Eva van Rooijen

# Happy nurses

## Optimization for nurse scheduling satisfaction

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By

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# Sense*Model*-Making

Mathematics can help us solve problems as long as we can write the problem in mathematical language. Unfortunately, not all of us are math-fluent but more importantly, some things seem impossible to measure and reduce to mathematical formulations. Take satisfaction for example, how can we measure job satisfaction? We can ask people to rank their job satisfaction in comparison to other jobs but that will not be reliable as they do not have full information. Decision-making under incomplete information leads to suboptimal decisions (Nash). With this thesis, I have tried to make sense of a "vague" or latent concept such as job satisfaction and translate it to a mathematical model using input from nurses and planners.

Let's imagine for a moment that we would know all the possible effects of our decisions and could consider all the options before choosing. That would make it easier for us to rank them based on some objective or goal. Then, all that is left to do is make the decision. Unfortunately, even with a lot of (complete) information this can still put us in tricky situations.

This is where operations research tools come in to support decision-making (in operational business processes). By defining a problem in mathematical language, we can collaborate and use the benefits of computation to process many options and select the "best". Now, this requires a clear definition of the objective of the problem and the restrictions on the outcome. This is our responsibility as humans and (indirect) users of such systems and designers of such systems to take into account.

This thesis covers an intersection of mathematics (operations research), design, and job satisfaction research. It aims to design a software system that aids the scheduling process using operations research methods. However, since scheduling has a large impact on employees' personal lives, such a system should be designed with users in mind. In this thesis, a value sensitive design approach is applied to account for the human values of (in)direct users throughout the design process.

The thesis is split into three parts. Part A and C jointly form the Communication Design for Innovation thesis and part B is the Econometrics and Operations Research thesis.

# Part A

# Contents

# Chapter 1

# Introduction

A recent study in The Netherlands reports an expected shortage of 140,000 healthcare employees by 2031. Two main reasons for this shortage are an increased demand for healthcare by a growing elderly population and a shortage in the healthcare labour market. Based on this study, the Dutch ministry of Long term Healthcare assigns high priority to the development of policy to increase the attractiveness of healthcare work (of General Affairs, 2022). Nursing schedules are one aspect of such healthcare work attractiveness.

Nurses are often required to work irregular shifts, such as night shifts and working on weekends. However, the conventional approaches to scheduling often neglect the impact on nurses' well-being and job satisfaction, potentially leading to burnout, reduced productivity, and increased turnover rates. Nurses play a critical role in delivering high-quality care and ensuring patient well-being. The creation of balanced and healthy nursing schedules is paramount to maintaining a well-functioning healthcare system.

Recognizing the significance of nurse schedule satisfaction, this thesis investigates the application of Value Sensitive Design (VSD) as a novel framework to enhance scheduling practices. Value Sensitive Design is an interdisciplinary approach that integrates ethical and human-centered considerations into the design process, acknowledging the various stakeholders' values and needs. By employing VSD principles, we aim to develop a comprehensive and empathic approach to scheduling that prioritizes the well-being and satisfaction of nurses while ensuring the efficient operation of healthcare facilities.

VSD is becoming increasingly important as technology becomes more integrated into our daily lives, and as the potential consequences of technology become more complex and far-reaching. By incorporating values into the design process, VSD can help ensure that technology is developed in a way that is consistent with the needs and values of its users and stakeholders.

The underlying assumption of this research is that when nurses' schedules align with their values, preferences, and personal lives, they experience higher job satisfaction, leading to improved performance and ultimately benefiting both the nurses and the healthcare organization as a whole. This thesis leverages both qualitative and quantitative research methods, such as literature, interviews, and a survey, to gather valuable insights.

## 1.1 Research aim

So, this thesis sets out to explore how Value Sensitive Design can be leveraged to improve nurse schedule satisfaction, benefiting both nurses and healthcare organizations. By adopting a holistic approach and considering the diverse perspectives of stakeholders involved, we aim to develop a framework that fosters well-being, job satisfaction, and ultimately leads to enhanced patient care. Through this research, we strive to advance the understanding of scheduling practices, shed light on the importance of nurse satisfaction, and offer actionable insights to drive positive change in the healthcare industry.

## 1.2 Research relevance

The anticipated outcomes of this research are manifold. First, it is expected to provide empirical evidence on the values driving schedule satisfaction. Second, it proposes a practical design of a mathematical optimization system based on identified user needs and values. Finally, this research aims to contribute to the broader field of Value Sensitive Design by demonstrating its applicability and efficacy in the context of healthcare scheduling.

## 1.3 Research questions

Complementary to the aim of the project, the main research question can be formulated as follows: **How can value sensitive design help to design an optimization (software) system based on the values of its indirect users (nurses)?** To answer the main question, the following subquestions will be answered throughout this thesis:

RQ1. What values drive nurse schedule satisfaction according to literature?

RQ2. What values drive nurse schedule satisfaction according to nurses in the Martini hospital (Groningen, The Netherlands)?

RQ3. What values drive the scheduling decisions made by planners of the Zuyderland hospital (Sittard, The Netherlands)?

RQ4. How can these values be implemented in the design of a mathematical optimization problem to support the planning process?

## 1.4 Research strategy

This section outlines the methodology employed to investigate nurse satisfaction using a Value Sensitive Design approach. Value Sensitive Design (VSD) is a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process. It employs an integrative and iterative tripartite methodology, consisting of conceptual, empirical, and technical investigations (Friedman et al., 2002). Therefore, this research can roughly be divided into three parts.

- Conceptual: The first research question (RQ1) is answered based on a literature review of nurses' job satisfaction and how it is affected by scheduling decisions.
- Empirical: The insights from the conceptual phase are validated, reflected on, and tweaked based on interviews with nurses from the Martini hospital (Groningen). Second, the planners' decision making process is studied with one group interview with planners from the Zuyderland hospital (Sittard).
- Technical: The gathered information is used to shape and design a mathematical optimization formulation of the scheduling problem

The conceptual and empirical parts involve a combination of literature study, individual interviews, and a group interview to gather comprehensive insights into the factors influencing nurse satisfaction with scheduling. The technical part involves translating these insights into a (mathematical) description of the scheduling problem involving nurse satisfaction.

Ethical considerations were given utmost importance throughout the research process. Informed consent was obtained from all participants, ensuring their voluntary participation, confidentiality, and the right to withdraw from the study at any point.

## 1.5 Thesis structure

Chapter 2 discusses relevant theories and literature on job satisfaction and motivation related to nurses. Chapter 3 discusses the interviews with nurses on what schedule satisfaction means to them and their views on the current scheduling process. Chapter 4 describes the results of the group interview with planners to study their scheduling decision making process and the role of optimization technology within that process. Part B shows how the optimization problem can be formulated and solved including nurse scheduling preferences guided by the identified values (this part can be read as a separate thesis). Part C includes the conclusion and discussion chapters of this thesis. The thesis strategy is visually presented in figure 1.1.

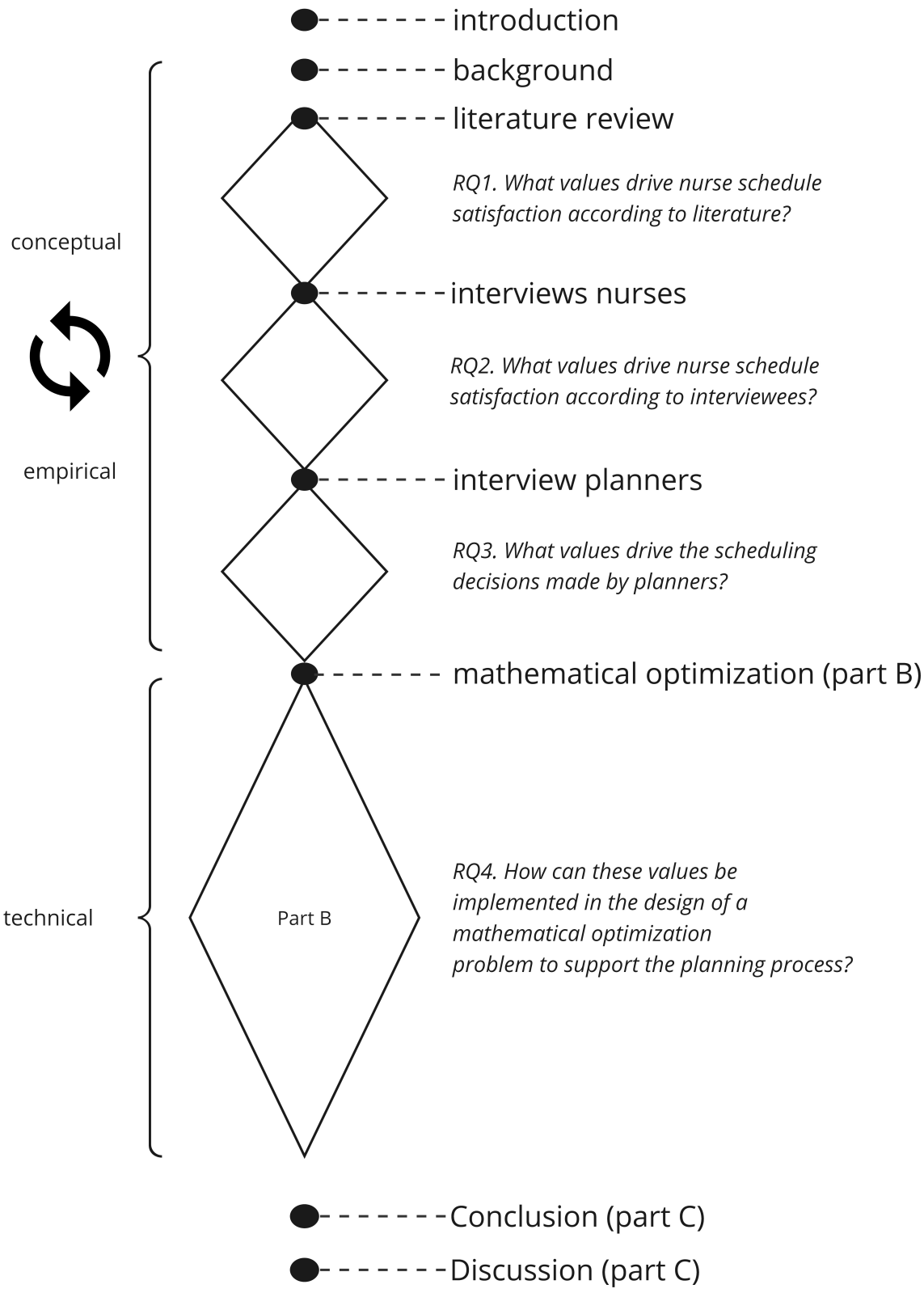


Figure 1.1: Research strategy

## 1.6 Case Description

This study uses a case study on the scheduling of nurses using an intelligent optimization system. The scheduling of nurses to shifts is a complex process since the schedule needs to adhere to restrictions set by labour laws. Besides these restrictions, nurses should be satisfied with their schedule and its effect on their work-life balance and other factors. This thesis focuses on a specific optimization software system developed by ORTEC B.V. (The Netherlands) called ORTEC Workforce Scheduling. This system utilizes mathematical optimization algorithms to support planners in hospitals in The Netherlands.

### 1.6.1 Mathematical optimization

Mathematical optimization or mathematical programming is the selection of a best element, with regard to some criterion, from some set of available alternatives. The set of available alternatives is described by a set of hard constraints. In the nurse scheduling problem, this means that schedules have to adhere to the collective labour agreement and laws on labour times. Additionally, a mathematical optimization problem requires a formulation of an objective. This objective is used to evaluate alternative (feasible) schedules and find the optimal solution. In the nurse scheduling case, this objective is a combination of keeping the workforce satisfied and meeting the capacity requirements. For example, a good schedule from a workforce satisfaction perspective could be to give nurses more time off. However, this would be at the cost of having enough workers on the floor to meet demand from patients.

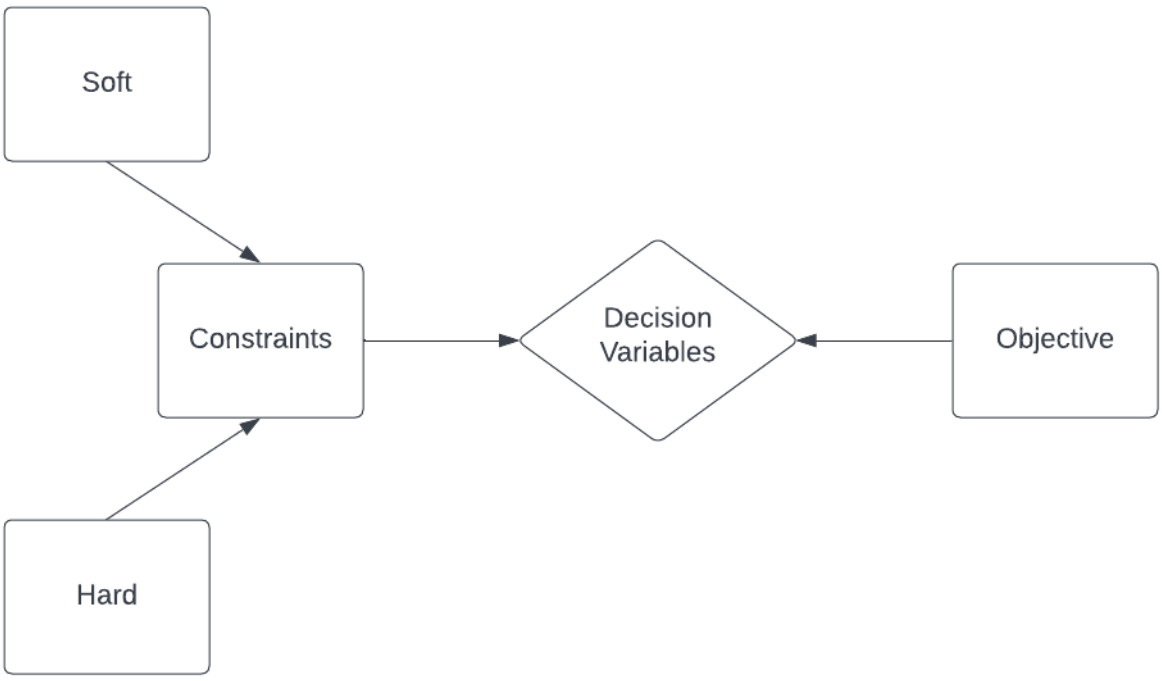


Figure 1.2: Structure of a mathematical optimization problem

The scheduling problem can be modeled as an optimization problem with the objective of meeting capacity demand as best as possible given the set of available nurses. Of course, the resulting schedule should not violate any labour rules or agreements. Within the set of feasible schedules, the aim is to meet personal scheduling preferences as best as possible (without sacrificing capacity or violating labour agreements). The goal of the software system is to support the planners' decision-making process and help deliver the best possible schedule given nurse preferences and capacity requirements.

### 1.6.2 Collaboration and communication

This research aims to improve the interaction between planners and nurses through the design of a scheduling (software) system that support planners based on mathematical optimization. Both planners and nurses are users of this system. Planners use it to create and publish the schedule. Nurses use it to communicate their wishes and view the schedule. However, the value of the solution generated by an optimization system is highly dependent on the input from both direct and indirect users. Direct users, planners, should communicate capacity requirements and hard constraints such as labour agreements. Indirect users, nurses, should communicate their preferences and requests. Unfortunately, interaction between a software system and human users is complicated as users often do not speak the technical language required by software.

### 1.6.3 Current situation

Currently, based on discussions with ORTEC consultants, planners are accepting the OWS scheduling system as a planning tool but rarely use the optimization functionality. Instead, planners manually create schedules and only (mainly) use the software for bookkeeping and publication of schedules. However, it has been shown by consultants that the optimization functionality creates schedules with fewer violations of labour laws and agreements. Nonetheless, planners do not trust (believe) that the optimization considers all the same rules when making a schedule as they do themselves. Thus, they do not accept the functionality and instead prefer to make schedules manually.

The system currently also supports nurses to self-schedule, which means scheduling is a 3-step process. In a first round, nurses can sign up for shifts and create their preferred schedule. In the second round, the software calculates missing shifts or overassigned shifts (more than required that day). Nurses are expected to change their schedules to meet the capacity requirement together. In a third round, the planner checks the schedule and makes necessary changes before publishing the schedule. This way, scheduling becomes a group process. Each nurse can decide which shift to work or not and, in the end, the goal is to obtain a good schedule together. Here, good means a balance of nurse satisfaction and quality care which is measured by meeting the capacity requirement. Research shows that the use of self-scheduling can be specifically attractive to Millennials as an opportunity that allow them to create a better work–life balance (Campbell and Patrician, 2020).

# Chapter 2

# Background

This chapter presents theories on job satisfaction that were studied in our master's courses. After presenting an overview of these generic theories on job satisfaction and motivation, literature is discussed on nurse job satisfaction specifically.

## 2.1 Theories on job satisfaction

### 2.1.1 Self Determination Theory

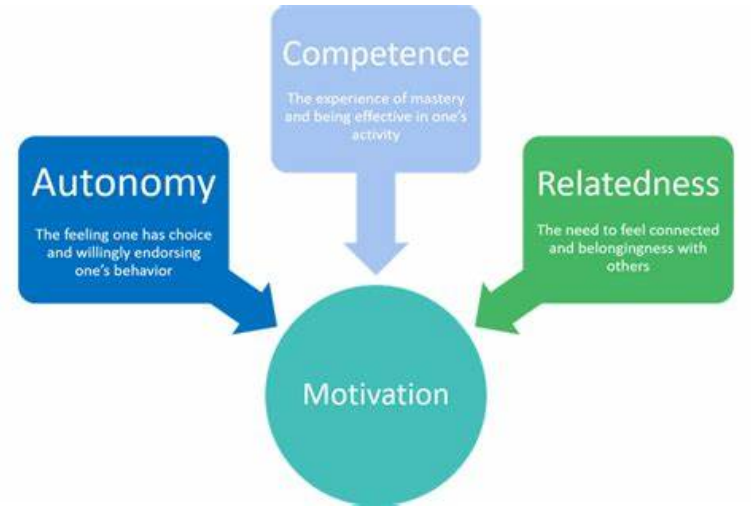


Figure 2.1: Self-Determination Theory of Motivation *(Center for Community Health & Prevention - University of Rochester Medical Center, n.d.)*

Job satisfaction and motivation are strongly related concepts. When job satisfaction of the workforce is high, happy employees will be more motivated to work. Therefore, theories on job satisfaction often are linked to theories on motivation such as the self-determination theory. This theory states that motivation depends on three concepts: autonomy, competence, and relatedness.

Relatedness implies the need to feel connected and belongingness with others, this could be seen as a motivation factor in Herzberg's model. Competence implies the experience of mastery and being effective in one's activity which also is a motivation factor. Finally, autonomy is the feeling one has a choice and willingly endorses one's behaviour. To improve autonomy, we want to make the scheduling a group process. Nurses should feel like they have some impact on their schedule as it affects their personal lives and work-life balance.

The design of the workforce scheduling system can have an effect on the autonomy nurses feel regarding their schedules. If nurses are allowed to exchange shifts or self-schedule, this might increase their sense of having power/control over one's schedules and work-life balance.

### 2.1.2 Herzberg's Two Factor Theory of motivation

According to Herzberg's two-factor theory, there are two sets of factors that have an effect on job satisfaction. First, a set of hygiene factors measures the value of job dissatisfaction. If these factors are absent, an employee is dissatisfied with their job. However, if these hygiene factors are present that does not imply the employee is satisfied with their job. The motivation factors help distinguish between satisfied and not-satisfied employees.

This theory has been applied not only in job satisfaction research (Dion, 2006) but also specifically to study nurse job satisfaction. These studies support the theory and show that hygiene factors are less important considering job satisfaction than motivation factors. The motivation factors actually lead to job satisfaction (Kacel et al., 2005; Mitchell, 2009; Jones, 2011).

| **Hygiene Factors** | **Motivation Factors** |
|---|---|
| Interpersonal Relationship | Advancement |
| Salary | Work itself |
| Policies and administration | Possibility of growth |
| Supervision | Responsibility |
| Working conditions | Recognition |
| | Achievement |

Table 2.1: Motivation and Hygiene factors in Herzberg's Two Factor Theory (Alshmemri et al., 2017)

According to Pardee (1990), managers should carefully review what they are incorporating into reward systems. If the rewards are predominantly extrinsic factors, then all that can be hoped for are employees who are not dissatisfied with their work. Satisfying hygiene needs is relatively simple, but the satisfaction is short-lived and these types of needs are not additive in nature. Motivation can be achieved only by satisfying a very limited area of complex needs, which are additive in nature and whose satisfaction results in much longer lasting effects. What is actually required, therefore, is a two-way effort which is directed first at the hygiene and then at the development of motivation (Haimann, 1973).

In this study however, satisfying hygiene factors can be a complicated task. The work agreement includes a large set of constraints on the schedule, hospitals can have a shortage of nursing staff and the workload for nurses is demanding. When working agreements are met, job satisfaction can be increased by motivation factors such as advancement, responsibility, and recognition (Table 2.1).

### 2.1.3 McGregor's X Y Theory

To conclude this section on general theories about job satisfaction and motivation in the workplace, we discuss another critical theory, namely McGregor's X Y Theory. McGregor believed that the beliefs of a manager have an important effect on the operations in an organisation. Therefore, the beliefs of a manager affect the motivation and hygiene factors in the workplace.

First published in 1960 in The Human Side of Enterprise, Theory X and Theory Y classify two opposing management styles. Theory X is a view of strict direction and control whereas theory Y managers focus more on the integration of personal and organisational goals. Theory Y incorporates a pseudo-democratic environment to the workforce (Carson, 2005). This environment allows the employee to co-design, -construct and -create their work according to their preferences. Naturally, this requires a sense of responsibility from the employee to finish the work on time and maintaining a certain level of quality.

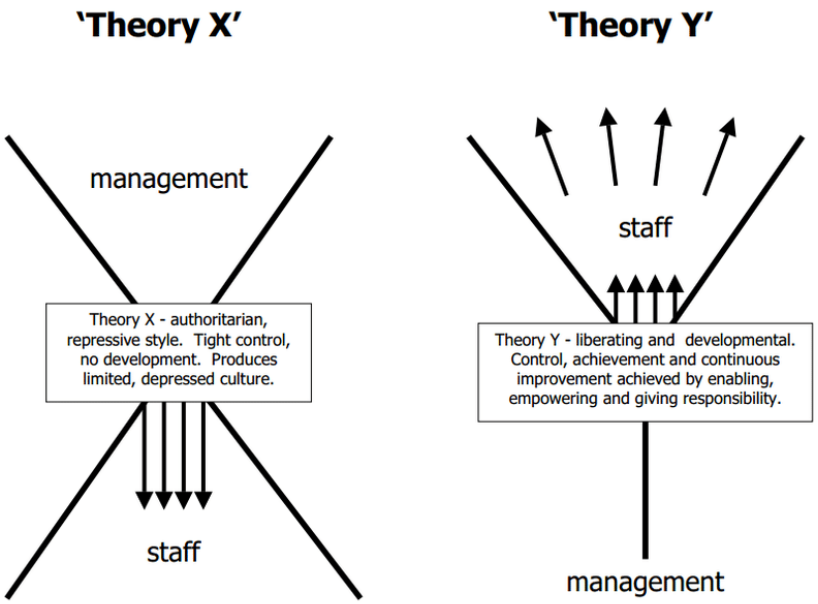


Figure 2.2: McGregor's X Y Theory (Markopoulos, 2016)

This theory shows the effect of autonomy and a sense agency on job satisfaction. Giving employees more autonomy could increase satisfaction and retention.

### 2.1.4 Literature on nurse job satisfaction

Several papers have presented a framework for measuring job satisfaction among nurses. Mueller and McCloskey (1990) measure nurse satisfaction by eight concepts: satisfaction with extrinsic rewards, scheduling, family/work balance, co-workers, interaction, professional opportunities, praise/recognition and control/responsibility. Here, control is measured by a sense of control over work-conditions (hygiene factors in Herzberg's model) and decision-making. The effect of scheduling on job satisfaction is measured by six variables: number of hours, flex-schedule hours, straight days, weekends-month, flex-weekends off and compensation-weekends.

Al Maqbali (2015) presents a literature review on factors that influence nurses' job satisfaction, also grouping factors that are personal separately from organisational and job-related factors. Personal factors such as age, education, department, and years of experience affect job satisfaction. Considering organisational and job-related factors, a distinction is made between interpersonal (between nurse and patients or colleagues) and extra-personal (those external to nurses). Interpersonal factors such as autonomy, co-working interaction and patient-care activities were found to have a large effect on satisfaction. Extra-personal factors such as scheduling, staffing levels, educational support by nurse managers and promotion opportunities all seem to enhance nurses' well-being and satisfaction.

So, nurse job satisfaction is affected by personal and work-related concepts which vary from well-being and emotional health to extrinsic rewards and the connection with patients and colleagues. Nurse managers can create policies to increase nurse satisfaction, improve their well-being and balance their workload. Rizany et al. (2019) showed the impact of nurse scheduling management on their satisfaction and commitment to the hospital as well as performance. When nurses are more satisfied with their job and schedules are made with their well-being in mind, the quality of patient care also seems to increase.

Their framework also shows the need for flexibility in the scheduling process and an effect of the type of scheduling. As mentioned before, a sense of autonomy also has an effect on nurse satisfaction. Self-scheduling is a type of scheduling that gives nurses this autonomy and a sense of freedom to manage the demands of work and home. It can improve nurses' work-life balance by creating more flexible work schedules (Koning, 2014). However, implementing and sustaining such a process can be a challenge.

The implementation of self-scheduling specifically seems to affect the nurse satisfaction of younger generations (Wilson et al., 2008). It helps to create a shared governance framework which is a nursing practice model that integrates core values and beliefs embraced by professional practice to pursue and achieve quality care (Anthony, 2004). It is a working model characterised by participatory decision-making in which nurses and other interdisciplinary team members follow organised decision-making processes regarding quality improvement, practice standards, professional development, and research. Tim Porter-O'Grady defines shared governance as "a structural model through which nurses can express and manage their practice with a higher level of professional autonomy." (O'Grady and Clavelle, 2021).

### 2.1.5 Theoretical Framework

Based on the described theories, the following theoretical framework is created. Based on the self-determination theory, we see a positive relation of autonomy, relatedness, and competence on motivation. Feeling more motivated about work increases the chance you will keep your job. The perceived level of autonomy is negatively related to the (perceived) level of supervision. Next to this, job dissatisfaction depends on the conditions of your work and job satisfaction depends on the work itself.

