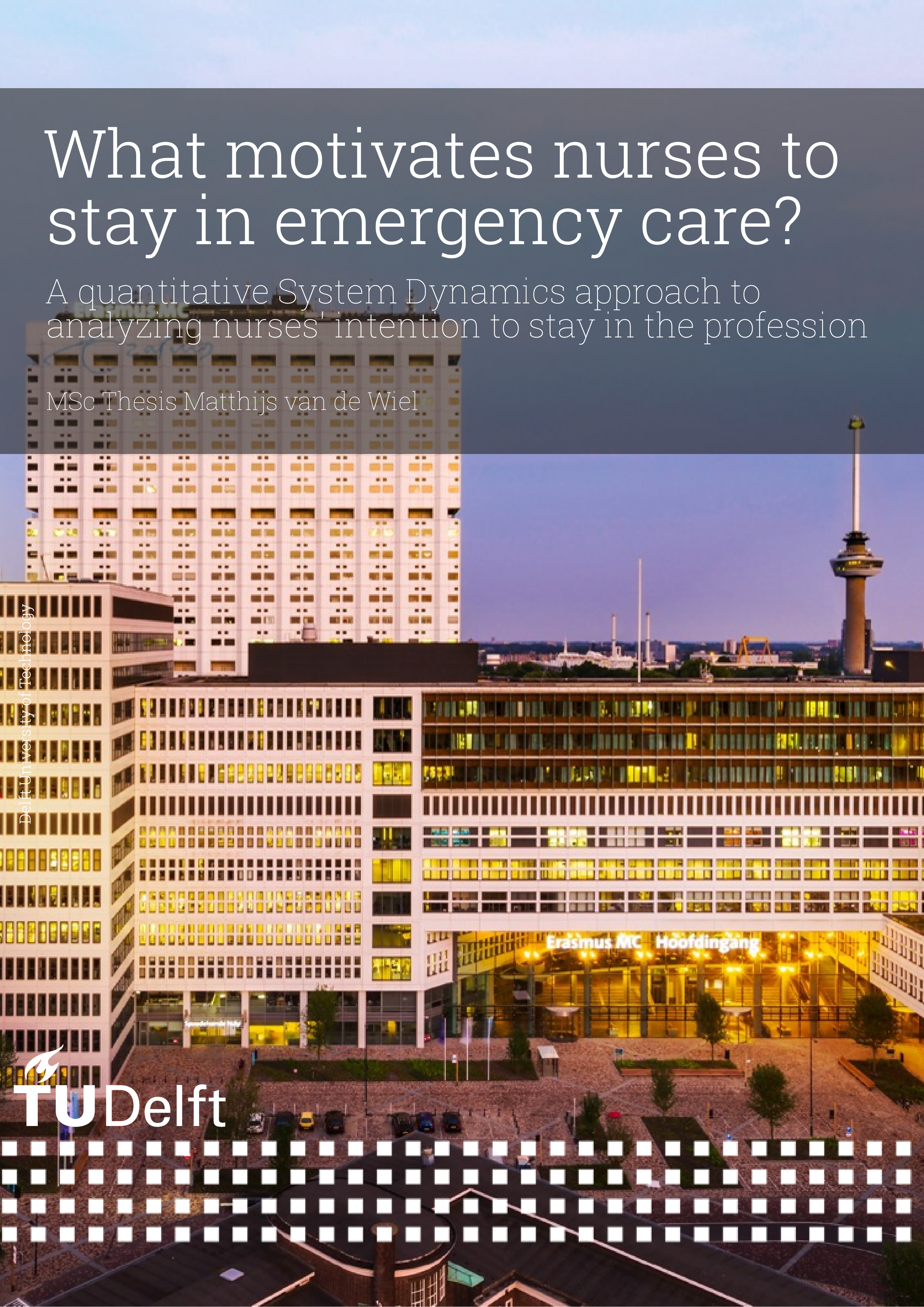
What motivates nurses to stay in emergency care?

A quantitative System Dynamics approach to analyzing nurses' intention to stay in the profession

MSc Thesis Matthijs van de Wiel



Delft University of Technology

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by

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Preface

Come and work in healthcare, it is horrible! - Lennard Pierey, doctor not in specialist training

I came across this quote during my thesis and it stuck with me ever since. Growing up in a healthcare family, with a mom who is doctor and a father who is a nurse, I heard all the stories. From tough patients, heavy incidents, sad family members to poor management. But what stuck with me, are the beautiful recoveries, loving care for elderly and the sick, and a true passion for improving other human being lives. While that did not spark a career in healthcare for myself, it has always been in the back of my mind to contribute to the sector. But adding to the already negative tone in the media on the healthcare sector is not contributing. I do not want to contribute to this narrative of healthcare being a horrible sector to work in; it's beautiful! And I think that is where we should be heading with research on the problems in the healthcare sector: why is this such an amazing sector to work in and how do we get that spirit roaring? That is what will inspire future generations to attempt to become a doctor, a nurse or to become involved in healthcare.

I want to thank an emergency waiting room full of people. First, I want to thank the nurses that participated in the GMB sessions for their enthusiasm and honest participation. I hope you see your valuable efforts reflected in this thesis. I want to thank Wietse, Hans, Isabel and Marjolein, for being open and welcome at the Emergency Department and facilitating the sessions between me and the nurses with ease.

Next, I want to thank my thesis committee, in particular, Irene and Willem. Thank you Irene, for sharing your inspirational passion for healthcare with me. It has been a pleasure to brainstorm about all kinds of problems in healthcare and to have you as my first supervisor. Thank you Willem, for pushing me and this project towards heights I did not know it could go. From the beginning, you have been strict with me, and it is exactly what I needed to pursue this thesis.

I want to thank my parents for supporting me throughout my whole student time, so that I had the time and space I needed to develop into the person I am today. More so, it was your passion for healthcare that sowed the seed for this thesis.

I want to thank my housemates, for the moment I being on the frontline of my frustrations and for always choosing my side, even though you already knew I was naive or wrong.

And last but not least, I want to thank Clara, for her unconditional love and support. I am super proud of how we managed both our theses at the same time from a distance. I cannot wait to start the next adventure of life with you.

Matthijs van de Wiel
Rotterdam, May 2025

Summary

Healthcare systems in the Netherlands and across the Western world are currently facing a growing crisis characterized by increased demand for care coupled with a shrinking workforce. Central to this challenge is the retention of nurses, especially in high-pressure environments such as Emergency Departments. The Erasmus MC, a Level I trauma and academic hospital, presents a particularly dynamic and demanding setting, making it an ideal use case for understanding workforce dynamics. This thesis investigates the key factors that influence nurses' intention to stay in the profession, with an emphasis on the idea that perceived workload may have a stronger impact on retention than objective workload metrics. While previous research has often explored individual factors through surveys or linear cause-effect approaches, this study advocates for a systems science approach to capture the complex interplay among team dynamics, various types of stress, job satisfaction, and intention to stay. The primary research question explored is:

"How can a systems science approach contribute to the understanding of nurses' workload and their intention to stay in the profession in the Emergency Department at Erasmus MC?"

This question is addressed through the use of System Dynamics (SD) modeling and participatory Group Model Building (GMB) with nurses, supported by an extensive literature review and a simulation analysis using Exploratory Modeling Analysis (EMA).

This study employs a participatory systems science approach using System Dynamics, focusing on the team level rather than individual characteristics to highlight systemic and organizational factors. A single-case design centered on the Erasmus MC Emergency Department was chosen to gain deep, context-specific insights rather than broad generalizations. The research began with an iterative literature review that identified key factors influencing nurses' intention to stay in the profession. These included distinctions between subjective and objective workload, different types of stress such as emotional, physical, moral distress, and eustress, as well as concepts like sustainable employability, burnout, intention to leave, job satisfaction, and career expectations. The Job Demands-Resources (JD-R) model and Self-Determination Theory were especially influential in conceptualizing how job stressors and motivators relate to outcomes.

Two participatory Group Model Building sessions and a validation session were conducted with nurses from Erasmus MC Emergency Department to capture tacit knowledge and mental models about workload and stress in relation to their intention to stay. Instead of constructing models entirely from scratch, nurses interacted with predefined causal loop diagrams (CLDs) derived from the literature. This approach facilitated discussion, consensus, and model modification. Subsequently, a quantitative System Dynamics model was developed based on these sessions and literature findings. The model simulated the evolution of perceived workload, job satisfaction, and intention to stay over a two-year period with weekly time steps. It incorporated variables such as shifts and shift balance, direct versus indirect care time, team dynamics, various types of stress and their accumulation, as well as job satisfaction and intention to remain in the profession. To address deep uncertainty in the modeling process, Exploratory Modeling and Analysis (EMA) and the Patient Rule Induction Method (PRIM) were employed. These tools helped identify scenarios and parameter combinations that lead to desirable outcomes of job satisfaction and intention to stay.

The study produced several key insights. First, it became evident that perceived workload has a greater impact on nurses' decisions to remain in the profession than the objective workload measured by task volume or patient-to-nurse ratios. This supports the deeper understanding gained through the systemic model, which reveals how intention to stay emerges from complex interactions among variables such as team cohesion, moral distress, and supportive leadership, highlighting multiple reinforcing feedback loops that shape nurses' experiences and decisions. Among the concepts emerging from the model, "shift balance"—which reflects whether a nurse experiences more good shifts than bad ones over time—stood out as a critical metric, echoing nurses' own emphasis during Group Model

Building sessions on the importance of shift experience and work-life balance over more traditional workload measures. The model also revealed the importance of distinguishing among four types of stress: emotional distress resulting from emotional labor and patient interactions; physical distress, which was less prominent in this Emergency Department context; moral distress caused by ethical dilemmas; and eustress, a positive type of stress that motivates and energizes nurses, acting as a protective buffer. These stress types interact in reinforcing feedback loops that, if unmanaged, can lead to negative spirals of burnout; however, nurses' own adaptive behaviors often mitigate these spirals temporarily, which suggests that policy interventions must carefully consider where in the cycle nurses currently operate to be effective.

Team dynamics emerged as a significant influence on nurses' stress perception and job satisfaction, with factors such as cohesion, psychological safety, and leadership style helping to transform high workloads into manageable—or even rewarding—experiences. Furthermore, the ability to recover between shifts and maintain healthy levels of eustress emerged as critical leverage points for sustaining a motivated and committed nursing workforce. The PRIM analysis reinforced these findings by identifying specific combinations of conditions that produce high job satisfaction and a strong intention to stay. In particular, a balance of direct and indirect care time that allowed for meaningful patient contact, low initial emotional distress, fulfilled career expectations, and a high-quality private life were key predictors of intention to stay. Notably, even in the presence of job satisfaction, unmet career aspirations could still cause a negative outcome of intention to stay.

This thesis contributes a novel, systems-level perspective on nurse retention within emergency care. Unlike reductionist approaches that isolate burnout or turnover intentions, it frames the problem as a dynamic interplay of feedback loops involving stress, satisfaction, team behavior, and policy. The study introduces a multi-type stress taxonomy with practical modeling implications, highlights shift balance as a valuable and practical metric for perceived workload, and reconceptualizes eustress not as an inherently positive fixed factor but as a contingent buffer influenced by the work environment and individual experience.

From a practical standpoint, policy interventions should focus on improving team dynamics, recognizing and supporting career goals, and optimizing shift scheduling to enhance nurses' perceived workload and satisfaction. The System Dynamics model developed can assist hospital managers in stress-testing potential policy changes under conditions of uncertainty. Furthermore, the Group Model Building process itself proved beneficial, providing moments for reflection and strengthening group cohesion among participating nurses.

There are several limitations to note. The single-case study design means that findings are specific to Erasmus MC and may require adaptation to generalize to other settings. Many assumptions in the model were shaped by perceptions and qualitative data, underscoring the need for further empirical validation. Finally, while the model simulates behavior over two years, real-world longitudinal data on nurse retention was not collected, which could be addressed in future research.

In conclusion, this research demonstrates that nurses' intention to stay in the profession cannot be attributed simply to salary or staffing levels. Instead, intention to stay depends on a complex web of interrelated factors, including perceived workload, various types of stress, team dynamics, and personal life satisfaction. By leveraging a System Dynamics model enriched through participatory Group Model Building, this thesis provides a foundation for policy design in the face of complexity and uncertainty. The key takeaway is that subjective experience lies at the core, team-level interventions have the power to influence systemic outcomes, and systems science tools such as System Dynamics and Exploratory Modeling and Analysis can offer actionable insights for tackling real-world healthcare workforce challenges. Future research should aim to generalize and test this model across multiple departments and hospitals while incorporating more granular data and evaluating interventions in controlled settings.

Contents

Abbreviations

Abbreviations

Abbreviation	Definition
MC	Medisch Centrum
SD	System Dynamics
CLD	Causal Loop Diagram
GMB	Group Model Building
EMA	Exploratory Modeling Analysis
PRIM	Patient Rule Induction Method
VAS	Visual Analog Scale
JDT	Jones Dependency Tool

1 Introduction

A healthcare crisis is developing in the Netherlands and other parts of the Western world. Demand for healthcare is increasing due to an aging Dutch population putting more pressure on the whole sector [1]. Meanwhile, aging healthcare workers and a declining number of young people willing to work under the current working conditions [2] are thinning the healthcare workforce which leads to an imbalance between older and younger healthcare workers [3]. Moreover, healthcare workers have higher risk of burnout symptoms [4, 5, 6, 7, 8] and therefore a higher turnover rate [9, 10]. This has been a problem in home care and long-term care in the Netherlands, where Vries and Vrijmoeth [11] found that 32% of nurses has the intention to leave the profession within a year. Without policy interventions to at least retain the available healthcare workers, the current situation regarding the work environment in healthcare will not improve. This trend of increasing intention to leave among nurses may extend to other areas of the healthcare sector. While recent budget cuts have been postponed [12], discussions around fair compensation for nurses continue. At the same time, long-term financial constraints remain, as healthcare expenditures are projected to nearly double due to an aging population [13]. However, keeping healthcare professionals in the profession is not solely a matter of financial incentives. In addition to fair salaries, factors such as autonomy, professional development, and a sense of purpose play a crucial role in sustaining motivation. To ensure high-quality care, strategies must therefore address both intrinsic and extrinsic drivers of nurses' engagement.

In reviewing the thesis by Wagenaar [14] on the performance of the transfer care system under conditions of resource scarcity, we identified the workload of formal caregivers as a key and influential factor shaping the system's overall effectiveness. This observation prompted a broader inquiry: could the workload of formal caregivers be a critical variable influencing the performance of the healthcare system as a whole? To explore this possibility, we conducted a small literature review and developed a research scope centered on understanding the systemic impact of caregiver workload.

In the model from Wagenaar [14], the workload of formal caregivers is reduced to one variable. However, workload among formal caregivers is a multifaceted concept, involving various demands and pressures beyond a simple metric. Given the multifaceted nature of workload and the need to understand it in a high-stress, fast-paced environment, we chose to focus on nurses in the Emergency Department to narrow our focus. The Emergency Department setting acts as a 'canary in the coal mine' for systemic workload pressures and workforce sustainability, offering valuable insights that can inform broader healthcare contexts, which is further elaborated on in chapter 2.1. Therefore, we chose to study nurses specifically, as they are the primary group of formal caregivers in the Emergency Department, where certified nurses play a central role in patient care. Nurses in the Emergency Department often coordinate both direct and indirect care, manage their own workload, and serve as pivotal communicators and collaborators within healthcare teams [15, 16].

In light of ongoing staffing shortages, challenges with workforce retention, and the low influx of new healthcare professionals, this study focuses on the relationship between workload and nurses' intention to stay in the profession. In this research, the term intention to stay in the profession is used to refer to nurses' willingness and motivation to remain employed within the nursing field over time. This term is adopted for its positive connotation and to maintain conceptual consistency. A more detailed discussion of the term and its relation to alternative constructs such as turnover intention, job retention, or sustainable employability is provided in section 2.3.

Overall, this led us to further explore the knowledge gaps and potential research questions on the workload of nurses and their intention to stay in the profession.

1.1. Knowledge gaps and research questions

Healthcare systems are complex, dynamic environments consisting of medical experts and formal caregivers, uncertain patient flows, individual influences of employees and patients, operational failures and organizational structures [17, 18, 19, 20]. A lot of research has been done to find causes, antecedents, consequences and predictors of objective and subjective workload [21, 22], turnover intention [23, 9, 24, 10], emotional and moral workload [5, 25, 26], and stress and burnout [4, 27, 28, 6, 7, 29, 30, 8, 31]. Concepts that might positively influence workload and perceived workload have also been reviewed, such as sustainable employability [32, 33, 34] and personal resilience [35, 36].

However, isolating variables and designing questionnaires to find correlation or causality between factors somewhat ignores the complexity of the healthcare system [37, 38, 39]. According to Bynum, Varpio, and Teunissen [40], there has been a heavy reliance on deductive quantitative research causing a shaky conceptual foundation of well-being used in rapid solutionism towards interventions through a lens of diagnosable disease. A problematic approach, since solving one symptom (of the ”disease”) can cause other symptoms to worsen or new diseases to occur. A systems approach that analyzes workload as a whole system and moves past this disease-model approach is deemed valuable by these sources.

Several metrics and approaches exist to analyze and measure workload for healthcare workers, such as patient dependency using the Jones Dependency tool [41, 42, 43, 44], Demand/control-model [45], Workload Assessment of Nurses and Emergency (WANE) tool [46] and other more systemic approaches to analyzing workload [47, 48, 49]. What we can see here, is that there is no consensus on the metrics used by hospitals to measure nurses’ objective workload based on patient flow. This could be an indication of a knowledge gap on how workload works in healthcare.

In summary, the current literature lacks consensus on the measurement of (objective) workload and lacks a comprehensive, systems-level understanding of how nurses perceive their workload and how this perception influences their intention to remain in the profession. There is a particular need for methods that can capture dynamics and complex interactions in real-world healthcare settings.

1.1.1. Methods

We presume that a hyper accurate measurement of objective workload based on patient flow is not what is needed to address the current problems in the healthcare sector. We assume that perceived workload - how nurses experience their workload- contributes more than objective workload to problems related to intention to stay in the profession. This is further highlighted in chapter 2.4.

Given the identified gap in understanding the dynamic and systemic nature of perceived workload, we employed a participative System Dynamics approach. This method enables modeling of feedback loops and interactions among variables influencing nurses’ workload perception and their intention to stay, addressing the shortcomings of previous isolated and static analyses. This method allows us to dive deeper into the dynamics and feedback within the complex system of healthcare. We chose a participative method in the form of Group Model Building to actively involve nurses in the model building process which enabled us to include nurses’ understanding of their perceived workload into the model.

Due to limited existing data on nurses’ perceived workload at scale, our study emphasizes system mapping and scoping as foundational steps before any large-scale surveys, positioning this research as a critical groundwork for future empirical investigations.

1.1.2. Research questions

In summary, while much is known about the challenges facing healthcare systems and the factors influencing nurses’ workload and turnover, there remains a critical gap in understanding how nurses perceive their workload within the complex, dynamic healthcare environment—and how this perception shapes their intention to stay in the profession. By focusing on the Emergency Department as a high pressure representation for broader systemic issues, this research aims to apply a participative System Dynamics approach that captures the feedback loops and interactions. Through actively involving nurses in model building, this study seeks to develop a comprehensive, systems-level understanding that can inform more effective policies and interventions to improve nurse retention, well-being, and ultimately, patient care quality.

Considering the research gaps in the previous section, the following research question was formulated:

"How can a systems science approach contribute to the understanding of nurses' workload and their intention to stay in the profession in the Emergency Department at Erasmus MC?"

With the following subquestions:

- SQ1: "What key factors influence the nurses' workload and their intention to stay in the profession and according to relevant current literature?"
- SQ2: "What do the mental models of the nurses at Erasmus MC Emergency Department look like regarding workload and their intention to stay in the profession?"
- SQ3:"Which policy levers from the model are most valuable to be targeted by policy interventions to influence the nurses' intention to stay in the profession?"

This study focuses on the team level of analysis, as explained further in Background Information chapter 2.2. While individual traits like stress coping skills or job-person fit are important, they are not the focus here. Instead, this research targets the deeper, structural and organizational issues that shape working conditions. By improving these systemic factors, the aim is to create a work environment that is supportive and sustainable—regardless of who fills the role.

The goal of this research is to explore both the existing literature on stress and perceived workload as well as the mental models of nurses in an actual care setting. Mental models are internal representations of how the person understands and reasons about a topic, in this case workload and their intention to stay in the profession. The resulting model aims to provide deeper insights and identify potential policy levers-potential points in the system where targeted interventions could yield meaningful change.

1.1.3. EPA relevance

This thesis is written to obtain a master's degree in Engineering and Policy Analysis (EPA). EPA is focused on addressing grand challenges with an inherent social and technological component. Dealing with a part of the problem regarding demand for healthcare and an aging society can be seen as a grand challenge. Furthermore, the healthcare sector has significant societal relevance and has become more of a complex socio-technical system over the years with adaptive systems made up of interdependent personal, social, technical and organizational components. Finally, this thesis is one of the first to apply a systems science approach to the workload of nurses in a quantitative matter, applying an innovative method based on modeling techniques from the curriculum.

The knowledge gaps are addressed through the use of quantitative modeling techniques that try to simulate the behavior of stress and workload and model the potential consequences of scenarios and policies. These models aim to enhance understanding and highlight key elements for future research, ultimately contributing to better decision-making.

1.1.4. Thesis outline

This thesis consist of 10 chapters, with the first being this introduction. The second chapter lays foundation of background information to understand concepts such as subjective & objective workload, intention to stay in the profession, different types of stress and the context of the Emergency Department. Next, the methodology is presented. The fourth chapter shows the literature review, which concludes the answer to SQ1. The next chapter displays the process and results of the Group Model Building sessions, answering SQ2. The sixth chapter describes the conceptual model by reviewing an aggregated model and the subsystems. The seventh chapter explains the process of quantifying this conceptual model into a Vensim simulation model. Chapter eight displays the results from the PRIM analysis, which will answer SQ3. Finally, the thesis concludes with a discussion and conclusion in the ninth and tenth chapter.

2 Background Information

This chapter will examine the sources provided in the introduction and the literature review to provide a body of background information. The goal is to highlight relevant literature as well as concepts that are eventually used in the conceptual model. This chapter strives to clarify the concepts of subjective workload, intention to stay in the profession, different types of stress, sustainable employability and burnout. It also shines a light on the context of the Emergency Department and the choices for team level and the timeline.

2.1. Context of Emergency Department

The research design revolves around one use case: the Emergency Department at Erasmus MC in Rotterdam. Erasmus MC is a Level I Trauma Center, so it serves as a referral hub for patients with severe and multifaceted injuries [50]. It tells us something about the context the nurses operate in. Baltesen [51] report that the quality of care is on a higher level for Level 1 Trauma Centers: they take action faster, are more readily available with complete trauma teams and manage to reduce the mortality of severely injured patients by half compared to other hospitals. The knowledge of nurses is consistently tested on critical and complex cases, potentially creating overwhelming and taxing situations for nurses.

Erasmus MC is also an academic hospital. Iordache et al. [46] stated that academic Emergency Departments are complex nursing environments with concurrent academic activities, such as research. They deal with higher volumes of students and with more people shadowing their work. Furthermore, when patients have rare diseases or uncommon diagnoses, they are more likely to end up at an academic hospital. This shapes the context of the nurses environment strongly.

Erasmus MC is also the largest hospital of the Netherlands, with a neurosurgical and cardiothoracic centre, an air ambulance and the Sophia children's hospital as part of their facilities. For the Emergency Department, this means they have to deal with a high variety of patients.

However, the size of the hospital does not determine that the work is more demanding. Iordache et al. [46] documented that large hospitals often have more assistive staff for transport, administration and clean-up, reducing the amount of indirect care tasks for nurses.

We chose the context of the Emergency Department because we presume it to serve as a canary in a coal mine for other departments in the hospital. Compared to other departments, it is a high pressure, high patient turnover environment that is likely to highlight consequences of any organizational issues quicker than other departments.

Analyzing a specific, real-world context, such as single Emergency Department, provides valuable insight into how factors interact over time. Within these factors, we are able to distinguish between organizational, personal, structural and contextual factors. By focusing on a well-defined setting, this research aims to uncover how sustained stress develops while remaining mindful of the contextual factors specific to this use case.

2.2. Team level

As highlighted in the Introduction, nurses play a central role in managing the workload of the Emergency Department. Moreover, at this point in time, there is a larger shortage in nurses than in physicians and doctors in the hospitals in the Netherlands [52]. Therefore, this study focuses on understanding workload dynamics at the level of the nursing team.

Although individual experiences of workload and stress are important [6, 35, 30], other studies such as Landsbergis [53] found that individual demographics did not predict job strain. More recently, De Veer et al. [25] found no or mixed relationships between moral distress and gender, age, religion, professional experience or education level. This suggests that focusing on individual characteristics alone does not provide the full picture.

Instead, we aim for structural dynamics on team level of stress and subjective workload in a functioning work environment. By analyzing group-level dynamics, we aim to reduce the influence of individual variability and focus on systemic factors that can improve the work environment. We assume that there are similarities between nurses' experiences of workload which can be aggregated to a team level [38]. This allows us to focus on the persistent, structural and organizational factors that can influence the overall perceived workload of the team and find policy levers relevant for the whole nursing team.

2.3. Intention to stay in the profession

Intention to stay in the profession is the term used to encompass other terms used in literature such as 'intention to leave the profession', 'turnover intention', 'turnover rate', 'staff retention' or 'job retention'.

Previous research has explored this topic from various theoretical and empirical angles. For example, Jourdain and Chênevert [10] linked the Job Demands-Resources (JD-R) theory to nurses' intention to leave the profession in the Canadian healthcare context, illustrating how work environment factors can influence professional retention. A broad review by Hayes et al. [9] examined the expanding body of literature on nursing turnover, noting a shift toward including perspectives of organizational stakeholders and broader systemic influences—an approach that is in alignment with the systems thinking applied in this research. Jun et al. [54] also made a qualitative selection of articles researching nurses' job satisfaction and/or their intent-to-leave.

Sasso et al. [55] further investigated the dynamics behind nurses' decisions to leave, identifying a range of push and pull factors among over 3,600 medical and surgical nurses in Italy. In an earlier contribution, Janssen et al. [24] suggested that unmet career expectations—such as limited opportunities for advancement or higher salaries—were more influential in shaping turnover intentions than dissatisfaction with job content itself. These articles serve as input to better understand the concept of nurses' intention to stay.

This research adopts Intention to stay in the profession for its positive connotation. Furthermore, it describes clearly what we mean without the need for extra elaboration. With this, we aim to examine why nurses stay, instead of wish to leave. This variable is considered the primary output factor in the study and forms the end node for examining how workplace dynamics and systemic influences interact to shape an intention to stay in nursing.

2.4. Subjective and Objective workload

As discussed in the Introduction, there are various metrics available to assess the objective workload of nurses. Several studies conceptualize nursing workload as comprising direct patient care, indirect patient care, and non-patient care activities, along with the time or cognitive effort required to complete these tasks [39, 48, 46, 20, 49, 22]. Hoogendoorn et al. [22] argue that focusing on the workload per nurse provides a more accurate picture than simply examining the number of patients assigned to each nurse. Therefore, we adopt this into our view of objective workload per nurse.

We consider objective workload metrics that are relevant, but the impact on intention to stay in profession is likely limited. Studies have shown a weak or inconsistent relationship between objective and perceived workload. For instance, Hoogendoorn et al. [22] found no significant correlation between observed workload per nurse and perceived workload. Similarly, Fischbacher et al. [21] demonstrated that objective workload was only associated with certain domains of subjective workload among critical care nurses. Additional research has highlighted how subjective factors, such as perceived stress and job satisfaction, are linked to turnover intention [23], and that the quality of interpersonal interactions with patients is as (if not more) important as their quantity [5]. How nurses perceive their work ultimately determines if they want to stay in the profession or not.

For example, even when objective workload is relatively high, it may be perceived as manageable or even fulfilling if supported by positive dynamics in the work environment. Conversely, a moderate objective workload may feel overwhelming in the absence of such dynamics. While some correlation between objective and subjective workload is expected, it is not linear and should be interpreted with nuance.

Alghamdi et al. [37] noted that the concept of nursing workload is often poorly defined in the literature. To address this, this study clearly distinguishes between the two: objective workload refers to the time needed to complete tasks driven by patient flow, team efficiency, and individual performance, while subjective workload reflects how this objective workload is perceived by the nurse; either positively or negatively.

2.5. Sustainable employability

Another term that has gained attention in recent years is Sustainable Employability, defined as ”individuals' long-term abilities to work and remain employed” [33]. Research on physicians' sustainable employability has shown that group dynamics, group norms, and alignment with professional standards are key long-term influences [34], further supporting a team-level perspective for this research.

While there is some conceptual overlap between Sustainable Employability and Intention to stay in the profession, this study focuses on the latter to better address the staffing challenges outlined in the Introduction. Sustainable employability is a more individually oriented concept, emphasizing the capacity to remain active in the labor market through health, development, motivation, and adaptability [33]. Intention to stay in the profession focuses more specifically on an individual's decision-making process about remaining in their current role or profession. This is much more targeted and concerns direct attachment to the profession, making it better aligned with the specific research goals of this study.

2.6. Burnout

Christina Maslach has been the most influential figure in burnout research. She defines burnout as a prolonged response to chronic emotional and interpersonal stressors on the job, characterized by three dimensions: exhaustion, cynicism, and inefficacy [56]. Together with her co-authors, Maslach introduced terms such as emotional exhaustion, depersonalization, and reduced personal accomplishment, giving language to a widely shared but often unspoken experience.

Over time, researchers have sought to represent burnout through System Dynamics models [29, 57], while within nursing studies, other have applied the Job Demands-Resources (JD-R) model to explore its antecedents and consequences [27, 10, 53]. Other investigations have connected nurse burnout to patient safety and quality of care outcomes [8, 47], or framed it in terms of effort-reward imbalances [4, 24]. People work and its interactions has also been explored as a contributing factor [5].

This thesis draws on burnout theory and the attempts to model burnout presented to conceptualize otherwise tacit aspects of occupational stress and to anchor them in a well-researched psychological framework.

2.7. Types of stress

Workplace, occupational or job stress has been researched extensively over the past decades, most often in relation to health & well-being of nurses or patient safety [30, 23, 7, 53, 18]. In this research, four types of stress are considered relevant: emotional distress, physical distress, moral distress, and eustress. Emotional distress primarily arises from overwork and the depletion of emotional resources. It reflects the input side of burnout, focusing on how external demands overwhelm internal reserves [56]. Physical distress relates to the physical demands of nursing and the toll it takes on the body, including irregular work hours and shift work. Moral distress is treated separately from emotional distress, as it captures the stress that emerges in ethically challenging situations where nurses feel unable to uphold all values or interests involved [25]. Finally, eustress refers to the positive stress experienced during the job. This type of stress acts as a buffer against distress and is, according to McVicar [30], experienced subjectively, shaped by the interaction between an individual and their environment. For instance, when good team work and effective communication makes the difference in saving a patients life, the stress following this situation is more likely to be experienced positively. McVicar [30] also highlights that the transition from eustress to severe distress is strongly linked to staff absenteeism, poor intention to stay in the profession, and deteriorating health. Therefore, we included eustress in our model.

2.8. Timeline

One of the key consequences of sustained distress, closely linked to the intention to stay in the profession, is burnout [56]. According to the Dutch Institute for Psychologists (NIP), recovery from burnout can take several months, and even severe distress symptoms may require weeks to subside [28]. This is an argument to set the timeline of this research on the middle-long term.

Another argument is that Intention to stay in the profession usually does not depend on single incidents but on experience over the longer team (months or even years). Therefore, the model focuses on fluctuations over the middle-long term, which results in aggregated stress levels of weeks.

3 Methodology

In this chapter, we outline the boundaries and context of our study. Several scientific sources call for more innovative approaches to analyze workload of nurses and their well-being [40, 58, 24, 53, 30, 8]. This research aids to this call for more innovative approaches by combining literature and existing models with nurses' input to create a quantitative model of dynamics around nurses' workload and their intention to stay in the profession. In this section we discuss the methods to accomplish this, including a literature review, System Dynamics, Group Model Building and Exploratory Modeling Analysis.

