.0	2.0	1.0	5.0
Goal Programming	0.1	0.1	0.5	0.3	0.2	1.0

Involve Nurses						
	Linear Programming	Own Development	Artificial Intelligence	Heuristics	Metaheuristics	Goal Programming
Linear Programming	1.0	0.3	2.0	5.0	0.5	3.0
Own Development	3.0	1.0	5.0	9.0	2.0	7.0
Artificial Intelligence	0.5	0.2	1.0	3.0	0.3	2.0
Heuristics	5.0	3.0	2.0	1.0	0.5	4.0
Metaheuristics	2.0	0.5	3.0	7.0	1.0	5.0
Goal Programming	0.3	0.1	0.5	2.0	0.2	1.0

Speed						
	Linear Programming	Own Development	Artificial Intelligence	Heuristics	Metaheuristics	Goal Programming
Liner Programming	1.0	0.5	0.3	0.3	0.2	2.0
Own Development	2.0	1.0	0.5	5.0	0.3	3.0
Artificial Intelligence	3.0	2.0	1.0	7.0	0.5	3.0
Heuristics	3.0	0.2	0.1	1.0	0.1	2.0
Metaheuristics	5.0	3.0	2.0	9.0	1.0	7.0
Goal Programming	0.5	0.3	0.3	0.5	0.1	1.0

Software Availability						
	Linear Programming	Own Development	Artificial Intelligence	Heuristics	Metaheuristics	Goal Programming
Linear Programming	1.0	3.0	7.0	2.0	0.5	5.0
Own Development	0.3	1.0	3.0	0.5	0.2	2.0
Artificial Intelligence	0.1	0.3	1.0	0.2	0.1	0.5
Heuristics	0.5	2.0	5.0	1.0	0.3	3.0
Metaheuristics	2.0	5.0	9.0	3.0	1.0	7.0
Goal Programming	0.2	0.5	2.0	0.3	0.1	1.0

SKILLS						
	Linear Programming	Own Development	Artificial Intelligence	Heuristics	Metaheuristics	Goal Programming
Liner Programming	1.00	0.50	7.00	2.00	5.00	3.00
Own Development	2.00	1.00	9.00	3.00	7.00	5.00
Artificial Intelligence	0.11	0.11	1.00	0.20	0.50	0.33
Heuristics	0.50	0.33	5.00	1.00	3.00	2.00
Metaheuristics	0.20	0.14	2.00	0.33	1.00	0.50
Goal Programming	0.33	0.20	3.00	0.50	2.00	1.00

Figure 14 Nurse Scheduling methods ranked relative to objectives

After the weighted matrix for each objective matrix was determined as shown in Figure 15, the overall score for each scheduling method was computed in the final ranking matrix depicted in **Figure 16**. This was achieved by summing the score of each scheduling method of the objective multiplied by the weighting of the objective, which was recorded in matrix w.

Reduce Cost		**Involve Nurses**		**Software Availability**		**Accuracy and Repeatability**		**Speed**		**Skills**	
SCORES		SCORES		SCORES		SCORES		SCORES		SCORES	
Linear Programming	0.41	Linear Programming	0.12	Linear Programming	0.25	Linear Programming	0.41	Linear Programming	0.07	Linear Programming	0.25
Own Development	0.23	Own Development	0.32	Own Development	0.09	Own Development	0.26	Own Development	0.15	Own Development	0.41
Artificial Intelligence	0.06	Artificial Intelligence	0.07	Artificial Intelligence	0.03	Artificial Intelligence	0.05	Artificial Intelligence	0.24	Artificial Intelligence	0.03
Heuristics	0.15	Heuristics	0.25	Heuristics	0.15	Heuristics	0.09	Heuristics	0.08	Heuristics	0.15
Metaheuristics	0.10	Metaheuristic	0.20	Metaheuristics	0.41	Metaheuristics	0.15	Metaheuristics	0.41	Metaheuristics	0.05
Goal Programming	0.04	Goal Programming	0.04	Goal Programming	0.05	Goal Programming	0.03	Goal Programming	0.05	Goal Programming	0.09

Figure 15 Score calculated for each objective

FINAL Ranking =

Linear Programming	24.2
Own Development	28.3
Artificial Intelligence	6.5
Heuristics	18.6
Metaheuristics	17.4
Goal Programming	5.1

Figure 16 Final ranking matrix

From the result in **Figure 16** which is again in terms of percentages that sum to 100, linear programming and a self-developed algorithm with a basic feasible solution are the best options according to the AHP. Consequently these methods are used to develop the day and night assignment as well as the wards assignments. The next section deals with the formulation and development of these scheduling methods.

4.8 Developing algorithms

Adopting ideas from the literature study, and referring back to Figure 7, the scheduling problem is subdivided into two sub problems. These are a linear programming model or integer programming model and a model that is self-developed. As the day and night scheduling is relatively simple, it is modelled with linear programming. The ward assignments are solved with an algorithm that imitates the unit managers' approach when scheduling. This idea too is adopted from the literature study. The day and night scheduling model acts as an input to the monthly ward assignments. This is illustrated below the process body in Figure 7.

4.8.1 Linear and integer programming

When setting up a linear programming model the following prerequisites as described in Winston (2003) must be respected:

Proportionality and additivity assumptions – The model must be linear

The contribution of the objective function from each decision variable is proportional to the value of the decision variable. For example, the cost to the objective function for four4 staff nurses is exactly four times the contribution of one staff nurse. Additionally, the contribution to the objective function for any variable is independent of the other decision variables. ~~For example, no matter what the value of x_2, the cost of x_1 nurses will always add R3$x_{1\ (????)}$ to the objective function.~~

Divisibility assumptions

Each decision variable may be allowed to assume a fractional value otherwise the problem is an integer programming problem. In this problem nurses cannot assume fractional values, thus the problem is an integer programming problem. This however is no obstacle as "an integer programming problem is a linear programming problem in which some or all of the variables are required to be non-negative integers" (Winston, 2003).

Certainty assumption

Every coefficient on the right hand side of an objective function must be known with certainty. This is the case as unit managers can exactly specify nurses required.

4.8.1.1 The model

The day and night scheduling is split into three parts: sister scheduling, assistant nurse scheduling and staff nurse scheduling. Each one of these is solved in the same manner. The first constraint is implemented in the structure of the model. Nurses have to work at least three months of night shifts per year. Thus, the year is split into four quarters.