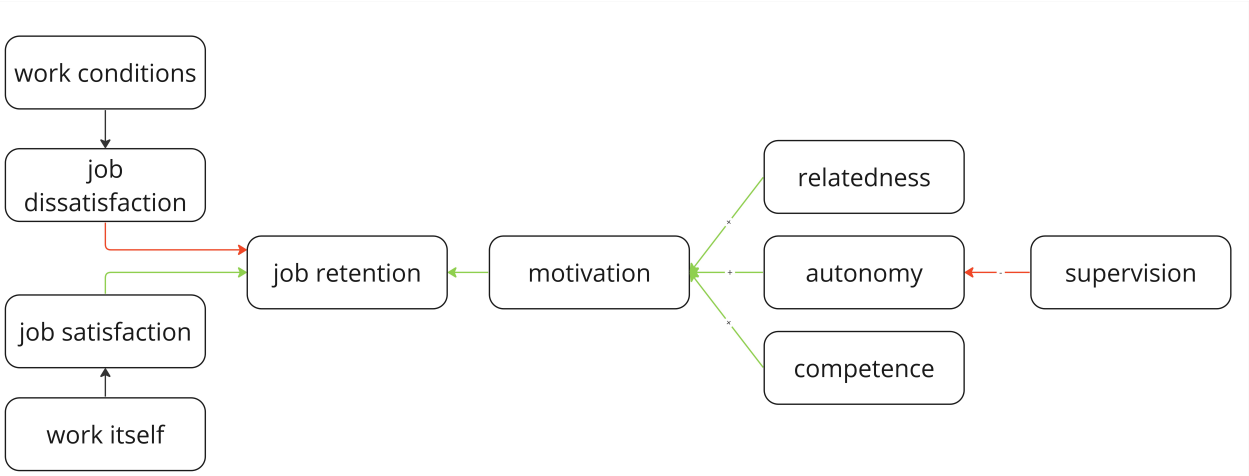


Figure 2.3: Theoretical Framework

So, according to literature, job satisfaction can be increased by improving schedule satisfaction if it is seen as a motivating factor. Motivation can be improved by a combination of increased competence, relatedness and autonomy. The level of supervision has an effect on the sense of autonomy and is based on the chosen management style. From McGregor's theory of X and Y, we see that less supervision (more autonomy) could lead to more satisfied workers by giving them more autonomy.

## 2.2 Scheduling in the Collective Labour Agreement

In The Netherlands, nurses' interests are defended by the Nurse Union. For example, the Union negotiates with employers about the Collective Labour Agreement which stipulates agreements on salary, scheduling rules, and other job aspects. There are multiple unions specifically aimed at nurses in The Netherlands. However, there is only one (collective) labour agreement for nurses in The Netherlands. This collective labour agreement results from negotiations between the hospitals and union representatives. Additionally, the Dutch labour law states laws on minimal resting times etc. The collective labour agreement cannot violate these labour laws.

The Collective Labour Agreement for 2022-2023 for nurses in The Netherlands is divided in nine chapters with one specifically focusing on scheduling (FNV, 2022). This chapter can be

found in Appendix A.1[1]. The chapter states that the agreement intends to enable the design of good and balanced schedules where:

- working hours are predictable;
- sufficient rest and recovery time has been included;
- excessive changes in the schedule are prevented;
- there is a good balance between work and private life;
- there is a balance between taxability and load.

In practice, such good and balanced schedules adhere to the following scheduling agreements:

- Recurring day off
- Maximally work five days in a week Monday-Sunday (unless agreed upon)
- Shift cannot take longer than ten hours
- No nightshifts after 55 years old
- Maximum of five consecutive nightshifts (unless agreed upon, then max. 7)
- A minimum of 46 hours free after three or more consecutive nightshifts

All of these agreements are extrinsic and seen as hygiene factors. However, they are still as complex and difficult to measure as motivation factors. Therefore, they will have a large effect on job dissatisfaction (motivation) but need to be operationalized such that we can measure them. The balance between taxability and load is related to the work itself so could be seen as a motivating factor.

[1]Complete Collective Labour Agreement can be found at: https://www.fnv.nl/cao-sector/zorg-welzijn/verpleeg-verzorgingshuizen-thuiszorg/cao-verpleeg-verzorgingshuizen-thuiszorg

# Chapter 3

# Literature on scheduling for nurse satisfaction

To answer the first sub question, "*What values drive nurse schedule satisfaction according to literature?*", a systematic literature review is conducted. The study focuses on literature about the effect of planner's scheduling decisions on nurse job satisfaction.

## 3.1 Methodology

Literature is collected with a document search in the Web of Science database using the following search terms: "nurse" AND "satisfaction" AND "preferences" AND "scheduling". To include scheduling preferences in a mathematical optimisation model requires quantitative data on such preferences. Therefore, an inclusion criteria in this review is the use of a survey on the relation between scheduling decisions and nurse job satisfaction. Second, to be included in this review, studies should focus on nurses in the population. Search results are first screened based on the abstract to check these criteria (Appendix B.1). After screening, the remaining articles are read in full. The articles that meet the criteria are analysed based on the methods, population, results and quality. Data is extracted from the articles based on the data extraction protocol (Appendix B.2).

## 3.2 Results

### 3.2.1 Search results

The search results include 71 articles, proceedings papers and editorial material. After reading the abstracts, 63 results were excluded since they did not study the effect of scheduling decisions on nurse job satisfaction. Most of the excluded 63 articles focused on developing a mathematical optimisation model that includes variables for nurse preferences without empirical evidence. The remaining 8 results are read in full after which 5 articles were excluded from this review. Two articles did not specify scheduling aspects as independent variables. Two articles did not use schedule or job satisfaction as an outcome (dependent) variable. One article did not use a survey. A PRISMA Flow Diagram can be found in Appendix B.1.

### 3.2.2 Characteristics of studies

Because of the criteria, all included results use a survey to gain insight into the relation between scheduling and nurse job satisfaction. Sample sizes range from 17 to 843 where the sample of size 17 consists of all 17 nurses of one department in a private hospital with 200 beds in Thailand. This small sample size seems relatively small but the study done in New York covered thirteen hospitals instead of only one (Table 3.2.2).

Table 3.1: Characteristics of studies

| Citation | Method | Population |
|---|---|---|
| Rerkjirattikal et al. (2020) | Questionnaire survey | 17 Operating room nurses in a private hospital with 200 beds in Pathum Thani, Thailand, conducted during December-January 2019/2020 |
| Stone et al. (2006) | Anonymous self-report questionnaire | Thirteen New York City nonspecialty hospitals participated with median bed size of 300 (805 surveys were examined; 12-hour shifts, n = 301; 8-hour shifts, n = 504) |
| Morrow et al. (1994) | Written questionnaire | Staff nursing personnel (N=843) within Nursing Services Department at large midwestern teaching hospital |

### 3.2.3 Operationalization

The concepts of job or schedule satisfaction as well as scheduling decisions can be interpreted and measured in various ways. All three selected studies used job satisfaction as (part of) the dependent variables in their study. Job satisfaction is measured by the arithmetic mean of answers to statements based on a five-level Likert scale (1=strongly disagree, 5=strongly agree) in Morrow et al. (1994). The statements are:

- "My current work schedule is not as good for my health as I would like it to be"
- "All in all, I am satisfied with my work schedule"
- "My current work schedule allows me to perform at my best"
- "I am dissatisfied with my present work schedule"

A similar approach is taken in Stone et al. (2006) where job satisfaction is measured based on five-level Likert scale answers to seven statements.
However, in the third paper included in this review, it is unclear how job satisfaction is included in the survey questions. The survey asks nurses to share their preferences for specific shifts or days off but the article does not specify questions on job satisfaction. The authors seem to make the assumption that minimising the number of request violations implies improving the satisfaction thus the preferences serve as a proxy for nurse satisfaction.

Two studies explore the relationship between scheduling policy on job satisfaction where one focuses on the duration of shift types (Stone et al., 2006) and the other on a more generic view of scheduling policy using the six options presented above (Morrow et al., 1994). Nurses were asked to state their preferred scheduling option out of a list and their actual scheduling option. The match (or not) between the actual and preferred scheduling options is used as the independent variable. The hypothesis here is that nurse job satisfaction and commitment are positively related to having a match between actual and preferred scheduling option.

In the survey, nurses could select one out of the following scheduling options:

- Rotating 8-hour schedule: A cyclical (recurring), 4-week schedule where nurses work 8-hour shifts and rotate the different shift types.
- Straight shift schedule: Nurses can work either 8 or 12-hour shifts but always work the same shift type (no rotation of shift types).
- Twelve-hour schedule: Nurses only work 12-hour shifts, with or without rotation.
- Flex: A 4-week, rotating schedule with 8-hour shifts that adapts to nurse requests. Nurses can request a day on or off through a software tool and the tool creates a schedule accordingly. Requests are limited to one request per weekend.
- Select-a-plan: This option may include a combination of 4-, 6-, 8-, 10-, and/or 12-h shifts as well as rotating and straight shift patterns.
- On-call and supplemental staff may work any combination of schedules.

However, in practice, the scheduling options for nurses depend on the hospital's policy. For example, the policy can state the use of cyclical schedules or the option of requests for (not) working specific days and shifts. Also, these scheduling options do not provide specific information on what about the scheduling option increases a nurse's satisfaction. It could be the duration of the shift or the fact that shift types rotate, or both. Asking more specific questions could help to provide more detailed insight on what drives nurse schedule satisfaction.

Table 3.2 gives an overview of the variables in each of the articles.

Table 3.2: Operationalization

| Citation | Independent variable | Dependent variable |
|---|---|---|
| Rerkjirattikal et al. (2020) | 4 most and second-most preferred shifts and days off across the 28-day scheduling period | nurses' job satisfaction |
| Stone et al. (2006) | type of staffing (12 hour or 8 hour shifts) | job satisfaction, scheduling satisfaction, scheduling preferences, intention to stay |
| Morrow et al. (1994) | preferred vs actual schedule selected out of 6 options | satisfaction and commitment |

### 3.2.4 Results and quality

The results of these studies indicate some positive relations between scheduling and job satisfaction but also raise some quality concerns. For example, when asking for preferences in a survey, the article by Rerkjirattikal et al. (2020) does not make clear how the relation with satisfaction can be concluded. Authors seem to assume that adhering to preferences increases satisfaction which might be a fair assumption but is not clearly explained in the article.

Additionally, a positive effect of working 12-hour shifts compared to 8-hour shifts is concluded in Stone et al. (2006) but the duration of shifts is only one dimension of nurse schedules and is often determined by higher-level policymakers, not planners. Therefore, to improve nurse satisfaction by helping planners make better scheduling decisions, requires more insight on the effect of planner's scheduling decisions. Also, results of Morrow et al. (1994) show a positive relation between work satisfaction and commitment, but these results can be outdated considering the survey was done in 1994.

Finally, asking nurses to list their preferences per day requires a lot of participation from respondents. Instead, it could be more interesting to use schedule attributes that are not linked to specific day requests but apply to the complete schedule.

Table 3.3: Results and quality

| Citation | Results | Quality |
|---|---|---|
| Rerkjirattikal et al. (2020) | shift and day off preferences are important contributors to nurse job satisfaction | not clear if nurses were asked in survey how preferences affect their satisfaction |
| Stone et al. (2006) | nurses with 12-hour shifts are more satisfied than nurses with 8-hour shifts | shift length only, which is limited and also a policy decision (nurse do not have influence) |
| Morrow et al. (1994) | positive effect of aligning schedule and shift preferences with actual schedule on satisfaction and commitment | outdated, limited scheduling options |

## 3.3 Interpretation - RQ1

To answer the first sub question, a systematic literature review is done to study the relationship between scheduling and job satisfaction among nurses. This review focused on studies that collect empirical data through a survey. Three articles resulted from a search using Web of Science and a set of criteria.

The main findings of these articles are a positive relation between receiving the preferred scheduling type on job satisfaction and commitment and higher rates of satisfaction among nurses working 12-hour shifts rather than 8-hour shifts. However, the operationalization of both job satisfaction and scheduling is difficult. Only Morrow et al. (1994) combines multi-

ple aspects of scheduling by asking respondents to choose from a set of scheduling options. However, these scheduling options do not provide specific information on what about the scheduling option increases a nurse's satisfaction.

More research is required to develop an understanding of what scheduling aspects can be used as an indicator of nurse satisfaction besides the shift duration. Therefore, later in this thesis (Chapter 4, Part B), a survey is designed to study the scheduling preferences and satisfaction of nurses in The Netherlands. Before doing so and to get a grasp of the context, interviews are designed and done with nurses and planners. Nurses are interviewed about their experience of the scheduling process and scheduling satisfaction.

# Chapter 4

# Interviews on nurse scheduling preferences

Based on the literature and discussion with planners and consultants, I developed an interview methodology to collect data on factors affecting nurses' satisfaction. The purpose of the interviews is to explore the perception of nurses on the scheduling process and explore what factors drive their schedule satisfaction.

## 4.1 Methodology

To gain a firsthand understanding of nurse experiences and perspectives regarding scheduling and job satisfaction, individual interviews were conducted. Participants for the interviews were selected based on their willingness to participate and availability. Over the span of two days, I visited the three departments at the Martini Hospital in Groningen, The Netherlands. The sample consisted of a diverse group of nurses with varying experience levels and contract types. A semi-structured interview protocol (Appendix C.1) was developed based on the insights derived from the literature study. The interviews were conducted face-to-face at the hospital. During the interviews, participants were asked open-ended questions regarding their experiences with their scheduling process (communication of wishes); factors influencing their job satisfaction; and suggestions for improving the scheduling process. Probing questions were used to explore emerging themes and gather in-depth information. All interviews were audio-recorded with the participants' consent and transcribed for subsequent analysis.

The dialysis department at the Martini Hospital creates schedules by self-scheduling. This process works with multiple rounds where nurses register their preferred schedule in the first round. Then, in a second round shifts with over- or under-staffing are highlighted and nurses can reschedule their shifts such that staffing requirements are met. During a group interview with the dialysis department, I evaluated this scheduling process with two planners and 12 nurses. In a 30 minutes discussion, I got to join and observe a discussion between the planners and nurses about the success of self-scheduling. Previously, nurses could share requests with the planners and planners made the schedule. The participants agreed to an audio recording of the discussion. There was no specific protocol or set of questions.

### 4.1.1 Participant Sampling

The sample consists of nurses working in the Martini hospital in Groningen. I interviewed nine nurses individually who worked at the Surgical and Internal Medicine departments. Additionally, a group interview was done with 12 nurses from the Dialysis department. The Dialysis department applies self-scheduling whereas in both the Surgical and Internal Medicine department, schedules are made by a planner.

| nurse ID | contract hrs/week | experience (yrs) |
|---|---|---|
| 1 | 32 | 0.5 |
| 2 | 32 | 1.5 |
| 3 | 20 | 2 |
| 4 | 32 | 3 |
| 5 | 24 | 4 |
| 6 | 32 | 4.5 |
| 7 | 24 | 5 |
| 8 | 32 | 6.5 |
| 9 | 32 | 32 |

Table 4.1: Attributes of sample

The sample consisted of nine interviews excluding a group discussion on the use of self-scheduling. All interviews were with nurses who do not use self-scheduling so their schedules are made by a planner. In the sample, contract hours (FTE) are on average 29 hours per week with six nurses working 32 hours per week, two nurses working 24 hours per week and one nurse who works 20 hours per week (Table 4.1.1). The years of experience range from a nurse who started only six months before the interview to a nurse who is already working as a nurse for 32 years (in different departments).

### 4.1.2 Ethics

Participants are informed about the goals of the research through an information sheet (Appendix C.2) beforehand. All participants have to read and sign this sheet before the start of the interview. If they do not agree, participants withdraw themselves from the study. After the collection of the data, confidential and sensitive data is anonymised.

### 4.1.3 Coding

The interviews are transcribed and coded using ATLAS.ti software and two coding methods. First, attribute coding is applied to provide basic descriptive information such as participant characteristics and interview settings. Second, In Vivo coding is used to code excerpts of the interview using the exact words as spoken by the participant. Here, attention is paid to specific aspects of the schedule that are linked to job satisfaction by the participant.

In the second cycle of the content analysis, pattern coding is applied to group similarly coded excerpts into unified themes. These themes represent commonly discussed concepts regarding schedule satisfaction. After coding the transcripts and analysing the common themes in the interviews, the results are summarised using descriptive statistics. The importance of a concept (code) is measured by its frequency across all interviews.

## 4.2 Results

Based on the methodology described, interviews were performed and coded. This results in insights on six main themes described in this section after a description of the attributes of the sample.

### 4.2.1 Themes

The most discussed themes during the interviews are the consecutiveness of shifts (63 times); communication of wishes (41 times); the perceived workload (25 times); predictability (19 times); fairness (18 times); and transparency of the process (7 times). Figure 4.1 shows the distribution of codes across interviews. All themes were discussed fairly equal during all interviews except transparency which only 2 nurses and the group interview discussed. However, fairness was mentioned by all nurses which could be linked to transparency. The next subsections explain these in more detail and using quotes from the interviews.

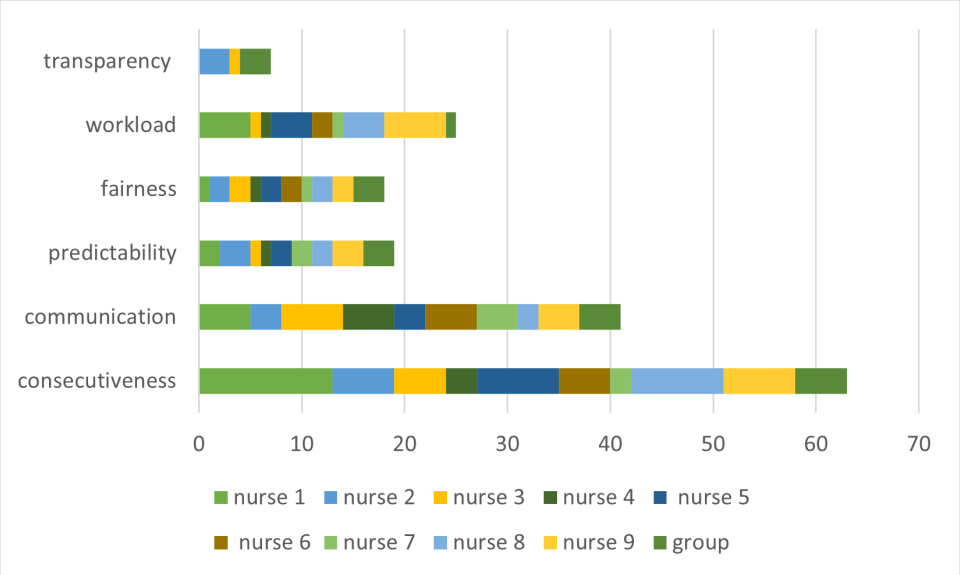


Figure 4.1: Distribution of codes across interviews

#### 4.2.1.1 Consecutiveness of shifts

With the increase of their contract hours (FTEs), nurses expressed a stronger preference to work their shifts per Monday-Sunday week consecutively as opposed to split in blocks of only one or two shifts. For example, one nurse stated: "*I work 32 hours per week according to my contract but if only I could ever work those four shifts consecutively... My schedule would be great!*" (nurse 1). The effect of consecutiveness on the schedule satisfaction depends on the type of shift as well. For most nurses, working 1-3 day shifts is fine but from then on the fourth and fifth are perceived as a lot more taxing. Most would prefer to work a mix of day and evening shifts as it is perceived as less taxing. When you finish a day shift at 15:30, and you only have to be back to work at 15:30 the day after, it creates more rest hours compared to another day shift (starting at 7:30).

Nurses also mentioned it takes time to read up on a patient and get to know their details. Working more consecutive shifts means you are already familiar with the patient and need less time to read in the morning. At the same time, nurses mentioned that caring for the same patients for too long can make them "annoyed" with the patient. Also, there is a limit to the number of consecutive shifts a nurse prefers as after some point it becomes too tiring. This maximum differs per person due to personal circumstances. Some nurses are willing to work longer series of consecutive shifts if that means they also get longer series of consecutive days off. So, the value of preferred consecutiveness differs per nurse but the concept seems to affect every nurse's perceived schedule satisfaction.

"*This won't work... I should work 32 hours a week but I feel as if I'm only alive to work*" *(nurse 1)*
"*without smaller blocks of (consecutive) shifts, I am out of here*" *(nurse 9)*

#### 4.2.1.2 Predictability

Another interesting result from the interviews lies in the effect of the publication date of the schedule on schedule satisfaction. Nurses were asked how far in advance they would like their schedule to be published and all nurses mentioned either two or three months in advance (mostly three months).

*"We plan our work around our personal/social activities" "If I could plan ahead (dentist/APK/weekend trips), I am more flexible and can take the wishes of colleagues into account but now... I do not know" (nurse 5)*

Currently, nurses receive their schedules rather late. In some cases, the schedule is published only one month in advance. This causes nurses to start making private appointments such as dentist visits, car checkups, and social plans which results in wishes not to work those days because of these appointments. However, if the schedule would be published earlier in advance, private appointments would be made taking the schedule into account. This would result in fewer wishes for days off which in turn makes it easier for the planners to meet all demands and fulfil nurse wishes.

#### 4.2.1.3 Communication of wishes

There is a clear divide in the types of wishes between nurses who work part-time and full-time. For example, there are many nurses who start working part-time when they have (young) children. However, due to daycare appointments, these nurses are also restricted to specific days they prefer to work. Therefore, this group of nurses has specific recurring wishes to work on days they have childcare. The combination of working part-time and not being flexible increases the burden on the schedule for full-timers. Full-time nurses often experience very scattered schedules. For example, the length of their series of shifts varies a lot week-by-week which hurts their perceived rest. Although full-time nurses do not have specific recurring wishes, they do have structural wishes on aspects such as the consecutiveness.

*"Of course, you can request them to take consecutiveness into account, and they will! But after a while, they just seem to forget again." (nurse 7)*

*"If you have a recurring wish, you have to manually add a request for it every week. If you forget, they will just schedule you because there was no request, but there is no functionality for a recurring wish." (nurse 1)*

In the current process, these structural wishes are rarely communicated to planners. This causes an unfair balance between nurses who communicate their wishes and nurses who stay silent. When asked about this, nurses say that wishes are listened to but also quickly forgotten about.

#### 4.2.1.4 Fairness

Nurses do not know how many wishes others have, they want it to be fair and transparent. One nurse explained how she used to work in a hospital with a simple printed schedule that would be hung on the wall. When someone wants to request a day off, you would simply put a cross on the printed schedule on that day and in your row. This way, she said it was very clear to see what others asked for which helps to understand what is fair.

"*When I know three colleagues have requested the same weekend off, I can understand why my request will be tough to allow. In that case, I could just plan my weekend away another time but I would like to know what requests other colleagues have and why mine is rejected.*" *(nurse 2)*

"*We used to have a printed schedule on paper which would hang in the coffee corner. When you had a request for a day off, you would simply cross it.*" *(nurse 4)*

Some nurses feel like they have to agree to swap earlier than others which can create unfair schedules in terms of satisfaction. For example, a nurse who has a good schedule is not agreeing to swap whereas a nurse with a slightly worse schedule agrees to swap because he/she is a nice person who does not want to say no.

#### 4.2.1.5 Perceived workload

From the interviews, it becomes quite clear that perceived rest can diverge a lot from actual rest. For example, days off after a series of night shifts is perceived as less "time off" than days off after a series of day or evening shifts because of the shift in natural rhythm. Even taking into account one day to "sleep it off", nurses mentioned they are not enjoying their personal time as if it would be a normal day off. So, the order of the shift types in a series affect the perceived workload. For example, ending a series with an evening shift on a Friday, having two days off, and working a day shift on Monday is "terrible" for some nurses.

"*When instead you work a day shift on Friday (finish at 15:30) and start a new series with a Monday evening shift (start at 15:30), it effectively creates a lot more weekend.*" *(nurse 8)*

"*I live solely to work*" *(nurse 9)*

Overall, the shared consensus states that the day shift is the most intense to work because all disciplines are present. This implies there are many doctor's visits, and checks and patients get sent home for example. There is a difference between weekdays and weekend days though, on a Saturday or Sunday day shifts are perceived as less taxing than on weekdays. In some of the interviews, nurses also mentioned that working with more experienced colleagues or becoming more experienced yourself reduces the perceived workload of the shift.

"*With more years of experiences, later you think: if it does not work out, it does not. All will be alright*" *(nurse 5)*

At the same time, being the most experienced can be stressful.

"*Now, if I am struggling with someone, to whom can I go for help? There is no one left with more experience than me so they are all leaning on me... I have felt unhappy at times, thinking who would be there for me.*" *(nurse 3)*

#### 4.2.1.6 Transparency

The nurses mentioned that the scheduling process should be more transparent. They want to understand why certain scheduling choices are (not) made. Especially, when requests are not met. When they communicate their wishes to the planners, there is no feedback on feasibility of these wishes. This causes nurses to not feel heard and demotivates them to communicate wishes in the future. For example, a nurse mentioned how in the current process it can feel like the planner deliberately ignores your wishes. However, the planner replied that from her perspective it is out of necessity. Wishes often clash amongst nurses such that multiple nurses request the same weekend off. The schedule still has to cover the capacity demand for that weekend so some wishes are not met. The same goes for consecutiveness preferences. Given all the rules, demands and preferences it becomes hard to adhere to preferences. During the interviews, nurses showed understanding and compassion for the planners but mentioned that transparency of the choices made would help reduce frustration and increase motivation to actively participate in the collaboration.

*"Where do all of my hours go?" (nurse 1)*

Nurses who work 32 hours experience a lot more pressure from their job, which does not seem to be proportional to their working hours. They feel like they are at the hospital almost every single day of the week.

*"I work 32 hours but it feels like I'm working every single day" (nurse 6)*
*"Colleagues tell me, it seems like you are always here" (nurse 1)*

#### 4.2.1.7 Self-scheduling

After observing the discussion, nurses can roughly be divided into three groups. The first group consists of nurses who enjoy the self-scheduling process as they take their time filling out their preferences. Some of them mentioned how they sit together with their partner to make sure their schedules overlap, especially when the partner also works irregular shifts. These people showed a lot of understanding toward the planner and were patient throughout the multiple rounds of the process.

A second group, however, takes the time to fill in all their preferences as well but was doubtful of the effectiveness. For example, a nurse mentioned that she felt like every time she carefully selected certain shifts, the planner would shuffle things around in the third round so she never ended up with the schedule she actually wanted. This created frustration and demotivated people in this group to take the time to self-schedule.

Finally, there is a third group of people who work mostly part-time and are flexible. These people do not really care when they have to work as they do not have obligations at home or sports or other activities. These people do not bother filling in the desired schedule so the planner has to assign them shifts in the final third round. This round is for the planner to make some final decisions about over- or under-staffed shifts.

In the group interview on self-scheduling as well as during individual interviews, nurses expressed a need for understanding planning choices. For example, when they communicate a request for a shift off which is not respected in the final schedule or when the planner changes their desired schedule in the third self-scheduling round, nurses would like to get some explanation.