3.1. Research Design

Limitations in several studies on workload of nurses and related themes have stressed the difficulty of generalization of results because of diversity of contextual factors [5, 6, 21, 22]. Because generalizability is limited by contextual variability, our approach focuses on depth and local specificity, using participative systems science to incorporate experiential knowledge that is often excluded from top-down analyses. Without first-hand input from nurses about their working context, we risk overlooking critical contextual factors—factors that are highly dynamic and shaped by organizational, personal, and external influences, ultimately limiting the relevance and applicability of survey findings. Engaging directly with nurses in interviews and gaining insight into their lived experiences is considered a valuable method for understanding their workload and professional intentions. Therefore, we adopted a participative systems science approach, positioning nurses as central contributors in gathering and validating tacit knowledge. A single use case approach (Emergency Department at Erasmus MC) allows for deeper contextual understanding and aligns with our goal of uncovering tacit, situated knowledge. It allows for identifying specific factors to this context that might or might not be present elsewhere. These are interesting points to review for policy makers when constructing policies for a specific hospital. If these contextual factors are of influence, the insights gained may suggest the value of tailoring policies to the specific needs and contexts of departments or hospitals, instead of overarching policies for the whole healthcare sector.

3.2. Literature review

We conducted a literature review to investigate key themes related to nursing workload, occupational stress, and nurses' intention to stay in the profession. Given the exploratory and context-sensitive nature of the study, we adopted an iterative search strategy rather than a fully structured systematic review. While fully structured systematic reviews are valuable for aggregating findings in well-established research domains, our objective is to identify conceptual frameworks, recurring themes, and influential studies relevant to our specific focus, to then combine and expand this base of knowledge with a model.

The iterative approach allowed us to follow citation trails and emerging themes, providing flexibility to incorporate diverse perspectives as they surfaced during the review process. We prioritized highly cited and thematically relevant studies, guided by the evolving list of keywords detailed in Table 4.1. This method supported the construction of the conceptual model and informed our understanding of the multifaceted factors influencing nurses' professional retention and perceived workload.

3.3. System Dynamics

System Dynamics (SD) modeling is our method to apply the systems science approach. It is a deterministic type of computer simulation modeling that applies the principles of information feedback and state variables and is used to analyze the relationship between a social system's structure and its behavior over time [59]. System Dynamics has been used before to model workload and related concepts, such as burnout, demand and patient flows [60, 47, 29, 18, 61, 62, 57, 63]. This shows that we can conceptualize concepts related to the workload of nurses as stocks and flows, such as volume of meetings, administrative tasks, team resilience, and more.

We chose SD because it is particularly well-suited for exploring the structure and long-term behavior of complex social systems, such as workforce dynamics in healthcare. Its top-down approach allows us to model the system at an aggregate level, focusing on collective patterns rather than individual variability. This aligns with our goal to understand how systemic factors—like workload, organizational pressure, and feedback from experienced stress—contribute to nurses' intention to stay in the profession.

SD is highly effective in uncovering and visualizing feedback loops and time delays, which are crucial in understanding how perceived workload builds up over time and influences retention. The ability to visually represent these causal relationships enhances both communication and stakeholder engagement, making the model a powerful tool for both analysis and storytelling. By abstracting individual differences, SD helps us maintain a clear focus on the broader, policy-relevant dynamics within the nursing workforce.

We used quantitative SD modeling in this research. Gathering comprehensive, long-term data and conducting psychological and sociological experiments is resource-intensive and time-consuming, making this approach impractical midst the worsening healthcare crisis. Instead, this study offers quicker alternative to gaining insight by focusing on the behavior and interactions of key variables. Given the dynamic interactions and feedback mechanisms driving nurses' intention to stay, a quantitative SD model provides a structured means to simulate plausible system behaviors over time—something that qualitative approaches or observational studies cannot achieve. The quantitative approach allows for monitoring subtle changes while also providing a visual aid of the system dynamics and feedback loops.

To operationalize the timeline dimension described in Section 2.8, the quantitative SD model is designed to run over a two-year period, with weekly time units. This structure captures meaningful behavioral trends while maintaining a macro-level perspective on change over time.

While other methods, such as Agent Based Modeling (ABM) and Discrete Event Simulation (DES), also offer valuable frameworks for understanding health care dynamics, they present some limitations in the context of this study. First, ABM is a bottom-up approach that models individual entities (agents) and their interactions. While ABM allows for high levels of granularity, it often requires data on the agents themselves, such as their decision-making processes, behaviors, and individual variability. The lack of comprehensive data on these topics limits the practicality of this method. DES focuses on modeling systems where entities (e.g., patients, nurses) move through a series of discrete events, such as appointments, treatments, or shifts. While DES is effective for capturing specific workflows and individual processes, it struggles with representing the holistic and feedback loop dynamic of a complex system like the nursing workforce. DES operates on relatively short time horizon and requires detailed input on events and interactions. Therefore, we choose System Dynamics for this research.

3.4. Group Model Building

3.4.1. Theory of Group Model Building

This thesis employs Group Model Building (GMB) as a participatory method to engage nurses in developing a system dynamics model [64]. As Hovmand et al. [64] define it, GMB is a "form of group decision support that involves a group of stakeholders working with a modeling team to solve a focused problem within a complex system." In this study, the stakeholders are the nurses, and the complex system under examination is their subjective workload in the Emergency Department.

Our goal is to provide the Emergency Department at Erasmus MC with a tool to better understand nurses' workload and identify policy levers to support their retention. Direct stakeholder involvement enhances the practical applicability of simulation models, as Lane, Monefeldt, and Husemann [65] note: "Practical use of simulation models is generally seen to be less [about] technical accuracy [...] than [about] direct client involvement in the building of and experimentation with the model." To maximize our model's practical value, we engaged nurses in the GMB process, allowing them to contribute their perspectives and refine the model based on their experiences.

3.4.2. Group Model Building in this study

In this research, we conducted two GMB sessions for participative model building and a third validation session. GMB sessions offer several advantages. First, the nurses talk about the topic in groups, creating an arena of discussion where consensus has to be reached before it is written down. With this, we stay away from individual experiences and we are more able to look at the nurses as a group. Second, the sessions are a way of active participation, which could create feelings of being heard and problem ownership related to subjective workload. Third, the sessions can easily be conducted in the nurses' work environment, making it easier for the nurses to think about stress and workload related to that environment.

To provide transparency on how the modeling sessions have been conducted, we designed a script using the tool Scriptapedia [66]. On this open source website, scripts for GMB are gathered used to develop System Dynamics models. The "best-practice" script named "Creating Causal Loop Diagram from Connection Circles (Hovmand and Kraus)" has been altered to the goals of the sessions within this study. The full script can be found in Appendix A.

The original script indicates the use of so-called connection circles, which is a simplified version of a Causal Loop Diagram (CLD). Instead of starting from scratch and creating connection circles with the nurses, we provided the nurses with connection circles derived from a bigger conceptual model based on relevant literature. Pre-defining the connection circles enabled us to anchor discussions within a validated conceptual frame, ensuring conceptual consistency while still allowing nurses to refine and contest the relationships presented.

3.4.3. Final validation session

To review the implementation of the GMB session results, we conducted a final validation session with the participating nurses. The primary aim of this session was to enhance nurses' sense of ownership in the model-building process and to provide them with meaningful feedback on their contributions. In addition, the session served as an opportunity to validate the simulation results and assess their practical resonance.

During the session, we presented the nurses with the box plots from the PRIM analysis, including both the variable bandwidths and thresholds used in the output space. This allowed us to evaluate whether nurses could interpret and reflect on the quantified variables when presented in an accessible and structured way.

In conclusion, Group Model Building (GMB) was chosen for this study because it enables collaborative sense-making and shared understanding among nurses, who are the key experts in their subjective workload. This participatory approach allows nurses to actively contribute their knowledge and experiences, ensuring that the resulting system dynamics model accurately reflects the complex realities of their work environment. Engaging stakeholders directly supports the co-creation of meaningful policy solutions, increasing the likelihood that the model will be practically useful for identifying interventions to improve nurse retention in the Emergency Department.

3.5. Deep Uncertainty and Exploratory Modeling

3.5.1. Deep Uncertainty

According to Lempert, Popper, and Bankes [67], deep uncertainty describes a situation where analysts do not know, or the parties to a decision cannot agree on, (1) the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future, (2) the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models, and/or (3) how to value the desirability of alternative outcomes.

In this study, we aim to develop a consensus-based conceptual model to reduce as much of the structural deep uncertainty as possible. However, due to the lack of comprehensive input data, significant deep uncertainty will remain—particularly in the probability distributions, input variables, and parameter relationships. To address this, we employ scenario discovery techniques using the Exploratory

Modeling and Analysis (EMA) Workbench to identify plausible future scenarios within this uncertain space.

3.5.2. EMA Workbench and PRIM

Kwakkel [68] introduced exploratory modeling as a method to analyze the implications of deep uncertainty. To support this approach, he developed the Exploratory Modeling and Analysis (EMA) workbench, a Python library designed to facilitate the use of related techniques. This tool aids decision-making under deep uncertainty by enabling users to integrate existing models with the EMA workbench. By applying its methodologies, users can gain valuable insights into model uncertainties and derive meaningful policy recommendations.

To explore how behavior of intention to stay in the profession, perceived workload and stress changes over time, we apply time series clustering to examine the behavioral landscape. This reveals different patterns of dynamics, with some considered particularly relevant. To determine which uncertainties lead to the behaviors seen, we adapt the Patient Rule Induction Method (PRIM), a technique commonly used in scenario discovery (Friedman & Fisher, 1999; Bryant & Lempert, 2010; Lempert et al., 2008, as cited in Auping [69]).

The Patient Rule Induction Method (PRIM) is a scenario discovery algorithm used to identify regions of an outcome space that are of particular interest, based on a pre-existing dataset of model inputs and outputs. It operates through an iterative ”peeling” process that incrementally reduces the dataset by evaluating subsets—or ”boxes”—that exclude portions of the data based on single input variables. For categorical variables, each category is excluded one at a time, while for continuous or integer variables, ranges at either end of the distribution are removed in steps defined by the analyst. At each iteration, the box that yields the greatest improvement in the concentration of outcomes of interest is selected, and the process continues until a stopping criterion is met. This method is especially useful for analyzing large experimental designs and identifying conditions under which outcomes of interest are more likely to occur [70].

Using this method, we analyze both Intention to stay in the profession —the main outcome of this research— and Job Satisfaction. Job Satisfaction is included in the analysis as it represents the third dimension of Intention to stay in the profession, as seen in the conceptual model, that is not explicitly represented in the PRIM output space of Intention to stay in the profession. This is due to its high variability and dependence on different variables from other subsystems. A relevant threshold is set for both variables in the output space. We selected a threshold of 0.7 (or 70 on the Visual Analog Scale (VAS)) for both Intention to stay in the profession and Job Satisfaction. This means we focus on the parts of the output space where these variables are rated 70 or higher. The threshold is arbitrarily chosen to reflect a slightly above-average score on these measures.

To analyze the results of the PRIM analysis conducted using the EMA Workbench, several key visualizations were generated. The peeling trajectory graph illustrates the trade-off between coverage and density during the box-forming process. Based on this trajectory, a benchmark density of 80% was selected to ensure sufficient concentration of outcomes of interest within the identified box. In terms of coverage, we took the highest available number which guaranteed 80% density to maintain some balance between generalization and specificity. Once a suitable box was chosen, an inspection graph was examined to better understand its properties. This graph displays the bandwidth for each restricted uncertainty, highlighting both the range (edges of the bandwidth) and the statistical significance of each restriction, as indicated by corresponding p-values. By doing this, we can analyze to what extend certain variables shape the dimensions of the output space for the key performance indicators in our model. These variables are valuable for determining policy interventions or better understanding behavior of the system towards the key performance indicators.

The PRIM analysis helps identify policy-relevant leverage points by isolating uncertainty conditions under which desirable outcomes—such as higher intention to stay—are most likely to occur.

4
Literature Review

To create an overview of the current literature on concepts related to intention to stay in the profession, we conducted an iterative literature research. The search process was iterative in the sense that initial findings informed subsequent search rounds. For example, the identification of moral distress in early sources led to a targeted search using terms like ‘moral stress’. This chapter aims to explain the steps taken to conduct this literature review, includes a short analysis and gives a clear overview of factors and model sources used for the conceptual model.

4.1. Literature review setup

4.1.1. Search rounds and keywords

The literature review for this research was conducted through iterative searches in the databases Scopus, PubMed, and Google Scholar. We filtered for high citation counts to review the most relevant literature available. In the following table the search words and steps are displayed.

Table 4.1: Overview of Iterative Literature Search Rounds

Search Round	Keywords Used
1	”objective workload”, ”subjective workload”, ”stress”, ”burnout”, ”emotional exhaustion”, ”workload measurement”, *all individually combined with* ”nursing”, ”nurses”, ”healthcare”
2	emotional stress, physical stress, moral stress *all individually combined with* ”nursing”, ”nurses”, ”healthcare”
3	Dutch, System Dynamics (combined with keywords from previous rounds)

We combined all terms with profession-related keywords like nursing, nurses, and healthcare, to narrow the focus to the nursing profession. To understand workload in nursing, we began by searching with keywords such as objective workload, subjective workload, stress, burnout, emotional exhaustion, and workload measurement. These initial searches provided insight into stress in the workplace. Nurses experience emotionally demanding situations due to the high volume of interactions in a day, with both patients, colleagues, and other healthcare staff [5, 30]. This emotional demand can be defined as emotional exhaustion or emotional distress, which is a key component of burnout [56]. However, this is not the only type of distress nurses experience. We identified emotional, physical, and moral distress as the three dimensions of distress, each arising from distinct workplace challenges [21, 26, 25, 7, 53]. After identifying different types of stress nurses may experience, we conducted a search round specifically for studies that addressed these forms of stress.

To find research relevant to the Dutch healthcare system, we included the keyword Dutch. We also searched for System Dynamics to explore existing efforts to model nursing workload, stress, and intention to remain in the profession. The search was refined by prioritizing studies with high citation counts to ensure the relevance and impact of the literature. Once we reached a point where the most relevant and frequently cited studies were identified and no significant new findings emerged, we concluded the search.

4.1.2. Analysis

Aiken et al. [71] and Aiken et al. [72] are included in the factor and model sources for the moral dimension of patient mortality and its relevance for experienced moral distress by nurses. However, only two other articles were included that examined workload in relation to patient safety and patient outcomes [73, 74]. Although relevant to understanding the broader impact of workload, these studies focused primarily on patient outcomes rather than the nurse's subjective experience, which is the central focus of our conceptual model. Upon reviewing these studies, we concluded that their objectives did not align with the aim of our research. As a result, they did not address the subjective and perceived aspects of workload that were central to our study. Therefore, we chose not to include additional literature of this type.

Across both the factor and model sources reviewed, the Job Demands-Resources (JD-R) framework emerges repeatedly as a central conceptual lens through which workplace outcomes—particularly burnout and engagement—are interpreted. Many studies explicitly adopt or align with the JD-R model, highlighting a balance between demands (e.g., workload, emotional strain) and resources (e.g., autonomy, support, feedback) as crucial to employee well-being and performance [27, 10, 33, 57, 18]. Among these, motivation, control, and rewards are recurrently addressed. Motivation is linked to both coping capacity and engagement [6, 36, 57], while job control and autonomy are emphasized as key personal or organizational resources [4, 31, 7]. Similarly, the theme of (im)balance between effort and reward appears across several sources, underscoring its importance in predicting burnout and dissatisfaction [27, 4, 23]. These recurring elements ultimately converge with the foundational principles of Ryan and Deci's Self-Determination Theory [75], particularly the psychological needs for autonomy, competence, and relatedness as drivers of intrinsic motivation and sustainable well-being. Therefore, we adopted Self-Determination theory in the team dynamics of the conceptual model.

We conclude from the literature review that there are four types of stress for nurses: emotional, physical and moral distress and eustress. Secondly, direct and indirect care have to be divided when looking at the objective workload. Indirect care tasks are influenced by team dynamics and the presence of support teams for transport and administrative tasks. These conclusions served as a stating point for constructing the conceptual model, in combination with Iordache et al. [46] (a Dutch model source on measuring objective workload) and Jourdain and Chênevert [10] (a model source that related burnout to intention to stay in the profession in a conceptual model).

In the next two sections, we present the sources found, using their keywords to highlight the main themes they address. We divided the sources into two categories: factor sources, which mention relevant factors for the conceptual model, and model sources, which describe efforts to construct a conceptual or System Dynamics model. The model sources served as inspiration as well as literature backing up claims of causality and relationships between variables in the Conceptual Model. The literature gathered in this review also serves as input for the Background Information. The exact usage of these sources is found in these chapters 2 and 6.

4.2. Factor sources

Table 4.2: Factor Sources from Literature Review

Source	Tags	Factors
van de Voort et al. (2024)	Context, Physicians, Self-regulation, Sustainable Employability	Group Dynamics, Normative (mis)matches, Self-regulations (work, oneself, others)
Aiken et al. (2002)	Burnout, Nurses, Staffing, Patient Mortality	Burnout, Job dissatisfaction, Patient-to-nurse ratio, Patient outcome, Failure-to-rescue rates

Continued on next page

Table 4.2 continued from previous page

Source	Tags	Factors
Landsbergis (1988)	Job stress, Job characteristics, Decision making, Burnout	Job dissatisfaction, Depression, High workload, Decision making latitude, Job insecurity, Physical exertion, Social support, Hazard exposure
Keers et al. (2013)	Medication errors, Patient safety	Inadequate written communication, Problems with medicine supply and storage, High perceived workload, Problems with ward-based equipment, Patient factors, Staff health status, Interruptions/distractions
Brotheridge & Grandey (2002)	Burnout, Emotional demand, Emotional labor, Interactions	Frequency and quality of interactions, Accomplishment, Levels of hiding negative emotions, Demand as stressor and resource, Surface acting vs deep acting
Fischbacher et al. (2024)	Factors, Objective workload, Subjective workload, Definitions	Positive associations between day-to-day objective variables with subjective pace and amount of work, with physical and mental load but not with emotional-moral load and performance. Measured objective workload is associated with only certain subjective workload domains.
Hoogendoorn et al. (2021)	Objective workload, Subjective workload, Dutch	Objective workload, Subjective workload, Student or certified nurse, Severity of illness of patient
McVicar (2003)	Stress perception, Nurses	Eustress vs distress vs severe distress (as a continuum), Workload, Management/leadership style, Professional conflict, Emotional cost of caring, Lack of reward, Shift working
Bakker et al. (2000)	Effort-reward imbalance, Burnout, Nurses	Effort-reward imbalance, Intrinsic efforts, Extrinsic rewards, Control over job
Yu et al. (2019)	Factors, Nurses, Resilience	Resilience, Job demands: stress, burnout, PTSS, workplace bullying, Job resources: coping skills, self-efficacy, social support, job satisfaction, job retention, general well-being, Emotional exhaustion, Work engagement, Facing workplace challenges
Aiken et al. (2014)	Education, Patient mortality, Nurse staffing, Nurses	Education (bachelor’s degree), Patient-to-nurse ratio, Patient mortality
Swiger et al. (2016)	Definitions, Measurement, Patient Classification System, Workload	Organized, automated environment, Workload, Interruptions, Turbulence, Patient turnover, Experience and familiarity with procedure, Direct nursing care, Indirect nursing care, Documentation, Administration, Housekeeping, Miscellaneous activities
Upenieks et al. (2007)	Patient-to-nurse ratio, Workload, Work-flow dynamics, Value added and non-value added care	Direct care, Indirect care, Value added care, Non-value added care, Personal, waste, necessary care, Documentation
Myny et al. (2012)	Factors, Nurse, Workload	Most important factors: Interruptions and mental workload, High patient turnover rate, Registration (specific to Belgium), $>$20 years experience. From factor analysis: Work-fluency, Amount of work, ADT (admission, discharge and transfer)

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Table 4.2 continued from previous page

Source	Tags	Factors
Benner et al. (2002)	Factors, Nursing errors	Lack of attentiveness, Lack of agency/fiduciary concern, Inappropriate judgment, Lack of intervention on the patient's behalf, Medication errors, Lack of prevention, Missed or mistaken orders, Documentation errors
Applebaum et al. (2010)	Environmental factors, Job stress, Job satisfaction, Nurse turnover	Noise, Odor, Light, Color, Perceived stress, Job satisfaction, Turnover intention
Fiabane et al. (2013)	Work engagement, Job stress, Burnout, Factors	Energy, Involvement, Professional efficacy, Workload, Mental health, Job satisfaction, Community & social support, Values, Work environment, Burnout risk, Organizational factors, Perception of job demand
Hayes et al. (2012)	Factors, Nurse turnover (intent)	Generational differences, Job satisfaction, Age, Working evening shift, Career advancement, Interpersonal relationships, Workload, Low job control, Lack of team support, Effective management for positive environment, Perception of empowerment, Clearly defined roles, Kinship responsibilities, Years of experience, Level of education, Unpaid & longer than agreed hours, Consequences of nurses turnover
De Veer et al. (2013)	Factors, Dutch, Moral distress, Nurses	Perceived time for patient care, Consultation opportunities within the team, Instrumental leadership style, 30-40hr work week vs part-time, Gender, Religion, Age, Years of experience, Education level, Personal life, Professional life
Gelsema et al. (2006)	Dutch, Factors, Job stress, Nurses, Work conditions	Change in working conditions, Emotional exhaustion, Job satisfaction, Work and time pressure, Physical demands, Reserved relations ships, Stress feedback loop
De Lange et al. (2020)	Dutch, Factors, Sustainable employability	Calendar age, Occupational time perspective, Job demands, Job resources, Open future time perspective, Across-time changes in vitality, Work ability
van Leeuwen et al. (2022)	Factors, Dutch, Burnout	Job demands, High emotional workload, Job crafting, Job resources, (High) job autonomy, (High) employability, High quantitative workload
Scheepers et al. (2020)	Dutch, Physicians, Workload, Burnout	Patient-related burnout, High workload, Few development opportunities, Positive patient relations, Excessive bureaucracy
Jun et al. (2021)	Factors, Systematic review, burnout, organizational outcomes	Emotional exhaustion, patient safety, quality of care, intention to stay

4.3. Model sources

Table 4.3: Models from Literature Review

Source	Tags	Model Components
Carayon et al. (2006)	Conceptual model, Patient Safety, System	Work system: Technology and tools, Organization, Person, Environment, Tasks, Processes, Patient Outcomes, Employee and organizational outcomes
Bakker & de Vries (2021)	Conceptual model, Burnout, Self-regulation, Demands & Resources	Organizational and personal resources, Burnout, Job strain, Job demands, Job/personal resources, Maladaptive regulation, Adaptive regulation, Coping, Recovery, Leadership
Jourdain & Chênevert (2010)	Conceptual model, Demands & resources, Burnout, Nurse turnover	Intention to leave the profession, Professional commitment, Depersonalization, Emotional exhaustion, Psychosomatic complaints, Resources, Demands, Meaning of work, Quantitative overload, Health problems
Iordache et al. (2020)	Conceptual model, Metric, Nursing workload, Definitions	Direct care time, Indirect care time, Patient dependency, Age, Hospitalization
Crouch & Williams (2006)	Patient dependency, Metric, Emergency department	Direct care time, Indirect care time, Unavailable Patient Care Time, Patient Classification System
O'Brien & Benger (2007)	Metric, Patient dependency, Resource use, Nurse staffing, Workload	Patient demography, Patient flow
Morris et al. (2007)	Conceptual model, Workload, Nursing intensity	Level of work, Patient dependency, Complexity of skill mix, Amount of direct and indirect patient care, Severity of patient illness, Time taken to carry out nursing work, Non-patient-care related nursing work
Alghamdi (2016)	Conceptual model, Workload	Antecedents: patient, nurse, healthcare organization, Attributes, Consequences
Myny et al. (2011)	Conceptual model, System, Factors, Workload	Non-patient care, Hospital & the ward, Patient & family, Nurse team, Individual nurse, Meta-characteristics, Objective workload, Subjective workload
Fleuren et al. (2020)	Conceptual model, Sustainable employability, Definitions, Dutch	Person-environment fit, Perceived health status, Work ability, Fatigue, Need for recovery, Job satisfaction, Motivation to work (intensity), Perceived employability, Skill-gap, Job performance
Schwappach & Boluarte (2008)	Conceptual model, Emotional workload, Medical errors	Reciprocal cycle of error involvement, emotional distress, and future errors.
Wong et al. (2022)	SD model, Physicans, Burnout, Agitation management	Agitated patients and effects on task load, Clinicians affected by burnout and assault, Perceptions of safety, patients, and trust, Perceptions of control and team support
Veldhuis et al. (2020)	SD Model, Burnout	Self-efficacy, Task load, Demands, Mental effort, Motivation to meet demands, Stress, Capacity for effort, Perceive capacity for effort, Cognitive and emotional functions, Importance of work goals for self esteem

Continued on next page

Table 4.3 continued from previous page

Source	Tags	Model Components
Jetha et al. (2017)	SD Model, Workplace stress, Nurses	Job demands and resources model translated to a (small) SD model, Lack complexity
Barsties et al. (2023)	CLD Diagram, Burnout	Working conditions, Living conditions, Societal developments

5
Group Model Building sessions

This chapter explains the effort and the outcomes of the Group Model Buildings sessions. First, we explain how the sessions were conducted. Second, we list the outcomes and insights that led to several key updates to the conceptual model. Third, we shine a light on the validation sessions that were conducted with the nurses.

5.1. Group Model Building sessions

The GMB sessions were conducted to gain insight into nurses' mental models regarding their subjective workload in the Emergency Department. During these sessions, nurses reflected on connection circles created by the research team and developed their own Causal Loop Diagram (CLD) to illustrate factors influencing their workload (Appendix A.2 and A.3. The resulting CLDs, along with the session transcripts, provided valuable information that helped refine the dynamics of the conceptual model and identify additional relevant concepts based on nurses' perspectives.

5.1.1. The setup for the sessions

The sessions were structured to encourage group discussion and active participation. This approach enabled nurses to collaborate and reach consensus on the relationships between workload-related variables, rather than relying on individual perspectives. Conducting the sessions in the nurses' work environment was essential for ensuring that their experiences and insights were directly tied to their daily responsibilities.

The GMB sessions were held in small groups of nurses who volunteered after their morning shifts. Each session began with an introduction to the research focus and a brief explanation of the System Dynamics modeling technique. The script for this is found in appendix A.1. This was followed by an interactive exercise in which the nurses created a CLD based on predefined connection circles (displayed in Dutch in figure 5.1.1 below). Translation was carefully done based on the experience in healthcare from the thesis committee to carry the right weight to the terms while maintaining an accurate description. The connection circles were distilled from a conceptual model based solely on the literature review. This exercise allowed for an in-depth exploration of the variables that nurses considered most important in shaping their subjective workload, within the scope of this research. We guided the group by providing clarification and support as needed, ensuring that the causal relationships between variables were well-developed.

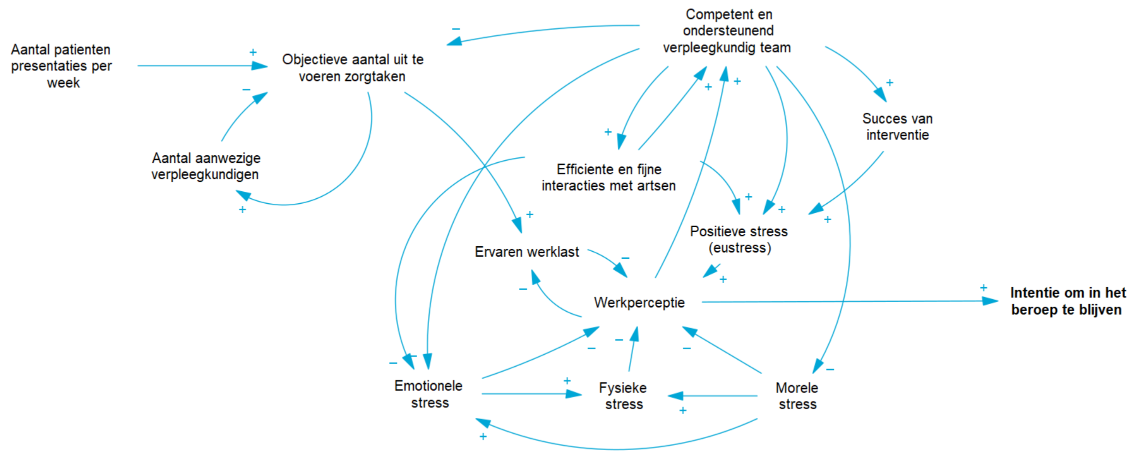


Figure 5.1: Connection Circles for Nurses

5.1.2. Outcomes and Insights

The first session was eventually conducted with two nurses, following a delay while waiting for a third participant. As a result, the session felt somewhat constrained; it was challenging to maintain both a fluid conversation and simultaneous engagement with the model. The discussion required frequent facilitation to maintain focus and to help translate the dialogue into model variables.

In contrast, the second session was held on time and involved four nurses. This session more clearly demonstrated the value of Group Model Building (GMB): the need for four participants to reach consensus created ground for rich discussion and reflection on their shared experiences. While two nurses were actively engaged in dialogue, the others had the opportunity to observe and reflect, giving them the mental space to engage with both the model on paper and the connection circles.

In analyzing the session outcomes, the second session was examined first and used as a reference point for interpreting the first session and the experiences discussed therein. This approach enabled a bidirectional validation of insights, allowing claims from one session to be supported by observations from the other. Additionally, it helped identify experiences and themes that were shared across both groups.

Across both sessions, we found genuine enthusiasm among nurses to discuss their perceived workload, stress, and how these relate to their intention to stay in the profession. Both groups immediately identified variables related to personal well-being and work-life balance as central to their decision-making. From there, each group followed a distinct path in further exploring the concepts presented in the connection circles.

The resulting causal loop diagrams (shown in Appendix A.2 and A.3) and the accompanying session transcripts provided a rich basis for analysis. Together, they revealed several key insights that informed the development of the final conceptual model.

- Shift Balance: Subjective workload was restructured into a ”shift balance” model, incorporating both positively and negatively perceived shifts, providing a more nuanced view of workload perception.
- Emotional demand during shift: Emotional demand during shifts is a contributor to the positive perception of the shift, and is influenced by feelings of responsibility, stress experienced and the match between competency and patient dependency.
- Absenteeism: Absenteeism was categorized into short-term and long-term types. Short-term absenteeism was linked to sickness, while long-term absenteeism was driven by psychosomatic complaints resulting from sustained stress.
- Work-Life Balance and Emotional Distress: Work-life balance was found to be significantly influenced by their quality of private life and emotional distress. A poor work-life balance negatively affected the ability to destress and contributed to increased stress factors such as emotional

stress and depersonalization. It was also identified as a key reason why nurses consider staying in the profession.
- Physical Distress: Physical distress was not seen as a significant stress factor in the Emergency Department. Nurses in both sessions indicated that the physical demands of the job did not substantially contribute to absenteeism or decisions to leave the profession.
- Scheduling and Responsibility: Satisfaction with shift scheduling was positively associated with more favorable work experiences. Increased responsibility during shifts, especially when there was a mismatch between the complexity of care and the competencies of the team, was linked to higher stress levels and a lower likelihood of experiencing positive shifts.
- Competence and Patient Complexity: A better match between nurses' competencies and the complexity of patient care was seen to improve the ability to deliver safe care, thus reducing stress.
- Impact of Long-Term and Short-Term Absenteeism on Emotional Distress: Seeing colleagues suffer from burnout was identified as a stressor, as it increased awareness of the consequences of sustained stress and contributed to additional emotional distress. Short-Term absenteeism caused last minute vacant shifts, reducing the ability to destress of nurses during their time off.

Two additional insights emerged from the Group Model Building (GMB) sessions that were not incorporated into the final conceptual model, due to either scope or methodological constraints.

First, team composition was consistently highlighted as an important factor influencing nurses' stress levels before and during shifts. Participants emphasized that working with a competent team—and equally important, one characterized by mutual trust and strong interpersonal connections—had a significant impact on the overall shift experience. While this insight is valuable, incorporating stochastic individual differences between team members to model team dynamics falls outside the scope, since we are not analyzing the ideal archetype of nurse or nursing team to deal with the stress of the job. Moreover, it better suits a different modeling approach than System Dynamics (SD) with more detail and more options to model individual differences in agents.

Second, the concept of job fit was frequently raised. Job fit refers to the degree to which a person's characteristics align with the demands and expectations of their role. Although highly relevant, this factor was not included in the model for two main reasons. First, the aim of this study was not to identify the ideal nurse archetype for the profession. Second, the model begins with an existing average nursing team and does not simulate nurse inflows, such as hiring or recruitment, where job fit policies might be applied as a policy lever. It would only create a stochastic archetype of the nursing team, which is outside the scope of this research. As a result, all nurses in the model are assumed to be adequately suited for their roles.