If one maximises the objective function, the programme assigns more shifts than needed by the shift coverage constraints. Consequently in this model the objective function minimises the dissatisfaction of the nurses.

J_{ij}= Nurse i preference for quarter j. J is a matrix with four columns for four nurses and a number of rows respective to the number of nurses that need to be assigned to a night shift. Nurses can choose J_{ij} as 0 (most preferred quarter for night shift), 5 (if they do not care to work night shifts during a specific quarter) or 10 (if they do not want to work night shifts during a specific quarter)

S_{ij}= Assigned shift of nurse i for quarter j. S is a matrix of ones (assigned shift) and zeros (no shift) with four columns for four nurses and a number of rows respective to the number of nurses that need to be assigned to a night shift.

R = Nursing requirements for three months to cover needs as specified by unit managers. It is assumed that the basic night shift nursing requirements are the same each quarter. This is realistic as wards are assigned fixed numbers of each nurse type each day. Additional nurses are added on short term.

$$\min z = \sum_{n=1}^{i}\sum_{m=1}^{j} J_{ij} \bullet S_{ij} \qquad ....4$$

Subject to:

Nursing requirements to be satisfied each quarter:

$$\sum_{n=1}^{i} S_{i1} \geq R \ldots Quarter1 \qquad ....5$$
$$\sum_{n=1}^{i} S_{i2} \geq R \ldots Quarter2$$
$$\sum_{n=1}^{i} S_{i3} \geq R \ldots Quarter3$$
$$\sum_{n=1}^{i} S_{i4} \geq R \ldots Quarter4$$

Minimum shifts to be assigned per nurse per year (each nurse has to work at least 1 quarter:

$$\begin{array}{llll} S_{11}+ & S_{12}+ & S_{13}+ & S_{14} \geq 1 \ldots Nurse1 \\ S_{21}+ & S_{22}+ & S_{23}+ & S_{24} \geq 1 \ldots Nurse2 \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ S_{i1}+ & S_{i2}+ & S_{i3}+ & S_{i4} \geq 1 \ldots Nursei \end{array} \qquad ...6$$

Where

$R \geq 0, Jij = 0{,}5 or 10$ and S_{ij} integer

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4.8.1.2 So

lving, validating and verifying the model

In the previous section the model was designed and built. This section deals with building, solving, validating and verifying the model. For the data input, the cells that the nurses enter values into are limited with a data validation function from Excel, such that the nurses can only input values 0, 5 or 10. Additionally, when choosing shifts, specialised nurses who can work in the trauma ward, maternity ward and in the theatre are asked to collaborate among each other such that one of each is assigned to a different quarter. This ensures that skill coverage is also catered for. Nurses with stretch shifts are not assigned night shifts. Their names are removed from the list before working out the schedule.

Using Excel Solver, the models' solutions were found. An example of the staff nurses' day and night scheduling solution with the Solver window is shown in Figure 17. In the first table nurses enter their preferences. The cells to be changed are in the "Workings" – table.

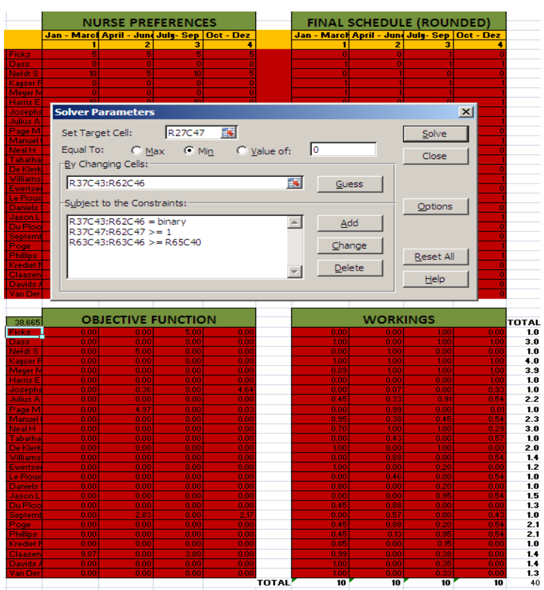

Figure 17 Staff nurse day and night scheduling Excel Solver solution

These cells should be containing binary values. The constraints are added next to and below the workings table. Each row has to be greater than one (such that each nurse works at least three months night shift) and the sum of each column has to be equal to R which is the number of staff nurses needed for optimal coverage. In this example R was assigned to be ten per quarter.

Unfortunately, the problem is complex with 104 variables and finding an optimal solution is nearly impossible (Excel Solver can handle a maximum of 200 variables) and thus the solution to some of the cells is displayed as a fraction. Summing the fractions yields optimal coverage R.

		NURSE PREFERENCES					FINAL SCHEDULE (ROUNDED)				
		Jan - March	April - June	July- Sep	Oct - Dez		Jan - March	April - June	July- Sep	Oct - Dez	
		1	2	3	4		1	2	3	4	
87	Ficks	5	5	5	5	Ficks	0	0	1	0	1
88	Dass	0	0	0	0	Dass	1	0	1	1	3
89	Nefdt S	10	5	10	5	Nefdt S	0	1	0	0	1
90	Kayser R	0	0	0	0	Kayser R	1	1	1	1	4
91	Meyer M	0	0	0	0	Meyer M	1	1	1	1	4
92	Harris E	10	0	10	0	Harris E	0	0	0	1	1
93	Josephs	10	5	10	5	Josephs	0	0	0	1	1
94	Julius A	0	0	0	0	Julius A	0	0	1	1	2
95	Page M	10	5	10	5	Page M	0	1	0	0	1
96	Manuel C	0	0	0	0	Manuel C	1	0	0	1	2
97	Neal H	0	0	0	0	Neal H	1	1	1	0	3
98	Tabatha H	10	0	10	0	Tabatha H	0	0	0	1	1
99	De Klerk M	0	10	0	10	De Klerk M	1	0	1	0	2
100	Williams M	10	0	10	0	Williams M	0	1	0	1	2
101	Ewertsen	0	10	0	10	Ewertsen	1	0	0	0	1
102	Le Roux I	10	0	10	0	Le Roux I	0	0	0	1	1
103	Daniels S	0	10	0	10	Daniels S	1	0	0	0	1
104	Jason L	10	10	0	0	Jason L	0	0	1	1	2
105	Du Plooy	0	0	10	10	Du Plooy	0	1	0	0	1
106	Septembe	10	5	10	5	Septembe	0	1	0	0	1
107	Poge	0	0	0	0	Poge	0	1	0	1	2
108	Phillips	0	0	0	0	Phillips	0	0	1	1	2
109	Krediet M	0	10	0	10	Krediet M	1	0	0	0	1
0	Claasen C	10	0	10	5	Claasen C	1	0	0	0	1
0	Davids A	0	10	0	0	Davids A	1	0	0	0	1
0	Van Der B	0	10	0	10	Van Der B	1	0	0	0	1
							12	9	9	13	

Figure 18 Final staff nurse day and night schedule next to nurse preference input

Analyzing and verifying the solution: inspecting whether the schedule provides sufficient coverage (R, nursing requirement satisfied) and whether model responds to nurse preferences.