"*The perception of having some control and understanding of why things sometimes cannot work out ... it could be less of something that is "done to you"* (nurse 2)

### 4.2.2 Discussion

In light of the background literature (Section 2.1.4) the main themes discussed in the interviews are new concepts affecting schedule satisfaction. However, most literature focuses on the general concept of job satisfaction whereas this study aims to develop a model for schedule satisfaction only. For job satisfaction, autonomy is an important requirement which can be provided by the implementation of self-scheduling and its flexibility (Koning, 2014). Nonetheless, interview results show that self-scheduling does not necessarily provide this flexibility or autonomy when the scheduling process still requires input from the planner in the third round to ensure a feasible schedule.

The role of the planner in the scheduling process can be viewed as either a type X or type Y manager where type X managers have tight control and provide little autonomy to their employees (Markopoulos, 2016). Type Y managers enable employees by assigning them the responsibility for making decisions such as creating a schedule for the next period. The theoretical framework showed a positive relation between autonomy and motivation to work and a negative relation between supervision and autonomy. Self-scheduling reduces the supervision and gives nurses control over their schedule. On the other hand, it requires nurses to deliver a feasible schedule that meets the capacity requirements. If not, planners take back control in the third round and nurses actually get demotivated as their input and effort can be reverted sometimes without any explanation.

Therefore, autonomy has a positive effect on nurse satisfaction but should be implemented carefully. Assigning nurses more responsibility for the scheduling process requires a sense of responsibility within the team to create a feasible schedule that meets the capacity demand.

The need for an explanation on certain scheduling choices was also mentioned by nurses in the individual interviews. With more options to communicate scheduling wishes, nurses' sense of control (autonomy) increases their satisfaction with the process. However, when wishes cannot be granted due to cover requirements or wishes of colleagues, nurses can get demotivated. Planners could provide nurses with an explanation when they cannot grant a wish to increase nurses' understanding and empathy. Relatedness thus appears in feelings of empathy and understanding towards the team but can be improved by creating more transparency in the process. Increasing nurses' sense of understanding, relatedness, and autonomy then helps to increase motivation and satisfaction with the scheduling process.

Overall, nurses care for the team, their patients, and the work itself. They want to provide quality care but that requires them to have enough time and a healthy work-life balance. The confusion about the reasoning behind the scheduling process can cause frustration. In light of Herzberg's 2-factor theory, work conditions such as proper capacity management and work-life balance for nurses are required hygiene factors. Interview results show that healthy schedules are required for nurses to keep them from leaving the nurse profession. Therefore, the collective labour agreement (2.2) defines a set of scheduling rules. Unfortunately, a lack of transparency in the scheduling process makes nurses view the process as unfair with planners favouring the wishes of some nurses over others.

### 4.2.3 Validity

The validity of the interview results is determined by the definition and operationalization of the concepts. Since satisfaction is a latent variable, it is difficult to make it measurable. Therefore, I used insights from the literature review to design the interview protocol. Also, using In Vivo coding, unexpected variables (that were not part of the operationalization table) will still be coded and included in the results. Validity is evaluated by a critical reflection of the interview results and the results from literature.

### 4.2.4 Reliability

Since this thesis is limited in time, testing the reliability by reproducing the interviews in another hospital is not possible. However, the reliability of the interview results is tested by discussing the results with a group of consultants and 4 account managers. These people work with more hospitals and can assess whether the results are recognisable for other customers. I also designed a survey (Part B, Chapter 4) on scheduling preferences based on the interview results. This survey has been shared with hospitals in The Netherlands and received 300 responses to provide a more reliable view on the scheduling preferences of nurses.

### 4.2.5 Summary - RQ2

Compared to previous literature, the interviews showed a more holistic view of what drives nurses' satisfaction with the scheduling process in the Martini hospital. Based on the interviews, I conclude that nurses value their autonomy and fairness throughout the scheduling process. This section explains both and concludes with a set of functional requirements.

#### 4.2.5.1 Autonomy

Nurses should get more autonomy in the scheduling process. The schedule has a large impact on their personal lives so nurses should get more opportunities to share their wishes, and these should be considered more often. Also, when designing a scheduling system to support planners, planners should also feel a sense of autonomy in making scheduling trade-offs.

By giving nurses more autonomy, we learn what defines a balanced schedule for them given their personal circumstances. This also allows us to be more transparent on the honoring of these requests and in doing so, measuring the fairness of the schedule given all preferences. Compared to the current situation with only limited options for requests, a group of nurses who claim to have "not many wishes" actually have wishes but are currently not able to express them. For example, the wish of full-time nurses to work their shifts consecutively on a weekly basis. Currently, part-time nurses have wishes for specific shifts which often get granted whereas full-time nurses do not have such wishes as they have to work "their hours anyway" but have other types of (structural) preferences.

#### 4.2.5.2 Fairness

Fairness is valued by nurses since they realize that their job comes with an irregular working schedule. Patients require care also outside of (typical) 9-to-5 working days. However, nurses do not want to sense that their schedules are worse than others. For example, working weekends is part of the job but has a big impact on your social life outside of work. Therefore, it is not perceived as fair if a colleague seems to work far fewer weekends than yourself. Most nurses also explained how they are very understanding of personal situations and are happy to cover for a colleague but with a limit since it creates tension with their perception of fairness.

Another example is the number of incidental requests (for a day on/off) nurses communicate to their planner. Most nurses only have a few of such requests a month (0-3). However, nurses explained how colleagues sometimes add requests for almost "every" day of the month to communicate their preferred schedule. It would not be fair for planners to give the same priority to all requests regardless of the number of requests someone communicates. Therefore, the design of the scheduling system should take this into account. For example, by rescaling the priority of requests such that nurses with fewer requests get a higher chance of having their requests met compared to nurses with many requests.

#### 4.2.5.3 Functional requirements

The design of a scheduling optimisation software system should:

- Generate schedules according to labour laws
- Generate a schedule that meets the cover requirements
- Keep nurses happy in the long run (track historical satisfaction scores)
- Divide satisfaction fairly over the team
- Create a sense of autonomy for nurses (allow wishes)
- Collaborate with planners (and nurses), creating a shared meaning of the problem (explainability)
- Be predictable (publish 2-3 months ahead)

# Chapter 5

# Planner's scheduling process

Chapters 2 and 3 explored the nurses' values and drivers of scheduling satisfaction. In this chapter, the scheduling process is explored to study the trade-offs planners consider when making scheduling decisions. Additionally, this chapter studies the acceptance of planners of the optimisation technology.

## 5.1 Theoretical framework

Scheduling nurses requires making many decisions. These decisions can be made by one individual or by a group of planners and, for example, a team manager. The quality of the decisions made is depending on successfully accomplishing five "*Functions of Decision Making*" (Table 5.1).

| Function | Means of Achievement |
|---|---|
| Problem analysis | Focus on the nature, extent, and likely causes of the problem. |
| Determine standards | Identify what an ideal solution would "look like". What are necessities and "nice-to-haves"? |
| Identify alternatives | Generate a large number of possible solutions: Quantity matters more than quality at this point. |
| Evaluate | Evaluate each alternative using the established goals. |
| Select | Based on the evaluation of alternative, group members select the "best" alternative, the one that best fulfills the characteristics and criteria established |

Table 5.1: Five Functions of Decision Making (Dainton and Zelley, 2022)

The group can be supported in these functions by optimisation software. For example, when identifying the set of alternatives. Human brains have a limited capacity whereas the software is designed to generate all possible alternatives within a set of restrictions as fast as possible. Also, the evaluation of these alternatives are simple calculations for a software program if the preferences and goals are established.

When planners collaborate with an optimisation system it could improve the number of alternative schedules considered and save the planner time evaluating these alternative schedules. However, the evaluation of schedules would require participation from the planner which depends on the planner's acceptance of the optimisation technology.

To study the acceptance of technology, two theories have been merged into the Consumer Acceptance of Technology (CAT) model (Figure 5.1). It is a combination of the Technology Acceptance Model (TAM) and the Pleasure, Arousal, and Dominance paradigm of affect (PAD) (Kulviwat et al., 2007). When users perceive the tool as useful, this has a positive effect on their attitude toward adoption which increases the adoption intention. Besides the perceived usefulness, the adoption of new technology also depends on the emotional state of users when they interact with the technology. This emotional state is represented by pleasure, arousal, and dominance as these factors combined can describe the diverse human emotional set of reactions.


Figure 5.1: Consumer Acceptance Technology (Kulviwat et al., 2007)

## 5.2 Methodology

The values of planners driving the scheduling process and acceptance of the optimisation technology is studied by a semi-structured group interview with myself, one ORTEC colleague, and four planners in the Zuyderland hospital located in Sittard, The Netherlands. This hospital is selected based on size and willingness to participate. These planners create the schedules for most of the departments centrally. Central planners create schedules for multiple departments and do not work in the department themselves. Their communication with the department goes through the team-lead.

The interview took place digitally on June 20, 2023. The participating planners were chosen based on availability on this specific day. Semi-structured interviews were chosen to provide the flexibility to ask follow-up questions while also using an interview protocol (Appendix D.1) to provide structure and keep the interview on topic. The interview took 90 minutes. The call was not recorded, instead notes were taken and summarised afterwards to be approved by the participants. The results are grouped based on occurring themes which are then linked to concepts in the theoretical framework.

### 5.2.1 Ethics

Participants are informed about the goals of the research through an information sheet (Appendix D.2) beforehand. All participants have to read and sign this sheet before the start of the interview. If they do not agree, participants withdraw themselves from the study. After the collection of the data, confidential and sensitive data is anonymised.

## 5.3 Results

The four planners each plan for their own list of departments so they do not create schedules in teams but are each responsible for their own list of departments. The planners receive the labour demand and a list of requests from nurses and managers before they start working on the schedule. Schedules are created monthly. When the planner finishes the schedule, it is sent to the team manager for approval. Once approved by the team manager, responsibility for the schedule is transferred to the team manager. Therefore, the planner is not responsible for rescheduling shifts when a nurse calls in sick for example.

### 5.3.1 Evaluating schedule quality

Planners responded that they evaluate the quality of a schedule based on the planned capacity first, and nurse satisfaction second. Of course, all schedules have to adhere to the labour laws and collective labour agreement but personal preferences are not considered a must. A good schedule meets the labour demand and the preferences as best as possible. Additionally, planners find it important to provide fair schedules.

### 5.3.2 Making trade-offs

During the focus group, I also asked the planners how they would like to be informed on potential improvements of the schedule. When making a schedule, planners are constantly making trade-offs. For example, trade-off between meeting the capacity requirement or keeping (everybody) satisfied. The planners were quite clear on their priorities as in Zuyderland the capacity requirement is set as the bare minimum to meet the patient demand. Therefore, they will never sacrifice coverage of this capacity to meet scheduling requests of nurses.

However, many trade-offs are made when trying to meet the preferences of nurse A at the cost of the satisfaction of nurse B. The planners explained how they try their best to keep the schedule fair. To get a fair schedule, they consider the preferences (known through a yearly survey) and a historical indication of satisfaction in the past schedules. For example, imagine nurses A and B who both prefer to work maximum four consecutive days. Due to limitations, you had to schedule nurse A to work five consecutive shifts last month. Now this month, you would rather schedule nurse B to work five consecutive shifts if four is impossible, instead of scheduling nurse A again to maintain fairness.

"*Every month, I try to remember who got a good schedule the previous month and who was unlucky. Then, in the new schedule, I try to compensate the unbalance by giving the previously unlucky nurse some good shifts now.*" *(planner 2)*

### 5.3.3 Working with optimisation system

When asked about the optimisation system within the scheduling software, planners reacted very disappointed and said they tried using it in the past but the results made no sense.

"*The results were to laugh at and we had to redo everything manually. The system does not take into account a lot of specifics like team meetings or preferences that we know nurses value deeply like their weekends off when they have their kids in case of divorced parents.*" *(planner 2)*

To conclude the focus group, we discussed potential useful ways the software could support the scheduling process. Planners were most interested in having a set of quality indicators such as personal preference violations to be calculated automatically per potential schedule of assigned shift. Just like the count of preference violations in one schedule, a historical count of such violations is very difficult for planners to keep in mind when planning schedules for 200+ nurses.

"*It would be really useful if we could select an open shift and get a list of nurses available to work that shift with the satisfaction indicators next to it. Then, I could easily select a nurse based on historical planning and current needs.*" *(planner 4)*

Planners were not interested in a tool that would solve the entire schedule for them as they said they would never trust such a solution and would "always want to check the schedule by hand" (planner 1). However, instead of a complete solution, they would welcome assistance

from an optimisation system to calculate the quality indicators per schedule and help to create an overview of the fairness and quality of the schedule in terms of meeting personal preferences of nurses. Planners want to make the trade-offs themselves but would like to make it with better information on the consequences of their decisions as they involve too many factors to consider all at once.

Based on the CAT model (Figure 5.1), the relative advantage of the functionality is too low for planners to have an intention to adopt the technology. The optimization system is also not causing any emotional responses such as pleasure as it mainly causes frustrations and negative amazement. Since planners described the functionality as "*the button we don't touch*" they could sense some dominance or feeling of superiority. Regarding the perceived ease of use, the case gets interesting as "the button" is very easy to use. A planner only needs to click on the button and the schedule will be optimized. However, in practice this is not as easy since the resulting scheduling only works when all details of the problem are clearly defined and communicated to the system. Currently, planners complain that the "optimized" schedule creates unfair schedules by simply filling in the required shifts working in alphabetical order. Nurse A would always get more shifts than nurse Z.

### 5.3.4 Discussion

Compared to the theoretical framework for nurse satisfaction (Figure 2.3), planners also value their autonomy and competence. Planners want to be in control of the scheduling decisions made and want to understand the process. Therefore, they do not seem to trust the optimization technology as part of the scheduling software provided by ORTEC nor accept it as part of their process.

However, in light of the nurses' interview results, there does not seem to be much emphasis on the communication towards nurses in the planner's process. The need for explanations and transparency is unmet and planners mainly focus on their own task at hand: creating a schedule. As soon as the schedule is finished and published, they hand over responsibility to the team manager. The team manager is in charge of making changes when a nurse calls in sick or people want to trade shifts. However, the team manager cannot explain to a nurse why certain wishes were or were not met.

The self-scheduling process should help to create a shared governance model for participatory decision-making (Anthony, 2004). In light of these results, developing shared governance requires clear definitions of the roles and responsibilities in the scheduling process. For example, who would be responsible for explainability and transparency. With clear roles and responsibilities, autonomy of nurses could be increased by adopting a self-scheduling practice. However, in the current situation in the Zuyderland hospital, the planners create a schedule without direct communication to the nurses as they operate from a planning department that creates schedules for multiple nursing departments.

In light of the theoretical framework presented in this chapter, the planners can clearly express the problem they are solving and the standards they use to determine solution quality.

However, in identifying alternatives, they can get overwhelmed with the number of preferences and requirements they have to take into account and admit that sometimes this can lead to unfair schedules. Nonetheless, they try their best to keep the schedules fair. This is aligned with the need of nurses to receive fair schedules where one can relate to the wishes of colleagues and understand why sometimes requests cannot be met.

However, the use of technology to support the evaluation of alternatives does not lead to arousal or any pleasure in the view of the planners. Instead, they seem to perceive the technology as inadequate and not useful. Therefore, the benefit of working with optimization technology is not used and there is room for improvement by developing a collaboration between planners and such technology. The use of technology could help clarify the trade-offs made during the scheduling process by keeping track of schedule quality for nurse A compared to nurse B. By resulting in such a clear overview, the values fairness and transparency can be integrated in the design of the technology.

#### 5.3.4.1 Validity

The validity of the interview results is determined by the definition and operationalization of the concepts. As the interview with the planners focuses on the identification of the steps in the decision making process and the acceptance of optimization technology, concept definitions can be taken from literature. This helps increase the validity of the results.

#### 5.3.4.2 Reliability

The focus of this thesis is on nurses' schedule satisfaction. These schedules are the results of the scheduling process of the planners. Therefore, this chapter aims to improve understanding of this process and the decisions made by interviews. In part B of this thesis, the use of optimization technology to incorporate nurse preferences in the scheduling process is researched. Therefore, an understanding of the trade-offs made by planners is required. However, due to a small sample of one group of four planners in only one hospital, the reliability of these results would require more research. For example, the interview should be repeated with planners from other hospitals. Nonetheless, the group of four consisted of planners working for different departments.

### 5.3.5 Interpretation - RQ3

Currently, planners explain how they take all personal preferences into account when making a schedule as they are indicators of nurse schedule satisfaction. However, it is easy to imagine that planners lose track of such counts easily when they are in the midst of the scheduling process. Therefore, a software system could take over this cognitive work of keeping track of the indicators per nurse. However, to be adopted by the planners, the system must be designed to be useful and in line with planners' values. Planners do not want to accept a complete schedule solution just because a software system says it is the "optimal" schedule. The system should be explainable and build some trust with the planners that its solutions are indeed in line with the objectives of the planner.

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# Appendix A

# Document review

## A.1 Collective Labour Agreement (FNV, 2022)

zelf of je gehoor geeft aan een verzoek om te komen werken waarbij geldt dat je het aantal uren dat je op kalenderjaarbasis hebt afgesproken ook daadwerkelijk moet werken.
2. Je kunt aangeven wanneer je beschikbaar bent om te werken en waar je wordt ingezet.
3. Je salaris op basis van het aantal afgesproken uren op jaarbasis, wordt in 12-maandelijkse termijnen en onafhankelijk van het aantal uren dat je die maand hebt gewerkt, aan je uitbetaald.
4. Artikelen 3.1. en 3.2. zijn niet van toepassing op de regie-arbeidsovereenkomst. Voor het overige zijn alle bepalingen in deze cao op je regie-arbeidsovereenkomst van toepassing.
5. Als je je regie-arbeidsovereenkomst wilt aanpassen naar een arbeidsovereenkomst met een gemiddelde arbeidsduur per week zoals bedoeld in artikel 3.1., dan is dat mogelijk. Zodra er sprake is van een vacature of uitbreiding van de formatie, zal je werkgever een dergelijk verzoek honoreren.

Binnen een organisatie mag maximaal 10% van het aantal medewerkers werkzaam zijn op basis van een regie-arbeidsovereenkomst.

## Hoofdstuk 3 HEB JE TIJD

***Over arbeidsduur, werktijden en roosters, min-, plus-, meer-uren en overwerk***

**Wat is de bedoeling**
Over werktijden en roosters wordt veel en vaak gesproken in organisaties. Met deze cao willen we het mogelijk maken om goede en evenwichtige roosters vorm te geven .
Er is sprake van een evenwichtig rooster als:
- werktijden voorspelbaar zijn;
- er voldoende rust- en hersteltijd is opgenomen;
- te sterke veranderingen in het rooster voorkomen worden;
- er sprake is van een goede balans tussen werk en privé;
- sprake is van een balans tussen belastbaarheid en belasting.

Evenwichtige roosters dragen bij aan het verminderen van de ervaren werkdruk.

Werkgevers en vakbonden vinden het belangrijk om medewerkers en teams maximaal invloed en zeggenschap te geven op hoe werktijden en roosters vorm worden gegeven. Een goede digitale omgeving kan daarbij behulpzaam zijn .

In dit hoofdstuk is een aantal kaders en uitgangspunten opgenomen waar minimaal aan voldaan moet worden. Deze kaders en uitgangspunten moeten medewerkers voldoende invloed en bescherming bieden en moeten tegelijkertijd de werkgever in staat stellen om de continuïteit in de zorgverlening zo optimaal als mogelijk is te waarborgen.

### 3.1 De gemiddelde arbeidsduur – per 1 april 2022

1. De arbeidsduur die je met je werkgever overeenkomt, wordt uitgedrukt in een gemiddeld aantal uur per week gemeten over een periode van een kalenderjaar, tenzij je gebruik maakt van de mogelijkheid om dit per kwartaal te meten. Als je hiervan gebruik maakt, worden ook min-, plus-, en meer-uren aan het eind van het kwartaal afgerekend.
2. Bij een fulltime dienstverband bedraagt de gemiddelde arbeidsduur 36 uur per week. Het is mogelijk om een hogere gemiddelde arbeidsduur af te spreken, waarbij een maximum geldt van gemiddeld 40 uur per week.
3. Je werkgever geeft je tenminste elk kwartaal een overzicht, waaruit blijkt of je meer of minder hebt gewerkt dan jouw gemiddelde arbeidsduur. Het overzicht biedt de basis voor overleg tussen jou en je werkgever.

### 3.2 Kader voor vormgeven werktijden en roosters – per 1 april 2022

1. De volgende bepalingen moeten tenminste in acht worden genomen bij het vormgeven van werktijden en roosters:
   - Tenminste 28 dagen van tevoren wordt je rooster en daarbij behorende werktijden vastgesteld en aan jou bekend gemaakt. Wijzigingen binnen een periode van 28 dagen kunnen alleen worden aangebracht als jij daarmee instemt.

- Als je gebruik maakt van de mogelijkheid om de overeengekomen arbeidsduur per kwartaal te meten, dan heb je het recht om binnen deze periode voor 100% te worden ingeroosterd op grond van het gemiddeld aantal overeengekomen uren van je arbeidsovereenkomst. (bijvoorbeeld je hebt een contract met een gemiddelde omvang van 24 uur per week, dan moet je in staat worden gesteld om in een periode van een kwartaal 13x24 uur = 312 uur te worden ingeroosterd).
- Als je in een periode van een week (maandag t/m zondag) kan worden ingeroosterd, dan heb je het recht om een doordeweekse dag (maandag t/m vrijdag) aan te wijzen als je vaste vrije dag (etmaal). Op deze dag kun je niet ingeroosterd worden, tenzij je daar zelf mee instemt.
- In een periode van een week (maandag t/m zondag) kun je maximaal 5 dagen ingeroosterd worden, tenzij je ermee instemt dat je meerdere dagen ingeroosterd wordt.
- Je hebt het recht om niet bereikbaar te zijn buiten de werktijden, waarop je bent ingeroosterd.
- Je werkt niet langer dan 10 uur per dienst. Alleen in situaties, waarin sprake is van een onvoorziene en incidentele wijziging van de omstandigheden of op jouw uitdrukkelijke verzoek bij terminale zorg, kan dit worden uitgebreid naar maximaal 12 uur per dienst.
- Als je 55 jaar of ouder bent, word je niet ingeroosterd voor een nacht-, bereikbaarheids-, consignatie-, slaap- of aanwezigheidsdienst tussen 23.00 en 07.00 uur, tenzij je daar geen bezwaar tegen hebt.

2. Je werkgever maakt voor het vaststellen van de werktijden gebruik van de mogelijkheden die de Arbeidstijdenwet (Stb. 1995, 598, laatstelijk gewijzigd Stb. 2021, 592) en het daarop gebaseerde Arbeidstijdenbesluit (Stb. 1995, nr. 599, laatstelijk gewijzigd Stb. 2018, nr. 404) bieden, tenzij in deze cao iets anders is bepaald. De bepalingen in de Arbeidstijdenwet en het Arbeidstijdenbesluit gelden voor medewerkers vanaf 18 jaar. Voor medewerkers jonger dan 18 jaar past je werkgever de Arbeidstijdenwet of de Nadere Regeling Kinderarbeid toe.

### 3.3 Werktijden bepaal je zelf in overleg met je team – per 1 april 2022

*(In de voorgaande cao's stond dit artikel bekend onder de naam "Kanteling Werktijden")*

1. Je werkgever is verantwoordelijk voor evenwichtige roosters binnen de organisatie. Uitgangspunt is dat je in staat wordt gesteld om, in overleg met je team en/of je directe collega's, zelf invulling te geven aan het rooster en je werktijden. Diensten die niet door medewerkers zelf zijn ingevuld worden door de werkgever ingevuld met inachtneming van het kader zoals verwoord in artikel 3.2.
2. Tussen je werkgever en de ondernemingsraad of personeelsvertegenwoordiging worden spelregels afgesproken over hoe moet worden omgegaan met:
   - Concurrerende wensen en behoeften van teamleden.
   - Het vaststellen van de personele behoefte die nodig is om de gewenste zorg te kunnen leveren.
   - Hoe te komen tot een redelijke verdeling van lusten en lasten rond de werktijden binnen het team.
   - Hoe de continuïteit van de zorgverlening kan worden gewaarborgd.
   - Een roosterperiode kan bijvoorbeeld bestaan uit een periode van: vier weken, kwartaal of kalenderjaar.

### 3.4 Pauzes, hersteltijd en vrije weekenden – per 1 april 2022

1. Per ochtend, middag, avond of nacht kun je eenmaal gebruik maken van een koffie/theepauze. Als deze pauze korter is dan 15 minuten, dan behoort de pauze tot je werktijd.
   Als de pauze 15 minuten of langer duurt is het eigen tijd. Voorwaarde daarbij is dat je niet gestoord wordt in je pauze. Als je in je pauze wel opgeroepen kunt worden, dan wordt de pauze beschouwd als werktijd. Een koffie- en theepauze is aanvullend op de pauze als bedoeld in de ATW.
2. Bij het vaststellen van het rooster en de voor jou geldende werktijden moet je werkgever in elke aaneengesloten periode van 7x24 uur een onafgebroken rust– en hersteltijd van tenminste 36 uur toepassen of in een aaneengesloten periode van 9x24 uur tenminste 60 uur rust- en hersteltijd.
3. Je bent jaarlijks in ieder geval 22 weekenden vrij. Alleen op jouw verzoek kan dit worden teruggebracht tot minimaal 17 weekenden. Deze weekenden zijn exclusief de weekenden in je ingeroosterde vakantie.
   Als je uitsluitend werkzaam bent in de weekenden kun je je werkgever verzoeken afwijkende afspraken te maken over het aantal vrije weekenden.

### 3.5 Maximum aantal nachtdiensten – per 1 april 2022

Als je meer dan één uur tussen 00.00 en 06.00 uur werkt, dan is er sprake van een nachtdienst. De volgende bepalingen gelden dan voor jou:

- je mag maximaal vijf achtereenvolgende nachtdiensten werkzaam zijn, tenzij je met je werkgever overeenkomt meer nachtdiensten te werken met een maximum van zeven aaneengesloten nachtdiensten.
- De minimale rusttijd na een reeks van 3 of meer nachtdiensten bedraagt 46 uur.
- Je mag niet meer dan 35 nachtdiensten werken in een periode van 13 weken.
- In elke periode van 13 weken mag je niet meer dan gemiddeld 40 uur per week werken.
- Je mag maximaal 9 uur in een nachtdienst werken, tenzij er sprake is van een incidentele onvoorziene wijziging van de omstandigheden. In dat geval mag je maximaal 10 uur per nachtdienst werken.