After gaining these insights, we iterated through the conceptual model. The conceptual model is examined in subsystems in the next chapter 6.

5.2. Third Results Validation session

In this session, we validated the interpretation of the results from the previous Group Model Building sessions, focusing on the Conceptual Model as well as the simulation results. Three nurses participated, with nurses present that participated in both modeling sessions prior. This allowed for validation of results from both sessions and more consensus building on the implementation of the outcomes of the GMB sessions. Overall, the nurses were satisfied with the adjustments made to the Conceptual Model. They also agreed with the variables in the output space of the boxes in the simulation, and could reflect and agree on the bandwidth and numerical results from the PRIM results. Following this brief presentation, the nurses were invited to reflect on the process and the methodology. They were pleasantly surprised by the approach, finding it both effective and insightful.

During this session, we identified two areas where the simulation setup needed adjustments: the variables 'Loss of team cohesion from nurses leaving' and 'Competency lost by nurses leaving.' The nurses observed that the impact of nurses leaving or being absent was minimal and delayed due to the nature of shift work and the size of the team. Absences from burnout were often mistaken as part of irregular scheduling, and the nurses felt that most of their colleagues were replaceable without losing significant competency. Consequently, the uncertainty space for these two variables was adjusted from 0 to 1 to a more realistic range of 0 to 0.1. This change led to only minimal numerical adjustments in the PRIM results but allowed the model to better reflect real-world dynamics.

6 Conceptual Model

The conceptual model has been created over several iterations. It is based on both input from the literature review and in a later iteration the input from the Group Model Building (GMB) sessions in A. First, an aggregated conceptual model is presented to explain feedback loops across subsystems present in the model. After this, each section aims to explain assumptions made, relationships constructed and concepts used in each subsystem of the model.

In the figures in this chapter, arrows between variables are displayed. These represent polarity between these variables: a plus means positive polarity (moving in the same direction) and a minus means negative polarity (moving in the opposite direction). This creates feedback loops, which can either be reinforcing of balancing, of which the relevant ones will be highlighted in section 6.1.

6.1. Aggregated model

An aggregated version of the conceptual model is provided to offer an overview of the interactions among the various subsystems. The original model contains over 3.500 feedback loops, many of which follow similar paths or exert similar influences. This redundancy allows for aggregation, simplifying the model and reducing the complexity of reading through numerous feedback loops. The aggregated version presented here captures the essential dynamics while offering a clearer and more concise representation of the system.

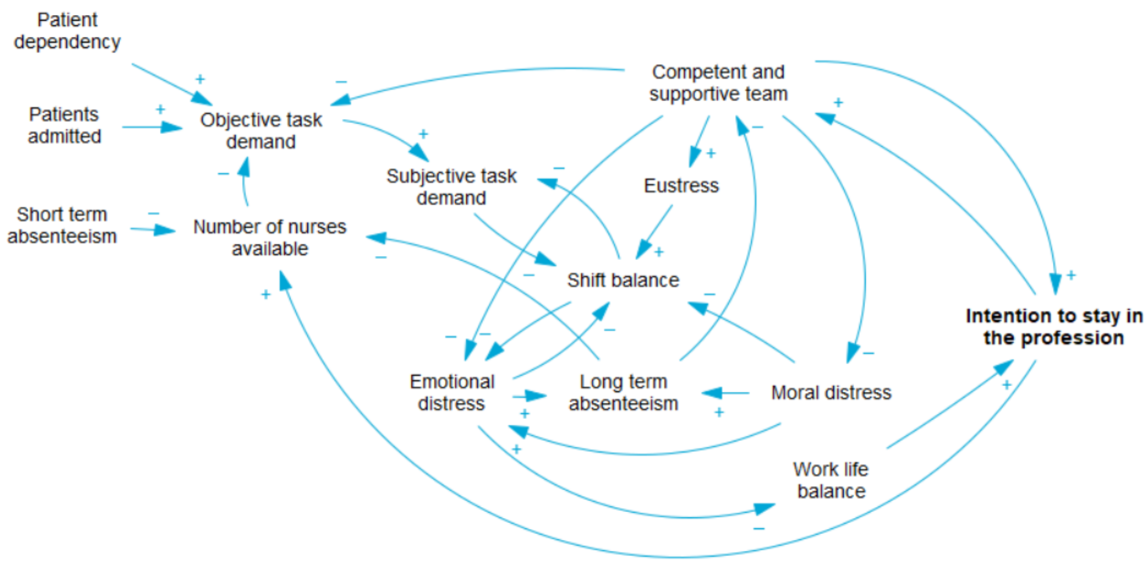


Figure 6.1: Aggregated version of conceptual model

It is possible to examine all feedback loops from the full Conceptual Model in Vensim. Simply open the model and select a variable of interest. Find the loops tool in the left border and click it. This opens a separate screen, where you need to click the Legacy Loops tool on the top. This allows you to visualize any loop, fading out the variables that are not included in the loop as much as preferred for clearer examination.

In the top left corner of Figure 6.6, variables from the Objective Task Demand subsystem are shown. At the top, the Team subsystem is simplified to represent a "Competent and Supportive Team." Centrally located, the Subjective Task Demand and Shift Balance elements illustrate the Shifts subsystem. At the bottom, the Stress subsystem is displayed, including different types of stress and the key outcome variable: Intention to Stay in the Profession. The relationships among the variables in this figure are complex and multifaceted, as further detailed in the following sections on the individual subsystems.

6.1.1. Shorter dynamics

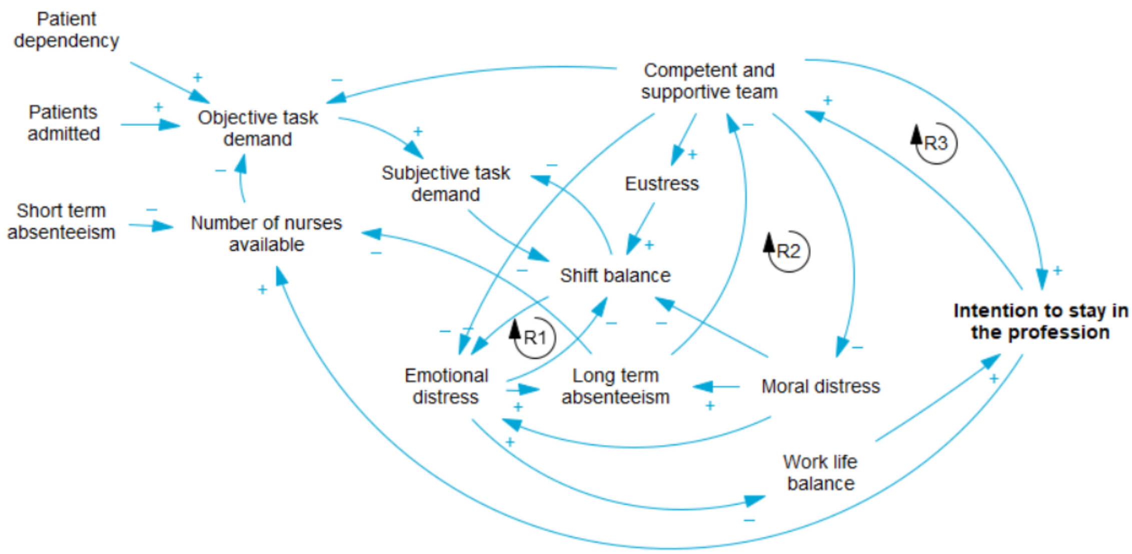


Figure 6.2: Aggregated version of conceptual model

Some of the smallest loops in the system already reveal central tensions. One example is the loop between Emotional distress and Shift balance (R1). As Emotional distress increases, Shift balance worsens, which in turn feeds back into higher levels of distress. This reinforcing loop can behave in a self-reinforcing way if Shift balance continues to decline and Emotional distress accumulates.

A second short loop (R2) connects Moral distress with Long-term absenteeism and the Competent and supportive team. Higher levels of Moral distress contribute to absenteeism, which leads to fewer stable team members. This weakens the team's ability to support each other, which again increases Moral distress. This is a reinforcing loop.

Another reinforcing loop starts from the Intention to stay in the profession, which contributes to the strength of the Competent and supportive team (R3). A strong team leads to better interpersonal dynamics and lower stress, which increases the intention to stay. Even though the loop is short, it plays a foundational role in maintaining or decreasing team stability.

6.1.2. Mid-length loops

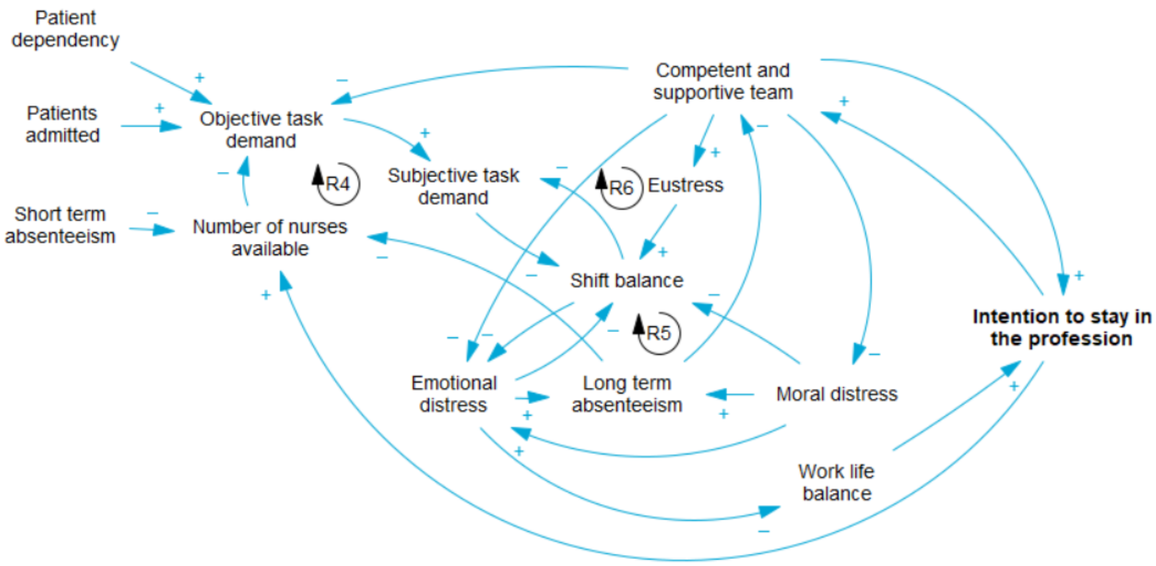


Figure 6.3: Aggregated version of conceptual model

As more variables are included, reinforcing behavior becomes more visible. A frequently recurring path (R4) is the one from Emotional distress to Long-term absenteeism, then to a reduced Number of nurses available, which increases both Objective and Subjective task demand. This causes Shift balance to deteriorate, which in turn increases Emotional distress. This loop forms a typical pressure spiral and is fully reinforcing.

Several loops (R5) branch off from Moral distress, either feeding into Emotional distress or starting at shift-level experiences and looping back through absenteeism and team stability. For example, Moral distress can reduce Shift balance, raise Emotional distress, and drive absenteeism. The resulting staff shortage affects the team's competence and cohesion, which leads back to more Moral distress. These loops highlight how moral and emotional strain are mutually reinforcing, especially when team conditions decline.

Another set of loops (R6) starts with a Competent and supportive team, which increases Eustress. This form of positive stress improves Shift balance, which reduces Emotional distress, absenteeism, and eventually contributes to keeping the team intact. These loops show the positive, stabilizing potential of good team dynamics and can be seen as potentially virtuous reinforcing cycles.

6.1.3. Complex feedback

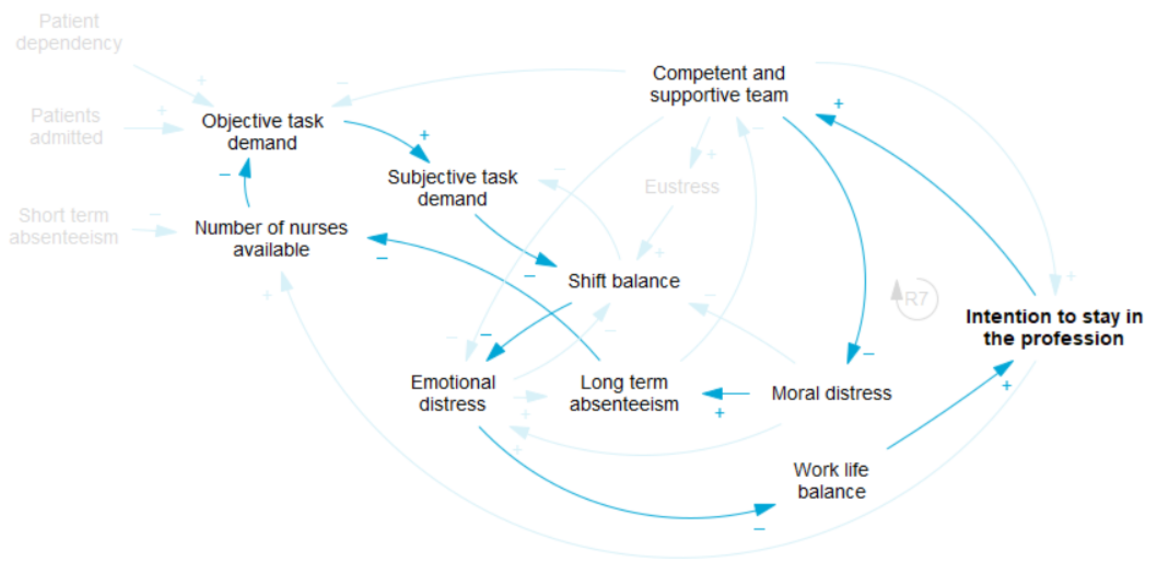


Figure 6.4: Aggregated version of conceptual model

The more extended loops combine all the above elements into broader systemic dynamics spanning across the subsystems. One such loop (R7) follows this sequence: Emotional distress leads to a worse Work-life balance, which reduces the Intention to stay in the profession. Fewer nurses remain, which weakens the Competent and supportive team and increases both Moral distress and Long-term absenteeism. This leads to fewer Nurses present, higher task demand, a worse Shift balance, and again more Emotional distress. The loop spans the psychological, interpersonal, and organizational dimensions of the model and is fully reinforcing.

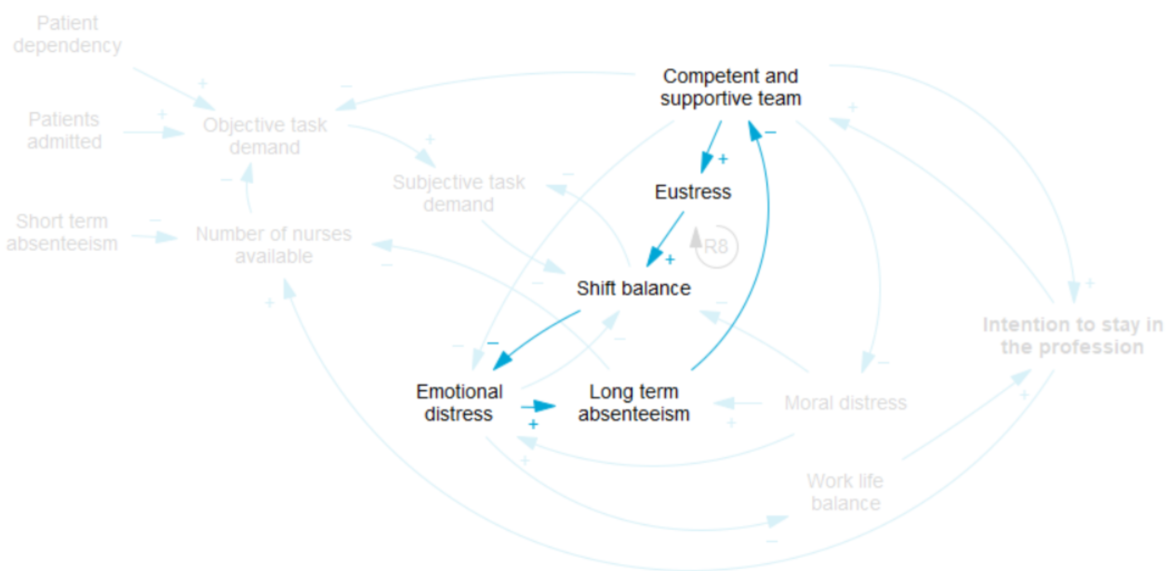


Figure 6.5: Aggregated version of conceptual model

Another large loop (R8) passes through Eustress and demonstrates how even positive mechanisms can be overwhelmed. Here, a supportive team increases Eustress and Shift balance, but if this is undermined by absenteeism, reduced staffing, and increased workload, the model loops back into Emotional distress and low Intention to stay in the profession.

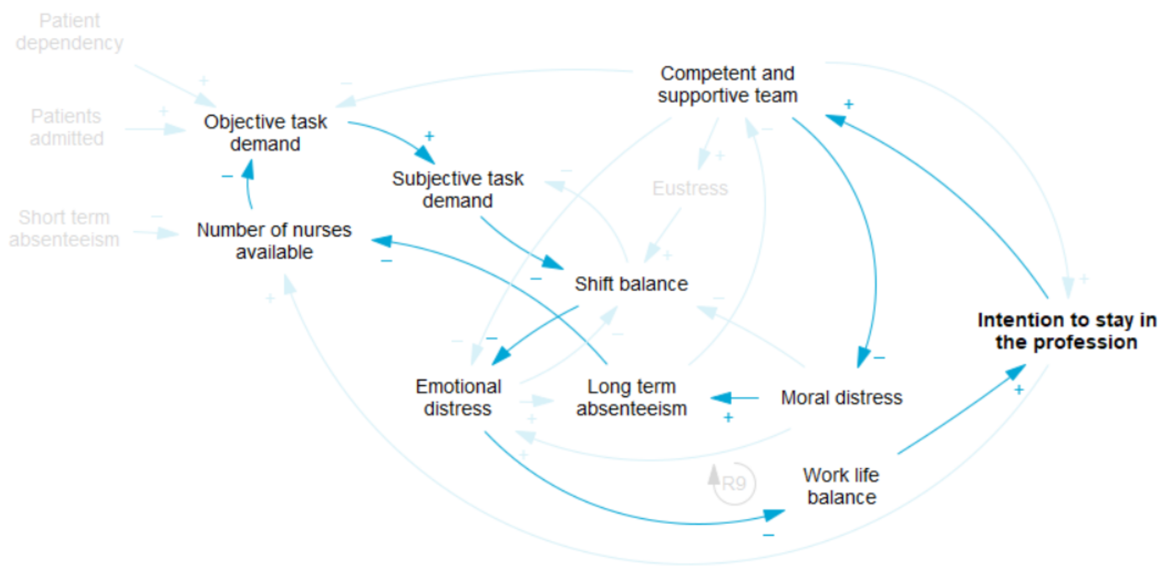


Figure 6.6: Aggregated version of conceptual model

In the most complex loops (R9), patient demand also plays a role. Objective task demand is increased by patient dependency and number of patients admitted, while the Number of nurses available decreases through absenteeism or a low Intention to stay. Combined, these effects raise Objective task task demand, put pressure on the Shift balance, and amplify stress. These dynamics feed through Emotional and Moral distress, absenteeism, and team breakdown, eventually impacting the Intention to stay in the profession.

6.1.4. Overview

Most of the feedback loops in the model are reinforcing. They contribute to either downward spirals—characterized by high stress, absenteeism, and weakened teams—or upward spirals, where supportive teams and positive stress strengthen each other and improve work conditions. This suggests that in many cases, once stress builds up or team conditions start to decline, the system tends to amplify these changes unless strong positive mechanisms are in place.

The next section explains the Objective task demand subsytem as the first subsystem from the full conceptual model.

6.2. Objective task demand subsytem

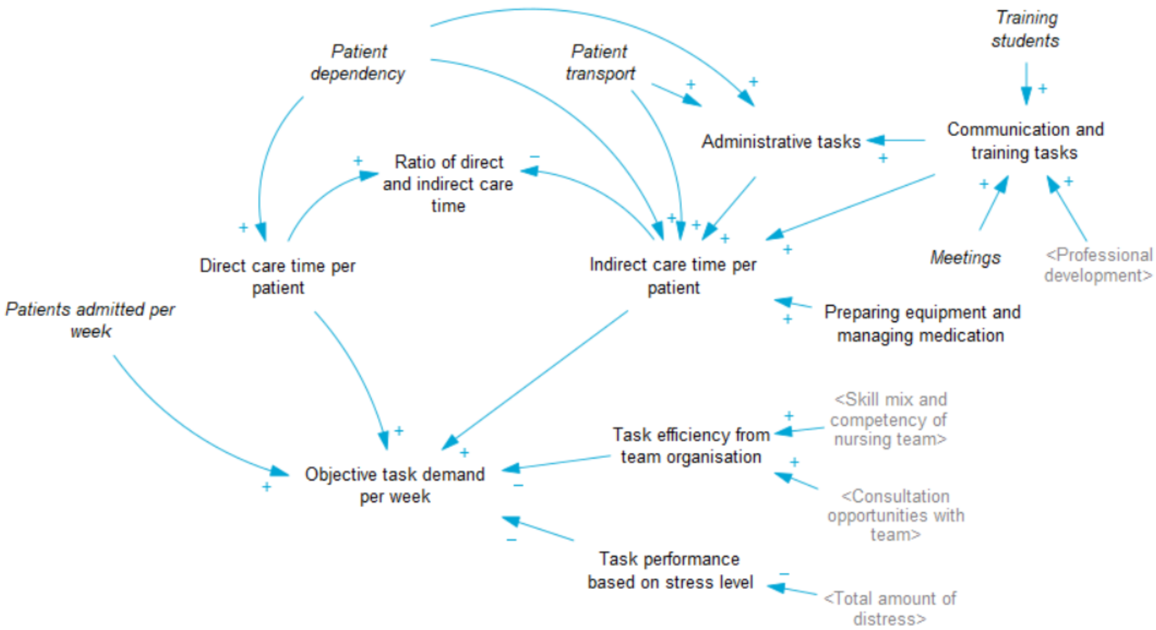


Figure 6.7: CLD of Objective task demand subsystem

Objective task demand is defined as the objective tasks measured in hours of work that the nurses have to fulfill in a week. An increase in Direct care time per patient, Indirect care time per patient and Patients admitted per week lead to an increase in the Objective task demand. Direct care consists of all the activities related to directly caring for the patient, such as wound care, medication, catheterizing, checking blood flow, plastering, temperature, and more [46]. Indirect care consists of all care activities that are not directly related to "making the patient better", such as restocking materials, preparing equipment, retrieving medication, communication, patient transport, patient administration, meetings, training students, and more [46].

These indirect care tasks have been specified further in the model to all increase the indirect care time per patient. These are all defined per patient and on average. Patient transport is the time nurses use for transportation of patients either to another institution or within the hospital to a different ward [49]. Training students, meetings, and professional development—time spent on student training, scheduled meetings, and nurses' education—are collectively categorized as Communication and training tasks [38, 46]. Additionally, Preparing equipment and managing medication serves as an umbrella variable for leftover previously mentioned indirect care tasks [46]. Lastly, Administrative tasks increase the Indirect care time per patient. Administrative tasks are assumed to increase due to higher Patient dependency, which requires additional and more complex documentation, Patient transport, which generates forms and internal communication records, and Communication and training tasks, which produce reports, summaries, and evaluations.

Both direct and indirect care time per patient increase when the Patient Dependency increases [41]. In other studies, this concept is described as complexity of care [37, 44]. In this thesis, Patient dependency is defined following Iordache et al. [46] definition when developing the Workload Assessment of Nurses on Emergency (WANE) tool. They used a Dutch version of the Jones Dependency Tool (JDT). This is a validated classification system that rates patient dependency through six major care domains: communication; ABC (airway, breathing, circulation); mobility; eating, drinking, elimination and personal care; environmental safety, health and social needs; triage [46]. Direct and Indirect care time per patient are used in the Ratio of Direct and Indirect care time, which will come back later in another subsystem.

Lastly, two factors decrease the Objective task demand per week. First, Task efficiency from team organization improves when teams are well-structured, with a strong skill mix and opportunities for consultation. Skill mix and competency of the nursing team and Consultation opportunities both contribute to greater efficiency. Second, Task performance based on stress level displays the effect of stress levels on task performance, resulting in a lower performance due to ill-health when the Total amount of distress is high [30], a common relationship in patient safety science [54] and burnout theories [56]. A well-organized team and a less stressed team is able to reduce the objective task demand by reducing the time necessary to complete a task.

6.3. Shifts subsystem

This section aims to explain the Shifts subsystem and why it is representative for Subjective workload. A shift balance is the result of this subsystem: how many positive shifts a nurse experiences compared to the negative shifts. This is done based on the output of the GMB sessions.

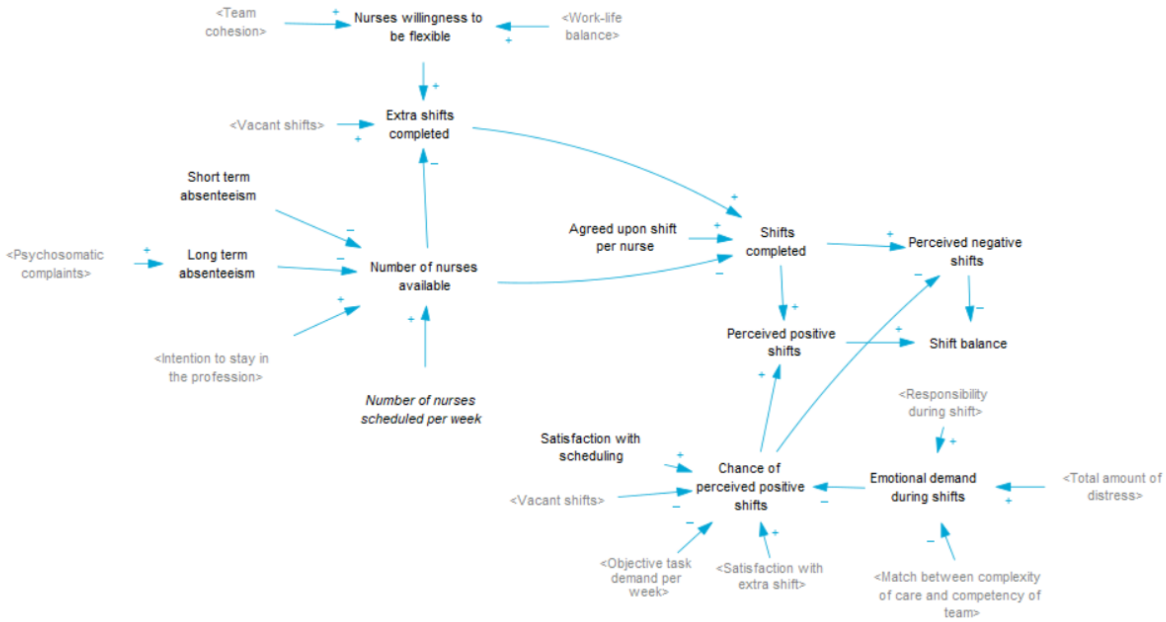


Figure 6.8: CLD of Shifts subsystem

Whether a shift is perceived positive or negative is determined by the Chance of Perceived Positive Shifts. This variable is influenced by three factors. First, Satisfaction with Scheduling or Satisfaction with Extra Shift increases the Chance of a Perceived Positive Shifts. These satisfaction factors shape the nurses' mindset entering the shift, which can influence how the shift is experienced. These variables and their relationships are an outcome of the GMB sessions. These variables are considered external in the model, as most nurses have limited control over scheduling or the occurrence of extra shifts through absence of colleagues. Second, a high Objective Task Demand per Week decreases the Chance of Perceived Positive Shifts, particularly when the workload becomes overwhelming and causes longer than agreed hours [56, 9]. Third, a high Emotional Demand during Shifts reduces the Chance of Perceived Positive Shifts, a conclusion drawn from the GMB sessions.

The Emotional demand during shifts is determined by three factors. Responsibility during Shift, identified in the GMB sessions, refers to the level of responsibility nurses feel over patient care. Total Amount of Distress increases the Emotional Demand during Shifts, as high stress levels reduce nurses' emotional stress reserves, making the shift feel more demanding than usual [56]. Lastly, the Match between Complexity of Care and Competency of Team influences Emotional Demand during Shifts. Findings from the GMB sessions indicate that when a team lacks the necessary competencies to handle complex patient cases, the emotional strain on nurses increases.

The Number of nurses available and Agreed upon shifts per nurse determine how many scheduled Shifts are completed. However, Long-term and Short-term absenteeism can reduce the Number of nurses available. Short-term absenteeism is an external variable representing temporary absence due to illness or other short-term factors. Long-term absenteeism is primarily the result of a burnout. An increase in Psychosomatic Complaints, the body's physical response to sustained high stress levels, contributes to higher Long-term Absenteeism.

Both types of Absenteeism lead to an increase in Extra shifts that need to be completed. However, not all Extra shifts are covered, as this depends on Nurses willingness to be flexible. A positive Work-life balance and strong Team cohesion can increase Nurses' willingness to be flexible; these factors are further explored in the Stress subsystem and Team subsystem, respectively. If Nurses' willingness to be flexible is low, more Vacant shifts occur, leading to understaffed shifts, which in turn reduce the Chance of perceived positive shifts. This effect of understaffed shifts was higlighted in the GMB sessions.

It is important to note that Agreed upon shifts per nurse and Nurses scheduled are not linked to the Objective task demand subsystem. This is due to the scope of this research, which does not focus on determining the specific number of shifts or nurses required to meet the Objective task demand per week.

6.4. Team subsystem

This section aims to explain the Team subsystem from the Conceptual Model. Jetha, Kernan, and Kurowski [18] conceptualized workplace stress for nursing aides in a small SD model, which is used as inspiration. They used the Self-Determination Theory from Ryan and Deci [75] on how to enhance intrinsic motivation, self-regulation and well-being. This theory includes concepts as needs for competence, relatedness and autonomy. Combining these concepts with the outcomes of the GMB sessions gives us the Team subsystem.

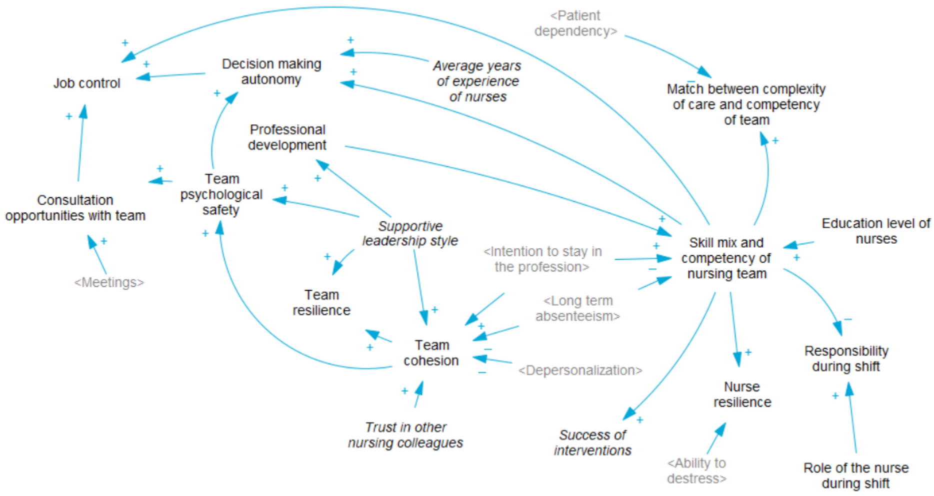


Figure 6.9: CLD of Team subsystem

This subsystem includes two key variables: Team cohesion and Skill mix and Competency of Nursing Team. We begin by examining Team Cohesion first. This variable represents cohesion within the team on work methods (from the GMB sessions), norms and values [6], co-worker support and connectedness [35, 75]. Team Cohesion is influenced by five factors in this model. First, Trust in other nursing colleagues - an external factor - sets the baseline and can strengthen Team Cohesion. Second, Depersonalization can decrease Team Cohesion. When nurses feel disconnected from themselves, they tend to also disconnect from the team and become less personally involved [56, 5]. Third, Team Cohesion is enhanced by a Supportive leadership style, which is explained in the next paragraph. Fourth, Long-term absenteeism and Intention to stay in the profession negatively influence the Team Cohesion through nurses leaving the team, which results in the team potentially losing spirit and connectedness. In this subsystem, Team Cohesion plays a central role by influencing two variables: Team's Psychological Safety and Team Resilience. We will first examine Team Psychological Safety.