In the final solution the figures from the workings table are simply rounded. A table of the solution next to the nurses' preferences is given in Figure 18. Rounding the figures is not the optimal solution, nonetheless comparing the solution to the nurses' preference yields that that 82 out of 104 cells positively correspond to nurse inputs which is a satisfaction percentage of 78.8.

The sum of the rows indicates the number of night shifts each nurse was assigned to. It is displayed to the right of the column in yellow. Some nurses prefer to work only night shifts, thus it is possible to assign up to 4 quarters of night shifts. Although this response is dependent on the nurse input and satisfaction percentages can vary with different inputs, this solution verifies that the system in fact does respond to the nurses' inputs.

The column totals which are representative of R are indicated in yellow below the table in Figure 18. The first and fourth quarter have more nurses than necessary (12 and 15 respectively) and quarter two and three have one nurse too few nurses assigned (both have 9); however the coverage constraint is more or less adhered to. Unit managers can adjust the schedule by shifting some assignments. The other models (sisters and assistant nurses day and night schedule) reacted similarly and are not displayed here. One can thus say that the objective of creating a point of departure for the day and night schedule has been achieved with a near optimal solution. This solution is an input to the next part of the model, the self-developed basic feasible solution.

4.8.1.3 Limitations of the model

Unfortunately, this way of modelling bears some limitations. As already mentioned the programme nearly never finds an optimal solution and thus only the fractions from the solution are rounded in order to force the cell to become either one or zero. This however, impacts the result of the solution and only an approximate solution is achieved. Additionally, this model is rigid. Nurses can only choose different quarters whose months are pre-set. If for example they would like to work three months from February to April, this model does not cater for that. Finally, solving with Excel Solver limits the size of the model. One cannot solve for more than 200 variables and thus, the problem cannot be solved for considerably larger models than the one presented, except if one uses another development platform which most likely have a cost attached to it. A user validation of the complete system is done at a later stage.

4.8.2 Self-developed basic feasible solution model

4.8.2.1 Set up

In the previous section the day and night schedules were determined, which is one of the inputs to the following self-developed basic feasible solution which is elaborated on in this section. The self-developed model is based on an idea from the literature study where the nurses scheduling process is imitated in the programme. The model is built with Excel which executes basic operations, where user input is admitted and read into VBA. Following the user input, the dynamic calculations are carried out in Visual Basics. Visual Basic interacts with Excel throughout the programme.

Inputs to the model as described in section 0 and as can be observed in Figure 7 are expanded with more detail on the Excel model. Please refer to the Excel model on the attached CD. On the sheet termed "User Input" a table with nurse attributes is input by the unit managers. The first seven nurse attributes columns are the wards. Each of these columns is divided in three to accommodate for sisters, assistant nurses and staff nurses. The ward columns are followed by an indication of "Wissel" shift or stretch shift (stretch shift nurses are not considered in day and night scheduling). After this a column with nurse availability is shown, where nurses who are not at work for some time during the month is indicated. Up to here unit managers indicate the nurses' capabilities and attributes in terms of ones and zeros. It is referred to as the nurse attribute matrix. The last few columns concern the nurse preference input for the day and night shift scheduling discussed in the previous section. The user interface of the whole model is explained later in the report.

Each nurse type has a dedicated amount of rows which is approximately 10 rows more than nurses available of the specific type at the hospital. This gives room for change. The nurse types are listed underneath each other in a column. First sisters are listed, then assistant nurses and finally staff nurses. The ward requirements per nurse type at daytime and night time are entered by the unit managers as indicated in the "user input" sheet in the excel file (this is also an input for the calculation of R in the day and night integer programming model).

In the nurse attribute table, a one indicates that a nurse can work in a ward (or prefers to work in a specific ward), a zero means the nurse is not trained for a specific ward or does not like to work there. In order to ensure data validation, all inputs from nurses are fixed with the data validation option in Excel. This ensures that no invalid numbers are input into the one and zero nurse attribute matrix.

4.8.2.2 Imitated thought process and description of model

The ward assignment thought process to be imitated is as follows: first unit managers consider which nurses are available during a month. Following this, wards which require nurses with special skills are assigned first. Finally, the rest of the nurses are assigned more or less with respect to their skills. Due to a lack of best practise methods and documentation unit, managers

have to remember all the nurses' attributes and iterate the schedule until a more or less valid outcome is achieved.

In the Excel-VBA model this simple process is automated which saves computational time and, at the same time, provides documentation of the nurses' attributes. The key to the model is a ratio array which calculates the nurses available per nurse type per ward over the nurses required per nurse type per ward. The smallest ratio indicates the ward with the most urgent need of nurse assignment. This idea stems from the nurses' thought process. The ratio changes with assigned nurses, thus providing for a dynamic scheduling process.

The nurses available per type per ward are simply sumtotalled each (ward and type section separately) in the nurse attribute table. For example, the sisters available in the maternity ward (referring to the "user input" sheet in the Excel file), would simply be the sum of the sisters rows in the maternity ward column. During the programme, rows of nurses who have been assigned are cleared and thus, that specific nurse cannot be assigned again and the ratio is adjusted accordingly.

The nurses required per ward is equally simple to compute: the initial value is calculated from the unit manager input which provides a requirement value per nurse type per ward at daytime and at night time, respectively. During the running of the programme nurses are assigned to their respective wards either at daytime or at night time. As soon as a nurse is assigned, the nursing requirement for that specific day or night shift, nurse type and ward are reduced by one. Consequently the nurses requirements are reduced by one and the ratio changes again.