### 3.6 Wat zijn min-uren – per 1 april 2022

1. Er is sprake van een of meerdere min-uren als je in een bepaalde week minder werkt, dan je in je arbeidsovereenkomst hebt afgesproken.
   Er kunnen verschillende redenen zijn om minder uren te werken dan je hebt afgesproken in je arbeidsovereenkomst. De volgende redenen komen het meest voor:
   a. je verzoekt je werkgever zelf om in een bepaald tijdvak minder uren te werken of ingeroosterd te worden, dan je hebt afgesproken in je arbeidsovereenkomst. In dat geval geldt dat:
      - je dan gelijktijdig afspreekt op welk moment in het kalenderjaar of kwartaal (afhankelijk van je keuze in artikel 3.1) je beschikbaar bent om deze uren te werken of ingeroosterd te worden. Je werkgever stelt je daartoe ook in staat.
      - Mocht het niet lukken de uren in het kalenderjaar/kwartaal (afhankelijk van je keuze in artikel 3.1) in te halen, dan moeten de min-uren, die op jouw verzoek van zijn ontstaan, in het daaropvolgende kalenderjaar/kwartaal worden ingehaald.
   b. Je werkgever verzoekt je om in een bepaalde periode minder uren te werken en/of roostert je na overleg minder in, dan je hebt afgesproken in je arbeidsovereenkomst. In dat geval geldt dat:
      - je werkgever dan verantwoordelijk is, om ervoor te zorgen dat je binnen het kalenderjaar/kwartaal (afhankelijk van je keuze in artikel 3.1) de uren kunt werken die je hebt afgesproken.
      - Als je werkgever je daartoe niet in staat stelt, vervallen de min-uren aan het eind van het kalenderjaar/kwartaal (afhankelijk van je keuze in artikel 3.1).
   c. Als je niet kunt werken, omdat de cliënt niet aanwezig is, is je werkgever ervoor verantwoordelijk om je vervangend werk aan te bieden. Lukt dat niet, dan gelden de niet gewerkte uren als werkuren. Het is je werkgever niet toegestaan om min-uren te schrijven als gevolg van het feit dat een cliënt niet aanwezig is. Een zogenaamde ‘no-show’ is voor rekening en risico van je werkgever.
2. Alleen op jouw verzoek kunnen je min-uren worden verrekend met je vakantie-uren.

### 3.7. Wat zijn plus-uren – per 1 april 2022

1. Er is sprake van plus–uren als je in een week meer werkt dan het aantal uren dat je in je arbeidsovereenkomst hebt afgesproken.
2. Als regel worden plus-uren op een ander moment in het kalenderjaar/kwartaal (afhankelijk van je keuze in artikel 3.1) gecompenseerd in tijd waardoor je aan het eind van het kalenderjaar/kwartaal het gemiddeld aantal uren hebt gewerkt dat is afgesproken in je arbeidsovereenkomst.
3. Als plus-uren niet (kunnen) worden gecompenseerd in tijd in het kalenderjaar/kwartaal (afhankelijk van je keuze in artikel 3.1) worden het meer-uren, zoals bedoeld in artikel 3.8. Ook tussentijds (afhankelijk van je keuze in artikel 3.1) kun je met je werkgever afspreken dat plus-uren beschouwd moeten worden als meer-uren.

# Appendix B

# Literature review

## B.1 PRISMA Flow Chart

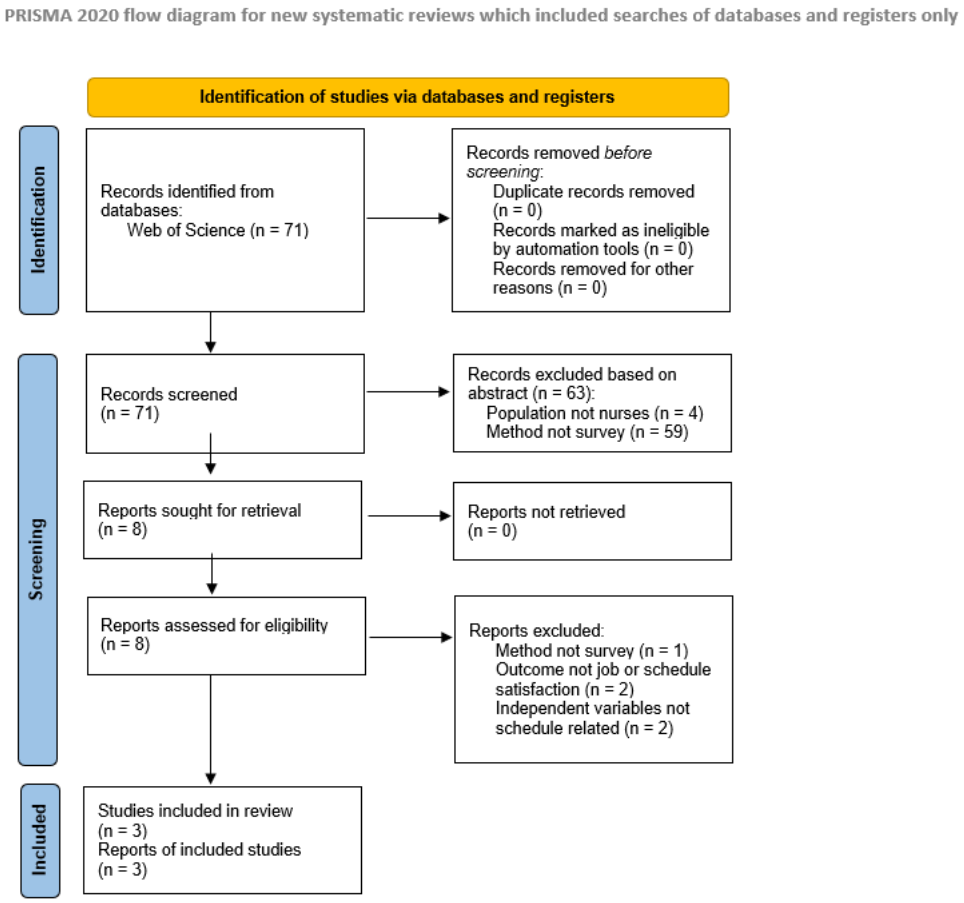


Figure B.1: PRISMA flow chart describing search process for literature review

## B.2 Data extraction protocol

**Selection criteria**
Articles are screened by reading the abstract and checking these selection criteria:

- Is the method applied a survey?
- Is the population a group of nurses? Country does not matter but midwives, social workers, physicians or other non-nurses groups should be excluded.
- Is the outcome variable job satisfaction or another metric of nurse (schedule) satisfaction?
- Is the dependent variable related to scheduling decisions?

**Data extraction**
While reading the selected articles in full, data is collected on the following variables:

- Method (survey design, method of distribution)
- Population (geography, sample size, sampling method)
- Dependent variable (operationalization)
- Independent variable (operationalization)
- Results (statistical significance)
- Quality (risks and limitations)

# Appendix C

# Interview nurses

## C.1 Interview Protocol

- Welkom en bedanken voor deelnemen
- Korte samenvatting van doel van onderzoek
  - Ik ben vandaag bezig met gesprekken over het roosteren binnen jullie afdeling voor mijn afstudeeronderzoek. Het doel van mijn onderzoek is het beter begrijpen van het roosterproces en het verwerken van persoonlijke voorkeuren van verpleegkundigen. Met de uitkomsten van deze interviews, ga ik onderzoeken hoe we het roosterproces kunnen aanpassen om meer rekening te houden met de wensen van verpleegkundigen. Vandaag probeer ik daarom beter te begrijpen wat belangrijk is aan een rooster en wat verbeterd kan worden wat betreft communicatie tussen planners en verpleegkundigen.
- Akkoord met opname audio
  - Ik zou dit gesprek graag willen opnemen, zodat ik het later kan analyseren en bijvoorbeeld quotes kan gebruiken in mijn onderzoek. De opname zal worden getranscribeerd (opgeschreven) en geanonimiseerd, daarna verwijder ik de opname. De transcripties blijven maximaal een jaar opgeslagen en dan ook verwijderd. Je hebt altijd het recht om teksten terug te lezen, aan te passen of te laten verwijderen. Ga je akkoord met een audio-opname van dit gesprek?
- Als nog niet getekend: toestemmingsformulier
  - Mocht je het nog niet getekend hebben, zou je dit formulier willen lezen en tekenen om toestemming te geven voor het verzamelen en gebruiken van de dit interview?

**Introductie vragen (3 min)**

- Je werkt als verpleegkundige op de afdeling X, klopt dat?
- Hoe lang werk je al als verpleegkundige?

- Werk je al die tijd bij dit ziekenhuis en/of op deze afdeling?

**Roosterproces vragen (5 min)**

- In hoeverre ben je betrokken bij het roosterproces?
- In hoeverre ben je tevreden met het roosterproces?
- Gebruiken jullie zelfroosteren? Zo ja, vind je dit een verbetering t.o.v. een centrale planner?

**Communicatie van voorkeuren (5 min)**

- Hoe bespreek je je roostervoorkeuren met de planners (andersom als persoon planner is)?
- Hoe vind je dat er wordt omgegaan met voorkeuren van verpleegkundigen?
- Heb je het idee dat deze voorkeuren worden meegenomen bij het maken van een rooster?
- In hoeverre heb je het gevoel dat je inspraak hebt op je rooster?

**Roostervoorkeur vragen (6 min)**

- Hoe ver van tevoren zou je je rooster graag willen vastleggen?
- In hoeverre heeft de voorspelbaarheid van een rooster effect op je tevredenheid?
- Hoe speelt de werkdruk/belasting een rol binnen je roostervoorkeuren?
- Krijg je over het algemeen voldoende rust tussen je diensten door om bij te komen?
- Hoeveel rust zou je willen hebben tussen diensten?
- Zijn er nog andere factoren die je rooster tevredenheid bepalen?

**Toekomst vs. nu (5 min)**

- Zou je kunnen omschrijven wat jouw ideale roosterproces zou zijn?
- Kun je de huidige situatie in één woord, beeld of gevoel omschrijven?

**Afsluiting (3 min)**

- Bedankt voor je medewerking en antwoorden, ik ga ermee aan de slag!
- Zijn er nog laatste ideeën, meningen of opmerkingen die je kwijt wilt?
- Nogmaals bedankt en fijne dag!

## C.2 Informed consent form

## Informatie over de studie

Deze interviews zijn onderdeel van mijn afstudeeronderzoek naar de roostervoorkeuren onder verpleegkundigen. Het doel van mijn onderzoek is het beter begrijpen van deze voorkeuren, zodat we de roostersoftware hier beter leren rekening mee te houden. Daarbij zoek ik vooral naar verschillen in voorkeuren, zodat we het rooster beter kunnen aansluiten daarop zonder anderen slechter af te maken. De interview vragen zijn vooral hierop gericht naast algemene vragen over het roosterproces.

Je kunt op elk moment beslissen je terug te trekken uit het onderzoek. Tijdens het interview worden aantekeningen gemaakt en wordt het met audio opgenomen. De opname van het interview wordt getranscribeerd en daarna verwijderd. Persoonlijke informatie wordt geanonimiseerd en de transcripties worden opgeslagen tot juli 2023. De deelnemer kan toegang vragen tot de opnames, aantekeningen of transcripties van zijn interview en vragen om rectificatie of verwijdering van persoonsgegevens. Publicatie van de gegevens zal alleen gebeuren met toestemming van de geanonimiseerde deelnemers.

Eind juni 2023 moet het onderzoek zijn afgerond. Mocht er vervolgonderzoek komen, worden de deelnemers gecontacteerd om toestemming te vragen om de verzamelde gegevens te gebruiken voor verder onderzoek. Voor vragen of opmerkingen kun je te allen tijde contact met mij opnemen via eva.vanrooijen@ortec.com

## Toestemmingsformulier interviews

| *Vink de juiste vakjes aan* | **Ja** | **Nee** |
|---|---|---|
| **Deelname aan het onderzoek** | | |
| Ik heb de informatie over de studie (gedateerd 27/02/2023) gelezen en begrepen, of werd mij voorgelezen. Ik heb vragen kunnen stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord. | □ | □ |
| Ik stem er vrijwillig mee in om deel te nemen aan dit onderzoek, met dien verstande dat deelname inhoudt dat ik vragen van de geïnterviewde beantwoordt en dat ik kan weigeren vragen te beantwoorden en me op elk moment kan terugtrekken uit het onderzoek, zonder dat ik daarvoor een reden hoef op te geven. | □ | □ |
| Ik ben me ervan bewust dat ik (de geïnterviewde) zal worden opgenomen met audio, inclusief schriftelijke aantekeningen, maar deze zullen niet worden gedeeld met anderen dan de interviewer zelf. Deze opnames en aantekeningen worden na afloop van het onderzoek (30 juni) verwijderd, tenzij deze nodig zijn voor verder onderzoek. | □ | □ |

*z.o.z.*

**Gebruik van de informatie in het onderzoek**

| | | |
|---|---|---|
| Ik begrijp dat de informatie die ik verstrek zal worden gebruikt ten behoeve van het onderzoek. Ik begrijp dat de resultaten kunnen worden gebruikt voor wetenschappelijke publicaties en dat deze resultaten kunnen worden gebruikt voor kennisdeling. | □ | □ |
| Ik begrijp dat persoonlijke informatie die over mij is verzameld en die mij kan identificeren, zoals bijvoorbeeld mijn naam, niet zal worden gedeeld met anderen. | □ | □ |
| Ik ga ermee akkoord dat mijn informatie anoniem kan worden vermeld in onderzoeksresultaten | □ | □ |

**Toekomstig gebruik en hergebruik van de informatie door anderen**

| | | |
|---|---|---|
| Ik geef toestemming om de audio--opnamen, tijdelijk lokaal op een pc te archiveren totdat ze zijn getranscribeerd en geanonimiseerd, waarna de opnames worden verwijderd. | □ | □ |
| Ik geef toestemming om het geanonimiseerde transcript van de opname tijdelijk te archiveren, zodat het kan worden gebruikt voor toekomstig onderzoek. | □ | □ |

**Handtekeningen**

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Ik heb het informatieblad nauwkeurig laten lezen (voorgelezen) aan de potentiële deelnemer en, naar mijn beste vermogen, ervoor gezorgd dat de deelnemer begrijpt waar hij vrijwillig mee instemt.

| _____ | _____ | _____ |
|---|---|---|
| Eva van Rooijen | Handtekening | Datum |

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# Appendix D

# Interview planners

## D.1 Interview Protocol

- Welkom en bedanken voor deelnemen
- Korte samenvatting van doel van onderzoek
  - Ik heb de afgelopen tijd onderzoek gedaan naar de voorkeuren van verpleegkundigen en hoe die worden meegenomen met het maken van roosters. Het doel van mijn onderzoek is het beter begrijpen van het roosterproces en het verwerken van persoonlijke voorkeuren van verpleegkundigen. Met de uitkomsten van deze interviews, ga ik onderzoeken hoe we het roosterproces kunnen aanpassen om meer rekening te houden met de wensen van verpleegkundigen. Vandaag probeer ik daarom beter te begrijpen hoe jullie keuzes maken tijdens het roosteren en wat daarin jullie afwegingen zijn. Daarnaast ben ik benieuwd naar jullie ervaringen met de Optimizer binnen OWS.
- Als nog niet getekend: toestemmingsformulier
  - Mocht je het nog niet getekend hebben, zou je dit formulier willen lezen en tekenen om toestemming te geven voor het verzamelen en gebruiken van de dit interview?

**Introductie vragen (5 min)**

- Voor hoeveel afdelingen maken jullie roosters? Hoe ver vooruit maken jullie roosters?
- Hoe lang werken jullie al als planner bij dit ziekenhuis?

**Meten van roosterkwaliteit (5 min)**

- Hoe bepalen jullie de kwaliteit van een rooster?
- Welke roostervoorkeuren neem je mee in overweging?
- Hoe kijken jullie naar een eerlijke verdeling van de werklast?

**Het maken van afwegingen (5 min)**

- Hoe maken jullie afwegingen in personeelsvoorkeuren t.o.v. van bezettingseisen?
- Wegen sommige type voorkeuren zwaarder dan anderen?
- Zijn er persoonlijke factoren die effect hebben op jullie afweging?

**Werken met OWS tijdens roosteren (5 min)**

- Hoe is het werken met OWS? indicatoren?
- Zou je kunnen omschrijven wat jouw ideale roosterproces zou zijn?
- Kun je de huidige situatie in één woord, beeld of gevoel omschrijven?

**Werken met OWS Optimizer (5 min)**

- Wat vind je van de kwaliteit van de roosters die OWS produceert? Zijn ze nuttig?
- Wat vind je van de manier waarop OWS de kwaliteit van een rooster bepaalt?
- Helpt het je bij het maken van afwegingen als je roosters aan het maken bent?
- Kan het helpen met overzichtelijk maken van tevredenheids- (kwaliteit) indicatoren?

**Afsluiting (3 min)**

- Bedankt voor jullie medewerking en antwoorden, ik ga ermee aan de slag!
- Nogmaals bedankt en fijne dag!

## D.2 Informed consent form

## Informatie over de studie

Dit interview is onderdeel van mijn afstudeeronderzoek naar de roostervoorkeuren onder verpleegkundigen. Het doel van mijn onderzoek is het beter begrijpen van deze voorkeuren, zodat we de roostersoftware hier beter leren rekening mee te houden. Daarbij zoek ik vooral naar verschillen in voorkeuren, zodat we het rooster beter kunnen aansluiten daarop zonder anderen slechter af te maken. Ik heb hiervoor interviews afgenomen met verpleegkundigen en ben in dit interview voornamelijk geïnteresseerd in de afwegingen van planners in het meenemen van deze voorkeuren.

Je kunt op elk moment beslissen je terug te trekken uit het onderzoek. Tijdens het interview worden aantekeningen gemaakt. Na afloop van het interview stuur ik jullie een samenvatting van deze aantekeningen ter goedkeuring. De aantekeningen bevatten geen persoonlijke informatie en zullen worden bewaard tot juli 2023. Iedere deelnemer kan toegang vragen tot de aantekeningen en vragen om rectificatie of verwijdering van gegevens. Publicatie van de gegevens zal alleen gebeuren met toestemming van de geanonimiseerde deelnemers.

Eind juni 2023 moet het onderzoek zijn afgerond. Mocht er vervolgonderzoek komen, worden de deelnemers gecontacteerd om toestemming te vragen om de verzamelde gegevens te gebruiken voor verder onderzoek. Voor vragen of opmerkingen kun je te allen tijde contact met mij opnemen via eva.vanrooijen@ortec.com

## Toestemmingsformulier interviews

| *Vink de juiste vakjes aan* | **Ja** | **Nee** |
|---|---|---|
| **Deelname aan het onderzoek** | | |
| Ik heb de informatie over de studie (gedateerd 27/02/2023) gelezen en begrepen, of werd mij voorgelezen. Ik heb vragen kunnen stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord. | □ | □ |
| Ik stem er vrijwillig mee in om deel te nemen aan dit onderzoek, met dien verstande dat deelname inhoudt dat ik vragen van de geïnterviewde beantwoordt en dat ik kan weigeren vragen te beantwoorden en me op elk moment kan terugtrekken uit het onderzoek, zonder dat ik daarvoor een reden hoef op te geven. | □ | □ |
| Ik ben me ervan bewust dat er tijdens het interview aantekening zullen worden gemaakt, maar deze zullen niet worden gedeeld met anderen dan de interviewer zelf. Deze aantekeningen worden na afloop van het onderzoek (30 juni) verwijderd, tenzij deze nodig zijn voor verder onderzoek. | □ | □ |

*z.o.z.*

**Gebruik van de informatie in het onderzoek**

| | | |
|---|---|---|
| Ik begrijp dat de informatie die ik verstrek zal worden gebruikt ten behoeve van het onderzoek. Ik begrijp dat de resultaten kunnen worden gebruikt voor wetenschappelijke publicaties en dat deze resultaten kunnen worden gebruikt voor kennisdeling. | □ | □ |
| Ik begrijp dat persoonlijke informatie die over mij is verzameld en die mij kan identificeren, zoals bijvoorbeeld mijn naam, niet zal worden gedeeld met anderen. | □ | □ |
| Ik ga ermee akkoord dat mijn informatie anoniem kan worden vermeld in onderzoeksresultaten | □ | □ |

**Toekomstig gebruik en hergebruik van de informatie door anderen**

| | | |
|---|---|---|
| Ik geef toestemming om de aantekeningen, tijdelijk lokaal op een pc te archiveren totdat ze zijn samengevat en goedgekeurd, waarna de aantekeningen worden verwijderd. | □ | □ |
| Ik geef toestemming om de samenvatting van het interview tijdelijk te archiveren, zodat het kan worden gebruikt voor toekomstig onderzoek. | □ | □ |

**Handtekeningen**

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| Naam | Handtekening | Datum |

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| _____ | _____ | _____ |
|---|---|---|
| Eva van Rooijen | Handtekening | Datum |

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Erasmus University Rotterdam
Erasmus School of Economics
Master Thesis Econometrics and Management Science

# Incorporating nurse preferences in the Nurse Scheduling Problem

Eva van Rooijen (443081)

| | |
|---|---|
| Supervisor: | dr. Twan Dollevoet |
| Second assessor: | dr. Wilco van den Heuvel |
| Date final version: | 8th November 2023 |

**Abstract**

A recent study in The Netherlands, reports an expected shortage of 140,000 healthcare employees by 2031. Two main reasons for this shortage are an increased demand for healthcare and a shortage on the healthcare labour market. The irregular shifts and unconventional working hours make nurses quit their profession or refrain others from applying. This thesis explores the effect of scheduling decisions on job satisfaction of nurses in Dutch hospitals. Applying mathematical optimization, we examine if nurse satisfaction can be improved and at what cost.

Incorporating results from interviews and a survey, this thesis presents a formulation of the nurse scheduling problem including both capacity coverage and nurse satisfaction in the problem's objective. The problem is solved using an exact (mixed integer programming) approach and a heuristic based on a Variable Neighbourhood Search approach. Using benchmark instances for the nurse scheduling problem, results show that nurse satisfaction can be improved at no cost of capacity coverage. Since these results are based on only simulated preferences, the thesis ends with some suggestions for further research.

*Keywords:* nurse scheduling problem; schedule satisfaction; nurse job satisfaction; mathematical programming; variable neighbourhood search

# Part B

# Contents

# Chapter 1

# Introduction

A recent study in The Netherlands, reports an expected shortage of 140,000 healthcare employees by 2031. Two main reasons for this shortage are an increased demand for healthcare by a growing elderly population and a shortage in the healthcare labor market. Based on this study, the Dutch ministry of Long term Healthcare assigns high priority to the development of policy to increase the attractiveness of healthcare work (Algemene Zaken, 2022). Nursing schedules are one aspect of such healthcare work attractiveness.

Nurses are often required to work irregular shifts such as night shifts and working on weekends. However, the conventional approaches to scheduling often neglect the impact on nurses' well-being and job satisfaction, potentially leading to burnout, reduced productivity, and increased turnover rates. Nurses play a critical role in delivering high-quality care and ensuring patient well-being. The creation of balanced and healthy nursing schedules is therefore important to maintain a well-functioning healthcare system.

## 1.1 Crew satisfaction in scheduling problems

The Nurse Scheduling Problem (NSP) is a well-known problem in operations research regarding the scheduling of nurses. The problem recurs every planning cycle and requires decisions on the trade-off between minimizing total costs, maximizing crew satisfaction and ensuring a fair distribution of the workload (Legrain et.al, 2015). Planners ideally take all these objectives into account. However, besides the total costs of a schedule, its fairness and satisfaction are more difficult to measure. The attractiveness of a schedule is based on an employee's personal preferences.

For example, someone might enjoy working all of their shifts back-to-back whereas another person might prefer to split them evenly throughout the month. With this thesis, we explore the trade-offs planners make between nurse schedule satisfaction and capacity coverage. We aim to reformulate the nurse scheduling problem such that we maximise satisfaction of nurses (fairly) while still minimising the number of unassigned shifts.

The incorporation of employee input has been used in the scheduling of railway employees as a solution to a massive strike in The Netherlands (Abbink et al., 2005). Research was done through focus groups and interviews into the requirements of the employees. At the same time, using a parallel approach, operations research methods were applied to add these new requirements to the existing crew scheduling solution approach.

The aim of this research is to provide insights into the effects of including crew satisfaction in the nurse scheduling problem. First, indicators of this satisfaction are explored through a survey. Second, given the results of the survey, nurse schedule satisfaction is formulated mathematically. Finally, using this formulation of nurse satisfaction, experiments are done to gain insight into the effect of including crew satisfaction on crew satisfaction levels and a trade-off between crew satisfaction and capacity coverage on the workfloor.

## 1.2 Research questions

The main research question used in this thesis is:

**What is the effect of incorporating nurses' personal scheduling preferences into the Nurse Scheduling Problem?**

To answer this question, the following sub-questions are considered throughout this thesis:

RQ1. What scheduling preferences can be used to measure (indicate) nurse schedule satisfaction?

RQ2. How can these preferences be translated using the decision variables in the nurse scheduling problem's mathematical formulation?

RQ3. What is the effect of including crew satisfaction in the objective function compared to only optimizing for capacity requirements?

RQ4. What is the trade-off between coverage and crew satisfaction in optimal schedules?

## 1.3 Contributions

Improving the satisfaction of nurses is important for society as retention is a large problem in the healthcare sector. By improving nurses' schedule satisfaction, we aim to improve their overall job satisfaction and keep them happily employed in the healthcare sector.

Also, since we are confronted with a growing number of applications of optimisation software in our daily (professional) lives, these systems should be adapted to our users' needs. When designing such systems, it is important to discuss the design of the system and what it actually optimises for. Originally, we might only care about minimising costs or maximising efficiency but social factors such as the well-being of employees and the environmental effect of business processes should be measured too. With this thesis, we aim to present a framework for incorporating such "soft" factors into a mathematical optimisation model.

Additionally, previous research on the optimisation of crew satisfaction has mainly taken a (personalised) satisfaction function as given (Bard and Purnomo, 2005; Dowsland, 1998). Here, satisfaction is taken as a sum of penalties assigned per nurse per schedule to get satisfaction scores for all possible schedules. However, the definition of the penalties or calculation of the actual score is not part of the research. Therefore, this thesis connects survey results on nurse scheduling preferences with the formulation of a satisfaction function in terms of the decision variables used in the mathematical (IP) formulation.

## 1.4 Overview

The remainder of this thesis is structured as follows. Chapter 2 presents an overview of related research on the incorporation of nurse schedule satisfaction in the nurse scheduling problem. Chapter 3 describes the scheduling problem in more detail and introduces benchmark problem instances. Chapter 4 aims to answer the first research questions using a survey on nurse scheduling preferences. Chapter 5 presents the mathematical formulation of the problem and explains the formula used for schedule satisfaction. Chapter 6 describes an exact solution method and heuristic to solve the formulated problem. Chapter 7 presents computational results of both of these solution approaches used to solve the benchmark problem instances. The thesis is concluded in Chapter 8.