Team Psychological Safety is an important ground for speaking-up behavior and open communication [76]. When healthcare professionals perceive the environment as psychologically unsafe, they fear negative consequences, such as negative or harsh reactions, being labeled negative or a trouble-maker, or they are afraid of a bad evaluation, retaliation or retribution [76]. Within this model, Team Psychological Safety positively influences two variables: Decision making autonomy and Consultation opportunities with team. (Decision making autonomy will be explained later in this paragraph.)

Consultation opportunities with team refers to moments - both scheduled and spontaneous - when team members can consult each other about patient treatment, task distribution and emerging challenges. A higher number of scheduled Meetings contributes to these opportunities. Together these opportunities positively influence Job Control, as they provide more avenues to take initiative and exert influence on their work.

Another factor influenced by Team Cohesion is Team Resilience. Team Resilience is the ability to deal with adversity, stress and tough decision making as a team [35, 36]. Resilience increases the nurses' ability to experience the stress from the nursing job positively. This increases Eustress, as elaborated in the next section 6.5.

An additional factor influencing both Team Resilience and Team Psychological Safety is the Supportive leadership style. Leadership has long been acknowledged in the literature as a key determinant of nurse workload and job stress [29, 30]. This leadership style is also referred to as *Healthy leadership* by Bakker and Vries [27], and as *Supervisor support* in studies such as Gelsema et al. [7] and Jetha, Kernan, and Kurowski [18]. In our model, Supportive leadership style is defined as a employee-oriented leadership approach in which the manager is considerate of team members' needs and perceived as friendly and approachable [25]. In contrast, Instrumental leadership is focused on clarifying expectations, setting goals, and ensuring task completion [25].

From the perspective of the nursing team, leadership style is considered an external factor. In addition to enhancing Team Resilience and Team Psychological Safety, Supportive leadership style positively influences two additional variables in this subsystem. First, it increases Team Cohesion by helping to resolve intra-team issues and cultivating a sense of collegiality and connectedness. Second, it promotes Professional Development by responding to nurses' developmental needs and encouraging a learning-oriented work environment. We define Professional Development as encompassing both formal educational opportunities and informal learning experiences during patient care. This, in turn, contributes to the Skill mix and competency of the nursing team.

Skill mix and competency of nursing team builds on Ryan and Deci [75]'s concept of competence, expanded with the diversity of skills within the team. This variable is determined by the Education level of nurses (how highly educated they enter the job) as an external factor and can increase over time by Professional Development. It can decrease through nurses leaving the team, either by being long-term absent of having low Intention to stay in the profession. Skill mix and competency of nursing team influences six variables:

1. Greater Decision making autonomy, as a more competent team is typically granted more freedom to make their own decisions. Management is assumed to worry less about potential negative outcomes and their consequences.
2. Improved Job Control, since a skilled team is better equipped to manage stressful and complex situations than a less competent one.
3. Better Match between complexity of care and competency of team. When the team lacks the necessary competence to meet care demands—especially with high Patient Dependency—this mismatch contributes to increased Moral Distress, as discussed further in the Stress subsystem. This was also highlighted in the GMB sessions.
4. Reduced Responsibility during shift. Nurses feel less individually responsible for workflow and patient outcomes when working within a competent team. This effect, noted in the GMB sessions, is also influenced by the Role of the nurse during shift, as nurses reported varying levels of responsibility depending on whether they had a coordinating or a more floating role.
5. Higher Success of interventions. A diverse and competent team is assumed to have a greater chance of success when delivering care, which contributes to positive stress (Eustress), as further explored in the next section.
6. Increased Nurse resilience. While similar to Team Resilience, this variable reflects individual rather than collective capacity [36]. Feeling well-equipped and competent helps nurses view stress more positively. Nurse Resilience is also supported by the Ability to destress (defined later) and by the Average years of experience of nurses.

Myny et al. [49] found a significant difference between nurses with less than 20 years of professional experience and those with more than 20 years. However, insights from the GMB sessions suggest that the perceived competence or suitability for the job may be more influential than the number of years worked. Based on this, we assume an average years of experience of nurses, rather than applying a categorical distinction. Average years of experience influences two variables positively. First, it increases Nurses Resilience. Nurses with more years of experience have typically encountered a broader range of stressful situations and are, on average, better equipped to cope with such challenges. Second, it enhances Decision making autonomy. More experienced nurses are generally granted more freedom to make decisions, and are often expected to take the lead in clinical judgment, even when its not always entirely justified.

Decision making autonomy follows Ryan and Deci [75] and is defined as the amount of freedom and trust the team gets to make their own decisions while doing their job [24]. It increases Job Control [10], because it gives nurses more opportunities to take action in a way they assume to be suitable.

Job Control is defined as the degree of control nurses have over their own job. This includes making decisions about patient care, distributing their time and effort, and choosing tasks based on their skills and preferences [18, 7]. Control, or a lack of control, is related to distress, job satisfaction, intention to leave the profession [6, 4, 7, 18] Other studies have used different terms such as self-regulation [34, 75] or job crafting [27]. This variable influences factors in the Stress subsystem, described in the next section of this chapter.

Together, these interlinked variables form Team subsystem, which ultimately influences how nurses experience and manage their workload and stress levels.

6.5. Stress subsystem

This section aims to highlight the Stress subsystem from the Conceptual Model. The subsystem draws inspiration from Jourdain and Chênevert [10], who constructed a Job demands-resources (JD-R) model relating emotional exhaustion (or burnout) and intention to leave the nursing profession. Other factors found in literature and highlighted by the nurses in the GMB sessions are explained a long the way. We have applied the four types of stress mentioned in Background Information section: Emotional distress, Moral distress, Physical distress and Eustress. Physical distress has been altered and only the Psychosomatic Complaints remain; the physical response of the body to sustained distress [10]. This is a result of the GMB sessions, where nurses indicated that the physicality of their care tasks is minimal. In the following diagram, the factors influencing these types of stress and interactions between them are displayed. Furthermore, the output variable Intention to stay in the profession has been broken down into several interacting variables and their influencing factors.

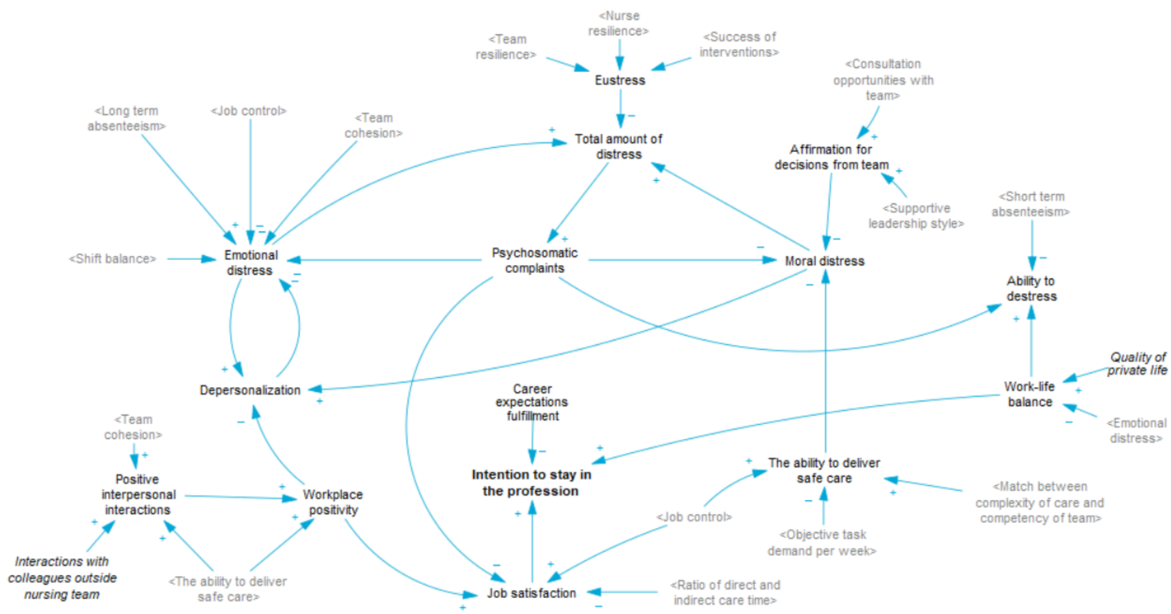


Figure 6.10: CLD of Stress subsystem

Eustress is influenced by three factors. Nurse and Team resilience, which have been further explained in the Team subsystem section 6.4, cause nurses to be able to experience stress more positively. Furthermore, Succes of Interventions increases the amount of Eustress experienced, which is one part of meaning of work. Meaning of work has been identified as the most important factor of Intention to stay in the profession by Jourdain and Chênevert [10]. The other part of meaning of work is the Ratio of Direct and Indirect care time, which is calculated in the Objective task demand system.

Emotional Distress is influenced by five factors. First, Long-Term absenteeism increases the Emotional distress. Nurses in the GMB sessions highlighted that colleagues absent due to burnout causes a reflection of their own stress levels, potentially becoming more aware of the consequences of these stress levels, which can result in an elevated experience of Emotional Distress. Second, a good Shift Balance reduces the Emotional distress, since nurses experience their shifts more positively than negatively. Third, Job Control allows nurses to control their own stress levels better and having poor control was shown as a stressor in corelation with burnout [27, 30, 56]. Fourth, good Team Cohesion can act as a buffer on Emotional Distress; it gives nurses more opportunities to destress and promote a sense of solidarity. Finally, Psychosomatic complaints causes more Emotional Distress, as they hinder the ability to recover from stress, which is supported by burnout theory [7, 27]. Emotional Distress influences three things in this subsystem. First, it contributes to the Total amount of distress negatively. Second, it contributes negatively to Psychosomatic Complaints as one of the forms of distress. Third, it is buffered by Depersonalization.

Depersonalization is related to the output side of burnout, representing a defensive coping mechanism to avoid emotional involvement, often described a feeling of begin detached from one's body or mental processes, like an outside observer [10, 56]. In this model, Depersonalization is in a short feedback loop with Emotional Distress to simulate this coping mechanism. Depersonalization is more associated with relational stressors, such as conflicts with clients, colleagues, or the emotional toll of caregiving roles [10, 56]. Therefore, it is only influenced by Moral Distress and Workplace Positivity. First, Moral Distress is elaborated on before we return to Workplace Positivity to further unwrap this subsystem.

Moral distress is influenced by three factors. First, Affirmation for decisions from team result in lower Moral Distress, which is described as sharing responsibility and being able to double check decisions. This variable is positively influenced by Supportive leadership style and Consultation opportunities with the team from the Team subsystem [25]. Second, The Ability to deliver safe care decreases Moral Distress. With this variable, we combine perceived quality of care [25] and the cause and effect of reduced patient safety [77] and medical error involvement [26]. This is assumed to consist of how much work the nurses have to do (Objective task demand per week), how much control the nurses have over their job (Job control) and if the team is competent enough to deal with the patients (Match between complexity of care and competency of team). Third, Psychosomatic complaints increase the amount of Moral Distress in a similar dynamic to Emotional Distress. Moral distress influences two variables. First, it contributes to the Total amount of distress. Second, it increases Depersonalization. When nurses are confronted with a lot of Moral Distress, they tend to take their personal interest out of the equation and distance themselves more from difficult situations with patients as a coping mechanism.

Workplace positivity is the positive version and the opposite of the commonly used term Workplace Adversity. Workplace Adversity refers to any negative, stressful, traumatic, or difficult situation of hardship that is encountered in the occupational setting [35, 18]. It is influenced by two variables. First, Positive interpersonal interactions increase the amount of Workplace Positivity experienced. These Positive interpersonal interactions occur when the Team Cohesion is high, when Interactions with colleagues outside nursing team are positive or when The ability to deliver safe care is perceived good, which can potentially result in more positive interactions with patients. Second, Workplace positivity is assumed to increase when the Ability to delivery to deliver safe care is high. Patients will be given the right and adequate care, resulting in good care, less triage, and potentially less adverse outcomes like sickness and death. Experiencing more positivity leads to less Depersonalization as a protective mechanism to not become too emotionally involved in the adversity and experience more stress. Workplace Positivity also directly positively influences Job Satisfaction, which will be explained in the next paragraph.

Job Satisfaction displays how the nurses respond to the question how much they like their job, from "my job is the worst possible job" to "my job is the best possible job" [25]. It is influenced by four factors. First, Workplace Positivity increases Job Satisfaction as described in the previous paragraph.

Workplace Adversity, the opposite of this variable, adds strongly to the demand side of the job [18] and reduces the feelings of rewards as well [7]. Second, how much control nurses have over their job (Job Control) increases Job Satisfaction [7]. Third, Psychosomatic complaints decreases Job satisfaction; the more physical complaints from sustained job distress the nurses experience, the less they will be satisfied with their job [25]. Fourth, a good Ratio of Direct and Indirect care time increase the Job satisfaction. With this, we aim to capture the second side of meaning of work, following Sasso et al. [55] and Jourdain and Chênevert [10] stating that ”performing core nursing activities” is a pull factor and ”performing non-nursing care activities” is a push factor for Intention to Stay in the Profession. This last variable is influenced by Job Satisfaction.

Intention to stay in the profession is influenced by three factors. First, Job Satisfaction, is explained the previous paragraph to contribute to staying the profession. Second, Career expectation fulfillment decreases the nurses' Intention to stay in the profession [24]. Third, in the GMB sessions, nurses highlighted that Work-life balance positively influences Intention to stay in the profession. Work-life balance is mainly influenced by the external factor Quality of private life; how content nurses are with their private life. Emotional Distress can negatively influence work-life balance since the Emotional Distress taken home can lead to a less pleasant private life. This Work-life balance influences the Ability to destress.

Ability to destress is defined as the nurses' ability to destress while being away from work. A good Work-life balance is known to help destress, as described in the GMB sessions. A second factor is Short-term Absenteeism, that negatively influences the Ability to destress. During the GMB sessions, nurses complained that managers asking to come work extra last minute vacant shifts due to absenteeism causes them to experience stress about work away from work. They are not fully able to decouple from their work environment and properly destress.

Altogether, these subsystems create a model that offers a comprehensive framework for understanding the origins, propagation, and mitigation of nurse distress, with a focus on their intention to stay in the profession.

7 Quantitative model

This chapter explains how the conceptual model was translated into a quantitative Vensim model, including the logic, assumptions, parameterization, and justification of modeling choices. The conceptual model has already been established in a previous chapter, so this section will not repeat those decisions.

When reviewing the model in Vensim, two steps allow for a clearer and more organized view of the Quantitative model. The first approach is to review the different subsystems, available through the select view option in the left bottom. Because the quantitative model has integrated more detail and more variables, two subsystems have been separated different from the Conceptual model: Nurses subsystem and Destress subsystem. However, the elements in these subsystems do not differ from the Conceptual model. A second approach is to review the model in Complete model view for a complete overview with either top depth or any depth below 10. This removes the weights, lookups and all other variables that reduce readability of the model.

The purpose of the quantitative model is to test the feasibility of translating the conceptual model into a formal, computational framework. While it can be used to identify the most influential uncertainties in the system, it also serves as a proof of concept to explore whether such quantification is possible. This chapter builds on the conceptual model discussed in the previous chapter and explains the process of assumptions and choices made to quantify the model. The full model description can be found in Appendix C.

7.1. From Concept to Simulation

In transitioning from a conceptual to a quantitative model, we identified a set of key variables to represent as *stocks*. These are variables that accumulate over time, retain memory of past states, and exhibit dynamic behavior. This is consistent with system dynamics modeling principles, such as those implemented in Vensim, where stocks represent the state of the system and are critical for capturing feedback mechanisms and time-dependent processes.

The model contains 14 stock variables, distributed across different subsystems. Their selection was based on their role in the system's evolution over time and the need to capture delayed or accumulative effects.

Objective Task Demand Subsystem

- *Objective task demand to date*: Accumulates the total demand for care over time. It is modeled in a similar fashion to the Vensim standard burnout model based on Homer [29]. This variable drives downstream effects of task demand in the system.

Shift Subsystem

- *Shifts*: Represents the number of scheduled shifts, accumulating based on nurses scheduled and agreed upon shifts per nurse, and depleting as shifts are completed or missed.
- *Vacant shifts*: Tracks the number of unfilled shifts due to absenteeism or nurses leaving the profession. It increases when shifts are not taken and is emptied every week.

- *Perceived positive shifts* and *Perceived negative shifts*: Represent a form of "mental accounting" of shift experiences. These accumulate through completion of shifts and fade over time, simulating memory decay and emotional processing.

Nurses Subsystem

- *Number of nurses available*: Reflects the number of available nurses, which can decrease gradually due to burnout or nurses leaving the profession.
- *Long-term absenteeism*: Tracks the cumulative number of nurses who have exited the active workforce due to burnout or related factors.

Stress Subsystem

- *Emotional distress*, *Moral distress*, *Depersonalization*, and *Psychosomatic complaints*: These exhibit complex accumulation and decay patterns, influenced by work conditions, coping mechanisms, their own values and feedback from other subsystems.

Ability to Destress Subsystem

- *Ability to destress*: Represents nurses' capacity to recover from stress. It accumulates and depletes based on exposure to stress and availability of recovery resources from team and personal life.

Team Subsystem

- *Team cohesion*: A tacit, slowly developing quality that can deteriorate rapidly due to negative team dynamics or nurses leaving the team.
- *Skill mix and competency of the nursing team*: Represents the team's aggregate competency. It increases through training and experience and degrades with staff loss.

Other Variables

All other variables in the model are categorized as *Flows*, *Inputs*, *Lookups*, or *Auxiliaries*. A detailed classification is provided in Appendix C.

7.2. Quantification and Assumptions

To model the polarities identified in the conceptual model, we made assumptions about input parameters and the modeling of both complex and less complex influences between variables. This section outlines the establishment of input variables, the rationale for using the Visual Analogue Scale (VAS), and the use of weights and lookup functions to model relationships.

7.2.1. Input Variables and Parameters

The variables and parameters derived from literature are primarily found in the *Objective Task Demand* and *Nurses* subsystems. Patient dependency was based on Iordache et al. [46]. Each domain mentioned in section 6.2 is scored on a three-point scale (from 1 to 3). This yields a total dependency score ranging from 6 to 18, with a higher score indicating a higher patient dependency on nursing care. The score is used to assign the patient into one of the four JDT dependency categories (low, score 6–8; medium, score 9–12; high, score 13–15; total, score 16–18) [46]. This influences both direct and indirect care time, of which base values are also drawn from Iordache et al. [46], measured in minutes per patient. Variables influencing indirect care tasks were therefore similarly defined in minutes per patient.

The number of initially scheduled nurses was based on discussions with nurses and Emergency Department management but was not formally counted or sourced from scheduling data. Similarly, the average number of agreed-upon shifts per nurse was not sourced from formal scheduling data but was instead estimated based on conversations with nurses, in which it was indicated that they work four shifts per week on average.

All other input variables were given a value by assumptions. Every subsystem has its own Input variables section in appendix C, where a base case is displayed as well as the lower and upper boundary. Due to the uncertainty associated with these assumptions, simulation runs were conducted with the widest possible uncertainty bounds, as described in Chapter 8.

7.2.2. Visual Analogue Scale (VAS)

We adopted VAS as the unit for all tacit concepts in the model, such as *Emotional distress*, *Team cohesion*, and *Intention to stay in the profession*. The Visual Analogue Scale (VAS) is a widely used, non-specific metric where a 100 mm line is used to mark the intensity of a sensation, measured from the low end [78]. It is familiar to nurses due to its frequent use in triage and evaluation. This choice facilitates easier interpretation of the model by nurses and provides a foundation for future survey-based data collection.

7.2.3. Weighting of Variables

Some auxiliary variables are influenced by others in a relatively linear way. These are considered variables that consist of a mix of an experience or valuation of other variables in the system. For these, we applied normalized weights. This allows for intuitive and consistent interpretation while simplifying future data collection. In practical terms, this means nurses can assign importance scores between 0 and 100 VAS next to the experience of a certain variable or concept without needing to account for interactions or proportional trade-offs between variables. Normalization supports both ease of interpretation and sensitivity to variables with no influence: a score of 0 will ensure the outcome variable remains within a normalized and interpretable range between 0 and 1.

7.2.4. Lookup Functions

To represent nonlinear relationships or effects with thresholds, we used lookup functions. These were especially useful in influencing flow variables with dimensionless multipliers ranging between 0 and 1. The construction of these lookups was based on assumptions, qualitative input from Group Model Building sessions, discussions with the thesis committee, and personal experience in stress-related dynamics. In appendix C, every subsystem is equipped with a subsection on the lookups, where every lookup is displayed with a graph and a table as well as thresholds and shape of the graph xplained.

7.3. Model Validation

Before using the model for scenario analysis, we carried out a structured validation process to ensure it behaves in a realistic, robust, and reliable way. This was important to confirm that the model's internal logic aligns with expected system behavior, particularly in a feedback-heavy environment like the Emergency Department.

The validation process involved three main steps: (1) selecting an appropriate time step, (2) running a univariate sensitivity analysis, and (3) testing the model's resilience to short-term stress.

First, we verified that the technical settings were appropriate and that no numerical errors were present. This included checking the integration method—Euler in this case. Although Euler is relatively imprecise, it is adequate here because the model is not focused on capturing fine-grained changes but rather broader behavioral trends in stress, workload, and intention to stay in the profession. The time step was set to 0.03125, based on an iterative halving process until no change in model behavior was observed, ensuring numerical stability (Appendix B.1).

Second, we conducted a univariate sensitivity analysis (Appendix B.2). This involved independently varying two parameters from each subsystem by ±10% to assess how sensitive the outputs were to small input changes. As expected in a well-structured feedback model, the results showed minimal output variability and no significant behavioral shifts. This supports the model's stability and internal consistency. It also suggests that more complex, multivariate methods (like PRIM) will be needed to uncover deeper insights about input interactions and behavioral tipping points.

Third, we tested the model's resilience by applying short-term shocks (”pulses”) to key variables such as patient dependency, patient admissions, and private life stress (Appendix B.3). These simulated temporary disruptions that commonly occur in real-world settings. In all three cases, the model outputs returned to baseline levels after the pulse ended—mirroring the resilience often observed in clinical staff. This behavior supports the model's ability to realistically simulate recovery from acute stressors.

One notable insight came from comparing the effects of increased patient volume vs. complexity of care. While a surge in admissions increased task demand, it had little effect on overall stress or professional motivation. In contrast, a temporary increase in patient dependency led to a spike in distress and a short-lived rise, then a dip, in the intention to stay in the profession. This suggests that care complexity, more than workload volume, may drive nurse well-being and job satisfaction—an insight the model is capable of capturing.

Taken together, these validation steps demonstrate that the model behaves in a realistic and reliable way and is ready to be used for further scenario testing to find potential policy levers.

7.4. Model simulation setup

The simulation aims to explore the uncertainty space of the model for potential policy levers in the model that could produce favorable outcomes. We ran the Vensim model using the VensimModel module from the EMA workbench in Pycharm. The model is fully deterministic and did not require a fixed random seed.

The model is configured to run over a simulated period of 104 weeks (2 years), using a TIME STEP of 0.3125 and the Euler integration method, as validated in the previous section. To ensure comprehensive coverage of the uncertainty space, the simulation was run 100,000 times, allowing for robust exploration of the full range of input variable combinations.

The 100,000 model runs were generated using random sampling as implemented in the EMA Workbench. Each scenario represented a unique configuration of the 61 input parameters, drawn independently from their defined uncertainty ranges. All the input parameters are shown in the table below. Due to the lack of comprehensive data as input for this model, the uncertainty spaces for the input parameters are setup as wide as (conceptually) possible. The are two exceptions following the third validation session with the nurses, which are the variables 'Loss of team cohesion from nurses leaving' and 'Competency lost by nurses leaving', which are setup with a bandwidth of 0 to 0.1.

We included 6 TimeSeriesOutcomes: Intention to stay in the profession, Job satisfaction, Total amount of distress, Job control, Team cohesion, Skill mix and competency of nurses. All output variables are normalized and expected to remain within the conceptual boundaries of [0, 1]. Time series results were visualized as Behaviour Over Time (BoT) graphs to verify model validity and detect any implausible trends or boundary violations. For PRIM analysis, two key indicators — Intention to stay in the profession and Job satisfaction — were selected. These indicators are of central importance to the main research question and serve as the primary basis for evaluating the effectiveness of policy scenarios.

Variable	**Unit**	**Low/High bound**
Objective task demand subsystem		
Initial direct care time per patient	minutes/patient	5/60
Average patient dependency	JDT	6/18
Preparing equipment and managing medication	minutes/patient	2/10
Patient transport	minutes/patient	2/10
Number of patients admitted per week	patients/Week	358/1530
Shift subsystem		
Nurses initially scheduled	nurses	40/80
Time of negative shift memory to fade	weeks	2/12
Time of positive shifts memory to fade	weeks	2/12
Perception of extra shifts	dmnl	0/1
Initial willingness to be flexible	shifts/nurse/Week	0/1
Satisfaction with scheduling	dmnl	0/1
Threshold for busy shift	hours/shift/Week	4/12
Nurses subsystem		
Short term absenteeism	nurses	0/10
Psychosomatic complaints to long term absenteeism threshold	vas	0/1
Intention to actually leaving threshold	vas	0/1
Stress subsystem		
Normal increase of emotional distress	vas/Week	0/1
Initial emotional distress level	vas	0/1

Variable	Unit	Low/High bound
Time for psychosomatic complaints to have effect on stress	weeks	2/12
Coping with emotional distress through depersonalization	dmnl/Week	0/1
Normal increase of depersonalization rate	vas/Week	0/1
Normal decrease of depersonalization	vas/Week	0/1
Time that moral distress leads to depersonalization	weeks	2/12
Interactions with colleagues outside of nursing team	vas	0/1
Preferred ratio of direct and indirect care time	dmnl	0.1/2
Career expectation fulfillment	vas	0/1
Time that stress turns into physical complaints	Week	2/12
Percentage that resting reduces psychosomatic complaints	dmnl/Week	0/1
Normal increase of moral distress	vas/Week	0/1
Team subsystem		
Normal rate of team cohesion	vas/Week	0/1
Loss of team cohesion from nurses leaving	dmnl/nurse	0/0.1
Trust in other colleagues	vas	0/1
Supportive leadership	vas	0/1
Meetings	minutes/patient	1/15
Training students	minutes/patient	2/10
Time before training is completed	weeks	6/52
Education level of nurses	vas	0/1
Competency lost by nurses leaving	dmnl/nurse	0/0.1
Success of intervention determined by competency	dmnl	0/1
Average experience of nurses	years	0/25
Ability to destress subsystem		
Quality of private life	vas	0/1
Initial ability to destress	dmnl	0/1
Normal ability to destress	dmnl/Week	0/1
Overall in the model		
All the weights in the model	dmnl	0/1

Table 7.1: Table that shows the input variables and the setup of the uncertainty space

8

Model simulation

In this section, the results from the scenario discovery analysis using PRIM are displayed. The PRIM algorithm was applied to the simulation results generated using the modeling setup described in the previous chapter. To interpret the results of the PRIM analysis performed with the EMA Workbench, several important visualizations are used. The peeling trajectory plot is first examined to explore the balance between coverage and density during the box construction. Density refers to the proportion of desirable outcomes within the box, while coverage indicates the proportion of all desirable outcomes captured by the box. An 80% density threshold was selected to ensure the identified box contained a sufficiently high concentration of the outcomes of interest. For coverage, the highest possible value that still maintained this 80% density is chosen to strike a balance between specificity and general applicability. After selecting an appropriate box, an inspection plot is reviewed to gain deeper insights into its characteristics. This plot shows the bandwidth for each constrained uncertainty, outlining both the limits of these constraints and their statistical relevance, as indicated by associated p-values. The PRIM algorithm was run with a threshold of 0.7 for Intention to stay in the profession and Job Satisfaction to find the uncertainty subspace for nurses to rate their Intention to stay in the profession or Job Satisfaction with a VAS score of 70 or higher.

8.1. Results

8.1.1. Intention to stay in the Profession

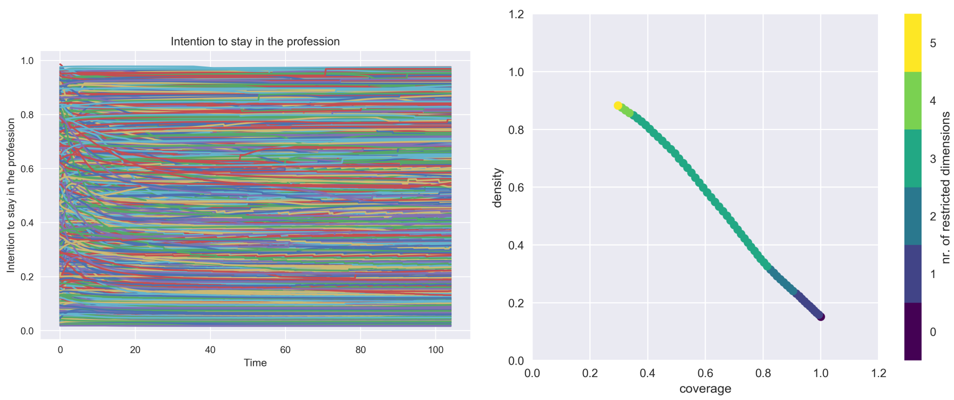


Figure 8.1: Behavior Over Time and Peeling Trajectory graphs of Intention to stay in the profession

On the left side of figure 8.1, the Behavior over Time graph is shown. Each line in the Behavior Over Time plot represents the trajectory of a single model run for the "Intention to stay in the profession" variable. With 100,000 simulations visualized, the plot appears saturated representing all the plausible variable behaviors. The model does not have a dominant trajectory for this outcome variable; we cannot distinguish any shape in the graph. This is likely due to the broad output space, where the large number of interacting variables creates many possible trajectories and outcome values.

Looking at the right Peeling Trajectory graph in figure 8.1, the trade-off between density and coverage of the data points following the PRIM algorithm is shown. From the bottom right to the top left, each dot represents a candidate box along the peeling trajectory, created by iteratively removing a small fraction of cases from the dataset to increase the density of desirable outcomes. From this graph, we can distinguish which boxes (or trade-offs) we want to display taking into account coverage and density as previously described. For further analysis, Box 20 and Box 50 are selected as representative trade-offs to illustrate the effects of prioritizing density versus coverage.

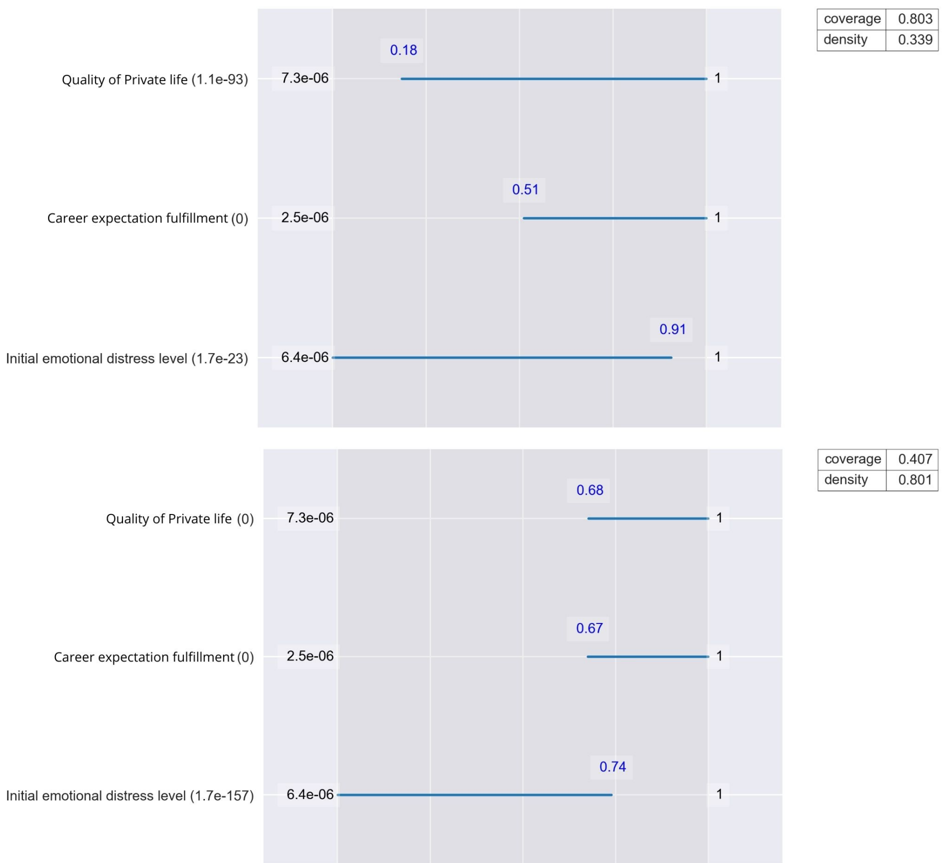


Figure 8.2: The dimensions of Box 20 and Box 50 as a result of PRIM of Intention to stay in the profession

Box 20 has a coverage of 0.803 and a density of 0.339. This indicates that 80.3% of all cases of interest are included in this box, while 33.9% of all cases within the box are relevant cases. Box 50, on the other hand, shows a coverage of 0.407 and a density of 0.801. This means 40.7% of cases of interest are included in this box, with 80.1% of all cases within the box being relevant.