In order to address the problem of division by zero as soon as all the nurse requirements for a specific ward and nurse type are satisfied, an "iferror" Excel function was used, that lets the ratio become 100 as soon as the requirements have been satisfied. Additionally, to prevent the programme from getting stuck on a ratio of zero which results when no more nurses are available of a specific type and ward, the "iferror" function was expanded to become 100 if no more nurses are available, too. The number 100 was chosen just as a high number such that the programme would not consider that specific ward/nurse type ratio for assignments again.

The ratio calculations and all the sums are done in Excel. Even though it slows the programme down, this is more convenient and more efficient than coding everything in VBA. The following section deals with the connection of Excel to VBA and provides a description of the VBA programme supporting the Excel setup.

4.8.2.3 VBA programme description

In Figure 19 flow the diagram is drawn up to in order to document the programme structure of the code and for clarifying purposes. In the first step the code reads in the values of the nurses required/nurses available ratios into an array. Following this the programme determines the minimum value in the ratio array. There are 21 ratios, three for every ward. In the next step the position (z) of the minimum value is determined as this provides information on the nurse type required as well as the ward which needs to be served first. Ratios which were assigned the value of 100, due to a fully assigned ward or due to no available resources, is not considered. Subsequently the population counter (p) is set to its starting value such that it always starts going through the table from the top.

For row p and position z the programme determines whether the nurse is qualified (a one in the cell indicates adequate qualification or preference) to be assigned to the specific ward. If the nurse is not qualified the population counter (p) is incremented and the next row is tested. If the nurse is in fact qualified, then in the nurse attribute table with a “case” command, the programme determines which nurse type an entry in the nurse attribute table corresponds to. If it is not the desired nurse type, p is incremented. If it is the desired nurse type, the next instance tests whether the nurse is available during a month or not. Nurses could be on sick leave, study leave, maternity leave or could just be on vacation. If nurses are away during days of the month, they are assigned to an “Unavailable Pool” and their attribute portfolio is cleared from the table of nurse attributes available for scheduling. This is essential such that the nurse is not be selected for assignment again, and such that the nurses available for scheduling numbers are reduced.

If the nurse is available during the month, the nurse can be assigned for either a day or a night shift in the specific ward. Either way, it is tested whether the ward has a requirement for that nurse type and day time or night time. This test is essential to avoid over assignment. In the case of a ward being already fully assigned, the one attribute in the nurses attribute portfolio is cleared and the nurse is written into the "Unassigned Pool". Nurses in this pool can be assigned as they are in the attribute table. They are just not considered for that specific ward and day time or night time again. If the ward is not fully assigned, the nurse is written into a specific ward at day time or night time, depending on their previous day and night time scheduling. If the nurse was assigned, her whole portfolio is cleared from the nurse attributes table. Furthermore, any entry in the "Unassigned Pool" is cleared.

Changes on the nurses' portfolios affect the ratio. Consequently every time a nurses' portfolio is cleared, the state of the system needs to be assessed. As the programme should not run in an endless loop, the stopping mechanism is the state where all the ratios have turned into a 100 either due to a lack of nurses to assign, or due to a fully assigned ward. The programme is driven with a "do while" loop which runs the programme as long as not all the ratios have turned into a 100. If not all of the ratios are 100 the programme starts at the top again to re-evaluate the ratio and determine which ward has the most crucial need of nurse assignment. The whole process is repeated. If however, all the ratios have turned to 100, before termination of the programme it runs through the nurse attribute table once more to find nurses not assigned. It clears their portfolios and writes them into the "Unassigned Pool".

4.8.2.4 Verifying and testing the programme

The outputs of the programme are the nurses assigned to different wards at day and night time and nurses assigned to the "Unavailable Pool" as well as nurses assigned to an "Unassigned Pool". In order to verify that the programme runs correctly, extensive testing was done during programming and after programme was completed. During programming after every programme change the following tests were done.

1. Testing ratio

The programme has to read the ratio in correctly as well as select the smallest ratio and then determine its correct position. Any errors in the ratios had to be tested for. This was achieved by printing the values of the ratio array and the selection and then manually inspecting whether they were in fact correct.

2. *Testing with input data*

The programme was tested with input data that was obtained from Linders and Skippers (personal communication, 12 September 2011) at Stellenbosch Hospital. These were basic data on the amount of nurses of each type are available and what attributes some of these nurses have as well as ward nursing requirements. No names or specific data was entered. The nursing requirements were however modelled as accurately as possible. Nursing attributes were changed, nurses added and removed, assigned unavailable as well as assigned day or night shifts. Every change in the input data table was verified to ensure correct working of the programme. Each column is further expanded on in points below the table.

Table 4 Testing table

	Testing Ratio	**Testing for correct assignments**	**Testing clearing procedure**	**Testing nursing requirements**
Test 1	Are the ratios updated correctly?	Nurses' assignments correctly corresponds to day/night schedule	Check procedure for single cell clearing and full portfolio clearing.	Nurse requirements must be >= 0
Test 2	Is the ward with the smallest ratio in fact selected?	Sum of assignments = 1	Nurse attribute table must be empty	If nurse requirements are >= 1 examine "Unassigned Pool".

3. *Testing for correct assignment*

Nurses' assignments must correspond to previously scheduled day or night shift as well as be of the correct type and qualification. Furthermore, a nurse may not be assigned more than once. This is tested by summing the nurse's day and night assignment tables. The sum of each row should not exceed one.

4. Testing clearing procedure

Nurses' attribute portfolio is cleared if assigned to wards or "Unavailable Pool". However, if a nurse is assigned to "Unassigned Pool", only one attribute may be cleared after which the programme runs on and allows the nurse to be assigned to another ward. At the end of the programme no nurse should be left unassigned. Each nurse must be assigned in either the day or night ward assignement, in the "Unavailable Pool" or in the "Unassigned Pool". It must be verified that the nurse attribute table is empty.

5. Testing nursing requirements

The nursing requirements may not become smaller than zero. This would indicate over assignment. The nursing requirement is computed by subtracting the nurses assigned for a specific ward and nurse type from the nurses required for a specific ward and nurse type. Additionally, after the programme has run, nursing requirements should be checked against nurses assigned to the "Unassigned Pool" and their portfolios of attributes. For example, if the nursing requirements for ward have a value greater than one, one has to check why this is the case and verify that no nurse has the appropriate attributes to fill the position.