# Chapter 2

# Related literature

This chapter reviews literature on the nurse scheduling problem and the optimisation of crew satisfaction. First, it describes different approaches to including and measuring crew satisfaction (fairly) in the mathematical formulation of the optimisation's objective. Second, approaches to solving the nurse scheduling problem are described.

## 2.1 Formulations of crew satisfaction

Social sciences research on nurse job satisfaction focuses more on factors such as salary rather than scheduling. However, scheduling has a large effect on nurses' personal lives and work-life balance. It determines the amount of rest nurses get between work and affects their perceived workload. In order to keep nurses healthy, not burned-out, their personal scheduling preferences should be incorporated in the scheduling process (Bergh et al., 2013; Al Maqbali, 2015).

### 2.1.1 Measuring crew satisfaction

Related literature on the incorporation of nurse schedule satisfaction into a mathematical formulation of the Nurse Scheduling Problem (NSP) started with studies by Warner (1976) and Miller et al. (1976). Warner (1976) presents a set of questions to gather input from nurses on their personal scheduling preferences. For example, nurses are asked to divide penalty points over a set of unpreferable components of a schedule (such as having only one day off in between blocks). Other research also uses penalty points per violation to incorporate nurse preference in the NSP formulation (Burke et al., 2001b; Randhawa and Sitompul, 1993).

Most recent OR research on nurse satisfaction, however, seems to assume a certain variable can be used to measure individual schedule satisfaction but does not cover the actual calculation of this variable (Bard and Purnomo, 2005; Dowsland, 1998). Also, most other studies generalise the scheduling preferences on a group or department level. This ignores the presence of personal preferences and differences among nurses. Previous research showed that nurses can differ substantially in their preferences (Rooijen, 2023). In practice, not only the preferences differ among nurses but also the priorities. For example, nurses might have a preference for two aspects of the schedule: workload division and requests for incidental day offs. Nurse A finds the work-

load division relative to incidental requests off much more important than nurse B. Therefore, we should not only focus on generalised scheduling preferences but make the formulation of a satisfaction score flexible such that it allows for differences among nurses.

Incorporating the (individual) preferences of workers is also relevant for scheduling problems in other sectors. Besides healthcare, the railway planning in The Netherlands is studying the soft preferences of their crew since a national strike (Abbink et al., 2005). Negotiations led to a new set of scheduling rules ('Sharing-Sweet-and-Sour' rules) aimed at increasing the quality of the schedules in terms of workers' preferences. Breugem (2020) explored the trade-off between fairness and attractiveness (measured by these rules) of schedules.

In preference scheduling, the satisfaction of a nurse ($i$) for a given schedule ($j$) is often denoted by a value, say $P_{ij}$ (Bard and Purnomo, 2005; Dowsland, 1998). However, the formulation of this value as a function of the shifts assigned to nurse ($i$) and the personal preference profile of this nurse ($i$) is rarely presented. This research aims to gain insight into formulations of a satisfaction taking as input the assigned shifts to a nurse and personal preferences to return a personalised satisfaction score.

### 2.1.2 Objective

The formulation of the objective in the Nurse Scheduling Problem (NSP) often contains multiple aspects. For example, Legrain, Bouarab and Lahrichi (2015) use an objective with three components in a weighted combination. First, the aim is to minimise the alternation of shift types. Second, to minimise the violation of cover requirements. Third, preferences should be adhered to as well as possible. This third part is a simple summation of all shifts assigned per nurse and multiplied by a binary parameter "wants to (not) work this shift". Therefore, this formulation of the problem requires us to know whether a nurse would like to work a certain shift. In this application, planners ask nurses to fill in their preferences every planning cycle through a simple spreadsheet (Figure 2.1).

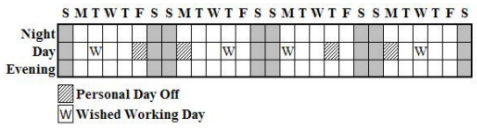



Figure 2.1: Example of schedule annotated with nurse preferences
(Legrain, Bouarab and Lahrichi, 2015)

Besides preferences per shift, nurses can also have preferences that are independent of specific days but are more about patterns in the schedule. For example, the number of consecutive shifts. Independent of the specific days a nurse is assigned to work, each block of consecutive shifts should not be longer (or shorter) than a specific number of days. Warner (1976) designs a survey to ask nurses about such preferences directly.

### 2.1.3 Fairness

Literature on fairness in optimisation objectives often mentions Rawls' Theory of Justice (Rawls, 1971). According to this theory, a fair distribution is determined by the worst-off person as *inequality is justified only when it improves the welfare of the worst off*. Therefore, the objective should be to maximise the satisfaction of the worst-off (most unsatisfied) nurse. Other approaches to fairness could be to optimise the average satisfaction of all nurses, the spread between minimum and maximum satisfaction, or the average deviation of the mean (Chen and Hooker, 2023).

## 2.2 Solution approaches

Approaches to solve the Nurse Scheduling Problem generally belong to one of two groups: exact methods and heuristics. Exact methods solve the problem to find an optimal solution, but require lots of computation time. For large problem instances, exact methods might never be able to find an optimal solution within reasonable running times (one hour) or more. Therefore, heuristics can be preferred to provide an acceptable solution within reasonable time.

### 2.2.1 Exact methods

Small instances of the nurse scheduling problem can be solved by a mathematical (multiple-choice) programming approach to assign a schedule out of a set of potential schedules per nurse (Warner, 1976). However, this approach does not solve problems with a larger scheduling horizon unless the problem is split into scheduling problems with small horizons and each problem is solved separately. Other examples of exact methods such as integer programming implementations can be found in Glass and Knight (2010) and M'Hallah and Alkhabbaz (2013). To reduce the computation time, a solver can also be supplied with an initial solution as a warm start (Rahimian, Akartunalı and Levine, 2017; Hesaraki, Dellaert and Kok, 2020).

### 2.2.2 Heuristics

Literature on the Nurse Scheduling Problem describes lots of previous work on heuristics such as the use of a Variable Neighbourhood Search (Lü and Hao, 2012). In a Variable Neighbourhood Search approach, the solver starts with constructing an initial schedule. Then, based on some predefined neighbourhoods, small changes are made to this initial schedule to iteratively look for improvements. A common neighbourhood is a swap neighbourhood. In a swap neighbourhood, swaps are made between shifts assigned to nurse A and nurse B such that the assigned shifts to both on a specific day are swapped. The process could iterate over all days in the scheduling period to look for improvements. Swaps can also be made within a schedule per nurse. For example, when a nurse was assigned a day shift on Monday and a day off on Tuesday, these could be swapped. At every iteration, the resulting schedule after swapping is checked for any violations of the hard constraints before comparing its objective value to the best-known objective until then.

Variable Neighbourhood Search heuristics can also be combined with integer programming (Rahimian, Akartunalı and Levine, 2017) or a stochastic approach (Tassopoulos, Solos and Beligiannis, 2015). Another type of heuristic that is commonly used is the Genetic Algorithm which is inspired by the process of natural selection(Ayob et al., 2013; Burke et al., 2001a). The performance of this heuristic is highly dependent on proper tuning of its parameters.

Sometimes, a neighbouring solution would improve the objective for one nurse but at the same time worsen the solution for another nurse. Therefore, an improvement in the total objective would require more changes. These changes can be represented by a chain of swaps. Making such a chain requires heuristics to select the next swap to add to the chain and when to stop the chain as described by Burke et al. (2013). Using this approach, Burke et al. (2013) were able to outperform previously published approaches. Since the optimisation of crew satisfaction should preferably not affect the already planned capacity, the chain implementation of swaps could be well suited for the problem to be solved in this thesis.

## 2.3 Summary

To summarise, there exists literature on including nurse preferences in the nurse scheduling problem. However, previous work often lacks an explanation of the measurement of nurse satisfaction or does not allow personalised preferences, but only generalised. Therefore, this thesis aims to gain insight in the indicators that affect an individual nurse's satisfaction score. Additionally, insights should be gained into the effect of adhering to such preferences at the cost of coverage or the satisfaction of other nurses. Therefore, literature on fairness presents several criteria for a fair distribution of satisfaction among nurses and solution approaches are presented to solve the scheduling problem including satisfaction. When possible, exact methods should be used to measure the exact cost of including satisfaction in terms of lost capacity or fairness trade-offs. However, when instances are too large to solve using an exact method, even with a warm start, in reasonable time, a heuristic such as a Variable Neighbourhood Search should be used instead.

# Chapter 3

# Problem description

The Nurse Scheduling Problem (NSP) is about matching nurses with shifts to be worked (per day). This chapter describes the input for the scheduling process and describes the set of indicators used to model nurses' schedule satisfaction based on previous research (Rooijen, 2023).

## 3.1 Input

The input to the nurse scheduling process, as considered in this thesis, is a set of days with cover requirements for all shift types; a set of shift types; a set of contracts with labour agreements; a set of nurses with requests for certain shifts (or days) on or off and other personal preferences. Except for the personal preferences input, all input is taken from benchmark instances to allow for comparable results to other academic literature on the nurse scheduling problem (Curtois and Qu, 2014). These instances are described in more detail in the remainder of this chapter.

### 3.1.1 Scheduling period

The scheduling period is defined by the number of weeks that should be planned. In the benchmark instances, this period ranges from two weeks to a year. Based on interviews, nurses prefer to receive their schedules three months in advance (Rooijen, 2023). This reduces the number of incidental wishes as nurses can plan their personal events around their work. Therefore, we consider benchmark instances with a scheduling period up to 12 weeks. Instances 1, 2, and 3 have a scheduling period of two weeks, instances 11 and 12 of four weeks, instance 14 of six, instance 16 of eight, and instance 18 of 12 weeks.

### 3.1.2 Shift types

Shifts are defined by a start time and duration. For example, a typical day shift starts at 9:00 and lasts for 8 hours until 17:00. However, the scheduling problem can also include early or late day shifts, starting at 6:00 or 14:00 respectively. Additionally, nurses can work a night shift of 10 hours from 22:00 till 8:00. In instance 14, the early day shifts start at 8:00 instead of 6:00 but also last 8 hours till 16:00.

Most instances include an early day shift (E), a day shift (D), a late day shift (L), and a night shift (N) described in Table 3.1. However, in instances 11 and 12, there can be different types of E, D, and N shifts with the same starting times and duration but requiring different skills. Therefore, these shifts are denoted as day 1 (D1), day 2 (D2) etc.

Table 3.1: Shift types

| Shift type | start time | end time | duration (hrs) |
|---|---|---|---|
| E, E1, E2, E3 | 6:00 | 14:00 | 8 |
| D, D1, D2, D3 | 9:00 | 17:00 | 8 |
| L, L1, L2, L3 | 14:00 | 22:00 | 8 |
| N, N1 | 22:00 | 8:00 | 10 |

### 3.1.3 Nurses

Nurses are assigned a certain contract specifying the number of contract hours they work. Additionally, nurses can have work agreements specifying the number of shifts nurses have to work per shift type. For example, nurses can be exempt from working night shifts when they are pregnant or reach a certain age. Table 3.2 shows the number of nurses per instance grouped into fulltime and parttime nurses depending on if they work more or less than 25 hours per week.

Table 3.2: Nurses by contract type

| instance | weeks | nr. nurses | fulltime | parttime |
|---|---|---|---|---|
| 1 | 2 | 8 | 8 | 0 |
| 2 | 2 | 14 | 10 | 4 |
| 3 | 2 | 20 | 15 | 5 |
| 11 | 4 | 50 | 50 | 0 |
| 12 | 4 | 60 | 50 | 10 |
| 14 | 6 | 32 | 27 | 5 |
| 16 | 8 | 20 | 20 | 0 |
| 18 | 12 | 22 | 22 | 0 |

### 3.1.4 Cover requirement

For every day in the scheduling period, a cover requirement is specified per shift type. For example, the scheduling process should result in 10 nurses working a day shift (starting at 9:00) on 01-08-2023. Usually, this requirement is a minimum capacity required to cover expected labour demand. Therefore, planning more nurses than required is preferred over planning less than the required number. In the benchmark problem, a penalty of 100 is assigned to every unassigned shift (less than required) and a penalty of 1 is assigned to every shift above the required number. Chapter 4 explains the calculation of these penalties in more detail.

### 3.1.5 Shift on/off requests on specific days

The input from the benchmark instances also includes a set of requests to (not) work certain shifts on specific days. Each of these requests is assigned a weight by the nurse to represent relative importance. These weights range from one to three. However, none of these requests are hard constraints since nurses should request official leave if they want a day off. These requests are only preferences and will be included in the satisfaction score. Nonetheless, nurses who can be scheduled during Monday-Sunday have the right to choose one recurring weekday off (see Section 3.2). This day is defined per nurse as a fixed assignment in the problem instance.

### 3.1.6 Work agreements

The benchmark instances define a set of work agreements as a contract which is then assigned to a nurse. These contracts can include personally agreed upon terms as well as terms defined by law or collective labour agreements. However, since the schedule satisfaction score will take into account the personal preferences per nurse, personalised contracts become obsolete. The schedule should only adhere to one type of contract which holds for all nurses and is defined by law and/or collective labour agreements. These are presented in Section 3.2.

## 3.2 Hard constraints

In the nurse scheduling problem, a set of hard constraints defines the set of feasible schedules. First, in a feasible schedule, a nurse can only be assigned to work one shift per day. The following hard constraints are taken from Curtois and Qu (2014).

- Certain shift types cannot be assigned following others, for example, a nurse cannot work the night shift starting on Monday (finishing Tuesday morning) and work the day shift on Tuesday. This is also referred to as "forward rotation" in other literature and labour agreements. It means nurses should get at least 16 hours off between assigned shifts.
- Nurses can only work a limited number of consecutive shifts before they have a day off (this number can vary per nurse depending on the contract).
- Nurses have to work at least a specified number of consecutive shifts (this number can vary per nurse depending on the contract).
- Nurses have to get at least a specified number of consecutive days off after each block of assigned shifts (this number can vary per nurse depending on the contract).
- Nurses work a limited number of weekends per scheduling period depending on their contract (working either Saturday or Sunday also counts as working a weekend)
- Nurses get to request days off throughout the scheduling period for vacation or something else, these are considered hard constraints as opposed to the requests in Section 3.1.5.

## 3.3 Multiple objectives

Within the set of feasible schedules, we want to find the *optimal* schedule. However, the quality of a schedule is subjective to multiple perspectives. First, a planner aims to meet the coverage requirements of the department as closely as possible. Second, the nurses should be sufficiently satisfied with the schedule to improve job retention in the long run. Therefore, this problem is multi-objective: coverage and crew satisfaction.

A solution (schedule) is evaluated based on two penalty types. First, a penalty is added for every unassigned or over-assigned shift. Here, the assumption is made that assigning too few nurses on a shift is worse than too many. Therefore, an unassigned (required but not assigned to any nurse) shift gets a higher penalty than an over-assigned (not required but assigned to a nurse) shift. These penalties do not depend on the (type of) nurse. Second, nurse satisfaction is measured based on penalties assigned when the schedule violates nurses' personal preferences. These preferences are studied using a survey which is described next in Chapter 4. This chapter also explains the calculation of the satisfaction penalties.

The coverage penalties can be seen as vertical penalties as they are measured per day (column). The satisfaction penalties can be considered per nurse (row). When evaluating a schedule, all individual schedule satisfaction scores are considered. To ensure fair incorporation of all these individual scores into the problem's objective, the Rawlsian Theory of Justice suggests the use of a MinMax criterion (Barsotti and Koçer, 2022).

The aim of the optimisation is to create schedules that improve the satisfaction of the worst-off nurse while maintaining the best possible level of coverage. Additionally, the trade-off is analysed when coverage is allowed to worsen at the benefit of crew satisfaction.

# Chapter 4

# Measuring nurse preferences

To answer the first research question, a survey has been designed to ask nurses working in hospitals all over The Netherlands about their personal scheduling preferences and the relative weight they assign to each of these preferences. This chapter describes the survey design and results before explaining the personalized calculation of satisfaction penalties per nurse.

## 4.1 Methodology

The survey is done using the online survey platform Qualtrics. The questions are based on the themes resulting from the coding of the interviews done in previous research (Rooijen, 2023). A link to the (digital) survey is shared with the hospital by account managers of ORTEC through an email with information about the survey, the use and storage of the data, and other information required for informed consent. The email also includes contact information in case nurses or their managers have questions about the survey.

The survey uses mostly closed questions since the aim is to gather data to use in the mathematical optimisation problem. The questions are direct and specifically ask about preferences such as the number of preferred minimum consecutive working days. However, the survey concludes with an open question asking the respondent for any other factors that may impact their schedule satisfaction and were not covered by the survey questions to allow them to share scheduling aspects previous questions might have missed.

To research the scheduling preferences of nurses, the target population is nurses who work in Dutch hospitals. This population consists of 218000 nurses at the start of 2023 according to Statistics Netherlands (CBS, 2023). However, the survey was shared through account managers at ORTEC so the sample consisted of nurses who work in a hospital that is using ORTEC software. The survey collected responses from May 5th, 2023 to June 29th, 2023, and collected 301 responses.

The responses are cleaned by removing incomplete responses and responses from employees outside of the target group (technicians, dietitians, etc.). After cleaning, the response data is statistically analyzed to explore patterns, trends, and correlations.

## 4.2 Results

After the removal of 32 respondents with other roles (dietitians, technicians, etc.), 19 incomplete responses, and 6 test responses, the sample consisted of 244 responses. The removed roles are specified in Appendix A.

### 4.2.1 Demographics

Most respondents (56%) worked between 25-32 hours per week according to their contract. The second largest group of respondents (33%) worked less than 25 hours a week and 11% works more than 32 hours per week. To explore patterns in preferences related to the number of working hours per week, nurses are grouped into parttime (24 or less hours/week) and fulltime (25 or more hours/week) nurses. On average, respondents have 19 years of experience working as a nurse with a minimum of 0 and a maximum of 57 years (both occur only once).

### 4.2.2 Consecutiveness and workload division

First, nurses are asked two questions about their preferred division of their workload throughout a (Monday-Sunday) week. Results show that, generally, 2/3 of nurses prefer to work their hours per week between Monday and Sunday instead of compensating hours. For example, with compensation, nurses might work five shifts in the first two weeks of the month and only three shifts in the last two weeks of the month. Also, generally, 2/3 of nurses prefer to work their shifts between Monday and Sunday consecutively instead of split into two (or more) blocks.

Table 4.1: Workload division

| | yes | no |
|---|---|---|
| Preference for working all contract hours on a Monday-Sunday basis | 165 (68%) | 79 (32%) |
| Preference for working all shifts per Monday-Sunday week consecutively | 159 (65%) | 85 (35%) |

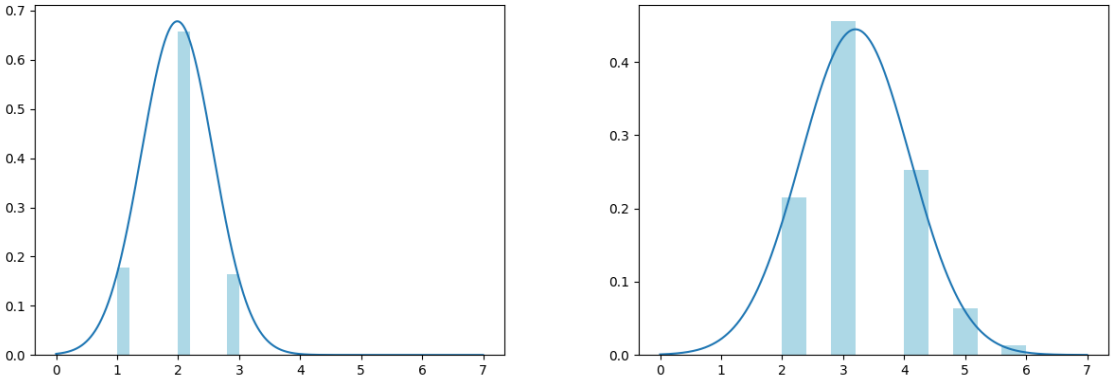
Nurses also answered questions about their preferences for a minimum and a maximum number of consecutive working days. These results are in line with the results above on working all shifts between Monday and Sunday consecutively. Nurses can be grouped based on a fulltime contract type when working 25 or more hours per week and parttime if they work less than 25 hours per week. Table 4.2 shows the consecutiveness preferences for nurses grouped by contract type. The consecutiveness preferences indeed increase with the number of contract hours.

Table 4.2: Consecutiveness preferences per contract type

| preference | contract | min | max | mean | std dev |
|---|---|---|---|---|---|
| min | parttime | 1 | 3 | 1.99 | 0.59 |
| | fulltime | 1 | 7 | 2.61 | 0.87 |
| max | parttime | 2 | 6 | 3.20 | 0.90 |
| | fulltime | 2 | 10 | 4.63 | 1.19 |

Parttime nurses, on average, prefer to work consecutive blocks of at least 1.99 shifts and at most 3.20 shifts. Given that parttime nurses should at most work 24 hours per week, this aligns with their preferences. Also for fulltime nurses, the consecutiveness preferences do not seem to raise a conflict with the preference to work all shifts consecutively and all contract hours between Monday and Sunday. Nonetheless, it might be difficult to adhere to these preferences in combination with capacity demands and other preferences. Chapter 7 explores such effects and trade-offs.

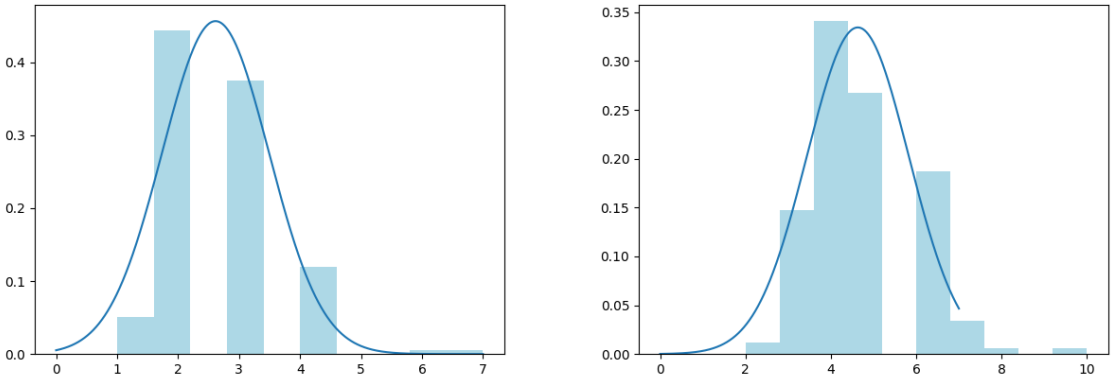
To explore the effects of including nurse satisfaction on the optimisation results, consecutiveness preferences will have to be simulated as they currently do not exist in the benchmark problem instances (Curtois and Qu, 2014). Based on the histogram of the survey results and the probability density functions of Normal distributions with corresponding mean and standard deviation values, simulating preferences using Normal distributions seems acceptable (Figures 4.1 and 4.2). As consecutive preferences are measured in numbers of days, the simulated values are discretized by rounding to the nearest integer.



(a) Minimum (days)

(b) Maximum (days)

Figure 4.1: Consecutiveness preferences distribution for parttime nurses



(a) Minimum (days)

(b) Maximum (days)

Figure 4.2: Consecutiveness preferences distribution for fulltime nurses

### 4.2.3 Shift types

Nurses are asked about their general preferences for shift types. Most nurses prefer to work a day shift which is in line with results from previous research (Rooijen, 2023). Day shifts are generally more intense but they allow for a good work-life balance which makes them preferable for most nurses over evening or night shifts. However, a large group of nurses also stated no preference for any of the shift types. The 11% of nurses who specified other preferences mainly stated a preference for variability in their textual answers (see Appendix A for the written answers). When asked about variability, 66% of nurses prefer variability in their assigned shift types.

Table 4.3: Preferred shift type

| | day | evening | night | no preference | other |
|---|---|---|---|---|---|
| Preferred shift type | 41.39% | 24.59% | 4.51% | 18.44% | 11.07% |

Based on the forward rotation rules specified in labour agreements, nurses are not allowed to work certain shift combinations. For example, when a nurse works a night shift on Sunday, planners cannot assign a day shift to the same nurse on Monday. This affects the common shift types assigned at the beginning and ending of a block. When asked about their preferred shift types to begin and end a block with, nurses prefer to start with a day shift and end a block with an evening shift (Table 4.4). Compared to Table 4.3, where only 4.51% of nurses preferred to work a night shift, actually 30.74% of nurses prefers to work a night shift when they are specifically asked about shift types to end a block with (Table 4.4). Based on interviews (Rooijen, 2023), nurses realise that night shifts are part of the job and have to be covered by the workforce.

Table 4.4: Preferred shift types at beginning and ending of a block

| | day | evening | night |
|---|---|---|---|
| Preferred shift type at the beginning of a block | 81.15% | 18.44% | 0.41% |
| Preferred shift type at the end of a block | 25.82% | 43.44% | 30.74% |

### 4.2.4 Weekend shifts

Regarding the scheduling of weekend shifts, most nurses prefer to work weekends spread throughout the month (57%) although a large group specifies no preference (32%). When working in the weekends, most nurses prefer to work a day shift (41%), 33% has no preference, 23% prefers an evening shift and only 3% prefer a night shift. These results clearly show a general preference for working day shifts, also in the weekend, but it also indicates a potential improvement in nurse satisfaction for a minor group of nurses who do prefer to work the night shift. The results are comparable to the results in Table 4.3, so working in weekends does not seem to affect the preferred shift type.

### 4.2.5 Night shifts

In the sample, 199 out of 244 respondents were working night shifts. This means 45 respondents are excluded from working the nights shifts possibly because of age or other contractual agreements. When asked about the scheduling of blocks of night shifts, 42% of nurses preferred to work isolated blocks of only night shifts whereas 58% preferred to combine their night shifts with also a day or evening shift. The second group thus prefers some variability in the shift types per block of working days. Before working a night shift, most nurses prefer to work an evening shift (Table 4.5).

Table 4.5: Preference for shift before night shift

| Before working a night shift, I prefer to be assigned... | choice count |
|---|---|
| a day shift | 40 (20%) |
| an evening shift | 96 (48%) |
| no preference | 63 (32%) |

### 4.2.6 Requests

Nurses can request to (not) work a specific shift because of personal reasons. These requests can be incidental or recurring. When nurses submit a request, they can assign a weight to each request to communicate relative priority. For example, a specific day off for a wedding might be worth sacrificing a recurring day off to play sports once. Based on the survey results, 70% of nurses seem to have more incidental requests than recurring requests. Also, most nurses seem to submit only 0-5 requests per month (Table 4.6). In this question, a recurring request for example for sports training on Monday evening counts as four requests per month.