Both boxes are defined by the same three dimensions. For the variable Quality of private life, the threshold in Box 20 ranges from 0.18 to 1, while in Box 50 it ranges from 0.68 to 1. The variable Career expectation fulfillment has a threshold of 0.51 to 1 in Box 20 and 0.67 to 1 in Box 50. The variable Initial emotional distress level ranges from 0.91 to 1 in Box 20 and from 0.74 in Box 50. All three variables are statistically significant for determining the output space ($p<0.05$), as shown by the numbers next to the variable name in the graph.

The more specific the box becomes towards outputs of interest, the further the thresholds and bandwidths move towards each other. For Quality of private life and Career expectation fulfillment, this means that the higher these variables are, the more likely Intention to stay in the profession is scored 70 VAS or higher. For Initial emotional distress level, it means that the threshold moves down, indicating the lower value of Initial emotional distress level is necessary for Intention to stay in the profession to be scored 70 VAS or higher by the nurses.

Box 20 captures more relevant cases overall, while Box 50 offers a more precise subset with higher relevance. We pursue Box 50 with a high density, because it captures cases of interest better, which makes it more suitable for identifying specific, high-confidence conditions associated with the outcome. A lower density means that we are most likely not talking about outcome cases of interest. Because the PRIM results for Job Satisfaction showed similar patterns in how thresholds and bandwidths narrowed with increasing density, we focus on a single box that meets the 80% density threshold. This approach avoids redundancy while still capturing the most relevant conditions for high Job Satisfaction.

We conclude by specifically looking at box 50, the box of interest. It reveals that when nurses rate their Quality of private life below 68, Career expectation fulfillment below 67, and Initial Emotional Distress above 74 (on a VAS scale), the likelihood of scoring Intention to Stay above 70 significantly reduced.

8.1.2. Job Satisfaction

The PRIM algorithm was run with a threshold of 0.7 for Job Satisfaction to find the uncertainty subspace for nurses rate their Job Satisfaction with a VAS score of 70 or higher. In figure 8.3 below, the Behavior Over Time and the trade off peeling trajectory are displayed for Job Satisfaction.

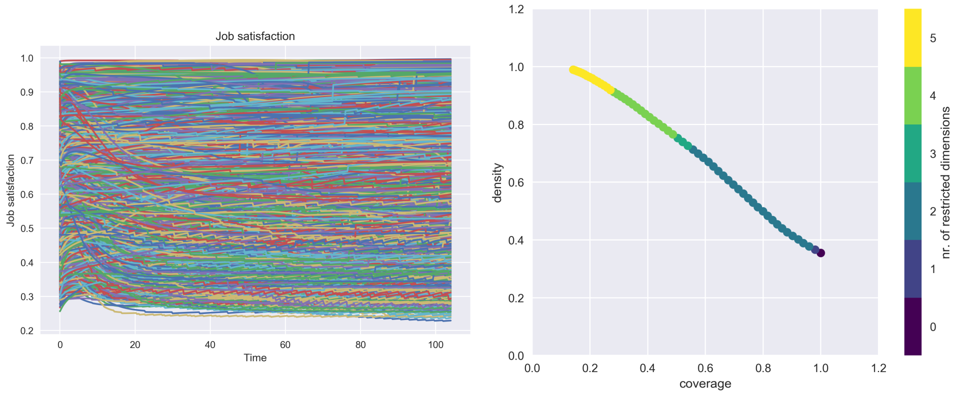


Figure 8.3: Behavior Over Time and Peeling Trajectory graphs of Job Satisfaction

Similar to the graph for Intention to stay in the Profession, the Behavior over Time graph is visually saturated with colorful lines. However, in this Behavior Over Time graph, we see some form of trajectory at the bottom of the graph. The lines at the bottom seem to wave up and over time decrease back and stabilize. However, the lines are not perfectly sorted and do not all follow this behavior. Together with the graph being visibly saturated, this indicates many different behaviors for Job Satisfaction in the quantitative model. Looking at the Peeling Trajectory graph, Box 32 was selected based on its high density (0.80), making it more suitable for identifying conditions strongly associated with higher levels of Job Satisfaction.

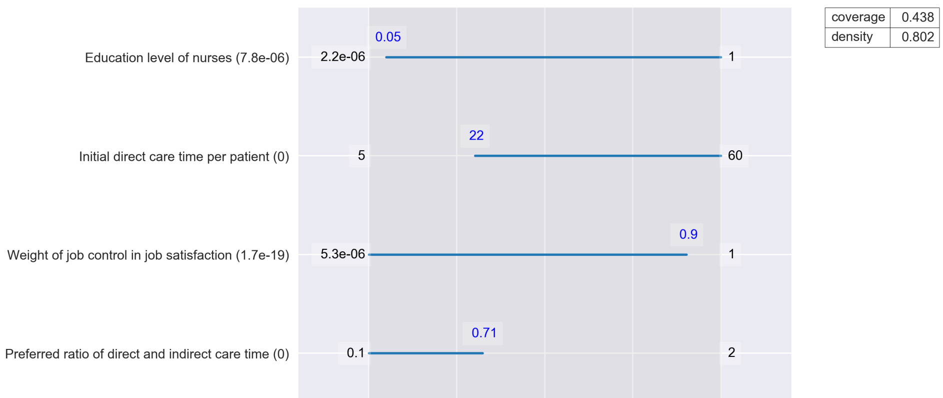


Figure 8.4: The dimensions of Box 32 as a result of PRIM for Job Satisfaction

In this box, we have caught roughly 44% of cases of interest, with the cases of interest comprising 80% of all cases in the box. There are four dimensions of this box. First, Education level of nurses is shown with a bandwidth of 0.05 to 1 VAS. Second, Initial direct care time per patient shows a bandwidth of 22 to 60 minutes per patient. Third, the Weight of job control in job satisfaction is shown with an upper threshold of 0.9. Fourth, Preferred ratio of direct care and indirect care time shows a bandwidth from 0.1 to 0.78. This means that for every minute of indirect care, a maximum of 0.71 minutes of direct care should be present. All four variables are statistically significant ($p<0.05$), shown by the values next to the variable names in the graph.

For this variable, the variables Education Level, Initial Direct Care Time per Patient, and the Preferred Ratio of Direct and Indirect Care Time played dominant roles in determining the output space. The bandwidth of Education Level spans nearly the full range, suggesting that while it is statistically significant, it does not act as a strong limiting constraint within the box. This indicates that while the variable influences the output space, it does not constrain it sufficiently to support specific policy recommendations. Notably, giving nurses at least 22 minutes of direct care time per patient and maintaining a care ratio near 0.71 (direct to indirect) were associated with higher satisfaction levels. The wide bandwidth of the 'Weight of job control in job satisfaction' variable suggests it contributes to the output space but does not act as a strong limiting constraint in this particular box.

9 Discussion

This thesis addresses the growing healthcare crisis in the Netherlands and other parts of the Western world, characterized by increasing demand for healthcare due to an aging population and a thinning healthcare workforce. Specifically, it focuses on the high turnover rate among nurses, who face burnout symptoms and challenging working conditions. We aimed to explore how a systems science approach can enhance understanding of nurses' workload and their intention to stay in the profession, focusing on the Emergency Department at Erasmus MC.

The systems science approach has allowed us to systematically create a detailed overview of the workload and stress system influencing the intention to stay in the profession of nurses. We contributed to the call for more systemic research that moves past the disease model of treating problems in healthcare. In the complexity of healthcare, it is sometimes difficult to spot the true culprits behind larger problems, such as high turnover and burnout rates. Instead of trying to "diagnose" the system quickly based on a couple of symptoms, we took a step back and took the time to analyze all relevant factors that we could identify, the interactions between them and the outcomes resulting from dynamics, all influencing intention to stay in the profession.

In our systems science approach, we included System Dynamics, Group Model Building (GMB) and Exploratory Modeling Analysis as methods. By applying Group Model Building sessions in the process of creating a System Dynamics model, we were able to find consensus on the inclusion of tacit concepts such as perceived workload, stress, team cohesion and work-life balance. The end result is a proof of concept quantitative System Dynamics model that provides a solid base for future research to expand it into a more accurate decision making tool.

In this discussion, we will first explore three key findings. First, we gained a deeper understanding of the system around intention to stay in the profession of nurses. Second, GMB turned out to be a valuable tool for participative modeling and a potential policy intervention. Third, we contributed to current research on burnout and stress by introducing team dynamics and revealing reinforcing behaviors. Next, we discuss the simulation results. After this, some other findings that are more detailed but worth mentioning are shortly discussed. Next, the policy recommendations based on the results are listed. Future research recommendations that build upon this research are proposed and we conclude the discussion by showing limitations of this study and its implications.

9.1. Key findings

9.1.1. Deeper understanding

This model aids in understanding that intention to stay in the profession is part of a complex system of variables with connections to other variables that cause complex behavior. Many studies have found causalities between variables within this system [55, 7, 25, 24, 49, 6]. Having combined all this literature into a systemic overview and reviewing it with nurses, the constructed model provides a more in-depth understanding on how factors are related within this system and where the causalities found in literature might originate from in the system around intention to stay in the profession.

For example, Sasso et al. [55] analyzed push and pull factors regarding intention to leave for nurses in Italy, where they found good relationships with staff, leadership, participation in hospital affairs, personal accomplishment and job satisfaction to be significant pull factors. Our research went one step further to explore these pull factors. For instance, we showed that good relationships with staff, in the model conceptualized as Team Cohesion, has multiple reinforcing interactions within the system. It influences moral distress by experiencing more affirmation for decisions; it influences depersonalization by experiencing less workplace adversity; it helps regulate emotional distress to have a space to ventilate, which in turn improves team cohesion between the nurses. Here, we show multiple points of influence for the pull factor 'good relationships with staff', contributing to previous research by showing the relationships that likely cause the causality found in Sasso et al. [55].

A similar example is how supportive leadership buffers moral distress, a conclusion from De Veer et al. [25]. In our model, supportive leadership has a direct and indirect buffering effect on moral distress. It increases affirmation for decisions directly, by providing a supportive base for the nurse to take their own decisions and support when mistakes are made. However, through team dynamics, a supportive leadership style can also contribute to the amount of consultation opportunities within the team. Supportive leadership style is assumed to increase team cohesion and team psychological safety by providing a safe social environment and space for healthy connection with colleagues, which both increase the number of consultation opportunities within the team by allowing for feeling safe to ask questions and spontaneous consultations and interruptions.

These nuances are important if you want to implement policies to change the outcome of variables within the system. Following the example of supportive leadership, you might want to influence leadership within the organization to achieve less moral distress experienced by nurses. By training managers and leaders within the organization to be supportive, there are multiple pathways to decrease the experienced moral distress. The other way around is also possible. While you might expect moral distress to decrease after implementing this policy option, other variables influencing team cohesion might hamper the outcomes. Therefore, by gaining an in-depth understanding of the connections and dynamics between variables, we have increased the knowledge on how stress and team dynamics influence nurses' intention to stay in the profession, creating a stronger knowledge base for policy interventions on intention to stay in the profession of nurses.

9.1.2. Group Model Buildings sessions

The Group Model Buildings sessions turned out to be a valuable tool for gathering tacit knowledge in a participative. It is particularly suitable due to its relatively low demands on time and resources, which are often scarce in healthcare settings. Nurses also showed to quickly adapt to a more systemic way of thinking about their own experience when set up in the right environment. This environment consisted of a room at the Emergency Department they are familiar with, judgment-free conversation space and no prior preparing tasks. Moreover, nurses were capable of interpreting the figures of the simulation results after a brief introduction to the point of reflecting on the numbers displayed. When adequately prepared, the methods employed in systems science pose no barrier to application in settings where participants lack prior familiarity, such as healthcare.

Consistent with our assumption of subjective workload being more important than objective workload, the nurses emphasized concepts such as shift experience, work-life balance and emotional distress as the leading factors in the intention to stay in the profession in the GMB sessions. This suggests that the key to keeping nurses in the profession is not a result of an accurate distribution of patients, higher salary or a reduction of administrative tasks, but rather in enhancing the overall experience of shifts and making sure work balances well with personal life.

9.1.3. Reinforcing behaviors

While previous work by Maslach, Schaufeli, and Leiter [56] and models made by Homer [29], Veldhuis et al. [57] and Barsties et al. [60] alluded to feedback loops in stress and burnout, our findings extend this understanding by showing their predominantly reinforcing nature when including team dynamics, highlighting a critical vulnerability in the system that had not been quantified to this extent. This indicates that the system, left unattended, may spiral into states of high stress and burnout without self-correcting tendencies. As such, interventions should not rely on the system regulating itself over time. However, the reinforcing nature also provides opportunities. When policy interventions target those variables that have multiple reinforcing feedback loops through the system, outcomes might become favorable more quickly. Therefore, the focus should be to aim to actively disrupt negative reinforcing cycles or utilize the reinforcing nature for policy design. Recognizing this structural tendency emphasizes the importance of proactive, systemic policy design. Finding out the strength of these reinforcing feedback loops allows for more insight into the system and requires further analysis.

However, the notion of a negatively spiraling system requires nuance. Nurses indicated in the Group Model Buildings sessions that they tend to just work with the stress that they get and do not allow the system to spiral as far on behalf of the safety of patients. A similar notion was found by Applebaum et al. [23] regarding nurses overlooking their physical environment and just ”do their job”. This has implications for policy interventions. If a situation is deemed negative within an organization, it is important to find out whether the nurses are already on the bottom of the spiral and upholding the whole system, or that they are still moving back and forward on the spiral. This is in line with finding the variable Initial Emotional Distress Level as a dimension of the output space for Job Satisfaction in the next section.

9.2. Simulation results

The PRIM analysis identified key uncertainty dimensions associated with nurses' high level of Intention to stay in the profession and Job satisfaction, both defined as VAS scores ≥70. For Intention to stay in the profession, outcomes were more likely to be favorable when nurses rated their Quality of private life and Career expectation fulfillment highly (VAS ≥ 68 and ≥ 67, respectively), while keeping Initial emotional distress low (VAS ≤ 74). For Job satisfaction, positive outcomes were linked to providing at least 22 minutes of direct care per patient, maintaining a preferred ratio of direct to indirect care time below 0.71, and the moderate influence of Education Level and Job Control. These results emphasize the importance of supportive personal circumstances and a well-balanced work environment in fostering sustained engagement and satisfaction among nurses.

The findings on Intention to stay in the profession allow for several conclusions. First, aspects influencing nurses' intention to stay —such as Quality of private life — lie partly outside the scope of direct policy intervention. While there are options to improve nurses' personal life by implementing policies that promote personal well-being, some parts of the quality of private life cannot be influenced. When nurses face difficulties or major changes in their personal lives, their likelihood of leaving the profession increases, beyond the control of organizational policies. Second, unmet career expectations appear to play a substantial role and represent a key area for targeted interventions, which we address later in this discussion. Third, a high level of Initial emotional distress significantly reduces intention to stay. This suggests that any intervention aiming to improve intention to stay should first address emotional distress, as other efforts may have limited impact if this underlying factor remains unaddressed.

The findings on Job satisfaction lead to two key conclusions. First, they indicate that nurses do not inherently object to indirect care tasks; rather, their satisfaction depends on maintaining a meaningful balance between direct and indirect care. This highlights the importance of considering workload composition, not just volume. Second, although Education Level exhibited a wide range within the data, it still influenced model outcomes, suggesting it plays a non-trivial role in shaping nurses' job satisfaction. With more precise data and improved model calibration, future studies may be able to identify specific educational thresholds that enhance intention to stay prospects.

The numerical thresholds found in this analysis should not be interpreted as fixed or prescriptive values. Due to limited access to comprehensive and larger volumes of input data, many parameter settings were based on informed assumptions and interpretations. On top of that, the PRIM results are influenced by the shape of the lookup functions in the model (simpler quantification of complex relationships between variables), which introduces additional uncertainty. So while the patterns and relationships we observed are meaningful, interpretation should be treated with caution due to the remaining high uncertainty. If this model is to be used for decision support in practice, the lookup functions and data inputs would need to be revisited and refined. Suggestions for how to approach this are included in the research recommendations later in the discussion.

9.3. Other findings

After considering these key findings, there are a few findings that, while not central to the core argument, are briefly worth noting due to their relevance in shaping the perception of workload of nurses. The first three are based on the literature review and the GMB sessions, while the last finding was a result of the quantification process of the conceptual model.

9.3.1. Eustress on the distress continuum

Eustress emerged as a protective buffer to distress- a concept often missing in existing research of burnout in nurses [4, 5, 6, 7, 8]. This eustress is a result of both individual characteristics and the team dynamics that are influenced by the nurses' stress and workload experience, which results in job satisfaction and intention to stay through several dynamic paths in the model.

Diving deeper into burnout research, we conclude that this continuum of eustress to distress can contribute to existing research on burnout of nurses. While Maslach, Schaufeli, and Leiter [56] defines engagement as the conceptual antithesis to burnout, she emphasizes that these are not mere opposites on a single continuum, but more interrelated. Building on this, our findings suggest that eustress may serve as an additional buffer to burnout, or at least to the stress that causes the burnout. This positions stress perception (eustress vs. distress) as a distinct but interacting continuum that influences both burnout and engagement. Particularly in emotionally demanding fields like nursing, individuals may simultaneously experience distress and engagement due to moral obligation, which may mask emerging burnout. Framing eustress as a buffer offers a more nuanced model of workplace well-being in a healthcare setting.

9.3.2. Shift balance as perceived workload

During the GMB sessions, a shift balance emerged as the perception of workload for nurses: a balance between positively and negatively experienced shifts. A form of mental accounting occurred when they talked to each other about how they perceive their workload. The main message was that perceived negative shifts will always be part of the job, but as long as the perceived positive shifts outweigh them, the overall perception of the job stays positive. This is adapted into the model.

Shift working has been identified as a stressor for nurses for a long time now [30]. Looking into more recent research that relates shift working to job satisfaction, we find that nurses report more job dissatisfaction when they work night shifts [79] and work 12h shifts compared to 8h shifts [80]. However, the result of either a night shift or a long shift is not mentioned in any research [81]: a higher potential for a negatively experienced shift. This research contributes to the existing research on job satisfaction by implying that the negative relationship of shift working with job satisfaction is a result of a negative perception of that shift, which is more nuanced than simply saying that shift working is bad.

9.3.3. Four types of stress

Following the literature review, we identified four types of stress for nurses: emotional, moral & physical distress, and eustress. During the GMB sessions, the nurses explicitly mentioned physical stress not being as much of a stressor as it might be for other nurses. Physical distress appears to be largely dependent on the context the nurses operate in. It depends on the type of care, the type of patients and the amount of support staff for physically demanding activities. In this model, we chose to change physical distress to psychosomatic complaints to display sustaining mental distress that results in physical complaints. However, physical distress might be a relevant stressor for nurses in different contexts, which should be considered in future research and the application of the model for policy making.

9.3.4. VAS scale as suitable metric for tacit concepts

We identified the Visual Analog Scale (VAS) as a suitable unit measurement in the quantitative model for tacit concepts such as intention to stay in the profession, emotional distress, team cohesion and work-life balance. Nurses are acquainted with this scale since it used for triage and evaluation. Therefore, it contributed to the understanding of the model by the nurses. It also lays a solid ground for expansion of the quantitative model with future research, which can then use the VAS scale to gather comprehensive data on the concepts from the quantitative model.

9.4. Recommendations

In the current phase of research, the model remains with uncertainties. Still, the model was fit for the purpose of this research: exploring the dynamics around nurses' perceived workload, stress, and their intention to stay in the profession. The simulation method supports this well, and PRIM is specifically designed for scenario discovery under deep uncertainty. That means it's not about producing precise predictions, but about exploring plausible ranges and uncovering structural patterns. This fits with the exploratory nature of the thesis, even though it limits the model's forecasting ability. What it does offer is a way to see how key variables behave across different parts of the parameter space—helpful for identifying trends and system-level effects. In that sense, the model is fit for purpose and can serve as a proof-of-concept that future studies can build on with richer data to improve both prediction and policy relevance. The model already highlights several potential policy levers, which will be addressed in the subsequent policy recommendations.

9.4.1. Policy recommendations

Based on the findings from both the conceptual and qualitative models, several key policy recommendations emerge that can support nurse well-being and keeping them in the profession.

Either break or utilize reinforcing feedback loops. The predominantly reinforcing feedback loops identified in the conceptual model suggest that, without intervention, the system may drift toward undesirable outcomes. The reinforcing nature also allows identifying areas within the system that can be target by policy interventions that can steer the whole system to accelerated favorable outcomes. Actively disrupting these cycles and using these reinforcing forces to advantage is therefore essential to prevent downward spirals and stabilize the system.

Facilitate open conversations about stress and perceived workload. The GMB sessions revealed the value of creating a safe, low-threshold space for nurses to reflect on and discuss workload and stress. Similar sessions - facilitated by an external, neutral moderator - should be implemented periodically. The emphasis should be on open dialogue about what adds to workload and causes stress, with no administrative burden or preparatory tasks for nurses, to ensure psychological safety and enthusiastic engagement.

Ensure clarity on career path and good career expectations management. Clear communication about career development opportunities and realistic job expectations is crucial for long-term nurses' intention to stay. The model showed that unmet career expectations significantly reduce the intention to stay. Policymakers and hospital managers should ensure that nurses understand potential growth paths early in their employment and that these expectations are aligned with actual possibilities. This helps prevent disappointment.

Align care task ratio with nurse preferences. The simulation results suggest that nurses are not inherently averse to indirect care tasks, but they value a balanced ratio between direct and indirect care. Policymakers should regularly review the actual vs. preferred ratio of direct to indirect care time and adjust staffing, task distribution, patient flow and support resources accordingly to maintain a perceived balance in workload.

Assess starting point of emotional distress before interventions. Initial emotional stress levels significantly influenced simulation outcomes of nurses' intention to stay in the profession. Before implementing new interventions or policy changes, it is advisable to assess the current emotional stress state of the nursing team. A high starting point of stress can alter how interventions are experienced and may lead to unintended negative effects, even if the intervention itself is well-designed.

Encourage and reinforce eustress. Eustress can help protect nurses from burnout and leaving the profession. Policymakers should actively explore what kinds of situations or tasks lead to eustress for nurses. This could include moment of effective teamwork, successful patient outcomes, or good connection between colleagues. By identifying and reinforcing these experiences, healthcare organizations can help make stress more manageable and even motivating.

9.4.2. Future research recommendations

Enrich the model input with surveys using Visual Analog Scale (VAS). To move toward a more data-driven and decision-support-ready model, surveys can play a crucial role in calibrating and validating input assumptions. Three examples of these surveys are outlined. First, they can help estimate the weights of variables—for example, through stated choice experiments that explore which types of shifts nurses prefer under varying conditions. Second, surveys can be used to collect baseline values for key input variables in the quantitative model, such as current levels of emotional and moral distress or nurses' perception of education levels. Third, nurses can be asked to draw or select the shapes of relationships between variables, helping to validate or revise the lookup functions used in the model. This participatory approach could identify common thresholds and consensus-based dynamics, strengthening the model's empirical grounding.

Include hierarchical and interdisciplinary dynamics. The current model focused on nurses at the team level, omitting detailed interactions with physicians, managers, and other staff. However, research such as Fiabane et al. [6] shows that hierarchical status and professional role significantly shape stressors, engagement, and job satisfaction. Future models should explicitly account for these cross-professional dynamics, especially in academic hospital environments where role complexity and power asymmetries might be more present [46].

Explore team composition and nurse profiles. Variations in experience level, tenure, and employment type (e.g., part-time vs. full-time) can critically shape resilience and coping strategies [38, 9, 25, 32]. These distinctions were also emphasized in the GMB sessions. Incorporating these differences into future models will help uncover more precise leverage points for intervention.

Conduct uncertainty analysis on lookups. The results of PRIM and simulation analysis are heavily shaped by the lookup functions used. A structured uncertainty and sensitivity analysis on these lookups, using Eker et al. [82] as inspiration, would clarify which relationships are most sensitive to behavioral change in the model and improve the ability to interpret the model's output under deep uncertainty.

9.5. Limitations

The research focused on a single use case to gain an in-depth understanding of the contextual factors influencing nurses' intention to stay, and the system of variables affecting this outcome. This focus limits the generalizability of the findings to other nursing work environments including other emergency departments. While certain dynamics are expected to be present in these contexts, this research does not provide a sufficient basis for drawing definitive conclusions whether or not this is the case. Therefore, the results should be viewed primarily as a reflective starting point and ground work for future research on stress and perceived workload in other nursing departments.

Another limitation of this approach is that the results from the conceptual and quantitative models are partially tautological. Many of the variables that turned out to be influential in the simulation were modeled that way in the first place, based on their perceived relevance from the conceptual model and GMB sessions. That they reappear as dominant in the simulation output can be seen as a form of circular validation—expected inputs producing expected outputs. While this does confirm internal consistency, it limits the model's ability to generate unexpected findings or new insights under the current input conditions. This effect is inherent on using known factors from previous research into the model. By validating the conceptual model and using a participative model building approach, we aimed to mitigate this limitation. Future research could further strengthen the model's empirical grounding by applying bottom-up approaches such as grounded theory methodology, enabling the identification of emergent variables and relationships based on real-world observations rather than prior assumptions, for a stronger validation.

Additionally, some variables in the conceptual model are based on research at the individual nurse level. The relationships and dynamics between these variables may be more complex than currently conceptualized. To address this, we aimed to aggregate these variables through consensus during the GMB sessions.

The influence of the modeler during the GMB sessions was particularly pronounced in the first session, where guidance and facilitation were necessary to maintain the flow of the conversation. To mitigate potential bias, a second reviewer was present to observe and assess the extent of the modeler's influence. In both sessions, the consensus was that the modeler's involvement did not become excessive or overly directive.

10 Conclusion

This thesis aimed to answer the central research question: “How can a systems science approach contribute to the understanding of nurses’ workload and their intention to stay in the profession in the Emergency Department at Erasmus MC?” Through a combination of literature review, Group Model Building (GMB), System Dynamics (SD) modeling, and scenario exploration, the research makes both practical and academic contributions.

Methodologically, this thesis demonstrates the value of applying a systems science approach to complex, human-centered problems in healthcare. By incorporating the voices of nurses through GMB and grounding the modeling in real-world dynamics, the research developed an in-depth understanding of the system and its feedback mechanisms.

This thesis deepens our understanding of how intention to stay in the nursing profession emerges from a complex, interconnected system of variables. The research shows that factors such as team cohesion and supportive leadership have reinforcing effects across emotional, moral, and organizational dimensions of stress, ultimately shaping perceived workload and job satisfaction. GMB sessions revealed that nurses emphasize subjective workload—such as emotional distress, shift experience, and work-life balance—over objective metrics like task distribution. These insights were supported by both the literature and the models co-developed during the participatory sessions.

A key contribution is the development of a dynamic model that captures feedback loops and systemic drivers of stress and professional sustainability among nurses. The system is characterized by strong reinforcing dynamics, which means that both positive and negative developments can self-reinforce over time. While this makes the system vulnerable to downward spirals of burnout, it also presents opportunities for targeted interventions to foster upward, self-sustaining improvements. The model shows that positive team dynamics and eustress can help trigger cycles that promote job satisfaction and intentions to stay, whereas negative stress can reinforce patterns leading to absenteeism and reduced team stability.

Using scenario discovery, the model identified specific conditions under which intention to stay met a meaningful threshold. Scenarios that emphasized strong work-life balance, fulfilled career expectations, and emotional distress support showed more robust long-term effects than those focusing solely on reducing patient numbers or task demand. This highlights the importance of understanding the interaction between systemic structures and the lived experiences of frontline staff.

In summary, the policy recommendations emphasize the importance of addressing nurse well-being through multifaceted and system-aware interventions. Rather than relying on single-lever solutions, effective policies should target multiple interacting factors, disrupt harmful reinforcing cycles, and cultivate positive stress experiences. Open communication, realistic career expectations, balanced task distribution, and sensitivity to nurses’ emotional starting points are all critical to designing interventions that support retention and resilience in the nursing profession.

In terms of future work, the model can be expanded to other hospital departments or enriched with more granular data from surveys or stated choice experiments. When combined with other modeling methods, this framework has the potential to become a policy decision-making support tool that helps healthcare organizations address nurse staffing shortages more effectively.

In conclusion, this thesis contributes new knowledge by combining system dynamics with participatory modeling to better understand the complex factors behind nurses' perceived workload and their intention to stay in the profession. The aim was to support efforts in addressing the growing issue of staff shortages in Dutch healthcare, and to contribute to the development of a sector that is not only more effective and safer, but also more enjoyable to work in. With this research, we are one step closer in the triage of the problems in the Dutch healthcare sector.

References

[1] Rijksinstituut voor Volksgezondheid en Milieu. *De vergrijzing heeft grote impact op de volksgezondheid en zorg - VTV 2018: Een gezond vooruitzicht*. Apr. 2018. URL: https://www.vtv2018.nl/impact-van-de-vergrijzing#:~:text=Door%20de%20vergrijzing%20zal%20de,de%20informele%20zorg%20(mantelzorg).

[2] James Buchan and Linda Aiken. "Solving nursing shortages: A common priority". In: *Journal of Clinical Nursing* 17.24 (Dec. 2008), pp. 3262–3268. ISSN: 09621067. DOI: 10.1111/j.1365-2702.2008.02636.x.

[3] Mirela Cristea et al. "The impact of population aging and public health support on EU labor markets". In: *International Journal of Environmental Research and Public Health* 17.4 (Feb. 2020). ISSN: 16604601. DOI: 10.3390/ijerph17041439.

[4] Arnold B. Bakker et al. "Effort-reward imbalance and burnout among nurses". In: *Journal of Advanced Nursing* 31.4 (2000), pp. 884–891. ISSN: 03092402. DOI: 10.1046/j.1365-2648.2000.01361.x.

[5] Céleste M. Brotheridge and Alicia A. Grandey. "Emotional labor and burnout: Comparing two perspectives of "people work"". In: *Journal of Vocational Behavior* 60.1 (2002), pp. 17–39. ISSN: 00018791. DOI: 10.1006/jvbe.2001.1815.

[6] Elena Fiabane et al. "Work engagement and occupational stress in nurses and other healthcare workers: The role of organisational and personal factors". In: *Journal of Clinical Nursing* 22.17-18 (Sept. 2013), pp. 2614–2624. ISSN: 09621067. DOI: 10.1111/jocn.12084.

[7] Tanya I. Gelsema et al. "A longitudinal study of job stress in the nursing profession: Causes and consequences". In: *Journal of Nursing Management* 14.4 (May 2006), pp. 289–299. ISSN: 09660429. DOI: 10.1111/j.1365-2934.2006.00635.x.

[8] Daniel S. Tawfik et al. *Evidence relating health care provider burnout and quality of care a systematic review and meta-analysis*. Oct. 2019. DOI: 10.7326/M19-1152.

[9] Laureen J. Hayes et al. *Nurse turnover: A literature review - An update*. July 2012. DOI: 10.1016/j.ijnurstu.2011.10.001.

[10] Geneviève Jourdain and Denis Chênevert. "Job demands-resources, burnout and intention to leave the nursing profession: A questionnaire survey". In: *International Journal of Nursing Studies* 47.6 (June 2010), pp. 709–722. ISSN: 00207489. DOI: 10.1016/j.ijnurstu.2009.11.007.

[11] Yvette de Vries and Vera Vrijmoeth. *Rondkomen in de VVT - Onderzoek naar de inkomenspositie, werkdruk en werk-privé balans van werknemers in de ouderenzorg*. Tech. rep. FNV, June 2023.

[12] Rijksoverheid. *Forse bezuiniging ouderenzorg van de baan, streekziekenhuizen open houden en geen bezuiniging op sport*. Sept. 2024. URL: https://www.rijksoverheid.nl/actueel/nieuws/2024/09/17/forse-bezuiniging-ouderenzorg-van-de-baan-streekziekenhuizen-open-houden-en-geen-bezuiniging-op-sport.

[13] Rob Aalbers and Anne-Fleur Roos. *Zorguitgaven, ons een zorg?* Tech. rep. CPB, Oct. 2022.