4.8.2.5 Problems encountered in the development process and debugging

The prevalent problem in developing the model concerned the logic of the flow chart and the way the problem needed to be set up such that it would yield valid answers and eliminate faults in the programme. One challenge was determining the logical points in the programme at which the ratio needed to be re-evaluated, and after which events the population counter p needed to be incremented in order to always assign nurses to the wards with the most urgent requirements, and not to increment p too often and skip rows. Additionally, the clearing procedure posed a problem initially, as well as the programme termination point which resulted in an endless loop frequently. However, after a flowchart was drawn it was considerably easier to follow through the programme, understand it as well as test and correct it. The flowchart was corrected and updated during the process of the programme development.

Building the model to follow the logical flowchart was another challenge as some commands were unsuitable for certain functions. For example, using a "for"-loop for clearing a nurse portfolio did not work as well as a “while”-loop and resulted in endless loops due to the set up of the programme. These types of things had to be learned to develop the programme further. The debugging of the programme and testing the execution of the programme was done using the toggle stop function in VBA. This was useful as one could exactly follow what happened in the excel sheet, while having the programme at hand. The programme could be stepped through and in this way variable values could be examined which was useful to determine faults in the programme and in the logic. For example, it could easily be pinpointed why a counter would not increment or why the programme printed in the wrong columns in the worksheet.

The programme was built block by block and tested while it was developed. Additionally, while developing, the programme and its logic were explained to fellow students such as to see whether they could detect any logical faults.

This chapter dealt with nurse scheduling. Nurse scheduling was introduced, its background and literature studied as well as appropriate scheduling models chosen for the Stellenbosch Hospital problem. Moreover, the models were developed and verified. The next section expands on the combination of the two models as well as communicate outputs and user validation results.

4.8.2.6 Limitations of the self-developed algorithm

The solution found by the self-developed algorithm is only a basic feasible solution and might be only a local maximum. This implies that there might be superior solutions to the problem. In order to find a global maximum, one must change the basic feasible solution each time a little bit such that it is feasible, and then select the best schedule by comparing all the solutions by for example their nurse satisfaction scores, and selecting the best solution. This process is followed in a metaheuristic. Furthermore, the algorithm is specifically made for Stellenbosch Hospital. It takes for example the nurse hierarchy and the number of wards as a fixed input. Moreover, the number of nurses of each type can vary only by ten nurses. Consequently the algorithm is not generic and cannot be implemented somewhere else easily, except if the other hospital has similar conditions like Stellenbosch Hospital.

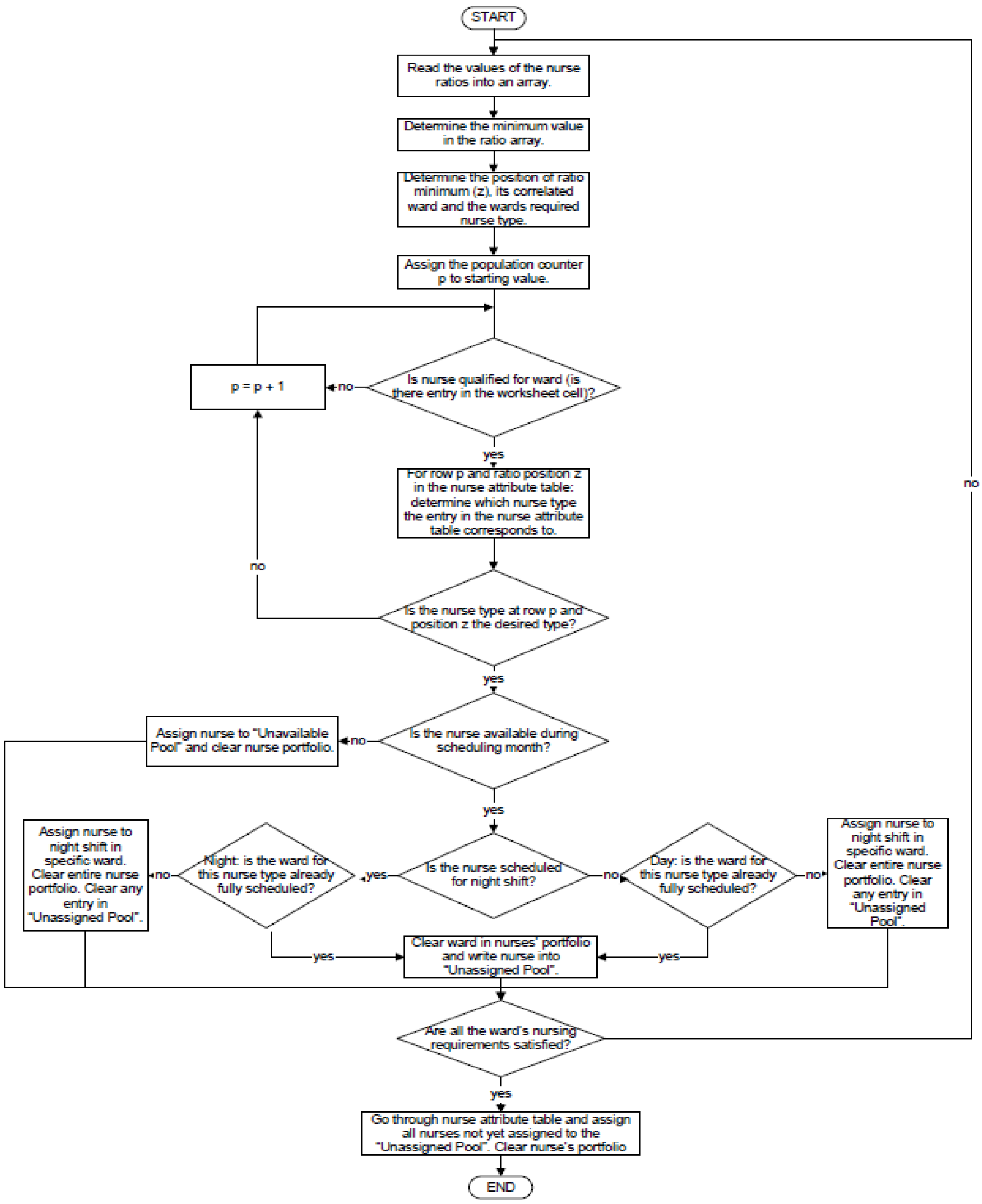

Figure 19 Flow diagram of programme

5. A decision support tool serving people and system

5.1 Introduction to the decision support tool serving people and system

While the previous chapter have analysed the problems at Stellenbosch Hospitals and developed a solution towards solving the problem of insufficient health care quality and nursing services, this chapter focuses on synthesising the previous work and validating the model with the users at Stellenbosch Hospital as emphasised in the road map model in Figure 20.