Table 4.6: Number of requests (per month)

| In an average month, you submit ... requests | parttime | fulltime |
|---|---|---|
| 0-5 | 66 (85%) | 134 (82%) |
| 5-10 | 10 (13%) | 23 (14%) |
| 10+ | 2 (2%) | 6 (4%) |

### 4.2.7 Priorities of preferences

After the questions about specific preferences, nurses are asked to sort the types of preferences based on importance for their schedule satisfaction in two final questions. First, nurses ordered the five types (consecutiveness, shift types, night shifts, weekend shifts, requests) based on importance. Most nurses selected the adherence to requests as most important for their satisfaction. Second most important for most nurses is the consecutiveness of blocks of shifts. Third most important is the (variability in) types of assigned shifts followed by the planning of weekend shifts. Least important seems to be the planning of night shifts (Table 4.7).

Table 4.7: Top 5 most important preferences to affect schedule satisfaction

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Requests | **138 (61%)** | 46 (20%) | 18 (8%) | 9 (4%) | 15 (6%) |
| Consecutiveness | 45 (20%) | **71 (32%)** | 66 (29%) | 23 (10%) | 21 (10%) |
| Shift types | 28 (12%) | 56 (25%) | **76 (34%)** | 44 (19%) | 22 (10%) |
| Weekends | 10 (5%) | 39 (17%) | 31 (14%) | **80 (35%)** | 66 (29%) |
| Nights | 5 (2%) | 14 (6%) | 35 (15%) | 70 (31%) | **102 (45%)** |

Second, nurses were asked to divide 50 points over the five types of preferences to indicate their relative importance. Figure 4.3 shows that, like before, most nurses care mostly about the adherence to requests and consecutiveness. In the next chapter, both are used to define a formula for nurse schedule satisfaction.

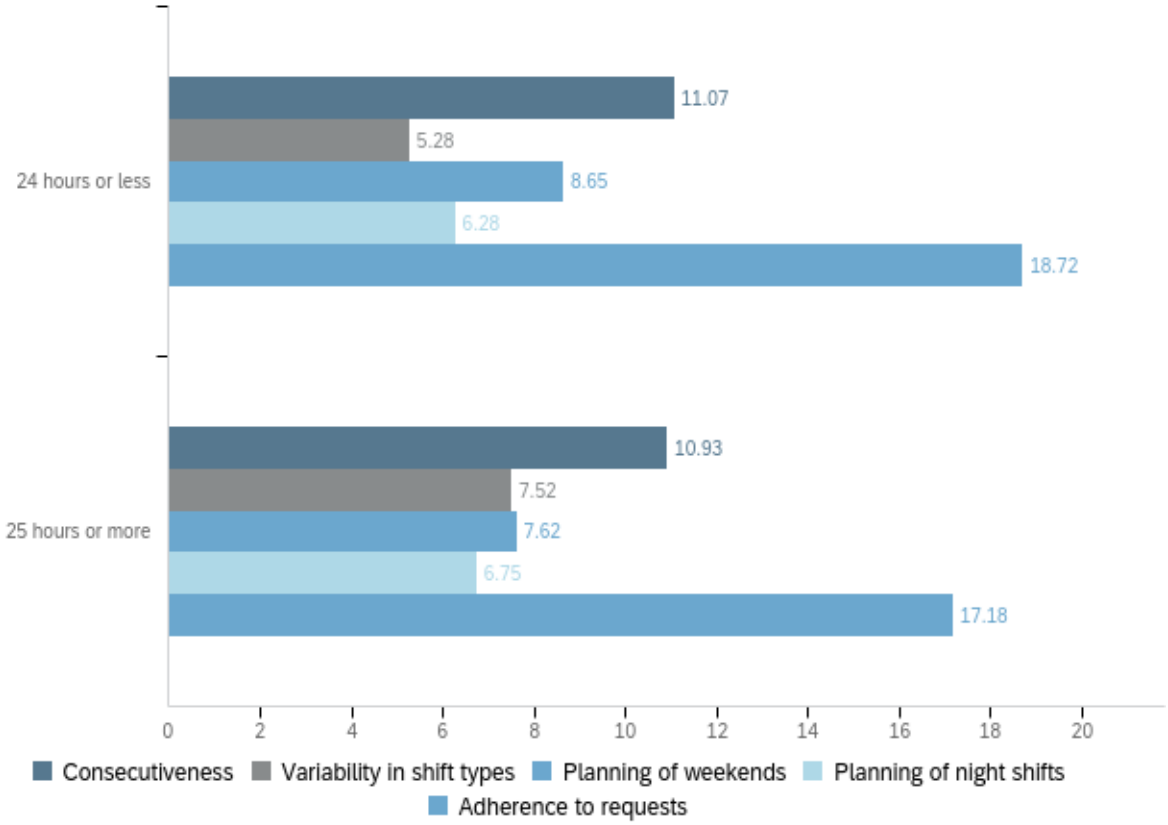



Figure 4.3: Average weight assigned to satisfaction indicator (out of 50)

## 4.3 Comparison to Dutch labour laws and agreements

Certain scheduling preferences can conflict with Dutch labour law and collective labour agreements. For example, according to the Collective Labour Agreement (CAO) for nurses in The Netherlands, nurses can only work up to five shifts per Monday-Sunday week unless they personally agree upon more. Nurses with a preference for more than five consecutive shifts should thus change their work agreement personally. Also, according to the CAO, nurses who can be assigned to work from Monday till Sunday get to select a recurring day off on a weekday (Monday-Friday).

Finally, according to the CAO, nurses can be assigned a maximum of seven consecutive working days. Comparing this to the survey results (Table 4.2), the CAO conflicts with nurses who prefer a maximum consecutiveness of 8, 9 or 10 shifts. In the survey, out of 244 respondents only two nurses have such a preference. Assuming a normal distribution of the maximum consecutiveness preferences, this implies not even 1% of nurses would have a preference above seven. Additionally, research shows that working long consecutive blocks increases the risk of making errors in patient care (Lockley et al., 2007). Therefore, a hard limit of a maximum of seven consecutive shifts seems reasonable.

## 4.4 Comparison to benchmark instances data

The benchmark problem instances include data on the minimum and maximum number of consecutive shifts allowed per nurse. These are used to specify the hard constraints. Table 4.8 shows the descriptive statistics of the parameter values for all instances. Compared to the results of the survey, some nurses seem to have preferences that are now infeasible because of the hard constraints (Table 4.2). For example, a fulltime nurse with a preference for seven consecutive shifts can never get the preferred schedule (in terms of consecutiveness) because of the hard constraint setting a maximum of six consecutive shifts in the problem instance. Additionally, when compared to the Dutch labour laws and agreement, nurses are allowed to work a maximum of seven consecutive shifts. Therefore, nurse satisfaction can be improved by relaxing these hard constraints depending on personalised consecutiveness preferences.

Table 4.8: Benchmark instances consecutiveness data

| | | min | max | mean | std dev |
|---|---|---|---|---|---|
| min. nr. of consecutive days | parttime | 1 | 2 | 1.4 | 0.49 |
| | fulltime | 2 | 3 | 2.03 | 0.17 |
| max. nr. of consecutive days | parttime | 3 | 5 | 4.75 | 0.66 |
| | fulltime | 4 | 6 | 5.16 | 0.43 |

The benchmark problem also includes data on requests for working (or not) specific shift types on specific days and some fixed days off where nurses do not work any of the shift types on that day. The benchmark problems include more requests per month, on average, per nurse than the most common survey answer of 0-5 requests per month per nurse.

## 4.5 Summary

This chapter describes the results from a survey designed to gain insights into the personal preferences of nurses. In the next chapter, these results are transformed into a mathematical formulation of nurse scheduling satisfaction to take into account during the optimisation process. Based on the priorities assigned by nurses (Table 4.7) most nurses selected the requests and consecutiveness as their top two priorities. The mathematical formulation will therefore focus on these two indicators of satisfaction. Focusing on two indicators instead of using all five aids interpreting the effects of changing the objective on the optimisation results later on.

# Chapter 5

# Mathematical formulation

This chapter presents a mathematical formulation of the problem described in Chapter 3 extended with the preferences described in Chapter 4. The formulation from Curtois and Qu (2014) is adapted to include nurse preferences measurements. The objective now includes optimisation of nurse satisfaction which is a function of personalised preference parameters as well as weights. These parameters are described in Section 5.2 following definitions of the sets used in Section 5.1. Then, Section 5.3 defines the decision variables and Section 5.4 explains the satisfaction function expressed using these decision variables. Section 5.5 and 5.6 describe how this satisfaction function is incorporated in the problem's objective. Finally, Section 5.7 presents the complete mathematical (IP) formulation.

## 5.1 Sets

| | |
|---|---|
| $D$ | set of days in the scheduling period {1, ..., $h$ } |
| $W$ | set of weekends in the scheduling period {1, ..., $h/7$ } |
| $I$ | set of employees |
| $T$ | set of shift types |
| $R_t$ | set of shift types that cannot be assigned directly after shift type $t$ |
| $N_i$ | set of days nurse $i$ cannot be assigned to work on |

## 5.2 Parameters

The mathematical formulation of the problem requires two types of parameters. The first type of parameters contain information about the hard constraints.

| | |
|---|---|
| $h$ | number of days in the scheduling period |
| $l_t$ | length of shift of type $t$ in minutes |
| $m_{it}^{max}$ | maximum nr. of shifts of type $t$ that can be assigned to nurse $i$ |
| $b_i^{min}$ | minimum nr. of minutes nurse $i$ must work during the scheduling period |
| $b_i^{max}$ | maximum nr. of minutes nurse $i$ must work during the scheduling period |
| $c_i^{min}$ | minimum nr. of shifts nurse $i$ must work consecutively |
| $c_i^{max}$ | maximum nr. of shifts nurse $i$ must work consecutively |
| $o_i^{min}$ | minimum nr. of consecutive days off nurse $i$ must be assigned |
| $a_i^{max}$ | maximum nr. of weekends nurse $i$ can work |

The second type of parameter is about preferences and penalties. These parameters are required to measure the objective value of a solution.

| | |
|---|---|
| $pc_i^{min}$ | preferred minimum nr. of shifts nurse $i$ wants to work consecutively |
| $pc_i^{max}$ | preferred maximum nr. of shifts nurse $i$ wants to work consecutively |
| $u_{dt}$ | cover requirement for shift of type $t$ on day $d$ |
| $v^{min}$ | penalty assigned per under-assigned shift |
| $v^{max}$ | penalty assigned per over-assigned shift |
| $q_{idt}$ | penalty for violation of shift on request for shift of type $t$ on day $d$ for nurse $i$ |
| $p_{idt}$ | penalty for violation of shift off request for shift of type $t$ on day $d$ for nurse $i$ |

The penalties per request are scaled such that the sum of all penalties assigned per nurse equals 1. This is done to improve fairness between nurses who submit many or only a few requests.

## 5.3 Decision variables

The problem is modelled using five decision variables where the variable $x_{idt}$ measures if nurse $i$ is working a shift of type $t$ on day $d$. The other decision variables are required to calculate the objective value or check if a hard constraint is violated.

| | |
|---|---|
| $x_{idt}$ | 1 if nurse $i$ is working shift type $t$ on day $d$, 0 otherwise |
| $k_{iw}$ | 1 if nurse $i$ is working weekend $w$, 0 otherwise |
| $c_{idr}$ | 1 if nurse $i$ is working $r$ consecutive shifts starting day $d$, 0 otherwise |
| $y_{dt}$ | total nr. of shifts of type $t$ assigned below the preferred cover for day $d$ |
| $z_{dt}$ | total nr. of shifts of type $t$ assigned above the preferred cover for day $d$ |

## 5.4 Satisfaction function

The satisfaction function $P_i$ takes the shifts assigned to nurse $i$ and calculates a satisfaction score based on the nurse's preferences.

$$P_i = \alpha_i * \text{consecutivenessPenalty}_i + (1 - \alpha_i) * \text{requestPenalty}_i \tag{5.1}$$

The weight $\alpha_i$ represents the relative importance of each concept to nurse $i$. They differ based on personal situations, for example, two nurses might have the same preferences regarding consecutiveness but also have requests for shifts off. Nurse A can assign more weight to the requests whereas nurse B might care more about consecutiveness. Then, even though both nurses have the same preferences, their satisfaction scores could differ when consecutiveness is met but requests are not.

### 5.4.1 Consecutiveness

Consecutiveness is measured by counting the number of consecutive shifts per block. The decision variable $c_{idr}$ is equal to 1 if nurse $i$ works a consecutive block of $r$ shifts starting on the day $d$. Therefore, the summation of $c_{idr}$ per nurse over all $r$ values outside of this nurse's preferences is the total number of blocks per scheduling period with a consecutiveness outside of the preferences.

$$\text{consecutivenessPenalty}_i = CP_i = \sum_{r=1}^{pc_i^{min}-1} (pc_i^{min} - r)c_{idr} + \sum_{r=1+pc_i^{max}}^{c_i^{max}} (r - pc_i^{max})c_{idr} \tag{5.2}$$

The penalty per block is calculated by taking the difference between the number of consecutive days per block and the preferred consecutiveness of the nurse. This implies that a block of six consecutive shifts yields a penalty of one when a nurse prefers to work a maximum of only five consecutive shifts but a penalty of three if a nurse prefers to work a maximum of only three consecutive shifts. The penalty thus increases with the distance between the actual consecutiveness of the block and the nurse's preferences. The total consecutiveness penalty per nurse $i$ for a scheduling period is the sum of penalties of all blocks in the nurse's schedule.

### 5.4.2 Requests

A second indicator of schedule satisfaction is the number of violated requests for shifts on/off. Nurses are less satisfied with a schedule when their requests are not met. Therefore, we count the number of times preferences to (not) work a specific day or shift are violated. Then, the calculation of satisfaction penalties due to request violations becomes a summation of the scaled weights assigned to violated requests per nurse $i$.

$$\text{requestPenalty}_i = RP_i = \sum_{d \in D} \sum_{t \in T} q_{idt}(1 - x_{idt}) + \sum_{d \in D} \sum_{t \in T} p_{idt} x_{idt} \tag{5.3}$$

As stated in Section 3.2, nurses also get to request days off for vacations or other personal reasons. These requests are limited by an agreed-upon (contractual) number of days off and are hard constraints. This type of request, on the other hand, is a request for a day on/off but the employer is not obliged to adhere to the request. Therefore, it affects nurse satisfaction and adds to the satisfaction penalties but violations do not affect the feasibility of a solution.

## 5.5 Objective including crew satisfaction

The objective including crew satisfaction combines minimization of both the coverage penalties and the crew satisfaction penalties.

$$\min \quad \gamma_1 * \max_{i \in N} P_i + \gamma_2 * \sum_{i \in N} P_i + \sum_{d \in D} \sum_{t \in T} y_{dt} v^{min} + \sum_{d \in D} \sum_{t \in T} z_{dt} v^{max} \tag{5.4}$$

### 5.5.1 Coverage penalty

$$\text{coveragePenalty} \quad = \quad \sum_{d \in D} \sum_{t \in T} y_{dt} v^{min} + \sum_{d \in D} \sum_{t \in T} z_{dt} v^{max} \tag{5.5}$$

The vertical part of the objective function is defined by the difference in the capacity planned to work versus the required capacity. This capacity is specified per day per shift. Therefore, this penalty part of the objective is measured per shift per day by adding penalties for over- or under-staffing. When a shift is understaffed by one (nurse), a penalty of $v^{min}$ is added, and when a shift is overstaffed with one (nurse), $v^{max}$ is added. Currently, these are set to 100 and 1 respectively as it is much worse to be understaffed than overstaffed.

### 5.5.2 Satisfaction penalty

$$\text{satisfactionPenalty} \quad = \quad \gamma_1 * \max_{i \in N} Pi + \gamma_2 * \sum_{i \in N} P_i = \quad \gamma_1 * \theta_1 + \gamma_2 * \sum_{i \in N} P_i \tag{5.6}$$

The horizontal part of the objective function aggregates the individual satisfaction penalties per nurse into one score. To incorporate fairness, we choose to minimize the satisfaction penalty of the worst-off nurse, the one most dissatisfied. To minimise the worst-off score, the maximisation needs to be linearised by using an auxiliary constraint and variable $\theta_1$ which should be higher than all $P_i$ such that it equals $\max_{i \in N} P_i$.

$$\theta_1 \geq \quad P_i \qquad \forall i \in N \tag{5.7}$$

If the objective would only be to minimize the value of the worst-off nurse, the number of nurses with that same value is not penalized. As we would like to improve crew satisfaction, the overall sum of dissatisfaction should be minimized as well. Therefore, $\gamma_1$ and $\gamma_2$ are both set to 1. However, these parameters can be adjusted based on scheduling objectives and policy.

### 5.5.3 Adding $\beta$ to explore trade-off

To explore the trade-off between crew satisfaction and meeting the cover requirements, the objective should be a convex combination of both. By increasing the (relative) weight $\beta$ on the crew satisfaction part of the objective, the schedule should prioritize schedules that adhere to nurse preferences over meeting coverage requirements. The edge cases of $\beta$ values of 0 and 1 yield schedules with the best possible coverage and crew satisfaction, respectively.

$$\min \quad \beta \left( \gamma_1 * \theta_1 + \gamma_2 * \sum_{i \in N} P_i \right) + (1 - \beta) \left( \sum_{d \in D} \sum_{t \in T} y_{dt} v^{min} + \sum_{d \in D} \sum_{t \in T} z_{dt} v^{max} \right) \tag{5.8}$$

## 5.6 MIP Formulation

The objective and hard constraints form an Mixed Integer Programming (MIP) formulation of the nurse scheduling problem. The objective (5.8) is as defined in Section 5.5.3 and the following constraints must be satisfied (mathematical formulation is presented on page 27).

Constraint 5.9 ensures that each nurse only works one shift per day, this can be one of any of the shift types. Every nurse also has to work a certain amount of hours in the scheduling period. Constraint 5.10 checks if the total number of worked hours in the scheduling period is within a certain range around this number. Forward rotation is ensured by Constraint 5.11. Here, $R_t$ is the set of shift types that cannot follow a shift of type $t$. Next, every nurse $i$ can have a limit on the number of shifts of type $t$ that can be scheduled in the scheduling period (5.12). This handles cases when nurses are exempt from working night shifts for example.

Constraints 5.13 and 5.14 check the maximum number of weekends nurses are allowed to work during the scheduling period. Fixed days off are defined in Constraint 5.15 where $N_i$ is the set of days off for nurse $i$ due to holidays for example. Constraints 5.16 and 5.17 check the maximum and minimum number of consecutive shifts allowed per nurse. Additionally, Constraint 5.18 checks the minimum number of consecutive days off. Constraint 5.19 defines the number of under- and overassigned shifts to calculate the coverage penalty. Constraint 5.20 defines the consecutiveness variable as explained in Section 5.4.1 and is used in 5.21 to calculate the satisfaction penalty per nurse. Additionally, an auxiliary constraint is used to linearize the maximisation of the satisfaction penalties (5.22). Finally, the decision variables are specified.

$$\sum_{t\in T} x_{idt} \leq 1 \qquad \forall\, i \in I, d \in D \tag{5.9}$$

$$b_i^{min} \leq \sum_{d\in D}\sum_{t\in T} l_t x_{idt} \leq b_i^{max} \qquad \forall\, i \in I \tag{5.10}$$

$$x_{idt} + x_{i(d+1)u} \leq 1 \qquad \begin{array}{l}\forall\, i \in I, d \in \{1,...,h-1\},\\ t \in T, u \in R_t\end{array} \tag{5.11}$$

$$\sum_{d\in D} x_{idt} \leq m_{it}^{max} \qquad \forall\, i \in I, t \in T \tag{5.12}$$

$$k_{iw} \leq \sum_{t\in T} x_{i(7w-1)t} + \sum_{t\in T} x_{i(7w)t} \leq 2k_{iw} \qquad \forall i \in I, w \in W \tag{5.13}$$

$$\sum_{w\in W} k_{iw} \leq a_i^{max} \qquad \forall\, i \in I \tag{5.14}$$

$$x_{idt} = 0 \qquad \forall\, d \in N_i, i \in I, t \in T \tag{5.15}$$

$$\sum_{j=d}^{d+c_i^{max}} \sum_{t\in T} x_{ijt} \leq c_i^{max} \qquad \forall\, i \in I, d \in \{1,...,h-c_i^{max}\} \tag{5.16}$$

$$\sum_{t\in T} x_{idt} + (s - \sum_{j=d+1}^{d+s}\sum_{t\in T} x_{ijt}) + \sum_{t\in T} x_{i(d+s+1)t} \geq 1 \qquad \begin{array}{l}\forall\, i \in I, s \in \{1,...,c_i^{min}-1\},\\ d \in \{1,...,h-(s+1)\}\end{array} \tag{5.17}$$

$$2 - \sum_{t\in T} x_{idt} + \sum_{j=d+1}^{d+s}\sum_{t\in T} x_{ijt} - \sum_{t\in T} x_{i(d+s+1)t} \geq 1 \qquad \begin{array}{l}\forall\, i \in I, s \in \{1,...,o_i^{min}-1\},\\ d \in \{1,...,h-(s+1)\}\end{array} \tag{5.18}$$

$$\sum_{i\in I} x_{idt} - z_{dt} + y_{dt} = u_{dt} \qquad \forall\, t \in T, d \in D \tag{5.19}$$

$$c_{idr} := \begin{cases} 1 \text{ if } 2 - \sum_{t\in T} x_{i(d-1)t} - \sum_{t\in T} x_{i(d+r)t} \\ \qquad\qquad + \sum_{d}^{d+r-1}\sum_{t\in T} x_{idt} = r+2 \\ 0 \text{ else} \end{cases} \qquad \forall\, i \in N, d \in \{1,...,h-(r+1)\} \tag{5.20}$$

$$P_i = \alpha_i * \mathrm{CP}_i + (1-\alpha_i) * \mathrm{RP}_i \qquad \forall i \in I \tag{5.21}$$

$$\theta_1 \geq P_i \geq 0 \qquad \forall i \in I \tag{5.22}$$

$$x_{idt} \in \{0,1\} \qquad \forall\, i \in N, d \in D, t \in T \tag{5.23}$$

$$k_{iw} \in \{0,1\} \qquad \forall\, i \in N, w \in W \tag{5.24}$$

$$c_{idr} \in \{0,1\} \qquad \forall\, i \in N, d \in D, r \in \{1,...,c_i^{max}\} \tag{5.25}$$

$$y_{dt}, z_{dt} \geq 0 \qquad \forall\, d \in D, t \in T \tag{5.26}$$

# Chapter 6

# Solution approach

## 6.1 Exact MIP solution

The mathematical formulation of Chapter 5 is solved using a CPLEX 22.1.1 implementation in Python 3.10.0. The running time is limited to one hour for all instances. Therefore, only some instances can be solved to optimality.

### 6.1.1 Warm start

First, the problems are solved using an objective without nurse satisfaction to find a solution that meets the coverage requirements as well as possible (within the feasible set). Then, nurse satisfaction is added to the objective to search for schedules that improve nurse satisfaction. To reduce running time, the solutions to maximise coverage are used as a warm start for solving the satisfaction problem. Also, the coverage penalty is constrained to be at least as high as in the warm start solution. This constraint reduces running time since it reduces the solution space by removing all schedules with coverage below the best possible solution.

## 6.2 Variable Neighborhood Search Heuristic

The formulation of an objective function presented in Chapter 5 is also used to evaluate solutions in a Variable Neighbourhood Search. This meta heuristic is implemented using the AutoRoster software developed by Staff Roster Solutions (2023). This chapter describes the solution approach used to solve the scheduling problem and find the optimal schedule to balance capacity coverage and nurse satisfaction.

The solver initially applies a constructive heuristic to create an initial schedule. Then, it generates new schedules by swapping shifts between nurses and evaluates these schedule using the objective function (Chapter 5). Based on the objective value, the solver returns the schedule with the lowest objective value. The solver takes as input a maximum running time and, optionally, a lower bound. The search terminates when the objective equals this lower bound or the maximum running time is reached. An outline of the approach is presented in Appendix C.

### 6.2.1 Constructive heuristic

The search is initialised by using a greedy approach. Starting with a set of shifts to be assigned, we assign each shift to the nurse that would get the smallest gain in penalty or highest loss. The search can be restarted using different initial solutions by randomisation of the order of shifts to assign. This approach is taken from Curtois and Qu (2014).

### 6.2.2 Neighbourhoods

Three types of neighbourhoods are implemented to iteratively look for improvements in the objective value. First, swaps can be made (horizontally) within one nurse's schedule. Second, shifts can be added to or removed from a nurse's schedule. Finally, (blocks of) shifts can be swapped completely between two nurses. The length of the blocks to be swapped, added or removed are of variable length. The maximum block length is a parameter that is set to 5 (Burke et al., 2013).

#### Swapping shifts within nurse's schedule

Per nurse, shifts can be swapped such that a shift of type 'D' used to be assigned to a nurse on Wednesday but is now swapped with a shift of type 'L' on Friday (Table 6.1). This swap changes the consecutiveness of the first block from three to two and introduces a single working day into the schedule. Generally speaking, this reduces the quality of a schedule. However, this swap might remove a request violation when the nurse would like to have the Wednesday off. Depending on the $\alpha_i$ weight assigned by this nurse, this swap could improve the roster quality. However, for a nurse who prefers long blocks of consecutive shifts and has a high $\alpha_i$, this swap would decrease the roster quality.

Table 6.1: Example of horizontal swap

| | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| before swap | D | D | D | | | | |
| after swap | D | D | | | L | | |

#### Adding or removing shifts per nurse

Per nurse (horizontal row), a shift can be added or removed per day to explore solutions which might improve upon the coverage penalty. Due to swapping shifts, there might be an opportunity to assign a previously unassigned shift to a nurse. Also, it might be beneficial to remove a shift for a certain nurse if it would improve the roster quality (satisfaction) as part of a chain of swaps. In the example (Table 6.2), the roster quality will be improved by adding a shift if the cover requirement was not met on Thursday before. Similar to the horizontal swap, nurse's schedule satisfaction can improve or decrease after the additional assigned shift depending on personal preferences for consecutiveness and requests.

Table 6.2: Example of adding a shift

| | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| before add | D | D | D | | | | |
| after add | D | D | D | L | | | |

**Swapping shifts between nurses**

Besides making changes (horizontally) per nurse, this neighbourhood searches for improvements in the schedule by swapping blocks between nurses. Table 6.3 shows an example of a single shift swapped between nurses A and B on Friday. Nurse A used to work five consecutive (week)days whereas nurse B used to work only on Saturday-Sunday. In case nurse B has requested a Saturday off and nurse A prefers to work a maximum of four consecutive days, this swap could improve nurse A's satisfaction score. Another swap affecting nurse B's schedule should be added to try and improve the total objective.