[14] Britt Wagenaar. *Transfer care system performance in relation to resource scarcity -Implications for sustainability of the healthcare system performance*. Tech. rep. Delft University of Technology, Oct. 2023.

[15] Qian Liu et al. "The experiences of health-care providers during the COVID-19 crisis in China: a qualitative study". In: *The Lancet Global Health* 8.6 (June 2020), e790–e798. ISSN: 2214109X. DOI: 10.1016/S2214-109X(20)30204-7.

[16] Patricia Potter et al. "Understanding the Cognitive Work of Nursing in the Acute Care Environment". In: *JONA Journal of Nursing Administration* 35.7/8 (July 2005), pp. 327–335. URL: http://journals.lww.com/jonajournal.

[17] Murat M. Gunal. “A guide for building hospital simulation models”. In: *Health Systems* 1.1 (June 2012), pp. 17–25. ISSN: 20476973. DOI: 10.1057/hs.2012.8.

[18] Arif Jetha, Laura Kernan, and Alicia Kurowski. “Conceptualizing the dynamics of workplace stress: A systems-based study of nursing aides”. In: *BMC Health Services Research* 17.1 (Jan. 2017). ISSN: 14726963. DOI: 10.1186/s12913-016-1955-8.

[19] Anita L. Tucker and Steven J. Spear. “Operational failures and interruptions in hospital nursing”. In: *Health Services Research* 41.3 I (June 2006), pp. 643–662. ISSN: 00179124. DOI: 10.1111/j.1475-6773.2006.00502.x.

[20] Valda V. Upenieks et al. *Assessing nursing staffing ratios: Variability in workload intensity*. Feb. 2007. DOI: 10.1177/1527154407300999.

[21] Sibylle Fischbacher et al. “A prospective longitudinal cohort study of the association between nurses’ subjective and objective workload”. In: *Scientific reports* 14.1 (Dec. 2024), p. 22694. ISSN: 20452322. DOI: 10.1038/s41598-024-73637-9.

[22] M. E. Hoogendoorn et al. “The objective nursing workload and perceived nursing workload in Intensive Care Units: Analysis of association”. In: *International Journal of Nursing Studies* 114 (Feb. 2021). ISSN: 00207489. DOI: 10.1016/j.ijnurstu.2020.103852.

[23] Diane Applebaum et al. “The Impact of Environmental Factors on Nursing Stress, Job Satisfaction, and Turnover Intention”. In: *Journal of Nursing Administration* 40.7-8 (2010), pp. 323–328. ISSN: 15390721. DOI: 10.1097/NNA.0b013e3181e9393b.

[24] Peter P.M. Janssen, Jan De Jonge, and Arnold B. Bakker. “Specific determinants of intrinsic work motivation, burnout and turnover intentions: A study among nurses”. In: *Journal of Advanced Nursing* 29.6 (June 1999), pp. 1360–1369. ISSN: 03092402. DOI: 10.1046/j.1365-2648.1999.01022.x.

[25] Anke J.E. De Veer et al. “Determinants of moral distress in daily nursing practice: A cross sectional correlational questionnaire survey”. In: *International Journal of Nursing Studies* 50.1 (2013), pp. 100–108. ISSN: 00207489. DOI: 10.1016/j.ijnurstu.2012.08.017.

[26] David L B Schwappach and Till A Boluarte. “The emotional impact of medical error involvement on physicians: a call for leadership and organisational accountability”. In: *Swiss Medical Weekly* 138.1-2 (2008), pp. 9–15. DOI: 10.5167/uzh-9997. URL: www.zora.uzh.chYear:2008URL:https://doi.org/10.5167/uzh-9997.

[27] Arnold B. Bakker and Juriena D. de Vries. “Job Demands–Resources theory and self-regulation: new explanations and remedies for job burnout”. In: *Anxiety, Stress and Coping* 34.1 (2021), pp. 1–21. ISSN: 14772205. DOI: 10.1080/10615806.2020.1797695.

[28] Melanie Bouwknegt. *Whitepaper burn-out: Meer dan een individueel probleem*. Tech. rep. Nederlands Instituut van Psychologen, June 2020. URL: https://nieuws.kuleuven.be/nl/2019/een-op-de-zes-werkende-vlamingen-kampt-met-burn-outklachten-of-loopt-er-risico-op.

[29] Jack B Homer. “Worker burnout: a dynamic model with implications for prevention and control”. In: *System Dynamics Review* 1 (1985), pp. 42–62. ISSN: 0883-7066.

[30] Andrew McVicar. *Workplace stress in nursing: A literature review*. Dec. 2003. DOI: 10.1046/j.0309-2402.2003.02853.x.

[31] Evelien H. van Leeuwen et al. “Burn-out and employability rates are impacted by the level of job autonomy and workload among Dutch gastroenterologists”. In: *United European Gastroenterology Journal* 10.3 (Apr. 2022), pp. 296–307. ISSN: 20506414. DOI: 10.1002/ueg2.12211.

[32] Annet H. De Lange et al. “An open time perspective and social support to sustain in healthcare work: Results of a two-wave complete panel study”. In: *Frontiers in Psychology* 11 (June 2020), pp. 1–15. ISSN: 16641078. DOI: 10.3389/fpsyg.2020.01308.

[33] Bram P.I. Fleuren et al. “Unshrouding the sphere from the clouds: Towards a comprehensive conceptual framework for sustainable employability”. In: *Sustainability (Switzerland)* 12.16 (Aug. 2020). ISSN: 20711050. DOI: 10.3390/SU12166366.

[34] Iris van de Voort et al. “What’s up doc? Physicians’ reflections on their sustainable employability throughout careers: a narrative inquiry”. In: *BMC Health Services Research* 24.1 (Dec. 2024). ISSN: 14726963. DOI: 10.1186/s12913-024-10924-1.

[35] Debra Jackson, Angela Firtko, and Michel Edenborough. “Personal resilience as a strategy for surviving and thriving in the face of workplace adversity: A literature review”. In: *Journal of Advanced Nursing* 60.1 (Oct. 2007), pp. 1–9. ISSN: 03092402. DOI: 10.1111/j.1365-2648.2007.04412.x.

[36] Fiona Yu et al. *Personal and work-related factors associated with nurse resilience: A systematic review*. May 2019. DOI: 10.1016/j.ijnurstu.2019.02.014.

[37] Mohammed G. Alghamdi. “Nursing workload: A concept analysis”. In: *Journal of Nursing Management* 24.4 (May 2016), pp. 449–457. ISSN: 13652834. DOI: 10.1111/jonm.12354.

[38] Dries Myny et al. “Determining a set of measurable and relevant factors affecting nursing workload in the acute care hospital setting: A cross-sectional study”. In: *International Journal of Nursing Studies* 49.4 (Apr. 2012), pp. 427–436. ISSN: 00207489. DOI: 10.1016/j.ijnurstu.2011.10.005.

[39] Pauline A. Swiger, David E. Vance, and Patricia A. Patrician. “Nursing workload in the acute-care setting: A concept analysis of nursing workload”. In: *Nursing Outlook* 64.3 (May 2016), pp. 244–254. ISSN: 00296554. DOI: 10.1016/j.outlook.2016.01.003.

[40] William E. Bynum, Lara Varpio, and Pim Teunissen. “Why impaired wellness may be inevitable in medicine, and why that may not be a bad thing”. In: *Medical Education* 55.1 (Jan. 2021), pp. 16–22. ISSN: 13652923. DOI: 10.1111/medu.14284.

[41] Robert Crouch and Susan Williams. “Patient dependency in the emergency department (ED): Reliability and validity of the Jones Dependency Tool (JDT)”. In: *Accident and Emergency Nursing* 14.4 (Oct. 2006), pp. 219–229. ISSN: 09652302. DOI: 10.1016/j.aaen.2006.06.005.

[42] Alison O’Brien and Jonathan Benger. “Patient dependency in emergency care: Do we have the nurses we need?” In: *Journal of Clinical Nursing* 16.11 (Nov. 2007), pp. 2081–2087. ISSN: 09621067. DOI: 10.1111/j.1365-2702.2006.01602.x.

[43] Pieternel Oden and Jeroen Leus. *De verpleegkundige werklast op de spoedeisende hulp*. Tech. rep. Enschede: Universiteit Twente, Gezondheidswetenschappen, July 2017.

[44] Wayne Varndell et al. “Measuring patient dependency-performance of the Jones dependency tool in an Australian emergency department”. In: *Australasian Emergency Nursing Journal* 16.2 (May 2013), pp. 64–72. ISSN: 15746267. DOI: 10.1016/j.aenj.2013.04.001.

[45] Robert Karasek. “Demand/control model: A social, emotional, and physiological approach to stress risk and active behaviour development”. In: *Encyclopaedia of occupational health and safety* (1998).

[46] Steluta Iordache et al. “Development and validation of an assessment tool for nursing workload in emergency departments”. In: *Journal of Clinical Nursing* 29.5-6 (Mar. 2020), pp. 794–809. ISSN: 13652702. DOI: 10.1111/jocn.15106.

[47] Mashal Farid, Nancy Purdy, and W. Patrick Neumann. “Using system dynamics modelling to show the effect of nurse workload on nurses’ health and quality of care”. In: *Ergonomics* 63.8 (Aug. 2020), pp. 952–964. ISSN: 13665847. DOI: 10.1080/00140139.2019.1690674.

[48] Roisin Morris et al. *Reconsidering the conceptualization of nursing workload: Literature review*. Mar. 2007. DOI: 10.1111/j.1365-2648.2006.04134.x.

[49] Dries Myny et al. “Non-direct patient care factors influencing nursing workload: a review of the literature Non-direct patient care factors influencing nursing work-load: a review of the literature”. In: *Journal of Advanced Nursing* 67.10 (2011), pp. 2109–2129. DOI: 10.1111/j.1365-2648.2011.05689.x. URL: https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2648.2011.05689.x.

[50] Landelijk Netwerk Acute Zorg. *Criteria voor levelindeling ziekenhuizen*. URL: https://www.lnaz.nl/trauma/levelcriteria.

[51] Frits Baltesen. *Half zoveel doden in level1-traumacentra dan in level2- en level3-ziekenhuizen*. Dec. 2022. URL: https://www.skipr.nl/nieuws/dubbel-zoveel-doden-in-regioziekenhuis-dan-in-traumacentrum/#:~:text=De%20level1%2Dtraumacentra%20zijn%3A%20Amsterdam,240%20pati%C3%ABnten%20per%20jaar%20behandelen..

[52] Maarten van Poll. *Het Financieele Dagblad: 'We hebben meer generalistische dokters nodig'*. Oct. 2024. URL: (https://www.sboh.nl/nieuws/te-weinig-artsen-aan-de-slag-buiten-het-iekenhuis/#:~:text=Nederland%20kampt%20met%20een%20tekort,60%25%20voor%20sociaal%20geneeskundigen%20onbezet.).

[53] Paul A Landsbergis. *Occupational Stress Among Health Care Workers: A Test of the Job Demands – Control Model*. Tech. rep. 3. 1988: Journal of Organizational Behaviour, July 1988, pp. 217–239. DOI: 10.1002/job.4030090303. URL: https://www.jstor.org/stable/2488075.

[54] Jin Jun et al. *Relationship between nurse burnout, patient and organizational outcomes: Systematic review*. July 2021. DOI: 10.1016/j.ijnurstu.2021.103933.

[55] Loredana Sasso et al. "Push and pull factors of nurses' intention to leave". In: *Journal of Nursing Management* 27.5 (July 2019), pp. 946–954. ISSN: 13652834. DOI: 10.1111/jonm.12745.

[56] Christina Maslach, Wilmar B Schaufeli, and Michael P Leiter. "JOB BURNOUT". In: *Annual Review of Psychology* 52 (2001), pp. 397–422. DOI: https://doi-org.tudelft.idm.oclc.org/10.1146/annurev.psych.52.1.397. URL: www.annualreviews.org..

[57] Guido A. Veldhuis et al. "A proof-of-concept system dynamics simulation model of the development of burnout and recovery using retrospective case data". In: *International Journal of Environmental Research and Public Health* 17.16 (Aug. 2020), pp. 1–28. ISSN: 16604601. DOI: 10.3390/ijerph17165964.

[58] Mohammad Reza Davahli, Waldemar Karwowski, and Redha Taiar. *A system dynamics simulation applied to healthcare: A systematic review*. Aug. 2020. DOI: 10.3390/ijerph17165741.

[59] David C. Lane. "The emergence and use of diagramming in system dynamics: A critical account". In: *Systems Research and Behavioral Science* 25.1 (Jan. 2008), pp. 3–23. ISSN: 10927026. DOI: 10.1002/sres.826.

[60] Lisa S. Barsties et al. "A system science perspective on burn-out: development of an expert-based causal loop diagram". In: *Frontiers in Public Health* 11 (2023). ISSN: 22962565. DOI: 10.3389/fpubh.2023.1271591.

[61] D C Lane, C Monefeldt, and J V Rosenhead. *Looking in the wrong place for healthcare improvements: A system dynamics study of an accident and emergency department*. Tech. rep. 2000, pp. 518–531. URL: www.stockton-press.co.uk/jors.

[62] Irene M.W. Niks et al. "Individual Workplace Well-Being Captured into a Literature- and Stakeholders-Based Causal Loop Diagram". In: *International Journal of Environmental Research and Public Health* 19.15 (Aug. 2022). ISSN: 16604601. DOI: 10.3390/ijerph19158925.

[63] Ambrose H. Wong et al. "A qualitative system dynamics model for effects of workplace violence and clinician burnout on agitation management in the emergency department". In: *BMC Health Services Research* 22.1 (Dec. 2022). ISSN: 14726963. DOI: 10.1186/s12913-022-07472-x.

[64] Peter S. Hovmand et al. "Group model-building 'scripts' as a collaborative planning tool". In: *Systems Research and Behavioral Science* 29.2 (Mar. 2012), pp. 179–193. ISSN: 10927026. DOI: 10.1002/sres.2105.

[65] David C Lane, Camilla Monefeldt, and Elke Husemann. *Client Involvement in Simulation Model Building: Hints and Insights from a Case Study in a London Hospital*. Tech. rep. 2003, pp. 105–116.

[66] *Scriptapedia*. Nov. 2022. URL: https://en.wikibooks.org/wiki/Scriptapedia.

[67] Robert J.. Lempert, Steven W.. Popper, and Steven C.. Bankes. *Shaping the next one hundred years : new methods for quantitative, long-term policy analysis and bibliography*. RAND, 2003, p. 187. ISBN: 0833032755.

[68] Jan Kwakkel. *Exploratory Modelling and Analysis (EMA) Workbench*. Dec. 2024. URL: https://emaworkbench.readthedocs.io/en/latest/.

[69] Willem Auping. “Modelling Uncertainty: Developing and Using Simulation Models for Exploring the Consequences of Deep Uncertainty in Complex Problems”. PhD thesis. Delft: Delft University of Technology, 2018. DOI: 10.4233/uuid:0e0da51a-e2c9-4aa0-80cc-d930b685fc53. URL: https://doi.org/10.4233/uuid:0e0da51a-e2c9-4aa0-80cc-d930b685fc53.

[70] Jan H. Kwakkel and Marc Jaxa-Rozen. “Improving scenario discovery for handling heterogeneous uncertainties and multinomial classified outcomes”. In: *Environmental Modelling and Software* 79 (May 2016), pp. 311–321. ISSN: 13648152. DOI: 10.1016/j.envsoft.2015.11.020.

[71] Linda H. Aiken et al. “Nurse staffing and education and hospital mortality in nine European countries: A retrospective observational study”. In: *The Lancet* 383.9931 (2014), pp. 1824–1830. ISSN: 1474547X. DOI: 10.1016/S0140-6736(13)62631-8.

[72] Linda H. Aiken et al. “Hospital Nurse Staffing and Patient Mortality, Nurse Burnout, and Job Dissatisfaction”. In: *JAMA* 288.16 (Oct. 2002), pp. 1987–1993. ISSN: 0098-7484. DOI: 10.1001/JAMA.288.16.1987. URL: https://jamanetwork.com/journals/jama/fullarticle/195438.

[73] P. Carayon et al. *Work system design for patient safety: The SEIPS model*. Dec. 2006. DOI: 10.1136/qshc.2005.015842.

[74] Richard N. Keers et al. “Causes of Medication Administration Errors in Hospitals: a Systematic Review of Quantitative and Qualitative Evidence”. In: *Drug Safety* 36.11 (Nov. 2013), pp. 1045–1067. ISSN: 0114-5916. DOI: 10.1007/s40264-013-0090-2.

[75] Richard M Ryan and Edward L Deci. “Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being Self-Determination Theory”. In: *American Psychologist* 55 (Jan. 2000), pp. 68–78. DOI: 10.1037110003-066X.55.1.68.

[76] Dimmy van Dongen et al. *Classification of influencing factors of speaking-up behaviour in hospitals: a systematic review*. Dec. 2024. DOI: 10.1186/s12913-024-12138-x.

[77] Ann E. Rogers et al. “The Working Hours Of Hospital Staff Nurses And Patient Safety”. In: *Health Affairs* 23.4 (July 2004), pp. 202–212. ISSN: 0278-2715. DOI: 10.1377/hlthaff.23.4.202.

[78] M.L. Bokhorst. *Uitgebreide toelichting van het meetinstrument Visual Analogue Scale (VAS)*. Tech. rep. de Fysiotherapeut - ZUYD, Apr. 2022. URL: www.meetinstrumentenzorg.nl.

[79] Paola Ferri et al. “The impact of shift work on the psychological and physical health of nurses in a general hospital: A comparison between rotating night shifts and day shifts”. In: *Risk Management and Healthcare Policy* 9 (Sept. 2016), pp. 203–211. ISSN: 11791594. DOI: 10.2147/RMHP.S115326.

[80] Chiara Dall’ora et al. “Association of 12 h shifts and nurses’ job satisfaction, burnout and intention to leave: findings from a cross-sectional study of 12 European countries”. In: *BMJ Open* 5.9 (Aug. 2015), pp. 1–7. DOI: 10.1136/bmjopen-2015. URL: http://dx.doi.org/10.1136/bmjopen-2015-008331.

[81] Hong Lu, Yang Zhao, and Alison While. *Job satisfaction among hospital nurses: A literature review*. June 2019. DOI: 10.1016/j.ijnurstu.2019.01.011.

[82] Sibel Eker et al. “Sensitivity analysis of graphical functions”. In: *System Dynamics Review* 30.3 (July 2014), pp. 186–205. ISSN: 10991727. DOI: 10.1002/sdr.1518.

A

Appendix A Group Model sessions

A.1. Script

A.1.1. Template

The script has been designed using the tool Scriptapedia (LINK). On this open source website, scripts are gathered used for GMB to develop System Dynamics models. The ”best-practice” script named ”Creating Causal Loop Diagram from Connection Circles (Hovmand and Kraus)” has been altered and specified for this studies.

This script has been used after a set of connection circles have been created identifying variables and associations between variables. We have created these ourselves to keep the CLD the nurses are going to create focused on the scope of our research. This script follows the structure as indicated in [64].

The next section displays the script. The script is displayed in English. Comments and the connection circles are shown in Dutch, since the language during the sessions was also Dutch.

A.1.2. The actual script

CREATING CAUSAL LOOP DIAGRAM FROM CONNECTION CIRCLES WITH NURSES FROM THE EMERGENCY DEPARTMENT AT ERASMUS MC

Status
Best practice

Primary nature of group task
Convergent

Time
Preparation time: 10 minutes
Time required during session: 60 minutes
Follow-up time: 30 minutes

Materials

1. Large sheet of paper for the nurses to write on
2. Laptop of modeler and facilitator to present the presentation and display the connection circles and definitions
3. Audio recording device (in this case, a phone)
4. Markers to write with

Inputs
Connection Circles made by the modeler (in Dutch)

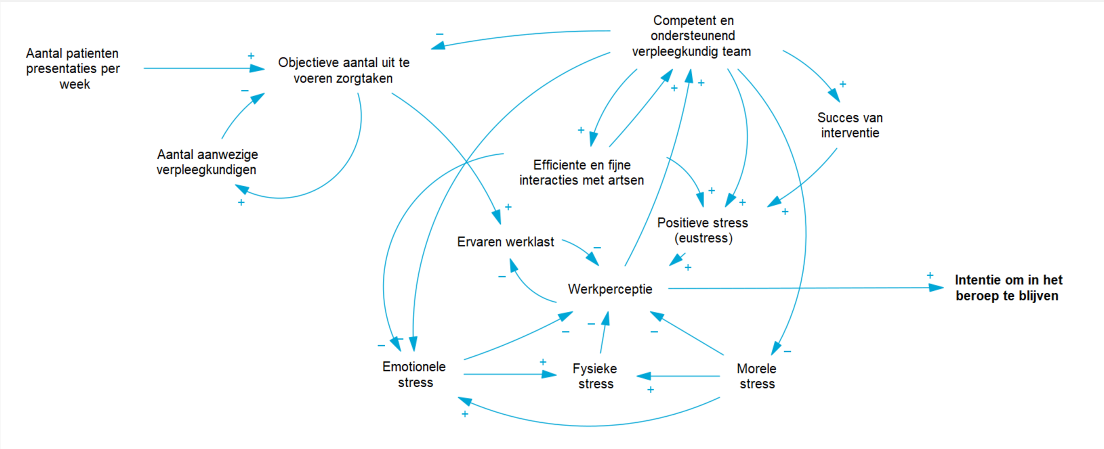


Figure A.1: Connection Circles for Nurses

Outputs
Causal Loop Diagram made by nurses

Roles
Modeler with experience drawing causal loop diagrams and comfortable introducing conventions. Facilitator as an extra pair of eyes and control of the modeler.

Steps

1. Introduce myself and the research I am conducting (5 min)
   (a) Matthijs van de Wiel, 24 years old, student EPA, passion for healthcare from parents
   (b) Creating a System Dynamics model on subjective workload of nurses in the Emergency Department, together with you, the nurses of SEH Erasmus MC.

   (c) Origin of my research, namely that the workload of formal caregivers was an instrumental variable in a previous study done at our faculty
   (d) Why the Emergency Department (canary in a coal mine due to high pressure, high patient turnover environment)
   (e) Mainly focused on their perception of the task demand, how that perception is influenced, and how that perception can change their behavior and performance at work

2. Introduce System Dynamics (3 min)
   (a) System Dynamics modeling is our method to apply the systems science approach. It is a deterministic type of computer simulation modeling that applies the principles of information feedback and state variables and is used to analyze the relationship between a social system's structure and its behavior over time (Lane, 2008).
   (b) Two diagramming methods are most prominent:
      i. Causal Loop Diagrams (CLD), a broad representation of variables and feedback structure.
      ii. Stock/Flow Diagrams (SFD), a more detailed representation discriminating both state and flow variables (Lane, 2008).

3. Introduce the exercise by reviewing the connection circles constructed by the facilitator and modeler (5 min)
   (a) "Polariteit van de pijl geeft richting aan: een plus geeft aan dat ze dezelfde richting op bewegen, dus je moet het lezen als: gaat de bron omhoog, dan gaat de variabele waar deze effect op heeft ook omhoog. Met een min op de pijl gaat het dus andersom, dan doet de bron de variabele waarop die effect heeft de andere richting op bewegen."

4. Instruct the team to now construct a causal loop diagram based on the connection circles (30-40 min)
   (a) We're now going to create a causal loop diagram identifying hypothesized causal relationships between variables. These connections can be based on research or literature you know, but it's also very interesting how these constructs work from your own experience.
   (b) To do this:
      i. Begin by picking the variables that are important or attract your attention immediately and transferring them to the sheet of paper.
      ii. Think of all the elements that revolve around this variable, and then draw a causal arrow from the cause to the effect.
      iii. Add a plus or minus sign to indicate the direction of influence:
         A. Plus signs represent change in the same direction (positive association).
         B. Minus signs represent change in the opposite direction (negative association).
      iv. If unsure about a link's sign, use a question mark.
      v. If a relationship could be both positive and negative, draw two separate causal links.
      vi. As the number of links increases, look for positive and reinforcing feedback loops.
   (c) Example relevant to nurses:
      i. Example 1: When more emotional stress is experienced, it affects work perception. A negative work perception eventually increases work stress, creating a **negative reinforcing feedback loop**. If work perception improves, emotional stress decreases, forming a **positive reinforcing loop**.
      ii. Example 2: When the **objective number of tasks** increases (and becomes too high), **work perception** decreases. This could lead to a less competent and supportive team due to high pressure and deteriorating communication. A weakened team is less effective at completing tasks, **further increasing task load**.

(d) The goal of this exercise is to develop a **causal loop diagram**, meaning we seek **both individual linkages and feedback loops**. A good strategy is to “close the loop”:

i. Look for variables without incoming arrows.
ii. Identify whether another variable in the model influences this variable.
iii. If so, draw a link to **close the feedback loop**.

5. As the group works on their causal loop diagrams, facilitators walk around the room, observe, and coach them. Focus shifts in three phases:

(a) **Beginning (first 5 minutes):** Clarify instructions and provide positive reinforcement.

i. Example: *”Ziet er goed uit! Ik zie een aantal variabelen die een Competent en ondersteunend verpleegkundig team omvatten en hoe deze aan elkaar gelinkt zijn met causale relaties.”*

(b) **Middle phase:** Improve diagramming skills and discussions.

i. Example: *”Onthoud, als een connectie of relatie tussen twee variabelen beide kanten op gaat, teken dan twee aparte lijnen.”*
ii. Example: *”Het lijkt erop dat jullie het niet eens kunnen worden of een variabele hetzelfde is voor iedereen binnen het team. Waarom proberen jullie niet een tweede variabele te maken zodat beide ideeën op papier komen, ook al lijken ze tegenstrijdig of alleen relevant in bepaalde gevallen?”*
iii. Example: *”Mocht je nou willen aangeven dat het effect van een variabele even duurt (dus niet direct), geef dat dan aan door twee strepen op de pijl te plaatsen: een vertraging wordt hiermee aangegeven.”*

(c) **End (last 5 minutes):** Stop writing, take a break, then review key themes.

i. Identify interesting feedback loops.
ii. Provide positive reinforcement.
iii. Example: *”Dat ziet er goed uit. Ik zie hoe [variabele 1] invloed heeft op [variabele 2], en hoe dit vervolgens [variabele 3] beïnvloedt, wat op zijn beurt effect heeft op [variabele 4]. Je hebt ook een paar feedback loops. Deze is versterkend (wijs naar de loop en leg het uit) en deze is balancerend (wijs naar de loop en leg het uit). Goed gedaan!”*

Evaluation criteria
Participants created a rich set of causal loop diagrams (CLD) based on their mental models

Authors
Matthijs van de Wiel m.vandewiel@student.tudelft.nl under supervision of dr. Irene Grossmann I.Grossmann@tudelft.nl

Evaluation criteria
Participants created a rich set of causal loop diagrams (CLD) based on their mental models

History
Created by Peter Hovmand and Alison Kraus, 2013, found here. Original script based on work with Raising St. Louis in 2013

References
Hovmand, P. S., Andersen, D. F., Rouwette, E., Richardson, G. P., Rux, K., & Calhoun, A. (2012). Group model-building “scripts” as a collaborative planning tool. Systems Research and Behavioral Science, 29(2), 179–193. https://doi.org/10.1002/sres.2105

A.2. Setup

The group of nurses was asked after their morning turnover by their managers who wanted to participate in the sessions. We did not have any say in which nurses participated. From this meeting, a small group of nurses came to a small meeting room where we conducted the sessions according to the script.

A.2.1. Description of the sessions

Reflection of session 1

The nurses did not come straight from the morning turnover, which caused some delay. The session started half an hour later than planned. Initially, three nurses were asked to participate in the first session. However, one of the nurses was held up in the Emergency room, which means we started the session with two nurses. Due to the delay, we only had an hour in total with 35 minutes of modeling, which is a short time to properly comprehend the definitions and scope of my research.

When we started modeling, the focus immediately went to factors related to personals details such as job fit, resilience, work-personal life balance. It was repeatedly hard to steer away from personal influences from the nurses, saying that everything was personal. I had to steer and intervene a lot in this session as modeler. The model on paper lacked some detail, but the conversation between the two nurses was valuable input. The conclusion of this session is that two nurses is not ideal and more time is necessary to conduct a session properly.

Reflection of session 2

This session started on time, with a last minute switch of one nurse. The session was also there first thing the nurses did in the morning. This contributed to their focus and being present. A group of four nurses, more diverse, attended the second session. This group size was better, since it allowed two people to have a conversation and discuss a topic, while others were free to think along or look at the model. It also helped that two of the nurses were very focused on the definitions and the connection circles and trying to put their own perceptions into that. There was again a immediate focus on personal factors and situations at home that influenced the stress levels. However, this group managed themselves to steer away from that and look at the connection circles and take inspiration from that.

A.2.2. Role of the modeler

I have thoroughly researched the subjective workload of nurses prior to these sessions. It was a real challenge to not seek for confirmation of the theories, dynamics and model I had created. Therefore, it felt much better to not intervene too much in the session. However, Lara (the facilitator) told me that it did not feel as if I was looking for answers. The sessions were conducted open and fair to the nurses experiences.

I felt a bit insecure how to share my knowledge on the topic of subjective workload of nurses. I am not a nurse, so it was tough to find the right language and abbreviations. I also did not want to make the nurses feel as if I already knew everything about how they perceived their workload. Especially in first session, I had to fill in a lot of gaps and steer the conversation. In the analysis, I made sure to include if nurses agreed with the suggestions I made.

A.3. Outcomes

A.3.1. Causal Loop Diagrams drawn by the nurses

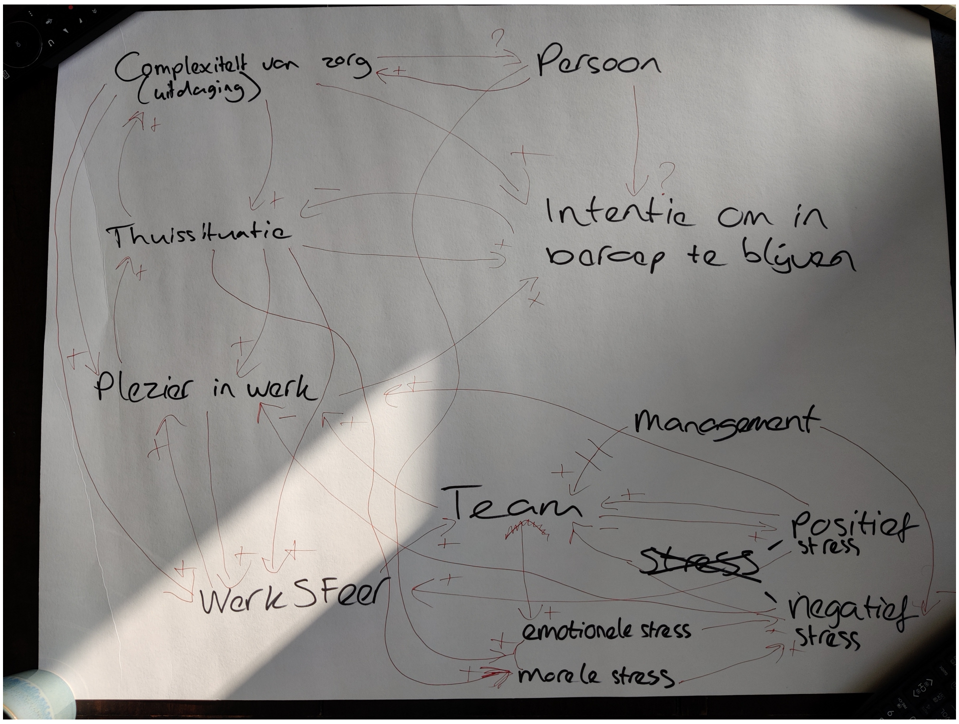


Figure A.2: CLD from session 1

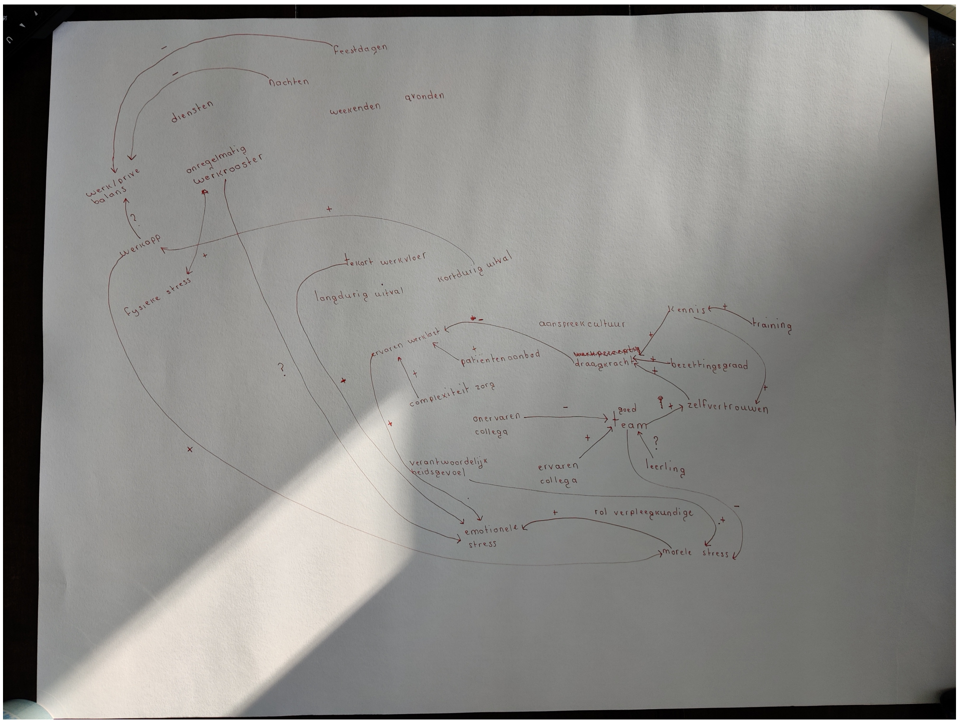


Figure A.3: CLD from session 2

A.3.2. Changes in the conceptual model

The most important outcomes of the sessions that resulted in changes in the conceptual model:

- Subjective workload restructured into shift balance, with perceived positive and negative shifts.
- Absenteeism can be divided into long-term and short-term absenteeism, as they are influenced by different factors. Short-term absenteeism is primarily due to sickness, whereas long-term absenteeism results from psychosomatic complaints caused by sustained distress.
- Short-term absenteeism affects the capacity to destress and is strongly related to the work app discussed in session 2. It leads to last-minute calls to fill shifts, which in turn reduces the capacity to destress for nurses considering taking those shifts.
- Work-life balance is influenced by private life and emotional distress. This, in turn, affects the capacity to destress, which has an impact on all stress factors, including emotional stress, depersonalization, and moral distress. Moreover, a poor work-life balance is a reason to leave the profession.
- Physical distress should be removed as a stress factor. Nurses in both sessions indicated that the physical aspect of the job is not demanding enough to contribute to absenteeism or decisions to leave.
- Satisfaction with scheduling positively influences the likelihood of experiencing positively perceived shifts.
- Increased Responsibility during a shift, either due to the Role of the nurse of the Match between complexity of care and competency of the team, leads to higher stress levels and lowers the probability of experiencing a positive shift.
- The match between nurses' competencies and patient complexity has a positive effect on the ability to deliver safe care.
- Long-term absenteeism was mentioned as a stressor for emotional distress. Seeing colleagues suffer from burnout increases awareness of the consequences of sustained stress, which in turn causes additional stress.
- Average years of experience does not play a big role in how nurses are perceived on their competence; job fit does.