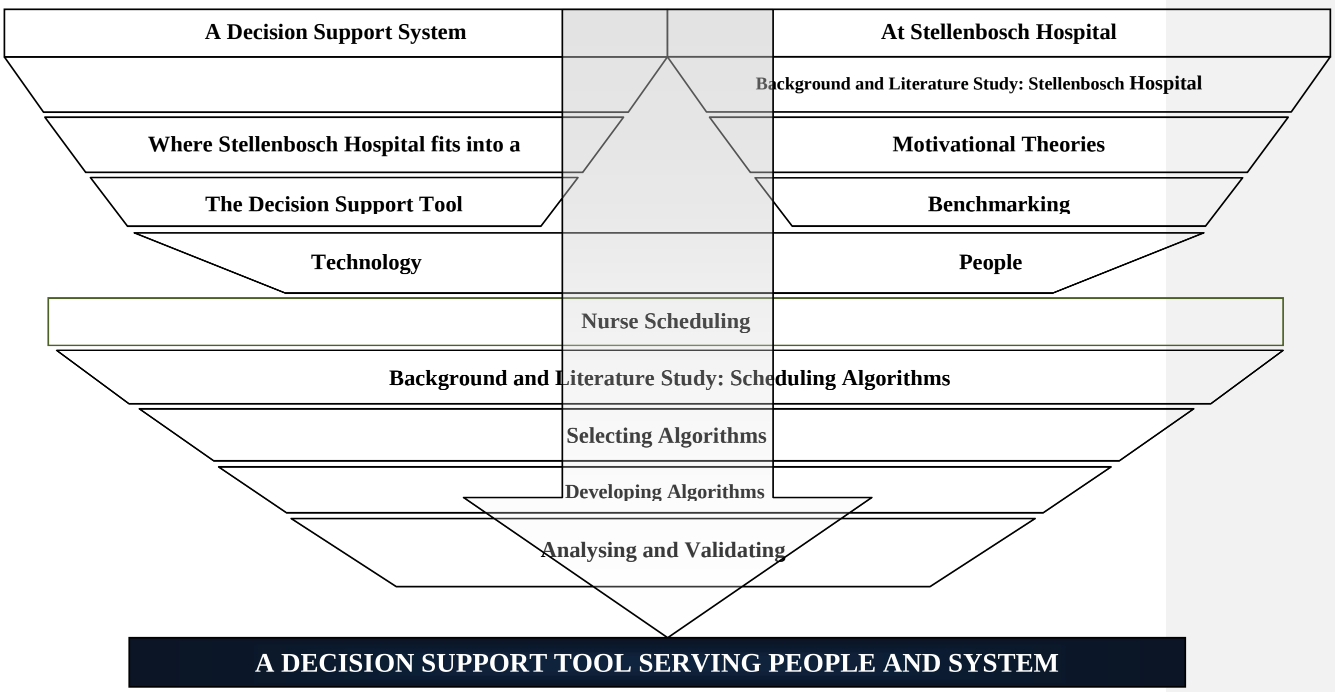

Figure 20 Road Map with focus on final decision support tool

Please refer to the Excel file on the attached CD. As the model uses only once a month for the nurse to ward assignment and once a year for the nurse day and night schedule, its interface does not need to be optimally compatible and simple. However, a comprehensive model was emphasised for the nurse to ward assignment model. The unit managers will be appropriately trained to use and execute the model.

The steps to be executed by the nurses in order to create a schedule are numbered and described on the “User Input” sheet. For the monthly procedure: First, unit managers are prompted to verify and if necessary update the nurses required per shift per ward. In the next step unit managers have to check and adjust the nurse attribute portfolio. Unit managers implement nurse preferences here. In order to ensure data validation, all the values in the table are secured with Excel’s data validation option, where only fixed numbers can be chosen. This ensures that the programme yields good results and prevents errors. Unit managers indicate a stretch shift or “wissel”- shift as well as the nurse availability in the next columns. If a stretch shift was chosen, the “wissel” – shift automatically changes to the opposite. This prevents that nurses are assigned to stretch and “wissel”-shift simultaneously. Unit managers are asked to enter nurses with a stretch shift last in order to simplify the night scheduling process. Finally, nurses have to change the quarter number in the night shift column to the current quarter number in order to select the correct values from the night assignment tables. Following this step, nurses are asked to click on the pen icon. In this icon a macro is assigned that clears the previous schedules, and writes the new information into sheet 1 where the calculations and the actual programme are executed. The unit managers do not interact with this sheet. The sheets they interact with are named and coloured in order to make their detection easy. Following the clearing and transferral of the user input information, the unit managers are required to press the “Assign nurses to wards” –button which runs the self-developed algorithm and assign nurses. The monthly model requires the annual model as an input. The annual model’s interface and its connection to the monthly model via the user interface is explained in the following section.

On the “User Output”- sheet the basic feasible solution to the nurse assignment model can be observed. The final output sheet was as far as possible adjusted to the existing output sheet displayed in Figure 9. The existing sheet is relatively concise, displaying all the information on one single sheet. For the decision support tool two outputs were created. The first few pages are the day ward assignments and the night ward assignments in their full format. The first few lines are shown in Figure 21. The full format highlights the nurse assignments in blue. This is done via Excel's conditional formatting function. Additionally, nurses assigned the "Unassigned Pool" as well as in the "Unavailable Pool" is indicated next to their names. Finally, each nurse's day or night assignment status is indicated next to their names.