Table 6.3: Example of swapping one shift between nurses

| | nurse | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|---|
| before swap | A | D | D | D | D | D | | |
| | B | | | | | | D | D |
| after swap | A | D | D | D | D | | | |
| | B | | | | | D | D | D |

During the search, depending on a predefined parameter for the maximum block size, the algorithm also explores larger block sizes to swap. An example of a swap of five consecutive shifts is visualised in Table 6.4. Both examples show that the coverage per day does not change as a results of swaps between employees. Therefore, these swaps can only change the satisfaction scores.

Table 6.4: Example of swapping three shifts between nurses

| | nurse | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|---|
| before swap | A | | | | | E | E | E |
| | B | | | D | D | D | | |
| after swap | A | | | D | D | D | | |
| | B | | | | | E | E | E |

### 6.2.3 Search Strategy

After initialising the algorithm with the constructive heuristic, the algorithm iteratively searches for improvements in the objective value by exploring the three neighbourhoods. However, sometimes a single swap between employees would not improve the objective value but a chain of sequential swaps would. This is an intuitive approach which works similar to manually changing a shift in one nurse's schedule (because of a new shift request for example) and sequentially making other changes until you reach an improvement in objective value. The length of the chain

of swaps is limited by the depth parameter of the search algorithm. When the depth parameter is set to one, this search method works just like a regular local search with only swapping (or adding/removing) shifts when it yields an immediate decrease in objective value. It is recommended to use a relatively small depth value to prevent extremely long chains of swaps such as 100. Similar to Burke et al. (2013), we found best results using a maximum depth of 40. An example chain of seven swaps is visualised in Figure 6.1.

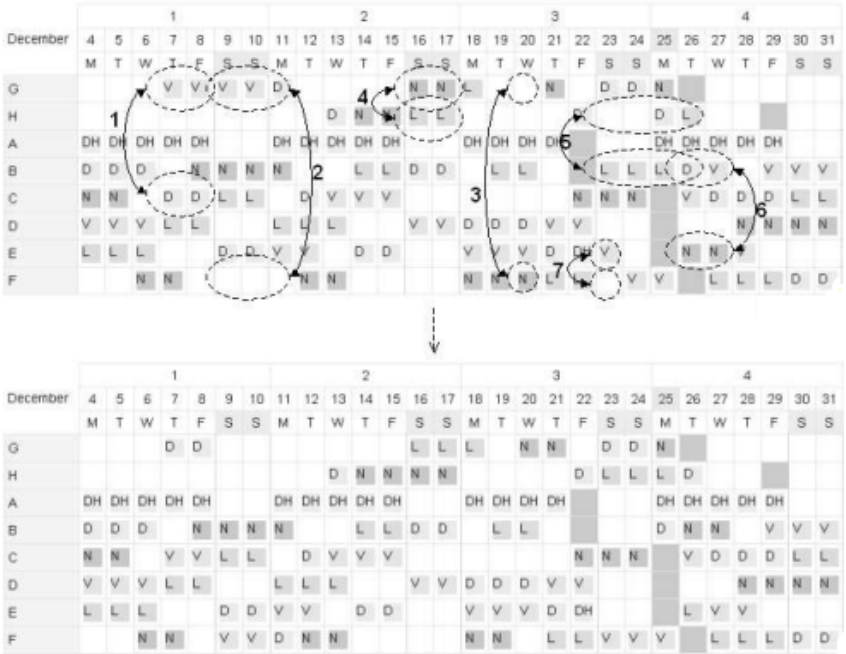


Figure 6.1: Example of swaps in a chain (Burke et al., 2013)

**Selection rule**

After initialising a solution using the greedy approach (Section 6.2.1), an unvisited neighbour is selected based on the neighbourhoods explained in Section 6.2.2. If this neighbour already yields a lower (total) objective value than the current solution, the current solution is updated and we start a new search iteration if time allows. If the personal penalties do not decrease for both of the nurses involved in the swap (or add/remove) or the maximum depth parameter is set to 1, we do not explore any additions to the chain but move on to another neighbour of the current solution. However, when the selected neighbour solution improves the penalty for only one nurse that is involved in the swap but not the other, we aim to add another swap to the chain such that we can improve the total objective.

In this case, say nurse A's schedule improved based on the swap and nurse B's schedule worsened based on this first swap. To find a next swap to add to the chain, we are only going to consider swaps involving nurse B and all other employees (C) to look for the second swap to add to the chain. A swap is only selected as addition to the chain if the resulting neighbour of that swap has a lower penalty than the current best solution, *ignoring the change in the other's (nurse C) penalty.* So, we only consider moves that improve the schedule of the worsened nurse B in the last move added to the chain when searching for the next move. When we find such an improving

swap, it could worsen the schedule of the other nurse (C) such that we start another search to add a swap that improves this nurse's (C) schedule until we reach the maximum allowed depth. However, if we find a schedule that improves the overall objective, we add it as the final move of this chain and update the overall best solution. If time allows, we start a new search iteration.

**Heuristics to reduce running time**

When setting the depth too high, the required running time will become too long as the heuristic gets stuck in long chains. To decrease the running time, two heuristics can be used to reduce the number of neighbours to consider. First, in the **violation flag heuristic**, all days which need repairing after either the addition, removal or swapping of shifts, in order to improve upon any violations are flagged during penalty recalculations (Burke et al., 2013). Then, only swaps that involve at least one of these days are tested to see if adding them to the chain would improve the solution's objective value. So, we only focus on parts of the schedule that need repairing when considering what to add to the chain, this approach is a common heuristic also used in the tabu search approach to solve the nurse scheduling problem, see for example Nonobe and Ibaraki (1998).

In the second heuristic, called the **worsened days heuristic**, we keep track of the days that were worsened since the last swap in the chain. For example, when a shift is removed which leads to violation of the minimum consecutiveness in the new schedule, the day of the removed shift is labeled as the worsened day, as the change on this day caused the increase in the penalty. When selecting a neighbour, we now only consider swaps that affect one of these worsened days. Compared to the violation flag heuristic, the set of available neighbours to select from is now smaller as days which contain violations will be ignored if they were not affected by the last swap in the chain (Burke et al., 2013).

Depending on the allowed maximum running time, a choice is made to use either the violation flag or worsened days heuristics. If the remaining run time is less than a set number of minutes, we switch from using the violation flag to the worsened days heuristic. We set this to 5 minutes.

# Chapter 7

# Computational results

This chapter presents the effects of including nurse satisfaction in the objective. To add preference data to the benchmark problem instances, preferences for minimum and maximum consecutiveness values are drawn from Normal distributions with $\mu$ and $\sigma$ from Table 4.2. The preference weights $\alpha_i$ are also simulated by a Normal distribution ($\mu = 0.5, \sigma = 0.5$) truncated on [0, 1]. The requests for (not) working specific shifts are already included in the problem instances. To be able to compare solution approaches and perform a sensitivity analysis, we fix one set of simulated preferences to use in the results. However, Section 7.1.3 presents results for multiple simulation runs to show that results do not only hold for this one set of fixed preferences.

First, results using the exact method are presented to provide insights in the effect of including crew satisfaction in the objective for the problem instances. Thereafter, results of the Variable Neighborhood Search are presented. These results together are used to answer the first research question. To answer the second, Section 7.3 presents results for when $\beta$ is varied between 0 and 1 to explore the trade-off between coverage and crew satisfaction. Finally, the chapter is concluded with a sensitivity analysis and summary.

## 7.1 Including crew satisfaction using exact method

All MIP results are obtained using an Intel Core i7 2.8 GHz processor and 16GB RAM.

### 7.1.1 Fixed preferences

Table 7.1 shows the exact results obtained from the MIP using the fixed set of simulated preferences. As expected, including the satisfaction reduces the crew satisfaction penalties (crew dissatisfaction) heavily. These results and fixed preferences will be used in the remaining sections to compare results of both methods and several implementations. Runtime is presented in total number of seconds and the gap is the MIP gap. The coverage column presents the total coverage penalty as defined in Equation 5.5. The worst and total column present the maximum and sum of the dissatisfaction scores of all nurses as defined in Equations 5.1 and 5.6. The total objective value of the solution is the sum of the coverage, worst and total column (Equation 5.4).

Table 7.1: MIP results for fixed preferences

| | excl. warm start | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | excl. satisfaction | | | | | incl. satisfaction | | | | |
| instance | time | gap | coverage | worst | total | time | gap | coverage | worst | total |
| 1 | 0.31 | 0 | 600 | 2 | 6.488 | 1.25 | 0 | 600 | 1 | 2.548 |
| 2 | 30.16 | 0 | 800 | 4 | 11.62 | 21.86 | 0 | 800 | 1 | 3.785 |
| 3 | 39.20 | 0 | 1000 | 4 | 24.648 | 887 | 0 | 1000 | 1.77 | 8.67 |
| 11 | 1349 | 0 | 3423 | 6 | 66.102 | 3600 | 0.061 | 3626 | 2.496 | 21.735 |
| 12 | 3600 | 0.024 | 4100 | 10 | 84.526 | 3600 | 0.573 | 9317 | 7.6 | 50.211 |

### 7.1.2 Warm start

As explained in Section 6.1.1, adding a warm start could reduce the runtime of the MIP as it is already provided with a schedule that meets the best possible coverage. Table 7.2 shows that with a warm start, we still cannot solve instances 11 and 12 to optimality. However, compared to not using a warm start (Table 7.1), the solutions to instances 11 and 12 now do have the best possible coverage value and the gap is reduced. For instances 14, 16, and 18 we are unable to find a warm start solution (optimizing coverage only) within one hour.

Table 7.2: MIP results using fixed preferences using warm start

| | incl. warm start | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | excl. satisfaction | | | | | incl. satisfaction | | | | |
| instance | time | gap | coverage | worst | total | time | gap | coverage | worst | total |
| 1 | 0.203 | 0 | 600 | 2 | 5.807 | 1.078 | 0 | 600 | 1 | 2.548 |
| 2 | 7.781 | 0 | 800 | 5 | 12.232 | 26.36 | 0 | 800 | 1 | 3.785 |
| 3 | 32.10 | 0 | 1000 | 4 | 21.371 | 490 | 0 | 1000 | 1.77 | 8.67 |
| 11 | 9.36 | 0 | 3423 | 4 | 60.432 | 3600 | 0.01 | 3423 | 4 | 33.163 |
| 12 | 3600 | 0.000 | 4001 | 9 | 82.062 | 3600 | 0.018 | 4000 | 9 | 70.872 |

### 7.1.3 Simulation results

The scheduling problem is solved using the objective function without satisfaction (only coverage penalty, $\beta = 0$) and the new objective including the satisfaction scores ($\beta = 0.5$).
Figure 7.1 shows the coverage penalty divided by 100 such that it shows the number of unassigned shifts (green, same results from solving with $\beta = 0$ and $\beta$=0.5), the results using the objective excluding satisfaction (red, calculating satisfaction scores in hindsight), and the objective including satisfaction (orange, results from solving with $\beta = 0.5$) for instance 1. The coverage penalty is the same for all runs (6 unassigned shifts). The red area shows that in every simulation run, not including crew satisfaction in the objective leads to a higher satisfaction penalty thus a worse objective value.

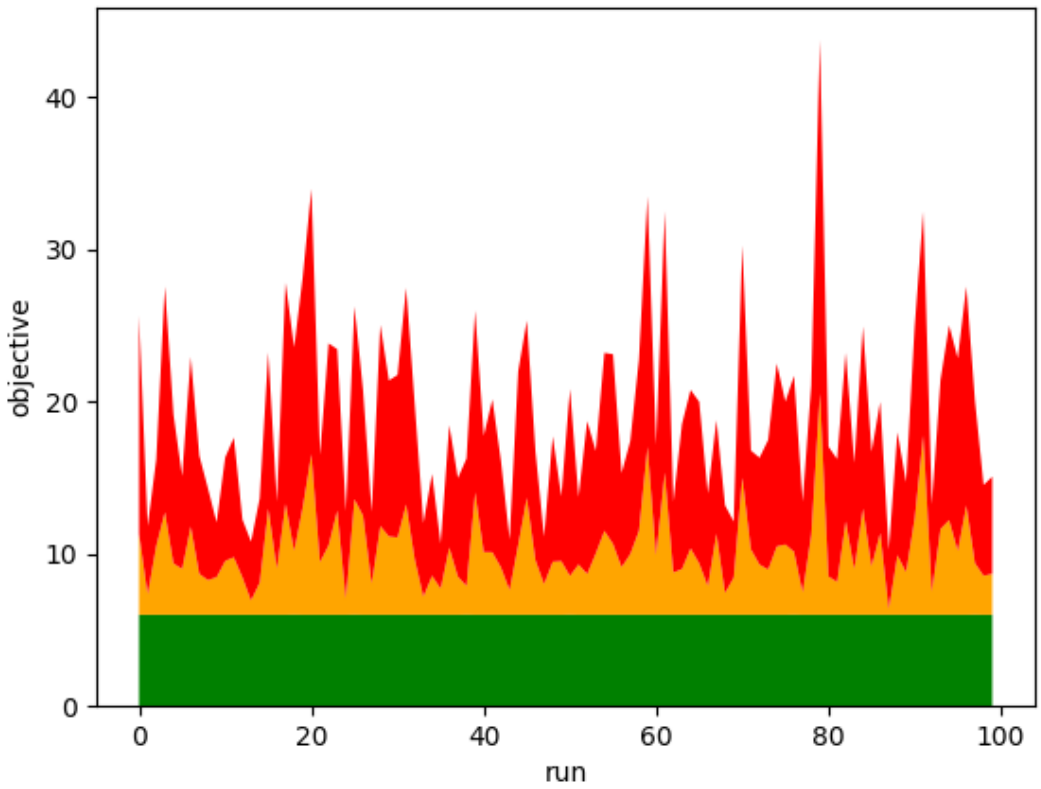
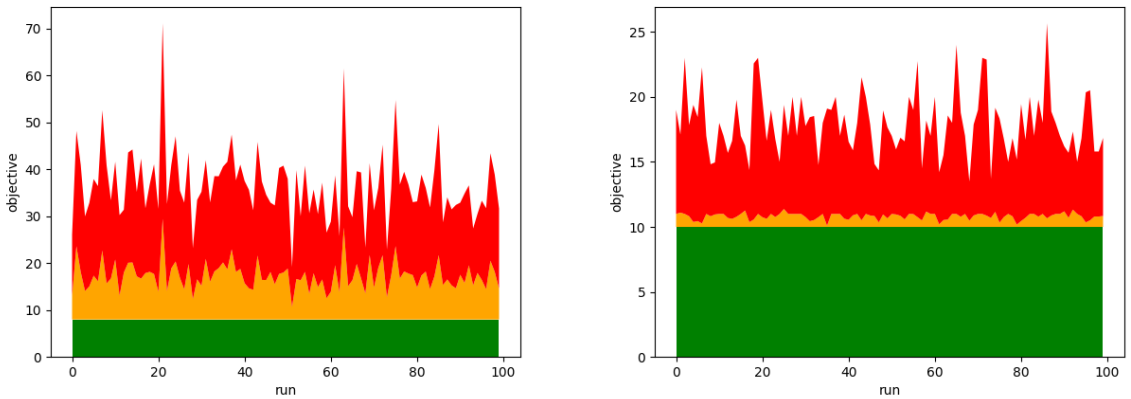



Figure 7.1: Simulation results for instance 1 ($v^{min}$=1 and $v^{max}$ =100)

The simulation results for instances 2 and 3 are visualised in Figure 7.2. Again, we see that the crew satisfaction part of the objective improves by including the satisfaction penalties in the objective at every simulation run. Also, the coverage penalties are the same so satisfaction does not come at a cost in terms of capacity coverage. The warm start and settings of the coverage penalties ($v^{min}$=1 and $v^{max}$ =100) ensure that the result after including satisfaction does not sacrifice this capacity coverage.

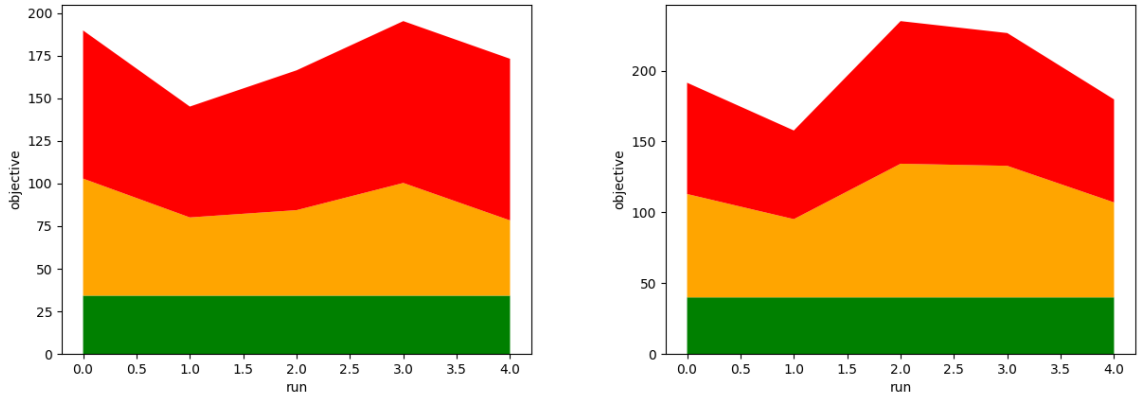



(a) Instance 2

(b) Instance 3

Figure 7.2: Simulation results per instance ($v^{min}$=1 and $v^{max}$ =100)

Also in the results for instances with a scheduling period of four weeks, we see an improvement in the worst-off satisfaction score for all simulation runs when including crew satisfaction in the objective. For instances 11 and 12, again, the coverage penalties stay the same. However, due to the size of the problem instances, we could run fewer simulation runs.




(a) Instance 11 (b) Instance 12

Figure 7.3: Simulation results per instance ($v^{min}$=1 and $v^{max}$ =100)

So, the results show that crew satisfaction can be improved at no cost in terms of coverage by including it in the objective function of the Nurse Scheduling Problem. This has been tested using multiple simulation runs to ensure positive results are not simply one case of easy preferences.

## 7.2 Including crew satisfaction using heuristic

After solving the scheduling problem including crew satisfaction with the exact method, this section presents results using the Variable Neighborhood Search (VNS) approach. This approach is based on Burke et al. (2013) and is used to obtain results on the same benchmark problem instances (Curtois and Qu, 2014). These results are reproduced using the selected set of eight benchmark instances and the version of the VNS algorithm created by Staff Roster Solutions and used by ORTEC. Reproduction results show some differences with Curtois and Qu (2014) but these differences seem to be due to randomness in the search (Table B.1). In this study, we use the default settings of a maximum search depth of 40 and runtimes of 10 and 60 minutes based on Burke et al. (2013) and Curtois and Qu (2014).

### 7.2.1 Heuristic results

Results using the heuristic show that, again, including crew satisfaction improves the satisfaction levels. Especially for larger instances, VNS finds better schedules within one hour than the MIP. However, on the smaller instances, the exact MIP solution is better than the VNS solution. For instance 1, both solution approaches find the same (optimal) solution. Nonetheless, for instances 14, 16, and 18, the exact method is not able to return any feasible schedule within one hour whereas the heuristic still does. Therefore, the VNS is fit to solve the larger instances.

Table 7.3: VNS results including crew satisfaction ($\beta = 0.5$)

| | 10min | | | 60min | | |
|---|---|---|---|---|---|---|
| instance | coverage | worst | total | coverage | worst | total |
| 1 | 600 | 1 | 2.548 | 600 | 1 | 2.548 |
| 2 | 900 | 0.333 | 0.965 | 900 | 0.333 | 0.965 |
| 3 | 1000 | 11.633 | 3 | 1000 | 2.36 | 10.773 |
| 11 | 3928 | 5 | 28.387 | 3827 | 5 | 27.36 |
| 12 | 5100 | 6.025 | 39.073 | 4900 | 6.025 | 38.386 |
| 14 | 1740 | 6.166 | 30.745 | 1740 | 6.157 | 30.754 |
| 16 | 3968 | 9.266 | 30.593 | 3968 | 8.555 | 29.984 |
| 18 | 6682 | 16.535 | 74.832 | 6177 | 14.326 | 60.955 |

### 7.2.2 Results coverage only

When comparing the VNS results to the MIP results, we see that the VNS solution approach does not find the optimal coverage penalties for most instances. However, results for $\beta = 0$ show that VNS is able to find better coverage values when we discard satisfaction in the optimization objective. Therefore, the VNS solution approach is not focused on prioritizing coverage penalty improvements over satisfaction improvements during the search. It would require more runtime to find the optimal coverage penalties and get the same coverage results as the exact MIP.

Table 7.4: VNS results for coverage only ($\beta = 0$)

| instance | MIP | 10min | 60min |
|---|---|---|---|
| 1 | 600 | 600 | 600 |
| 2 | 800 | 900 | 800 |
| 3 | 1000 | 1000 | 1000 |
| 11 | 3423 | 4332 | 3726 |
| 12 | 4000 | 5600 | 4900 |
| 14 | - | 1942 | 1841 |
| 16 | - | 4170 | 3867 |
| 18 | - | 6480 | 6278 |

## 7.3 Trade-off coverage and crew satisfaction

By varying $\beta$ between 0 and 1, the objective varies between solely optimising for coverage or solely crew satisfaction. The $\beta$ value determines whether the objective is dominated by one or the other so, at certain $\beta$ values, it becomes "worth it" to increase satisfaction at the cost of coverage or vice versa. Figure 7.4 shows the different solutions obtained by varying $\beta \in (0, 1)$ with steps of 0.1. This range is exclusive to prevent edge cases to be arbitrarily high. For example, at $\beta = 0$ we find the minimum number of unassigned shifts but the worst-off nurse's satisfaction penalty can be arbitrarily high. Using $\beta = 0.01$ instead makes results more reproducible as you will get the same worst-off score at every run. The number of unassigned shifts and worst-off score are

scaled such that the edge cases ($\beta = 0.01$ and $\beta = 0.99$) yield 1 on the number of unassigned shifts ($\beta = 0.01$) and the worst-off score ($\beta = 0.99$). This allows us to plot the results for all instances in the same figure (Figure 7.4). Each dot represents a solution and is plotted by its number of unassigned shifts and dissatisfaction score of the worst-off nurse. However, varying $\beta$ leads to a limited set of different schedules so only a few data points. It is difficult to improve on the undercoverage due to limited contract hours and hard constraints such as forward rotation and consecutiveness.

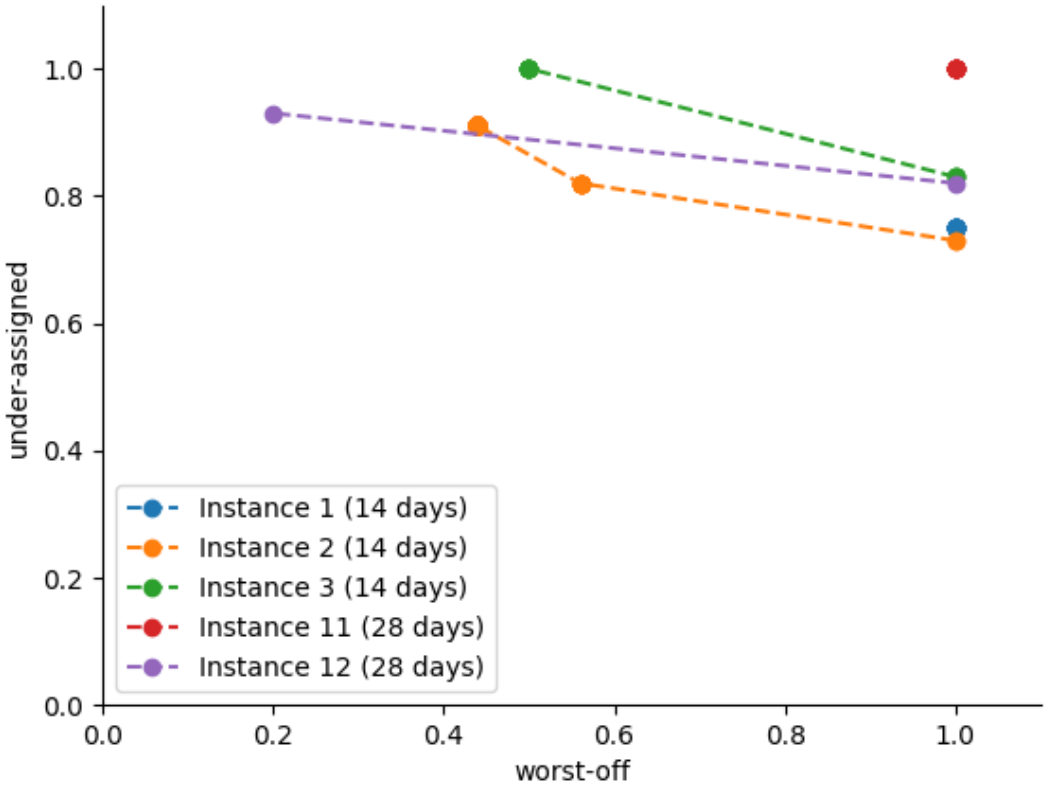



Figure 7.4: Results for varying $\beta \in (0, 1)$ per instance ($v^{min} = 1$ and $v^{max} = 100$, 1 run)

## 7.4 Sensitivity analysis

### 7.4.1 Relaxing hard consecutiveness constraints

Sometimes nurse preferences require exceptions to agreements such as the Dutch CAO. Often nurses are allowed to work, for example, more consecutive shifts than agreed upon by the Union if they prefer to do so. Therefore, some hard constraints can be relaxed which increases the solution space and could improve the optimal objective. However, it could also increase the running time or gap if the running time limit is reached. For this analysis, the hard constraint parameters $c_i^{min}$ and $c_i^{max}$ are relaxed if nurse $i$ had such exceptional preferences. This applied to only 10% of the nurses at most.

For all instances that can be solved to optimality within one hour, we see an improvement in the worst and/or total dissatisfaction score after relaxation (Table 7.5). However, for instances 11 and 12, we cannot find an exact solution within one hour and this does not apply.