Two additional insights are found. First, team composition was consistently highlighted as an important factor influencing nurses' stress levels before and during shifts. Participants emphasized that working with a competent team—and equally important, one characterized by mutual trust and strong interpersonal connections—had a significant impact on the overall shift experience. While this insight is valuable, incorporating stochastic individual differences between team members to model team dynamics falls outside the scope of this study and would require a different modeling approach than System Dynamics (SD).

Second, the concept of job fit was frequently raised. Job fit refers to the degree to which a person's characteristics align with the demands and expectations of their role. Although highly relevant, this factor was not included in the model for two main reasons. First, the aim of this study was not to identify the ideal nurse archetype for the profession. Second, the model begins with an existing average nursing team and does not simulate nurse inflows, such as hiring or recruitment, where job fit policies might be applied. As a result, all nurses in the model are assumed to be adequately suited for their roles.

B

Model Validation

This appendix outlines the full model validation process, which was carried out to assess the model's robustness, reliability, and overall suitability for further analysis. The validation followed a structured approach comprising three main steps: time step validation, univariate sensitivity analysis, and a resilience test.

First, the appropriate time step for the model was validated to ensure this aligns with the dynamics of the system being modeled. This step was critical in confirming that model outputs are both stable and responsive to relevant changes over time.

Following this, a univariate sensitivity analysis was conducted to evaluate how sensitive the model outputs are to isolated changes in individual input parameters. This helps identify which inputs have the most significant influence on key outcomes and ensures the internal logic of the model behaves as expected.

Lastly, a resilience validation test was performed to simulate the model's response to short-term, high-intensity stressors. This test aimed to confirm that the model exhibits recovery behavior similar to that observed in real-world scenarios—returning to baseline after temporary perturbations—thereby further validating its realism and robustness.

Together, these steps provide a comprehensive assessment of the model's validity and confirm its fitness for purpose in supporting further scenario testing and policy analysis.

Before we start, it is worth mentioning that the model shows no unit errors and runs for extreme values, since we use the widest possible bandwidths in the PRIM analysis.

B.1. Time Step

The first step in validating the model is to ensure that the settings have been configured correctly and that there are no existing errors. This includes reviewing the selected integration method, which is Euler in this case. While Euler is the fastest and most straightforward integration approach, it is also the least precise. However, because the model is intended to capture broader trends in subjective workload and stress among Emergency Department nurses rather than minor fluctuations, this level of accuracy is sufficient. We analyzed the model behavior of Psychosomatic Complaints, a stock variable in the model. The time step for the model is set at 0.03125, which was determined by running the model with a step size of 1 and halving it until there was no change in behavior. Figure B.1 shows this procedure for every step. The red and blue line on the bottom of the figure shows the behavioral change between the two smallest time steps, where we can see that 0.03125 and 0.015625 overlap. This means that the behavior of the model is consistent with 0.03125 as time step.

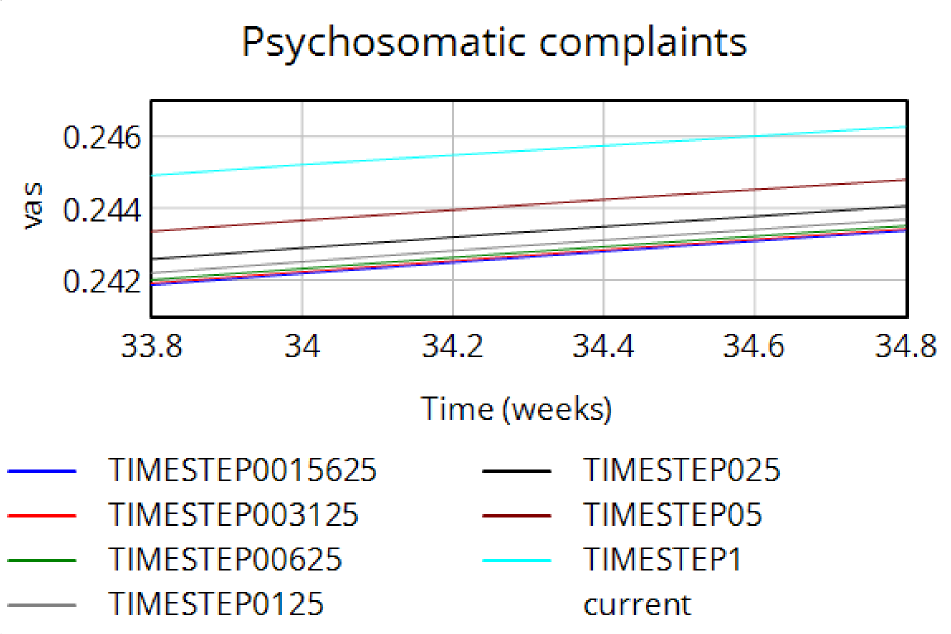


Figure B.1: TIME STEP validation displayed with Psychosomatic complaints

B.2. Univariate sensitivity analysis

The univariate sensitivity analysis was selected as an appropriate method due to the feedback-heavy nature of the model. In such systems, small changes in individual input variables should not result in significant shifts in behavior. This method allows us to verify that assumption and assess the model's stability under minor perturbations. If unexpected sensitivity is observed, this would indicate the need for further investigation using more advanced techniques, such as PRIM (Patient Rule Induction Method) analysis from the EMA Workbench.

To perform the sensitivity test, two constant parameters were selected from each subsystem of the model. These constants were chosen to represent different entry points within their respective subsystems, aiming to capture a wide range of potential sensitivity responses. Each constant was varied individually by +10% and -10% from the baseline value.

Expected outcomes for each parameter variation are outlined in the overview table below. All changes in output behavior are anticipated to be minimal, and the general shape and trend of the graphs are expected to remain consistent across all analyses.

B.2.1. Setup of Univariate sensitivity analysis

Variable Name	Expected	Base case	Unit
Satisfaction with scheduling	A little change in the height of emotional distress and shift balance, since it is the input for percentage of positivity in shifts	0.8	dmnl
Initial willingness to be flexible	It shows how willing nurses are to cover extra shifts. More vacant shifts results in more busy shifts which will negatively influence the whole system. It will have some effect on distress levels but no behavior change	1	dmnl
Career expectation fulfillment	This will result in a wider bandwidth of Intention to stay in the profession, but will not result in behavioral change in the model	0.8	Vas
Interactions with colleagues outside of nursing team	Very low impact on the system is expected	0.7	Vas
Quality of private life	Higher stress in the system expected, since quality of private life heavily influences the capacity to destress, which is used in the outflow of both moral and emotional distress	0.8	Vas
Initial ability to destress	Buffer the stress system by influencing nurse resilience, which means we will see some higher and lower lines in the total amount of distress	0.8	Dmnl
Average experience of nurses	Leads to more resilience and more competency, which will lower the overall stress experienced	5	years
Supportive leadership	Multiple ways this variable has effect in the system, so minor changes in the lines are expected but no behavioral change	0.9	Vas
Average patient dependency	A slight change in objective task demand is expected but overall no behavioral change	10	JDT
Number of patients admitted	Similar to Patient Dependency	770	patients

Table B.1: Univariate senstivity analysis setup

The variables in B.1 are individually run for three output parameters: intention to stay in the profession, total amount of distress and Objective task demand per shift. The first output parameter is the main research variable from the research question. The second output parameter tells us something about overall stress levels, which can be further investigated upon unexpected results. The third output parameter is the central stock variable of the team subsystem, which is involved in many feedback loops.

The sensitivity analyses each consist of 200 simulations under noise seed 1234. In the next section, the three output paramaters are displayed in graphs for each of the variables in B.1.

B.2.2. Results of Univariate sensitivity analysis

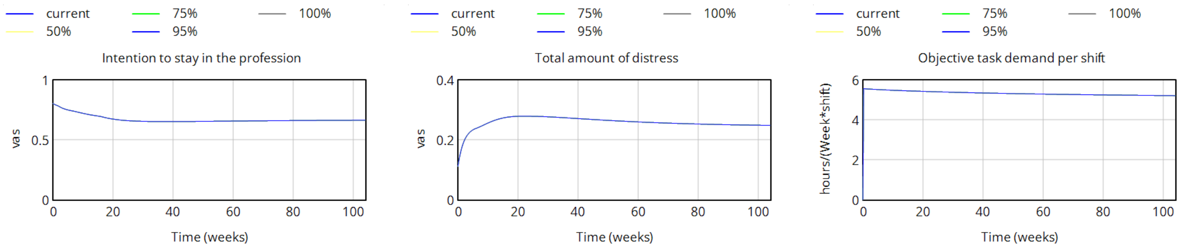


Figure B.2: Three output parameters for satisfaction with scheduling

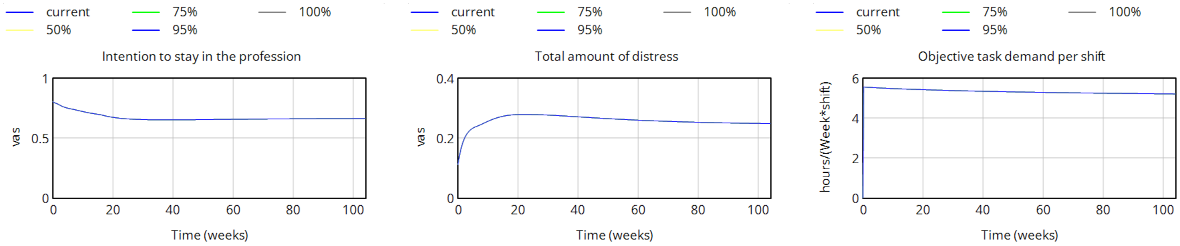


Figure B.3: Three output parameters for initial willingness to be flexible

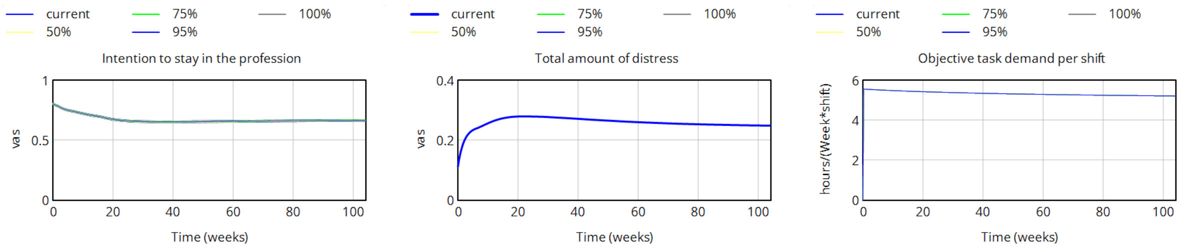


Figure B.4: Three output parameters for Career expectation fulfillment

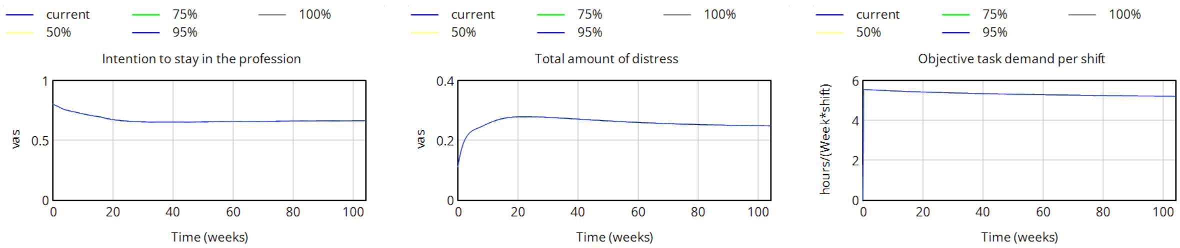


Figure B.5: Three output parameters for Interactions with colleagues outside of nursing team

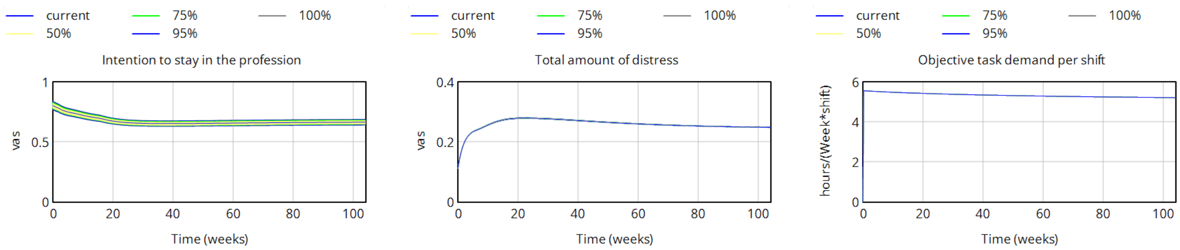


Figure B.6: Three output parameters for Quality of private life

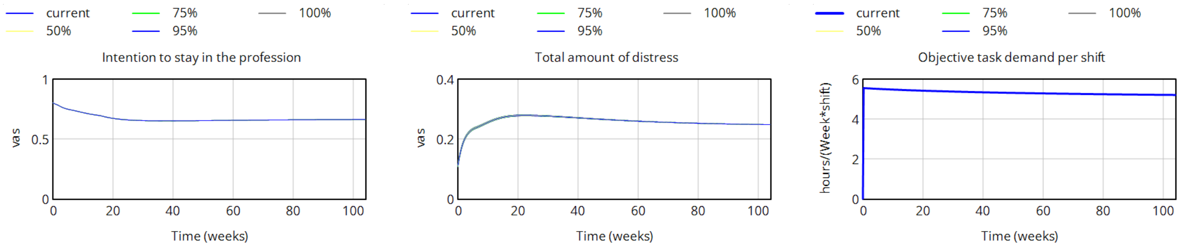


Figure B.7: Three output parameters for Initial ability to destress

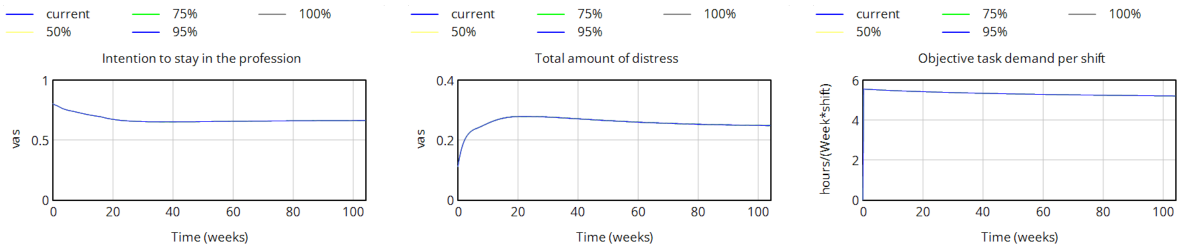


Figure B.8: Three output parameters for Average experience of nurses

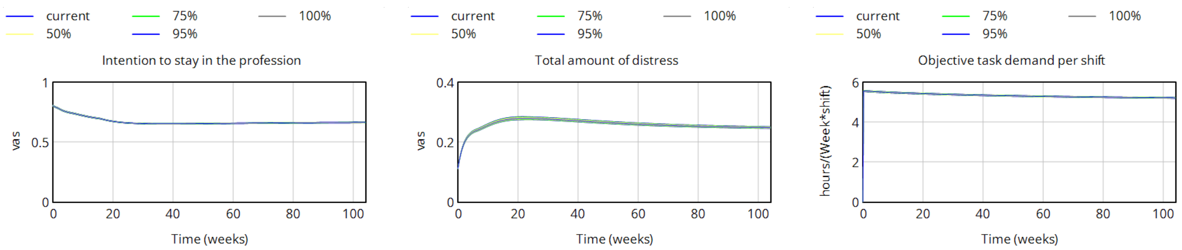


Figure B.9: Three output parameters for Supportive leadership

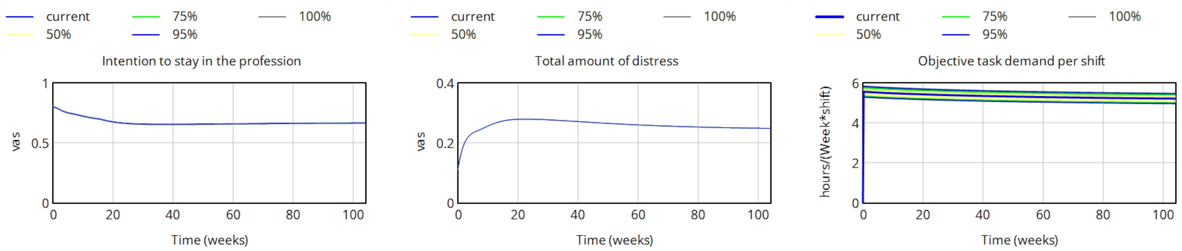


Figure B.10: Three output parameters for Average patient dependency

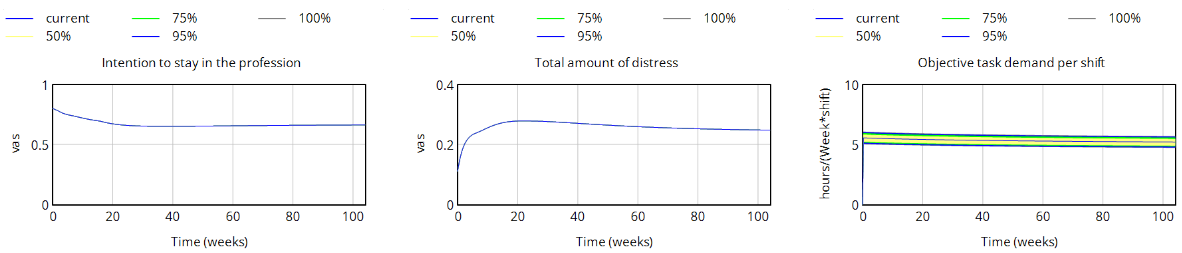


Figure B.11: Three output parameters for number of patients admitted

For all the output parameters, the results show the same behavior. There is some variability in the width of the lines in some cases, as expected for the variable Average Patient dependency B.10 and Number of patients admitted B.11.

Another interesting graph is Intention to stay in the profession in figure B.6. Quality of pivate life is a large predictor of Work life balance, which directly influences the Intention to stay in the profession. Therefore variability in private life causes a larger bandwidth in intention to stay results. Similar responses are seen for Career expectations fulfillment in B.4, which is directly linked to Intention to stay in the profession. The results are minimal, since the weights of these variables have not been changed.
We investigated Long-Term Absenteeism for all the test, since an increase in this variable would be a result of a significant behavior change of the model. None of the sensitivity tests carried out resulted in an increase of Long-Term Absenteeism.

Objective task demand per shift is not influenced by any of the investigated parameters from other subsystems. It will be interesting to see if there are any combination of input parameters that influences this variable.

Seeing all the graphs together, the hypothesis of the model having low sensitivity to small univariate changes can be accepted. There are no behavioral changes, so more complex analysis analysis will be necessary to find spaces of input variables that cause interesting changes to the output parameters.

B.3. Model Resilience Validation Test

To ensure the robustness and behavioral realism of the model, a validation test was conducted to evaluate its resilience in response to short-term, high-intensity stressors. Specifically, the aim was to examine whether the model exhibits behavior analogous to the known resilience of nurses during temporary periods of increased stress or workload. In real healthcare settings, such stressors are common—ranging from seasonal peaks in patient inflow to temporary personal life constraints—and professionals are expected to return to baseline functioning without long-term behavioral degradation. It is therefore essential that the model simulates this characteristic, exhibiting a return to normal states following such temporary perturbations.

In addition to aligning the model with real-world dynamics, testing for resilience also helps validate its recovery pathways and ensures that transient changes in inputs do not result in unrealistically persistent changes in outputs. This contributes to the model's overall credibility and stability, especially when used for scenario testing or policy simulations.

Three scenarios were tested, each involving a temporary pulse starting at **time step 4** and lasting for four weeks. The pulses are designed to stress the model in specific dimensions while monitoring for expected recovery behavior. The tested scenarios are:

- **High Patient Dependency Pulse:** The average patient dependency was increased by 8 JDT, pushing the model to its maximum patient dependency level for four weeks.
- **High Number of Admissions Pulse:** The number of patients admitted per week was increased by 760, also pushing this parameter to its upper limit for four weeks.
- **Quality of private life Stress Pulse:** The private life parameter was decreased by 0.3 for four weeks, resulting in a value of 0.5 during this period.

For each scenario, the model outputs were monitored for the following indicators, as in the univariate sensitivity analysis: *Intention to stay in the profession*, *Total amount of distress*, *Objective task demand*, and *Long-term absenteeism*. The focus of the analysis is on whether these outputs return to pre-pulse levels after the pulse ends, indicating that the system dynamics are appropriately resilient and reflective of realistic behavioral recovery.

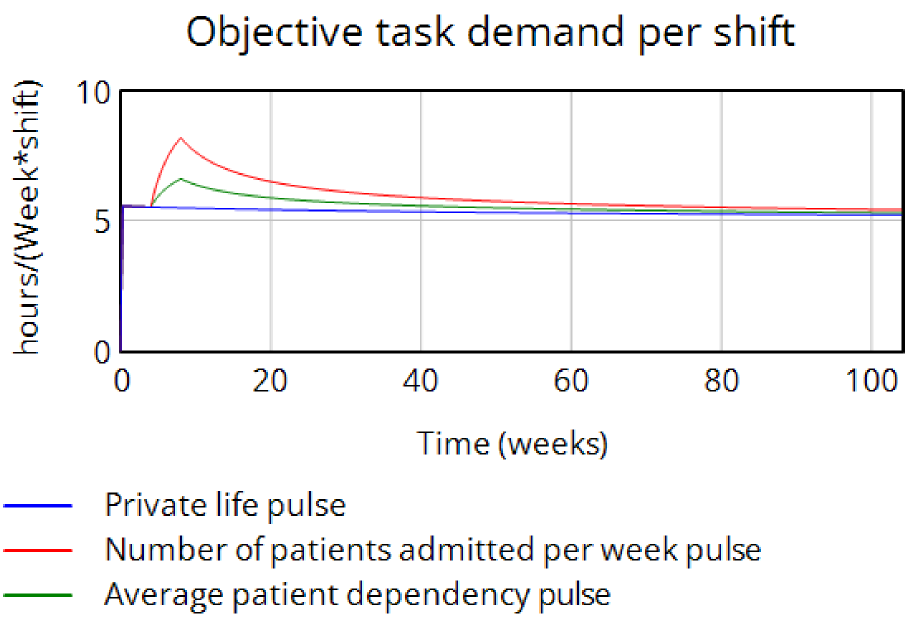


Figure B.12: Objective task demand per shift in model resilience test

The expected model behavior is observed in the graph for *Objective task demand per shift*. A reduction in the *Quality of private life* parameter does not affect this output, which aligns with the model structure. A change in task demand would only be expected if a drop in *Intention to stay in the profession* led to actual departures from the workforce, thereby reducing the number of available nurses. Since this does not occur during the private life pulse, the objective task demand remains unaffected.

What stands out is the difference between the pulses for *Number of patients admitted* and *Patient Dependency*. The admission pulse leads to a sharper, more immediate spike in objective task demand compared to the patient dependency pulse. However, both lines gradually return to the baseline, reflecting the system's resilience over time. This divergence in short-term response becomes even more significant when analyzing the corresponding distress levels.

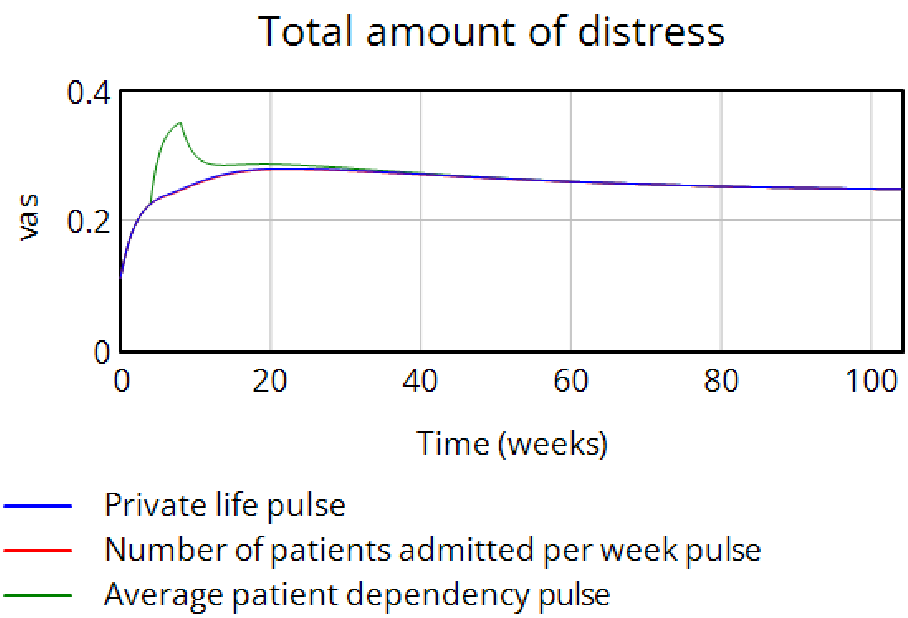


Figure B.13: Total amount of distress in model resilience test

In the next graph, we observe that the increased number of patient admissions does not lead to a noticeable increase in the *Total amount of distress* compared to the baseline. This contrasts with the *Patient Dependency* pulse, which causes a significant spike in distress levels, mirroring the spike seen in task demand. Over time, all scenarios converge, once again demonstrating the model's ability to simulate recovery and adaptation among nurses after short-term stress.

These results highlight the nuanced impacts of different stressors: while patient volume increases workload, it does not necessarily increase distress, whereas higher patient dependency, implying more complex care, does. This distinction could be key in understanding how different operational factors influence both performance and well-being.

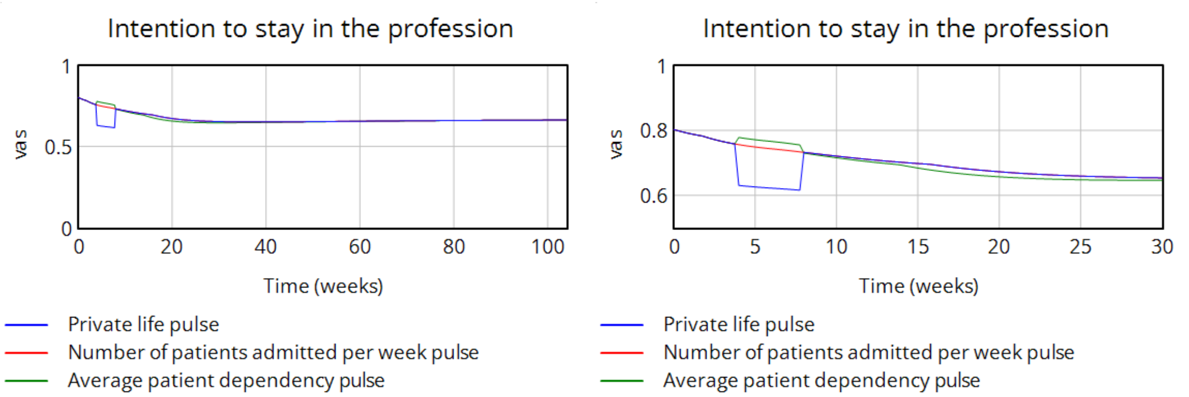


Figure B.14: Intention to stay in the profession in model resilience test

Lastly, we examine the model output for *Intention to stay in the profession*. The first graph confirms the expected long-term resilient behavior, showing that, overall, the model returns to baseline levels after the temporary pulses. The second graph provides a closer look at the short-term effects during the pulse period and reveals some notable differences between the scenarios.

The pulse in *Quality of private life* causes a clear and expected short-term drop in the intention to stay. Once the private life parameter returns to its normal value, the model quickly recovers, and the intention to stay aligns again with the baseline trend. This supports the idea that personal life stressors have a temporary but immediate impact on professional commitment.

Interestingly, the *Number of patients admitted* pulse has no visible impact on the intention to stay. This suggests that the overall volume of patients is not a key factor influencing nurses' decision to remain in the profession, at least not in the short-term.

The most notable response comes from the *Patient Dependency* pulse. Initially, there is a slight increase in the intention to stay, which could be explained by an increase in job satisfaction from providing more complex or meaningful care. However, this is followed by a small decline relative to the baseline, indicating that the added strain from higher dependency may lead to increased distress, which eventually reduces the intention to stay. This highlights a more complex dynamic where short-term engagement can shift into long-term strain if high demands persist.

Overall, these results provide valuable insights into how different types of stressors influence nurses' motivation to remain in the profession and validate the model's ability to reflect both short-term and longer-term behavioral trends.

B.4. Conclusion

This appendix has shown that the model works as expected and is ready to be used for further analysis. Three steps were taken to evaluate the model: checking the time step, running a univariate sensitivity analysis, and testing the model's resilience to short-term stress.

First, we confirmed that the chosen time step is small enough to give reliable results without making the model unstable. Then, the univariate sensitivity analysis showed that small changes to individual input values do not lead to big or unexpected changes in the outputs. This is important in a model like this, where feedback loops are key. Finally, the resilience test showed that the model can handle short periods of increased stress and returns to normal afterwards—just like real-life nurses often do in high-pressure situations.

Overall, these tests confirm that the model behaves in a stable and realistic way. This gives us confidence that it can be used to explore different scenarios and support further analysis.