DAY WARD ASSIGNMENTS

NAME	Maternity	Paediatric	Ward A (Chronic)	Ward B (Women)	Ward C (Men)	Theatres	Accident/Trauma	UNAVAILABLE POOL	UNASSIGNED POOL	Nurses With night sh
H Leith	0	0	0	0	0	0	0	0	0	1
Ebrahim	0	0	0	0	0	0	1	0	0	0
Lesley	0	0	0	0	0	0	0	0	0	1
Swart	0	0	0	0	1	0	0	0	0	0
Osman	0	0	0	0	0	0	0	0	0	1
Williams	0	0	0	0	0	0	1	0	0	0
Laubser	1	0	0	0	0	0	0	0	0	0
Katts	0	0	0	0	0	0	0	1	0	1
Marlow	0	0	0	1	0	0	0	0	0	0
D Williams	0	0	0	0	0	0	0	0	0	1
Roda	0	0	0	0	1	0	0	0	0	0
Geduld	0	0	0	0	0	0	0	0	0	1

NIGHT WARD ASSIGNMENTS

NAME	Maternity	Paediatric	Ward A (Chronic)	Ward B (Women)	Ward C (Men)	Theatres	Accident/Trauma	UNAVAILABLE POO	UNASSIGNED POOL	Nurses With night sh
H Leith	0	0	0	0	0	0	1	0	0	1
Ebrahim	0	0	0	0	0	0	0	0	0	0
Lesley	0	0	0	0	0	0	1	0	0	1
Swart	0	0	0	0	0	0	0	0	0	0
Osman	1	0	0	0	0	0	0	0	0	1
Williams	0	0	0	0	0	0	0	0	0	0
Laubser	0	0	0	0	0	0	0	0	0	0
Katts	0	0	0	0	0	0	0	1	0	1
Marlow	0	0	0	0	0	0	0	0	0	0
D Williams	0	0	1	0	0	0	0	0	0	1
Roda	0	0	0	0	0	0	0	0	0	0
Geduld	1	0	0	0	0	0	0	0	0	1

Fiaure 21

Although the total sheet seems to be a good output, it is not concise enough to support decision making effectively. Nurses would need to page through the information and cannot see at once whether the schedule is feasible. Consequently another output summarising the solution was developed. This sheet can be observed in Figure 21. Nurses press the rubber button to clear any previous sheets. Following this they select "Create Sheet". A code written in VBA goes through the full day and night assignment sheets and summarises them in one single sheet. In the top left, nurses not available during the month are entered along with their type. Nurses can make a note why these nurses are not available or how long they are not available. In the top right nurses who have not been assigned are entered including their type. In the top middle, space is left for general comments on the schedule for the nurses to fill in. Finally, all the wards are listed with the respective day assigned nurses and types (on the left) and night assigned nurses and their type (on the right). Theatres only have day assignments. Nurses can adjust and change assignments in the final sheet as they feel fit. Moreover, the scheduling outputs are sized such that they can be easily printed onto A4 pages for user convenience.

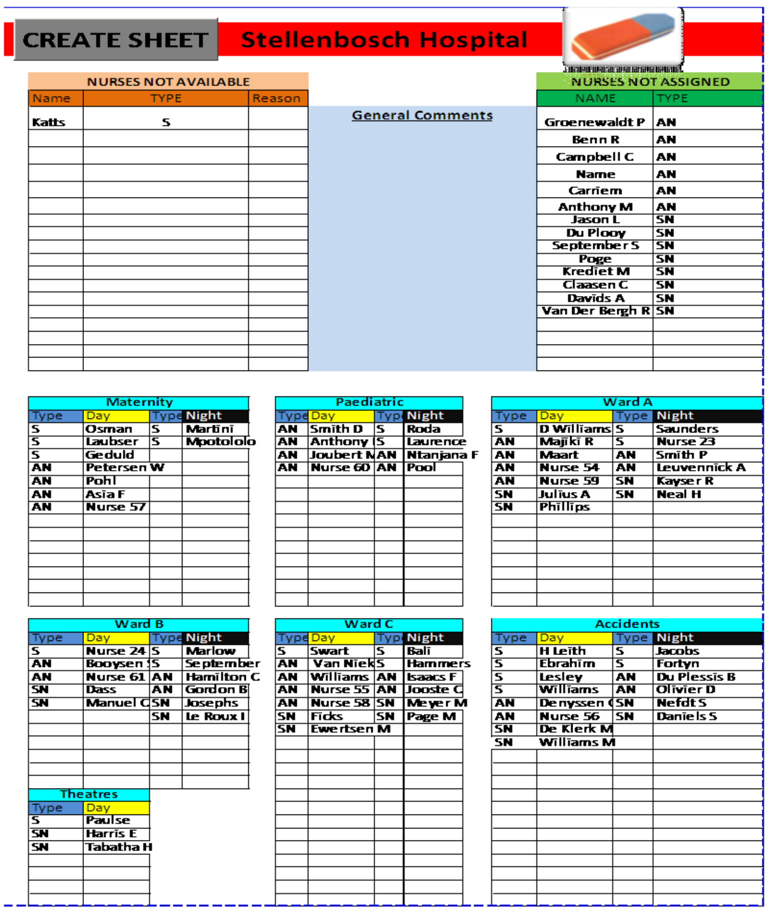

Figure 22 Final, summarised output sheet

Throughout the development of the tool, simplicity of user interface for user input and output was emphasised as the user is the most important part of the decision support tool. Consequently, the layout and description of the user interface was made as clear as possible in order to avoid confusion among unit managers and nurses and thus provide a higher quality schedule. This was achieved using different colours and clear descriptions as well as icons for the buttons.

5.3 User validation

The decision support tool validation underwent several iterations during its development phase. The tool was tested with the users and then taken back to do improvements. The final user validation was performed on 19/09/2011. The staff manger Mr Barbas as well as Sister Skippers and Sister Linders (unit managers) were present. Unfortunately not more nurses could be involved as it was an eventful day at the hospital. Figure 23 shows Sister Skippers and the author showing her the features of the decision support tool.

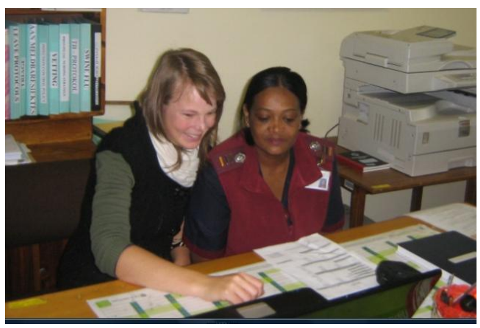

Figure 23 Validating the programme

Although the unit managers and Mr Barbas were sceptical about the outcomes and the use of final year project during its development phase, the feedback received about the last version of the model was positive and enthusiastic.

They were asked the following predetermined questions. The interview was conducted in Afrikaans, the language unit managers were most comfortable with. This was done in order to get optimal feedback.