Table 7.5: MIP effect of relaxing hard constraints in line with preferences

| | incl. warm start | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | before relaxation | | | | | after relaxation | | | | |
| instance | time | gap | coverage | worst | total | time | gap | coverage | worst | total |
| 1 | 1.078 | 0 | 600 | 1 | 2.548 | 2.719 | 0 | 600 | 0.938 | 2.542 |
| 2 | 26.36 | 0 | 800 | 1 | 3.785 | 48.64 | 0 | 800 | 0.731 | 2.986 |
| 3 | 489.5 | 0 | 1000 | 1.77 | 8.67 | 573.8 | 0 | 1000 | 1.77 | 7.164 |
| 11 | 3600 | 0.01 | 3423 | 4 | 33.163 | 3600 | 0.015 | 3423 | 4 | 49.928 |
| 12 | 3600 | 0.018 | 4000 | 9 | 70.872 | 3600 | 0.018 | 4000 | 9 | 69.558 |

### 7.4.2 Varying fairness metrics

Next, we explore the formulation of fairness in the objective function by comparing three different options. First, a focus on only the worst-off nurse is implemented by setting $\gamma_1 = 1$ and $\gamma_2 = 0$ in the objective (5.9). Second, a focus on only the total sum of satisfaction penalties is implemented by setting $\gamma_1 = 0$ and $\gamma_2 = 1$. A third option is combining both with equal weight, by setting $\gamma_1 = 1$ and $\gamma_2 = 1$. Table 7.6 shows the optimization results for these settings.

Table 7.6: Tuning results for fairness metrics $(\gamma_1, \gamma_2)$

| instance | objective (min) | $\gamma_1$ | $\gamma_2$ | worst | total | MIP gap |
|---|---|---|---|---|---|---|
| 1 | worst off | 1 | 0 | 1 | 2.956 | 0 |
| 1 | total dissatisfaction | 0 | 1 | 1 | 2.548 | 0 |
| 1 | both | 1 | 1 | 1 | 2.548 | 0 |
| 2 | worst off | 1 | 0 | 1 | 6.77 | 0 |
| 2 | total dissatisfaction | 0 | 1 | 2 | 3.785 | 0 |
| 2 | both | 1 | 1 | 1 | 3.785 | 0 |
| 3 | worst off | 1 | 0 | 1.5 | 11.847 | 0 |
| 3 | total dissatisfaction | 0 | 1 | 3 | 8.66 | 0 |
| 3 | both | 1 | 1 | 1.77 | 8.67 | 0 |
| 11 | worst off | 1 | 0 | 2 | 40.519 | 0 |
| 11 | total dissatisfaction | 0 | 1 | 7 | 31.318 | 0.003 |
| 11 | both | 1 | 1 | 4 | 33.163 | 0.01 |
| 12 | worst off | 1 | 0 | 6 | 67.362 | 0.049 |
| 12 | total dissatisfaction | 0 | 1 | 8 | 54.055 | 0.327 |
| 12 | both | 1 | 1 | 9 | 70.872 | 0.018 |

Results show that optimizing the score of the worst off nurse leads to a higher total dissatisfaction score. When the worst off score is obtained for one nurse, the scores for all other nurses are not minimized further after they reach this score. Therefore, a smaller total dissatisfaction

score can be obtained by setting $\gamma_2 = 1$. For smaller instances, assigning both equal weights ($\gamma_1 = 1, \gamma_2 = 1$) leads to the same total dissatisfaction score as optimizing for total dissatisfaction only ($\gamma_1 = 0, \gamma_2 = 1$). Nonetheless, the satisfaction penalty of the worst off nurse is smaller. For larger instances, assigning both equal weights of 1 leads to a slightly higher score on both total and maximum dissatisfaction but is a middle ground between both edge cases.

### 7.4.3 Varying weights of under- and overcoverage

Based on interviews with planners, an underassigned shift should yield a higher penalty than an overassigned shift. However, this analysis shows the result of assigning equal weights to an underassigned and overassigned shift. As we reduce the weight of an underassigned shift from 100 to 1, we increase the relative importance of the satisfaction scores. This implies that reducing one of the satisfaction measures by one now leads to the same improvement in the objective as reducing the number of unassigned shifts by one. Table 7.7 shows that assigning weights of one to all components of the objective (underassigned, overassigned, worst-off, and total dissatisfaction) reduces the satisfaction penalties but increases the coverage penalty. This analysis is done using the instances that can be solved to optimality within one hour only to analyse exact outcomes.

Table 7.7: Results with $v^{min} = 1$ and $v^{max} = 1$

| | $v^{min} = 1$ and $v^{max} = 1$ | | | | | $v^{min} = 100$ and $v^{max} = 1$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| instance | time | gap | coverage | worst | total | time | gap | coverage | worst | total |
| 1 | 1.157 | 0 | 7 | 0.72 | 1.475 | 1.078 | 0 | 600 | 1 | 2.548 |
| 2 | 9.078 | 0 | 9 | 0.54 | 2.393 | 26.36 | 0 | 800 | 1 | 3.785 |
| 3 | 650.9 | 0 | 12 | 1.18 | 5.273 | 490 | 0 | 1000 | 1.77 | 8.67 |

## 7.5 Summary

Based on Section 7.1, the effect of including crew satisfaction in the objective function is, as expected, an improvement in crew satisfaction. This improvement however, never has an effect on the coverage penalties of the optimal solutions. Only in larger instances that cannot be solved by the exact method within the running time of one hour, the coverage penalties can increase when including crew satisfaction. However, the results show that crew satisfaction can be improved by including it in the objective at no cost in terms of coverage.

Section 7.2 shows similar results for the smaller instances using a Variable Neighborhood Search (VNS) heuristic. Nonetheless, the heuristic is also able to return feasible solutions to the larger instances within a runtime of one hour. Section 7.3 showed the trade-off between coverage and crew satisfaction is limited by a set of feasible schedules. It is not possible to measure a marginal cost of improving undercoverage by one shift in terms of worst off satisfaction penalties. This is reasonable as the solution space is constrained by labour rules and contracts. This chapter concludes with a sensitivity analysis showing the effect of relaxing some hard constraints, varying the fairness metrics and the weights for the coverage penalties per under- and overassigned shift.

# Chapter 8

# Conclusion

The main research question answered in this thesis is:

**What is the effect of incorporating nurses' personal scheduling preferences into the Nurse Scheduling Problem?**

The two most important indicators of nurse schedule satisfaction are the adherence to requests made by nurses to (not) work specific shifts and the consecutiveness of assigned shifts in the schedule. When nurses are assigned too many consecutive shifts per block, their schedule satisfaction decreases as they cannot balance their workload with enough rest. However, the maximum number of preferred consecutive shifts differs per nurse because of personal differences. The same applies to a preference for a minimum number of consecutive days. Additionally, the importance of requests versus the consecutiveness of shifts differs per person. Therefore, including these personal preferences in the objective function of a nurse scheduling problem requires input from the nurses. In this thesis, nurse preferences are studied based on interviews and a survey. Based on the survey results, nurse preferences are simulated to explore the effect of including crew satisfaction in the objective function. Violation of the preferences are translated into penalties which are minimised. Besides minimizing the preference violations, the main aim of the nurse scheduling problem is to minimize the difference between planned nurses and required. Here, assigning too few nurses is considered worse than too many.

To make the results comparable to other research on the nurse scheduling problem, we use the data of benchmark instances provided by Curtois and Qu (2014). To solve the problem formulation, two methods are used. Because the scope of this thesis is scheduling problems with a maximum scheduling period of 12 weeks, most problem instances can be solved by a Mixed Integer Programming formulation using a CPLEX 22.1.1 implementation. However, as larger instances cannot be solved by the exact method, the second method is a Variable Neighborhood Search (VNS) heuristic. This method iteratively makes small changes in the solution to look for improvements in the objective value. While one change might not lead to an improvement, sometimes a chain of changes can. Therefore, the heuristic takes a specified maximum depth and explores chains of changes until this maximum depth.

The effect of including crew satisfaction in the objective function using the exact solution methods shows that on every instance, the satisfaction of the crew can be improved without hurting the coverage penalties. Therefore, it does not cost anything in terms of coverage penalties to improve the satisfaction of the crew. Results of the heuristic also show improvement in crew satisfaction but not as much as the solution of the exact method. However, for scheduling problems with a longer scheduling horizon ($\geq$ 6 weeks) the heuristic could still provide a feasible solution within one hour whereas the exact solution method cannot.

## 8.1 Suggestions for further research

Further research could move into three directions. First, more data should be collected on personal scheduling preferences of nurses and how they affect nurse job satisfaction. This research only focuses on nurses working in Dutch hospitals. With further research, a feedback mechanism could be implemented to continuously evaluate the fit of the objective compared to the needs of the nurses and the preference settings.

Second, further research could focus on the formulation of the scheduling problem including nurse satisfaction. For example, we currently ignore all shifts assigned in a previous scheduling period when calculating employee hard and soft constraints. This could have an effect on, for example, the consecutiveness penalty of a nurse $i$. Currently, we assume a nurse is not working the days before and after the current scheduling period. Nonetheless, a nurse could have worked the day(s) before the start of this new scheduling period which affects the consecutiveness of the schedule. Therefore, the measurement of the penalties could be improved. Regarding fairness, taking historical shifts into account could also prevent a nurse from receiving two bad schedules in a row.

Finally, a third direction for further research could be tailoring the VNS heuristic to the objective including crew satisfaction as opposed to the objective in Curtois and Qu (2014). The heuristic was developed to solve the benchmark instances with the benchmark objective. However, as we have made some changes in the objective formulation, the heuristic could be tailored to this objective to explore improvements. For example, the heuristic should exploit all possible swaps that affect the coverage first before exploring satisfaction related swaps.

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# Appendix A

# Survey

## A.1 Removed roles specification

Table A.1: Removed roles from survey respondents during cleaning

| |
|---|
| Anesthesiemedewerker |
| Applicatiebeheerder |
| Apothekers assistent |
| baliemedewerker |
| beveiliging |
| Business analist |
| coordinator Martini Flex |
| Facilitaire Dienst |
| functioneel beheerder |
| Installatietechnicus |
| Jurist |
| Kwaliteit coördinator |
| MBB'er (4x) |
| mdw bloedafname |
| medisch secretaresse |
| Operatieassistent |
| Planbureau medewerker |
| planner (3x) |
| procescoördinator |
| PROMs en onderzoeksmedewerker |
| Radiodiagnostisch laborant (2x) |
| Teamleider (2x) |
| Voedingassistent |
| zorgbeveiliger |
| Zorgcoordinator |

## A.2 Shift type preferences

Table A.2: Answers for 'other' shift type preference (mostly about variability)

| |
|---|
| Afhankelijk van prive situatie |
| zo min mogelijk nachten |
| Avond en nacht |
| Dag en avond |
| Liefst geen nacht, avond of dag maakt niet uit |
| Dag en daarop avond |
| In schoolvakanties voorkeur voor late dienst, anders geen voorkeur |
| dag of nacht |
| Alle 3 verdeelt over het rooster |
| Dag of laat |
| Dag en avond |
| Liefst dag en late. Geen nachten of 1 |
| Weekend dag en doordeweeks laat |
| afwisseling van alle diensten |
| variatie |
| dag en nacht/ geen liefhebber van late diensten |
| dag en avond |
| Alles in afwisseling |
| als er maar afwisseling in dag en avonddiensten zijn , vind ik het prima |
| liefst geen late ivm thuissituatie, nachten en dag geen voorkeur |
| alle diensten zijn wel OK, maar niet meer dan 2 dagdiensten achter elkaar. |
| Liefst dagdiensten in het weekend en ld en nacht door de week. |
| Voorkeur voor dag of avond |
| Vooral goed verdeeld, maar niet te veel dezelde achter elkaar |
| lieve rmeer avond en nacht dan dag |
| Vooral voorkeur voor afwisseling |
| goede afwisseling |
| dag en avond |
| van alle diensten bij voorkeur max 2 achter elkaar |

## A.3 Additional questions

Table A.3: Consecutiveness preferences

| | min | max | mean | st dev | variance |
|---|---|---|---|---|---|
| Preferred minimum nr. of consecutive shifts (per block) | 1 | 7 | 2.41 | 0.84 | 0.70 |
| Preferred maximum nr. of consecutive shifts (per block) | 2 | 10 | 4.19 | 1.29 | 1.67 |

Next, nurses are asked to divide 20 points over two options to get insights into their priorities. This question is based on previous research on nurse preference scheduling by Warner, 1976.

Table A.4: Preference for single days on/off

| | min | max | mean | std dev | variance |
|---|---|---|---|---|---|
| single day on (off-on-off) | 0 | 20 | 10.40 | 5.59 | 31.22 |
| single day off (on-off-on) | 0 | 20 | 9.6 | 5.59 | 31.22 |

Table A.5: Number of requests (per month)

| In an average month, how many requests would you submit | choice count |
|---|---|
| 0-5 | 200 (83%) |
| 5-10 | 33 (14%) |
| 10+ | 8 (3%) |

Table A.6: Incidental vs. structural requests

| Do you mainly have... | choice count |
|---|---|
| incidental requests (birthday, parties, private appointments, etc.) | 168 (70%) |
| structural requests (recurring sports training, babysitter, etc.) | 73 (30%) |

Table A.7: Incidental vs. structural requests

| Do you mainly have... | 24 hours or less | more than 24 hours |
|---|---|---|
| incidental requests | 50 | 118 |
| structural requests | 28 | 45 |

Table A.8: Preference for scheduling of weekends

| When you are working two weekends in a month, ... | choice count |
|---|---|
| I prefer to work them consecutively | 5 (2%) |
| I prefer to work them spread throughout the month (biweekly) | 138 (57%) |
| I have no preference | 101 (41%) |

Table A.9: Preference for shift type in weekend

| When working in the weekend, I prefer to be assigned... | choice count |
|---|---|
| a day shift | 100 (41%) |
| an evening shift | 56 (23%) |
| a night shift | 8 (3%) |
| no preference | 80 (33%) |

Table A.10: Variability in shift types per block

| | yes | no |
|---|---|---|
| Preference for variability in assigned shift types per block | 160 (66%) | 84 (34%) |

# Appendix B

# Reproduction

Table B.1: VNS reproduction (Curtois and Qu, 2014)

| instance | ORTEC 10min | 2014 10min | diff | ORTEC 60min | 2014 60min | diff |
|---|---|---|---|---|---|---|
| 1 | **607** | **607** | 0 | **607** | **607** | 0 |
| 2 | 924 | 923 | 1 | 832 | 837 | -5 |
| 3 | 1004 | 1003 | 1 | 1003 | 1003 | 0 |
| 11 | 4163 | 3967 | 196 | 3855 | 3661 | 194 |
| 12 | 5388 | 5611 | -223 | 4690 | 5211 | -521 |
| 14 | 2305 | 2542 | -237 | 2014 | 1847 | 167 |
| 16 | 4048 | 4343 | -295 | 3736 | 4048 | -312 |
| 18 | 7312 | 6404 | 908 | 6545 | 6404 | 141 |

# Appendix C

# Pseudocode VNS

Let
$penalty_r$ = the penalty for roster $r$.
$penalty_{r,n}$ = the penalty for the schedule of nurse $n$ in roster $r$.
0. set best roster := the current roster
1. set current roster := an unvisited neighbour
   in neighbourhood for best roster
2. if no unvisited neighbour available
     stop and return best roster
3. if $penalty_{\text{current roster}} < penalty_{\text{best roster}}$
     goto 0.
4. if neither of the penalties decrease for
   the individual schedules of the two employees
   involved in the swap OR maximum depth <= 1
     goto 1.
5. set E1 := the employee with increased penalty
   set current depth := 1
6. In the neighbourhood for the current roster
   where considering swaps of blocks between
   employee E1 and all other employees (E2)
   set current roster := neighbouring roster with
   lowest penalty where
   $penalty_{\text{neighbour}} < penalty_{\text{best roster}}$ or
   $penalty_{\text{neighbour}} - penalty_{\text{neighbour,E2}} +$
   $penalty_{\text{current roster,E2}}$
   $< penalty_{\text{best roster}}$
7. if no such neighbour
     goto 1.
8. else if current roster's penalty < best roster's penalty
     goto 0.
9. else if current depth < a preset maximum depth
     set E1 := E2
     set current depth := current depth + 1;
     goto 6.
10. else
     goto 1.

Figure C.1: Variable Neighbourhood (Depth) Search Outline (Burke et al., 2013)

# Part C

# Contents

# Chapter 1

# Values in Mathematical Optimization

In part B, a new mathematical formulation of the nurse scheduling problem is presented to answer the fourth research question: "*How can these values be implemented in the design of a mathematical optimization problem to support the planning process?*". This chapter will provide a small summary of part B as well as a discussion and conclusion.

## 1.1 Summary

To answer the fourth research question, I used my insights from the interviews both with nurses and planners to design a personal satisfaction function and new optimization objective. Then, I used two solution approaches to find the optimal schedules for a set of benchmark problems (Curtois and Qu, 2014). Both yielded feasible schedules (that adhere to labour law and collective labour agreements) incorporating my new satisfaction function. To analyse the impact of adding this new satisfaction element to the optimization objective, I also calculated the satisfaction scores of the schedules created by only optimizing for optimal coverage of the capacity requirements. By comparison, I was able to show that we can always improve upon our adherence to the nurse preferences when we add them to the objective function.

Additionally, running sensitivity analyses, satisfaction scores can be further improved by decreasing the relative weight of the number of unassigned shifts in the objective. However, as planners mentioned in their group interview (Part A, Chapter 5), they usually prioritise meeting the cover requirement over meeting (all) nurse preferences.

## 1.2 Discussion

Previous literature on nurse preference scheduling used a similar mathematical approach by defining a satisfaction function to be optimised (Burke et al., 2001; Randhawa and Sitompul, 1993). Most recent OR research on nurse satisfaction, however, seems to assume a certain variable can be used to measure individual schedule satisfaction but does not cover the actual calculation of this variable (Bard and Purnomo, 2005; Dowsland, 1998). Also, most other studies generalise the scheduling preferences on a group or department level. This ignores

the presence of personal preferences and differences among nurses. Compared to this previous research, I incorporated nurses' values in the formulation by deriving it on the interview and survey results. Therefore, this formulation could be better aligned with nurses actual preferences compared to other studies. For example, my formulation allows for a lot more personalization of the components of the satisfaction function but also their relative importance to improve nurses' perceived level of autonomy.

To solve the mathematical optimization problem, I have used two different algorithms. They differ in approach where one is more suited for smaller problems with a scheduling period of less than four weeks and the second approach is more suited for larger instances (Burke et al., 2013). However, the same problem formulation could be solved using other algorithms. Considering the scope of this research, the design of the mathematical formulation of the problem is where the values of (in)direct users should be considered to have a positive impact on the quality and usability of the outcome. A more elaborated discussion of the implementation of the values in the design of the mathematical optimization problem can be found in Part B.

## 1.3 Conclusion

During the design of this new approach to the nurse scheduling problem, there were many design choices that were based on user values that I identified in Part A. For example, fairness is incorporated in two ways. First, nurses used to be able to have as many requests as they wanted and each would get weights assigned by the nurse between 1 to 3. However, in the interviews, many nurses explained how they perceive the process as unfair due to big differences in the number of requests nurses make. Therefore, I decided to scale all the weights assigned per nurse per request such that the total number of weights assigned is equal per nurse. This means that nurses could assign higher weights to some requests than other requests to communicate their preferences but overall, all nurses get an equal opportunity to make their requests heard. Additionally, fairness is implemented in the calculation of the total score of a schedule (solution). This score is a combination of the score of the worst off nurse and the total sum of scores of all nurses. By taking the worst off nurse into account, the optimal solution will ensure that all nurses are at least as satisfied as the worst off nurse. This means you cannot make a couple nurses extremely unhappy as long as the average is acceptable but that you instead focus on maximizing the happiness of the worst off.

Second, autonomy is important to both nurses and planners which is improved by giving nurses more options to communicate their preferences and priorities. With the new implementation, nurses can share a broader set of preferences since, for example, consecutiveness preferences are added. Based on the survey, consecutiveness and shift requests are the most important but more preferences can be added in the future.

So, to answer the fourth research question, the identification of the values of the (in)direct users helped guide the design of the mathematical optimization problem by understanding what is important to them. Often, mathematical language is not a shared language between the (in)direct users of optimization software and its developers. Therefore, it can be though to

have a discussion about the design of the formulation. However, by taking the value sensitive design approach and having interviews with both planners and nurses before thinking in terms of mathematical optimization models, it was a lot easier to make design choices with the users in mind. For example, formulating the optimization objective was a lot easier knowing that planners will always value meeting coverage requirement over meeting nurse preferences (additionally to meeting labour agreements).

# Chapter 2

# Discussion

The aim of this joint thesis was to design a scheduling tool which creates nurse schedules based on an optimization algorithm taking into account nurse preferences. The aim of this tool is to develop schedules that increase nurse happiness and the attractiveness of the nurse profession. Before diving into the mathematics, a value sensitive design approach is used to study the values that drive nurse satisfaction and planner's scheduling process.

Based on theories and background literature, it was expected to see a positive relationship between scheduling satisfaction and job satisfaction. However, theories on job satisfaction and motivation did not specifically cover the scheduling aspect of the job. Therefore, a systematic literature review is done to answer the first sub question. The results of this review showed that not a lot of previous work is done on scheduling effects. This could be because scheduling is a practical aspect of work and not of scientific interest. However, literature does contain studies on the effects of shift work on health.

Based on interviews with planners and nurses, we observed that in practice, nurses can express preferences that conflict with the results of such studies on what makes a schedule with irregular shifts "healthy". Therefore, one can have a discussion about what is more important: schedules that are "healthy" or schedules that are "preferred". For example, nurses might want to work seven days in a row to get five days off the week after. This could be an unhealthy schedule based on literature but if nurses ask for it as it is their preferred schedule, who can claim otherwise? Also, based on interviews, nurses and planners both value their autonomy and fairness in the scheduling process. These values are relatable to other studies using a Value Sensitive Design approach for designing autonomous vehicles and AI tools (Thornton et al., 2018; Umbrello and Van de Poel, 2021).

Variables such as a satisfaction, health or happiness are difficult to define and measure. This makes it complicated to develop a mathematical model to optimize these variables. Currently, most mathematical optimization literature does not cover empirical evidence of the causal relationships assumed in their mathematical formulation. For example, most algorithms ask nurses to select some days they would prefer to (not) be working and use this to approximate nurse schedule satisfaction. In interviews however, nurses expressed other types of preferences than such single shift requests like a preference for the number of consecutive shifts.

Limitations of this research are, however, the limited sample size of the interviews with the nurses and the planners. Further research is recommended to study the decision making process of planners and how it could be supported by an optimization tool. Especially, the collaboration between a planner, nurse and software system (algorithm) is an interesting topic for further study. Currently, each of these have their own role in the scheduling process but there is a lack of structure and communication can be improved.

To be able to develop a pilot of the optimization system, preference data is simulated based on a survey. This pilot serves as a proof of concept by showing that by using a new mathematical formulation of the problem's objective, schedules could be tailored to fit personal preferences better at no cost in terms of capacity. This is a promising result, since planners could meet the nurses' preferences essentially for free. Nonetheless, more research should be done to evaluate the pilot with a group of nurses and planners.

To conclude this discussion, the obtained results show a potential for schedules that adhere better to nurse preferences by supporting a collaboration between optimization technology and planners. However, because of limitations of the methods, further research is recommended on the translation of the concepts of satisfaction and scheduling into mathematical indicators. The application of Value Sensitive Design is a promising approach to designing mathematical optimization problems that better fit their practical use case. The method encourages qualitative research methods such as interviews to better understand the values that drive (in)direct users. However, more research on the application of this approach to other types of mathematical optimization problems and the development of algorithms is required to study its effectiveness.

# Chapter 3

# Conclusion

To conclude, the answer to the main research question: "*How can value sensitive design help to design an optimization (software) system based on the values of its indirect users (nurses)?*" might lie in providing empirical evidence for mathematical problem design choices. When translating a complex problem such as scheduling nurses to a mathematical formulation, certain choices have to be made. These choices are made by the designer who understands mathematics but does not necessarily understand the practicalities of nurse scheduling. The aim of thesis was to design a scheduling tool to support planners making schedules that align with nurses' personal scheduling preferences. By applying Value Sensitive Design methods such as interviews with (in)direct users, the designer can collect empirical evidence when making design choices.

Based on a systematic literature review, providing nurses with the scheduling option they prefer has a positive effect on their perceived job satisfaction. However, the three studies selected based on selection criteria do not describe in detail what aspects of scheduling were measured. To include schedule satisfaction in an optimization model requires a translation into measurable scheduling aspects. Therefore, more research is required into what drives nurse schedule satisfaction.

Based on interviews with nurses, nurses value fairness and autonomy. The expressed preferences do not fit the current options for communicating requests. Therefore, nurses lack a sense of control (autonomy) over their schedule and how it affects their personal lives. Additionally, because of a lack of transparency, nurses feel like the scheduling process is not fair enough. A common perception is that some nurses get more preferable schedules than others.

Throughout the scheduling process however, planners feel like they take fairness into account as best as possible as well as all individual preferences. Nonetheless, in making trade-offs they will always prioritise meeting the capacity demands (within labour laws and agreements) over adhering to personal preferences. During the group interview, planners explained how they currently do not use any optimization tools as it performed bad in the past. They believe a software program will never be able to take all things into account like they can but would welcome support in evaluating the fairness of schedules.

To give nurses more of a sense of control (autonomy) over their schedule, the optimisation software should be able to work with personalized preference parameters. At the same time, to align with planners, it should prioritize meeting capacity demands and keep a fair balance of the satisfaction of all nurses. These requirements are used in a formulation of a mathematical optimization and solved using two algorithms. Results using simulated preferences based on a survey indicate that nurse schedule satisfaction can be improved without worsening the capacity for all considered benchmark instances.

# Chapter 4

# Reflection

Personally, I am really happy to have had the chance to combine both the degrees into one joint research project. As explained before, the combination of both the Value Sensitive Design approach and the mathematical optimization approach let to interesting and practical results. Personally, the most value to this interdisciplinary approach is the relatability I now feel towards nurses and planners while working on the optimization software. Before the interviews, it is hard to understand what they believe should be the right approach to scheduling so to design software to support their decision-making process seems very off.

However, it has also come with some challenges. For example, in both approaches, I had to define a clear scope for myself. Where in the interviews, I chose semi-structured interviews since it is interesting to hear their stories and learn about their experiences and perception of the scheduling process. On the other hand, I would need to limit myself to parts of the process I could affect with the optimization tool I am designing. In the interviews, many aspects of communication and collaboration were discussed that have nothing to do with the use of the software product. However, these stories were great input to understand what drives nurses in their daily work and what made them choose the profession. Some nurses I interviewed, had been working in healthcare for over 40 years.

Additionally, in the second part of my thesis when working on the optimization, I had to define a clear scope. The design of the problem, the translation from interviews and surveys to a clear mathematical problem formulation, was my main focus. However, when I got to the part of implementing a solver, it could have easily become another research project to adapt the algorithm such that it would find the best schedule adhering to the most preferences faster. Then, there came a point where I wanted to combine both the projects into one report and the structure of the writing became really messy. It took me some conversations with my supervisors to understand the scope and structure of my project but I feel like in the end, with help, I got to a combined research project that I am actually really proud of!

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