1. ***Is the decision support tool useful to you?***

   The unit managers Linders and Skippers (personal communication, 19 September 2011) stated that the decision support tool will be useful in future scheduling, as it performs the same algorithm that they have to do in hours in a few seconds. They assured that starting from an already pre-solved problem will speed up the scheduling process considerably and relieve them of the tedious iterations of preparing the schedule which often results in insufficient schedules and underutilised nurses as well as fights among unit managers who debate over where a specific resource needs to be allocated to. They can now simply make some changes in the user input and let the programme re-iterate or improve the schedule in the output sheet. Now, as opposed to the unit managers having to focus on producing a basic feasible solution, they can focus on improving the basic feasible solution to a good feasible solution, thus the tool supports their decision making, but does not take over control. This is important as human judgement is important in a variable environment.

1. Does decision support tool solve the problem?

According to Linders, Skippers and Barbas (personal communication, 19 September 2011) the decision support tool does solve problems for them at the hospital. Documentation of all the nurses and the “Unassigned Pool” and “Unavailable Pool” aids them to enhance nurse utilisation as unit managers have an overview of all staff and their attributes and can assign them in an optimal way. This will ultimately reduce overtime for nurses, as unit managers can now plan schedules in advance. Furthermore, the decision support tool involves nurses in important areas of their schedules. Linders and Skippers (personal communication, 19 September 2011) said that this, after implementation, will be an incredible contribution to the satisfaction of the nurses. Especially scheduling the night shifts one year in advance will make schedules fairer and give nurses the opportunity to be aware of upcoming night shift periods so that they can organise private matters well in advance. Involving nurses in the day and night scheduling decisions as well as being able to nominate wards they want to work in, gives nurses more control over their schedules. Although the choice for the day and night schedules is rigid, nurses now have more control now than before. According to Linders and Skippers (personal communication, 19 September 2011) a more convenient schedule for nurses will reduce absenteeism.

2. Do you understand the decision support tool?

The decision support tool and its basic workings were explained to the sisters. As the tool basically imitates the nurses’ scheduling process, they understood well how the tool works. They were pleased that their input was used so extensively in the development of the decision support tool.

3. Is the decision support tool user friendly?

The nurses understood the process of what to do and which buttons to press. They enjoyed the colourful design and the pictures used for the buttons. Furthermore, they appreciated the data validation function of Excel which prevents them from inputting wrong data. However, all of them being pioneers and beginners with handling computers, they requested a training session in using the decision support tool and especially Solver.

4. Is there anything important missing in the decision support tool?

Linders, Skippers and Barbas (personal communication, 19 September 2011) stated that they feel that the decision support tool was thoroughly developed and they cannot see anything missing for the purpose of scheduling.

5.4 Future work

Although a preliminary solution to the scheduling problem at Stellenbosch Hospital was found, there is ample room for improvement. The decision support tool is specifically designed to solve a scheduling problem for Stellenbosch Hospital. A future project could deal with making the model generic such that it can be applied to all South African government hospitals and thus aid to improve scheduling and to involve nurses in the scheduling process nation-wide. Additionally, one could expand the model to be instead of a decision support tool only, a DSS with a feedback system. For example, nurse schedules from previous months could be used as an input to favour nurses in the next schedule who have been neglected in the previous month's schedule. This idea was adopted from Bester *et al* in their article "Finding good nurse duty schedules: a case study" (2007). Moreover, instead of only finding a basic feasible solution, the self-developed algorithm could be adjusted to a metaheuristic, finding a large amount of feasible solutions and selecting the best one. This would support the model to find a global maximum solution instead of just a local one. Additionally, the day and night nurse scheduling choices could be made less rigid, by letting the nurses choose exactly which months they would be prepared to work night shifts. Also, the user interface and solving method for the day and night schedules can be improved. Lastly the model could be expanded to the day to day scheduling level by adopting an existing model, for example one like the NuroDSS developed by Bester *et al* (2007), and merge the two models to one master model. In the day to day model nurses could be assigned such that they have every

second weekend off, or that they can choose their own work patterns. This would further empower nurses to control their schedules.

In conclusion, this chapter synthesised all the previous work to one output and explained the user interface. The decision support tool was validated by the unit managers as well as the staff manager, all of who were impressed with the workings of the decision support tool and were enthusiastic to adopt it to their scheduling process, as they believe that it will be useful to them and aid them to create superior schedules in a shorter time, as well as making the schedules more convenient for the nurses by involving all the nurses in the scheduling process. Finally, possible future developments and improvements were outlined. In the next chapter the final year project will be concluded.

6. Conclusions and recommendations

6.1 Introduction to conclusion

In this final year project a problem at Stellenbosch Hospital was solved and followed through from the problem definition to development and validation of the solution by its future users. The purpose of this project more specifically was to design a user friendly system to support decisions related to the scheduling of nursing resources at Stellenbosch Hospital on a regular basis.

The following objectives were to be followed to achieve the purpose:

- Provide decision maker with a tool to support decisions
- Improve and enhance nurse utilization
- Involve nurses in scheduling
- Improve worker morale

6.2 Evaluating whether purpose of project has been attained

A tool that has not been developed in such a way and form before, to support decision making in the nurse scheduling process, has been developed. The unit managers at Stellenbosch Hospital will be provided with a basic feasible solution in a user friendly format which they can further modify in order to optimally suit the hospital's requirements. Nurse utilisation will be enhanced by foremost assigning nurses with scarce attributes to wards with the most urgent need. Secondly, the output sheet gives a clear list of an "Unassigned Pool" as well as an "Unavailable Pool". Unit managers thus know which nurses have not been assigned and can draw on the "Unassigned Pool" to fill positions. In this way nurse utilisation is enhanced and unnecessary overtime can be eliminated. Finally, the nurses' preferences are an essential input to the day and night schedule as well as to the nurses' portfolio. Although the system has not been implemented yet and impact on worker morale and absenteeism rates cannot be quantified, unit managers stated that including nurses in the scheduling process will be of significant importance to the nurses, as knowing their day and night schedule well in advance, will give the nurses time to plan personal lives according to their work shifts and thus come to work more regularly. This will potentially reduce overtime for other nurses as well as reduce friction with management. Nurses will be empowered to gain control over their schedules and consequently a more comfortable work environment can be created which will potentially lead to improved worker morale.

Even though the decision support tool provides unit managers with a feasible solution, the solution is not optimal and thus the tool can still be improved, made more flexible, generic, user friendly and expanded to include more features. Nevertheless, the aim of this study was to treat the root causes of problems at Stellenbosch Hospital and thus improve nurse utilisation as well as worker morale by providing a decision support tool to unit managers at Stellenbosch Hosptial to produce feasible nurse schedules while including nurses' preferences. This has been successfully done and thus the aim of the final year project has been achieved.

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