C

Model Description

C.1. Constants

Variable	Type	Symbol/Equation	Unit
Minutes in an hour	Constant	$M_{hour} = 60$	minutes/hour
Maximum patient dependency	Constant	$PD_{max} = 18$	JDT
Maximum vas score	Constant	$V_{max} = 1$	vas
Nurses per interval	Constant	$N_{interval} = 1$	nurse
Maximum level of distress	Constant	$D_{max} = 1$	vas
Maximum meeting time per patient	Constant	$T_{meet,max} = 15$	minutes/patient
Maximum years of experience of nurses	Constant	$E_{max} = 40$	years
Agreed upon shifts per nurse	Type	$S_{agreed} = 4$	shifts/nurse/Week

C.2. Objective task demand subsystem

C.2.1. Main variables

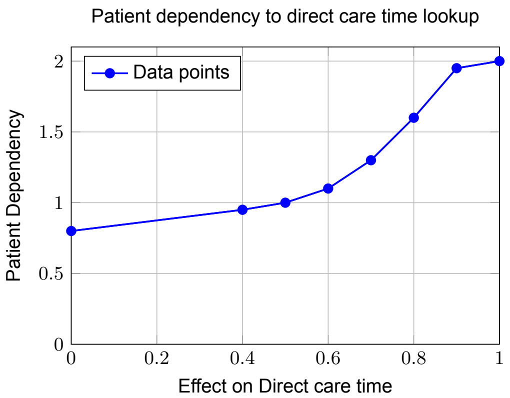
Variable	Type	Unit
Objective task demand to date	Stock	hours
$OTD_{date} = \int_0^t OTD_{week}\, dt$		
Average objective task demand per week	Auxiliary	hours/week
$OTD_{avg} = \text{ZIDZ}(OTD_{date}, t)$		
Objective task demand per shift	Auxiliary	hours/shift/week
$OTD_{shift} = \frac{OTD_{avg}}{S_{shifts}}$		
Objective task demand per week	Inflow	hours/week
$OTD_{week} = T_{care} \times P_{admit} \times Eff_{efficiency,care} \times T_{performance}$		
Care time per patient	Auxiliary	hours/patient
$T_{care} = \frac{T_{direct,patient} + T_{indirect,patient}}{M_{hour}}$		
Direct care time per patient	Auxiliary	minutes/patient
$T_{direct,patient} = T_{direct,init} \times PD_{direct,lookup}\left(\frac{PD_{avg}}{PD_{max}}\right)$		
Indirect care time per patient	Auxiliary	minutes/patient
$T_{indirect,patient} = T_{indirect} \times Eff_{depend,indirect}$		
Ratio of direct and indirect care time	Auxiliary	dmnl

Variable	Type	Unit
$R_{ratio} = \frac{T_{direct,patient}}{T_{indirect,patient}}$		
Effect of patient dependency on indirect care tasks	Auxiliary	dmnl
$Eff_{depend,indirect} = PD_{indirect,lookup}\left(\frac{PD_{avg}}{PD_{max}}\right)$		
Indirect care tasks	Auxiliary	minutes/patient
$T_{indirect} = T_{admin} + T_{comm} + P_{transport} + P_{equip}$		
Administrative tasks	Auxiliary	minutes/patient
$T_{admin} = P_{transport} + T_{comm}$		
Communication and training tasks	Auxiliary	minutes/patient
$T_{comm} = M_{meet} + T_{prof} + T_{students}$		
Task performance based on stress level	Auxiliary	dmnl
$T_{performance} = Eff_{distress,perf,lookup}\left(\frac{D_{total}}{D_{max}}\right)$		
Task efficiency from team organisation	Auxiliary	vas
$T_{efficiency} = w_{skill,efficiency} \times S_{comp} + (1 - w_{skill,efficiency}) \times O_{consult}$		
Effect of task efficiency on care time per patient	Auxiliary	dmnl
$Eff_{efficiency,care} = Eff_{efficiency,care,lookup}\left(\frac{T_{efficiency}}{V_{max}}\right)$		

C.2.2. Input variables

Variable	Base	Unit	Low/High boundary
Initial direct care time per patient $T_{direct,init}$	22	minutes/patient	5/60
Average patient dependency PD_{avg}	10	JDT	6/18
Preparing equipment and managing medication P_{equip}	5	minutes/patient	2/10
Patient transport $P_{transport}$	5	minutes/patient	2/10
Number of patients admitted per week P_{admit}	770	patients/Week	358/1530

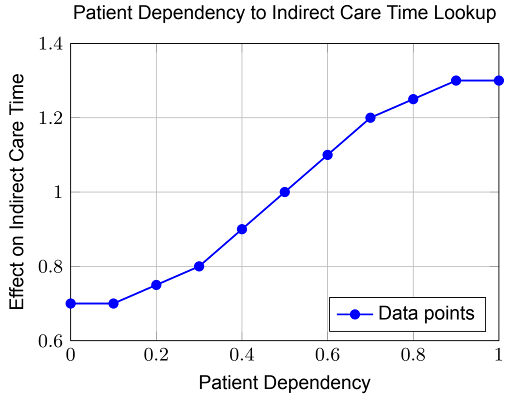
C.2.3. Lookups



Effect on direct care time	Patient dependency
0.0	0.80
0.4	0.95
0.5	1.00
0.6	1.10
0.7	1.30
0.8	1.60
0.9	1.95
1.0	2.00

Figure C.1: Patient dependency to direct care time lookup

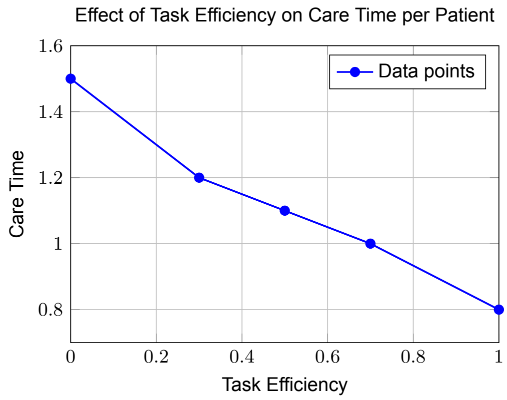
For this lookup, we are looking at a normalized value of patient dependency, which ranges from 6 to 18. If the patient dependency is relatively low (9 or lower), the direct care time is made smaller. For the values above 9 we decided on an increasing rise of direct care time, meaning that the direct care time for the highest value of patitent dependency increases the most marginally.



Patient Dependency	Effect on Indirect Care Time
0.0	0.70
0.1	0.70
0.2	0.75
0.3	0.80
0.4	0.90
0.5	1.00
0.6	1.10
0.7	1.20
0.8	1.25
0.9	1.30
1.0	1.30

Figure C.2: Patient Dependency to Indirect Care Time Lookup

This lookup reflects a revised assumption about the relationship between patient dependency and indirect care activities, incorporating a more S-shaped (sigmoidal) curve. The rationale is that tasks such as administrative work or patient transport are disproportionately influenced by changes in patient dependency at moderate levels of the JDT score. While more complex care is generally associated with increased indirect care time, the marginal impact of additional complexity diminishes at the extremes. In patients with very low or very high dependency, indirect care requirements tend to plateau, whereas in the mid-range, small increases in dependency can significantly affect the amount of indirect care needed.



Task Efficiency	Care Time Multiplier
0.0	1.50
0.3	1.20
0.5	1.10
0.7	1.00
1.0	0.80

Figure C.3: Effect of Task Efficiency on Care Time per Patient lookup

This lookup models the effect of task efficiency—primarily influenced by nurse stress levels—on care time per patient. The output serves as a multiplier applied to the baseline objective care time. When task efficiency is low, often due to elevated stress, care tasks take longer to complete, resulting in a slight increase in total care time. Conversely, low stress levels enhance task efficiency, allowing nurses to perform care more quickly and thereby reducing the time required. This relationship captures the nuanced impact of psychological and cognitive load on the delivery of care. We have chosen a light S curve, for a stronger effect in the extreme values of stress.

C.3. Shift subsystem

C.3.1. Main variables

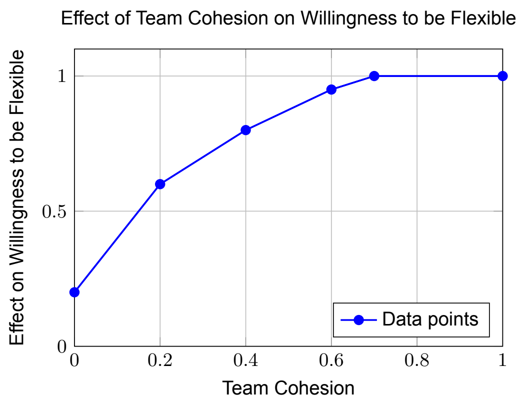
Variable	Type	Unit
Shifts	Stock	shifts
$S_{shifts} = \int_0^t (S_{added} - S_{neg,completed} - S_{pos,completed} - V_{week})\, dt + S_{init}$		
Vacant shifts per week	Flow	shifts/Week
$V_{week} = S_{extra,open} - S_{extra,completed}$		
Vacant shifts	Stock	shifts
$V_{shifts} = \int_0^t (V_{week} - V_{dissipation})\, dt$		
Vacant shift dissipation	Outflow	shifts/Week
$V_{dissipation} =$ DELAY FIXED$(V_{week},$"1 week"$, 0)$		
Added shifts per week	Auxiliary	shifts/Week
$S_{added} = N_{sched,init} \times S_{agreed}$		
Initial value of shifts	Input	shifts
$S_{init} = S_{agreed} \times N_{sched,init} \times$ "1 week"		
Perceived positive shifts completed per week	Flow	shifts/Week
$S_{pos,completed} = (S_{completed} \times P_{sched,pos}) + (S_{extra,completed} \times P_{extra,pos})$		
Perceived negative shifts completed per week	Flow	shifts/Week
$S_{neg,completed} = (S_{completed} \times (1 - P_{sched,pos})) + (S_{extra,completed} \times (1 - P_{extra,pos}))$		
Perceived negative shifts	Stock	shifts
$S_{neg} = \int_0^t (S_{neg,completed} - F_{neg})\, dt$		
Perceived positive shifts	Stock	shifts
$S_{pos} = \int_0^t (S_{pos,completed} - F_{pos})\, dt$		
Fading negative shift memory	Outflow	shifts/Week
$F_{neg} =$ SMOOTHI$(S_{neg,completed}, T_{neg,fade}, 0)$		
Fading positive shift memory	Outflow	shifts/Week
$F_{pos} =$ SMOOTHI$(S_{pos,completed}, T_{pos,fade}, 0)$		
Percentage of extra shifts that are positive	Auxiliary	dmnl
$P_{extra,pos} = P_{extra} \times (1 - E_{demand})$		
Scheduled shifts completed per week	Auxiliary	shifts/Week
$S_{completed} = S_{agreed} \times N_{present}$		
Extra shifts completed per week	Auxiliary	shifts/Week
$S_{extra,completed} =$ MIN(INTEGER$(N_{present} \times W_{flex}), S_{extra,open})$		
Extra shifts open per week	Auxiliary	shifts/Week
$S_{extra,open} = S_{agreed} \times (N_{sched,init} -$ INTEGER$(N_{present}))$		
Nurses' willingness to be flexible	Auxiliary	shifts/Week/nurse
$W_{flex} = W_{flex,init} \times Eff_{cohesion,flex} \times Eff_{balance,flex}$		
Effect of team cohesion on willingness to be flexible	Auxiliary	dmnl
$Eff_{cohesion,flex} = Eff_{cohesion,flex,lookup}(\frac{T_{cohesion}}{V_{max}})$		
Effect of work life balance on willingsness to be flexible	Auxiliary	dmnl
$Eff_{balance,flex} = Eff_{balance,flex,lookup}(\frac{W_{balance}}{V_{max}})$		
Effect of being understaffed during shifts	Auxiliary	dmnl
$Eff_{under} = Eff_{under,lookup}(\frac{V_{shifts}}{S_{shifts}})$		
Percentage of scheduled shifts that are positive	Auxiliary	dmnl
$P_{sched,pos} = S_{sched} \times (1 - E_{demand}) \times Eff_{under} \times Eff_{demand,pos}$		

Variable	Type	Unit
Effect of task demand on positivity of shift	Auxiliary	dmnl
$Eff_{demand,pos} = Eff_{demand,pos,lookup}(\frac{OTD_{shift}}{T_{threshold}})$		
Emotional demand during shifts	Auxiliary	dmnl
$E_{demand} = Eff_{distress,pos,lookup}(\frac{D_{total}}{D_{max}}) \times Eff_{match,pos,lookup}(M_{comp,depend})$		
Match between competency and patient dependency	Auxiliary	dmnl
$M_{comp,depend} = (\frac{PD_{avg}}{PD_{max}}) - (\frac{S_{comp}}{V_{max}})$		

C.3.2. Input variables

Variable	Base	Unit	Low/High boundary
Nurses initially scheduled $N_{sched,init}$	60	nurses	40/80
Time of negative shift memory to fade $T_{neg,fade}$	6	weeks	2/12
Time of positive shifts memory to fade $T_{pos,fade}$	6	weeks	2/12
Perception of extra shifts P_{extra}	0.4	dmnl	0/1
Initial willingness to be flexible $W_{flex,init}$	1	shifts/nurse/Week	0/1
Satisfaction with scheduling S_{sched}	0.8	dmnl	0/1
Threshold for busy shift $T_{threshold}$	8	hours/shift/Week	4/12

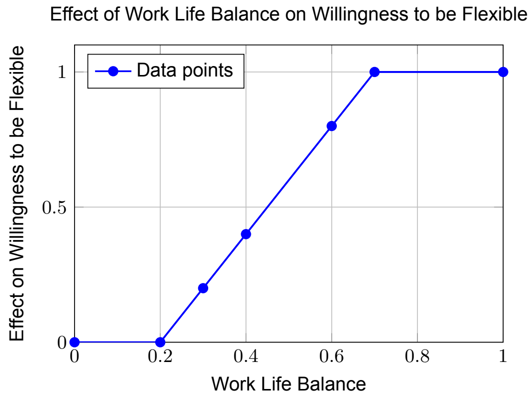
C.3.3. Lookups



Team Cohesion	Willingness Effect
0.0	0.20
0.2	0.60
0.4	0.80
0.6	0.95
0.7	1.00
1.0	1.00

Figure C.4: Effect of Team Cohesion on Willingness to be Flexible Lookup

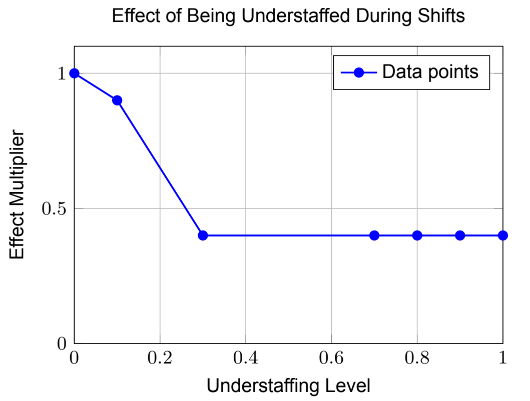
This lookup captures the influence of team cohesion on nurses' willingness to be flexible, with a threshold set at 0.7. Above this value, flexibility remains relatively stable and high, indicating that nurses are generally inclined to take on additional work regardless of the precise level of team cohesion. Below the 0.7 threshold, however, the function follows a downward-sloping trajectory, illustrating that declining cohesion increasingly undermines willingness to be flexible. This pattern aligns with findings from Group Model Building sessions, which suggested that while nurses are highly committed to supporting care delivery, poor team dynamics can eventually decrease their motivation to step in to help.



Work Life Balance	Willingness Effect
0.0	0.00
0.2	0.00
0.3	0.20
0.4	0.40
0.6	0.80
0.7	1.00
1.0	1.00

Figure C.5: Effect of Work Life Balance on Willingness to be Flexible Lookup

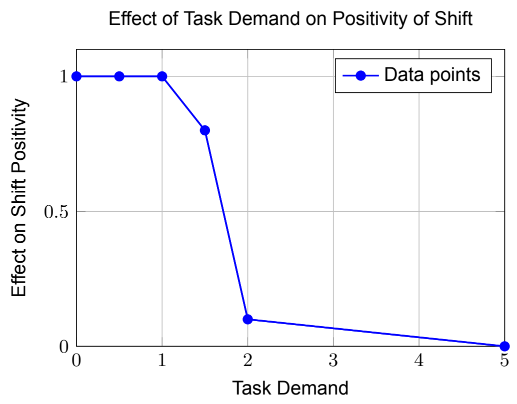
This lookup models the effect of work-life balance on nurses' willingness to be flexible, characterized by a steep S-curve with a sharp decline toward zero willingness. The function is bounded by a lower threshold at 0.2 and an upper threshold at 0.7. Below this range, willingness to be flexible—such as filling in vacant shifts—drops off rapidly. This formulation is grounded in insights from the Group Model Building sessions, where participants consistently identified work-life balance as a critical determinant of flexibility. Accordingly, the model reflects a strong negative impact when work-life balance deteriorates, capturing the point at which personal strain outweighs professional commitment.



Understaffing Level	Effect Multiplier
0.0	1.00
0.1	0.90
0.3	0.40
0.7	0.40
0.8	0.40
0.9	0.40
1.0	0.40

Figure C.6: Effect of Being Understaffed During Shifts Lookup

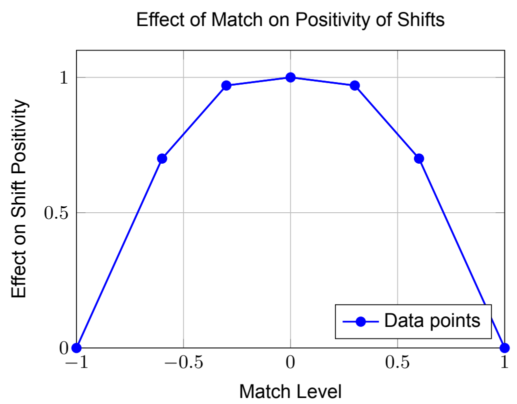
This lookup represents the impact of understaffing on the perceived positivity of shifts, with a lower threshold set at 0.4. The function is designed to decline rapidly as understaffing increases, capturing the strong negative response from nurses to vacant shifts. Once the 0.4 threshold is reached, the decline levels off, indicating that further understaffing does not proportionally worsen shift perception beyond a certain point. This modeling choice is based on input from the Group Model Building sessions, where understaffing was repeatedly cited as a major source of stress and dissatisfaction among nursing staff.



Task Demand	Positivity Effect
0.0	1.00
0.5	1.00
1.0	1.00
1.5	0.80
2.0	0.10
30.0	0.00

Figure C.7: Effect of Task Demand on Positivity of Shift Lookup

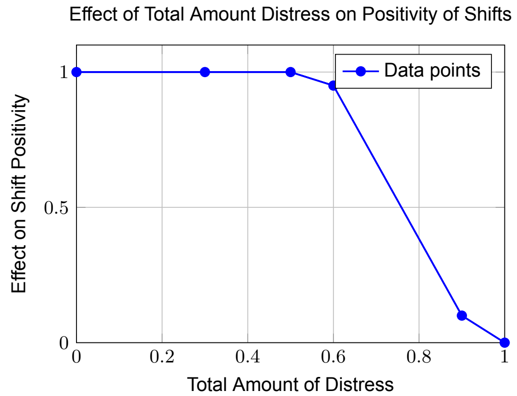
This lookup models the effect of objective task demand on positivity of shifts, with a steep downward slope beyond a critical threshold. As task demand increases—particularly up to a doubling of the baseline level—the negative impact escalates sharply. Beyond this point, however, the curve flattens, reflecting the reality that excessive workload reaches a saturation point where additional tasks no longer significantly worsen the subjective experience.



Match Level	Positivity Effect
-1.0	0.00
-0.6	0.70
-0.3	0.97
0.0	1.00
0.3	0.97
0.6	0.70
1.0	0.00

Figure C.8: Effect of Match on Positivity of Shifts Lookup

This lookup illustrates the effect of the alignment between nurse competency and patient dependency on the perceived positivity of shifts. The relationship follows an S-shaped curve, where the greatest mismatches—either due to overqualification or underqualification relative to patient care needs—have the most pronounced impact. These occur at the outer ends of the curve. In contrast, when there is a moderate alignment between competency and care complexity, the marginal impact on shift positivity is less significant. This reflects the understanding that both underutilization and overextension can detract from shift satisfaction, whereas a well-matched workload supports a more positive experience.



Distress Amount	Positivity Effect
0.0	1.00
0.3	1.00
0.5	1.00
0.6	0.95
0.9	0.10
1.0	0.00

Figure C.9: Effect of Total Amount Distress on Positivity of Shifts Lookup

This lookup models the effect of stress levels on the perceived positivity of shifts. A threshold is set at 0.5, below which stress does not significantly impact shift perception. However, once stress exceeds this level, there is a sharp decline in shift positivity. This reflects the understanding that moderate stress may be manageable or even motivating, but beyond a certain point, it becomes detrimental to the overall experience of the shift.

C.4. Nurses subsystem

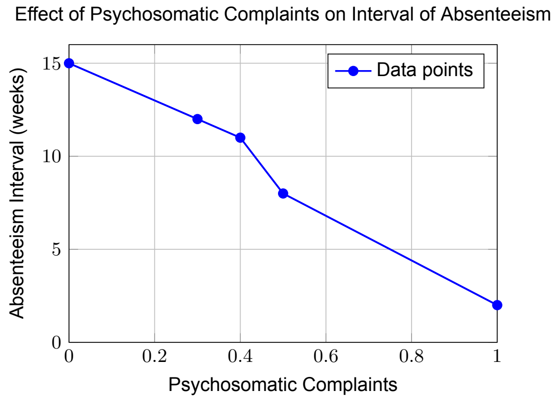
C.4.1. Main variables

Variable	Type	Unit
Number of nurses available	Stock	nurses
$N_{present} = \int_0^t (-A_{long,flow} - N_{leave})\,dt + N_{present,init}$		
Long term absenteeism flow	Flow	nurses/Week
$A_{long,flow} = A_{long,pulse}$		
Nurses leaving the profession	Outflow	nurses/Week
$N_{leave} = N_{leave,pulse}$		
Long Term Absenteeism	Stock	nurses
$A_{long} = \int_0^t A_{long,flow}\,dt$		
Initial number of nurses available	Auxiliary	nurses
$N_{present,init} = N_{sched,init} - A_{short}$		
Interval of nurses absent long term	Auxiliary	weeks
$I_{absent,long} = Eff_{psych,absent}(\frac{P_{complaints}}{V_{max}})$		
Long term absenteeism pulse	Auxiliary	nurses/Week
$A_{long,pulse} =$ IF THEN ELSE$(P_{complaints} > P_{threshold},$ (PULSE TRAIN$(T_{init}, T_{step}, I_{absent,long}, T_{final}) \times (\frac{N_{interval}}{T_{step}})), 0)$		
Nurses leaving pulse	Auxiliary	nurses/Week
$N_{leave,pulse} =$ IF THEN ELSE$(I_{stay} < I_{leave,threshold},$ (PULSE TRAIN$(T_{init}, T_{step}, I_{leave}, T_{final}) \times (\frac{N_{interval}}{T_{step}})), 0)$		
Interval of nurses leaving the profession	Auxiliary	weeks
$I_{leave} = Eff_{stay,leave,lookup}(\frac{I_{stay}}{V_{max}})$		

C.4.2. Input variables

Variable	Base	Unit	Low/High boundary
Short term absenteeism A_{short}	2	nurses	0/10
Psychosomatic complaints to long term absenteeism threshold $P_{threshold}$	0.3	vas	0/1
Intention to actually leaving threshold $I_{leave,threshold}$	0.5	vas	0/1

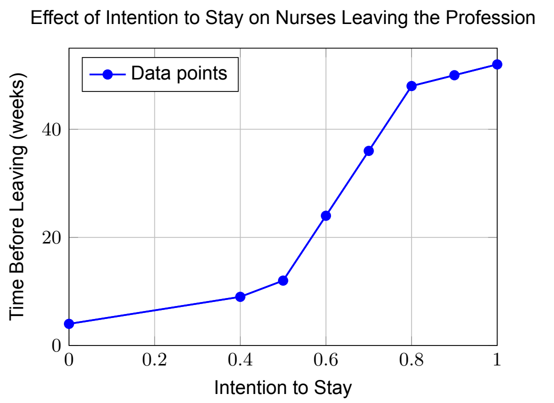
C.4.3. Lookups



Psychosomatic Complaints	Absenteeism Interval (weeks)
0.0	15
0.3	12
0.4	11
0.5	8
1.0	2

Figure C.10: Effect of Psychosomatic Complaints on Interval of Absenteeism Lookup

This lookup returns the expected interval of absenteeism, in weeks, as a function of psychosomatic complaints. It is primarily designed to facilitate unit conversion and to represent a nonlinear relationship between psychosomatic symptom severity and long term absenteeism. Importantly, the function does not imply that all nurses will experience a fixed absenteeism interval (e.g., 15 weeks) in the absence of complaints. Instead, actual absenteeism still depends on whether a defined threshold of complaints is exceeded, serving as a conditional trigger for the effect to manifest.



Intention to Stay	Time Before Leaving (weeks)
0.0	4
0.4	9
0.5	12
0.6	24
0.7	36
0.8	48
0.9	50
1.0	52

Figure C.11: Effect of Intention to Stay on Nurses Leaving the Profession Lookup

This lookup is adapted for similar purposes as the preceding one: to enable unit conversion and to represent a nonlinear relationship—this time in the context of intention to stay. Since intention to stay is a positively framed variable, the function is oriented in the opposite direction. An S-shaped curve has been adopted to reflect the idea that, beyond a certain threshold, increases in intention to stay are associated with disproportionately longer expected retention intervals. This allows for a more realistic modeling of marginal gains in retention once nurses express a strong commitment to remaining in their role.

C.5. Stress subsystem

C.5.1. Main variables

Variable	Type	Unit
Shift balance	Auxiliary	dmnl
$S_{balance} = \frac{S_{pos}}{S_{neg}}$		
Total effect on emotional distress	Auxiliary	dmnl
$E_{total} = \frac{Eff_{absent,emodist} + Eff_{balance,emodist}(S_{balance})}{2}$		
Effect of long term absenteeism on emotional distress	Auxiliary	dmnl
$Eff_{absent,emodist} = Eff_{absent,emodist,lookup}(\frac{A_{long}}{N_{sched,init}})$		
Increase of emotional distress	Inflow	vas/Week
$I_{emodist} = E_{total} \times (1 - \frac{E_{distress}}{D_{max}}) \times I_{emodist,norm}$		
Emotional distress	Stock	vas
$E_{distress} = \int_0^t (I_{emodist} - C_{deperson} - D_{emodist})\, dt + E_{distress,init}$		
Decrease of emotional distress	Outflow	vas/Week
$D_{emodist} = \frac{\text{DELAY1}((1-P_{complaints}), T_{psych,effect})}{T_{psych,effect}} \times Eff_{control,emodist} \times Eff_{cohesion,emodist} \times (1 - \frac{E_{distress}}{D_{max}})$		
Effect of job control on emotional distress	Auxiliary	dmnl
$Eff_{control,emodist} = Eff_{control,emodist,lookup}(\frac{J_{control}}{V_{max}})$		
Effect of team cohesion on emotional distress	Auxiliary	dmnl
$Eff_{cohesion,emodist} = Eff_{cohesion,destress,lookup}(\frac{T_{cohesion}}{V_{max}})$		
Coping through depersonalization	Auxiliary	vas/Week
$C_{deperson} = \min(E_{distress} \times C_{emodist}, (1 - D_{person}) \times C_{emodist})$		
Depersonalization	Stock	vas
$D_{person} = \int_0^t (C_{deperson} + I_{deperson} - D_{deperson})\, dt$		
Increase of depersonalization	Inflow	vas/Week
$I_{deperson} = Eff_{adversity,deperson} \times Eff_{moral,deperson} \times I_{deperson,norm} \times (1 - \frac{D_{person}}{D_{max}})$		
Decrease of depersonalization	Outflow	vas/Week
$D_{deperson} = \frac{D_{person}}{D_{max}} \times D_{deperson,norm}$		
Effect of moral distress on depersonalization	Auxiliary	dmnl
$Eff_{moral,deperson} = Eff_{moral,deperson,lookup}(\frac{\text{DELAY1}(D_{moral}, T_{moral,deperson})}{D_{max}})$		
Effect of workplace positivity on depersonalization	Auxiliary	dmnl
$Eff_{adversity,deperson} = Eff_{adversity,deperson,lookup}(\frac{W_{positivity}}{V_{max}})$		
Workplace positivity	Auxiliary	vas
$W_{positivity} = (1 - w_{safe,adversity}) \times I_{positive} + w_{safe,adversity} \times A_{safe}$		
Positive interpersonal interactions	Auxiliary	vas
$I_{positive} = \frac{w_{team,interact} \times T_{cohesion} + w_{interact,outside} \times I_{outside} + w_{safe,interact} \times A_{safe}}{w_{safe,interact} + w_{interact,outside} + w_{team,interact}}$		
Job satisfaction	Auxiliary	vas
$J_{sat} = \frac{w_{psych,sat} \times (1-P_{complaints}) + w_{positivity,sat} \times W_{positivity} + w_{control,sat} \times J_{control} + S_{ratio} \times w_{ratio,sat}}{w_{psych,sat} + w_{control,sat} + w_{positivity,sat} + w_{ratio,sat}}$		
Satisfaction with ratio of direct and indirect care time	Auxiliary	vas
$S_{ratio} = Eff_{ratio,sat,lookup}(\frac{R_{ratio}}{R_{preferred}})$		
Intention to stay in the profession	Auxiliary	vas

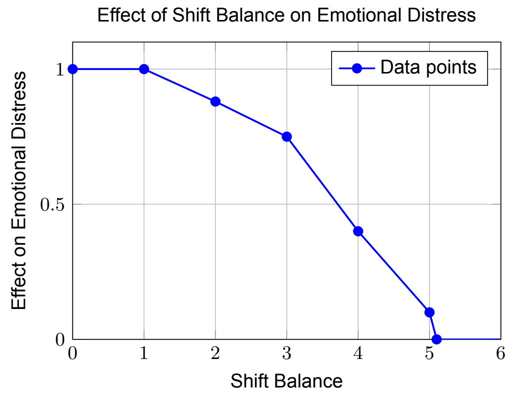
Variable	Type	Unit
$I_{stay} = \frac{w_{balance,stay} \times W_{balance} + w_{career,stay} \times C_{met} + w_{sat,stay} \times J_{sat}}{w_{career,stay} + w_{sat,stay} + w_{balance,stay}}$		
Psychosomatic complaints	Stock	vas
$P_{complaints} = \int_0^t (I_{psych} - D_{psych})\, dt$		
Increase of psychosomatic complaints	Inflow	vas/Week
$I_{psych} = \frac{\text{DELAY1}(D_{total}, T_{stress,physical})}{T_{stress,physical}} \times (1 - \frac{P_{complaints}}{D_{max}})$		
Decrease of psychosomatic complaints	Outflow	vas/Week
$D_{psych} = A_{rest}$		
Ability to physically rest in between shifts	Auxiliary	vas/Week
$A_{rest} = \text{IF THEN ELSE}(P_{complaints} > 0, \min(P_{rest,reduces} \times P_{complaints}, 0.05), 0)$		
Ability to deliver safe care	Auxiliary	vas
$A_{safe} = J_{control} \times Eff_{match,safe}(M_{comp,depend}) \times Eff_{demand,safe}$		
Effect of task demand per shift on ability to deliver safe care	Auxiliary	dmnl
$Eff_{demand,safe} = Eff_{demand,safe,lookup}(\frac{OTD_{shift}}{T_{threshold}})$		
Effect of ability to deliver safe care on moral distress	Auxiliary	dmnl
$Eff_{safe,moral} = Eff_{safe,moral,lookup}(\frac{A_{safe}}{V_{max}})$		
Increase of moral distress	Inflow	vas/Week
$I_{moral} = I_{moral,norm} \times (1 - \frac{D_{moral}}{D_{max}}) \times Eff_{safe,moral}$		
Moral distress	Stock	vas
$D_{moral} = \int_0^t (I_{moral} - D_{moral})\, dt$		
Decrease of moral distress	Outflow	vas/Week
$D_{moral} = \frac{D_{moral}}{D_{max}} \times Eff_{affirm,moral} \times \frac{\text{DELAY1}(1 - P_{complaints}, T_{psych,effect})}{T_{psych,effect}}$		
Effect of affirmation on moral distress	Auxiliary	dmnl
$Eff_{affirm,moral} = Eff_{affirm,moral,lookup}(\frac{A_{affirm}}{V_{max}})$		
Affirmation for decisions from team	Auxiliary	vas
$A_{affirm} = (1 - w_{lead,affirm}) \times O_{consult} + w_{lead,affirm} \times L_{support}$		
Task performance based on stress level	Auxiliary	dmnl
$T_{performance} = Eff_{distress,perf,lookup}(\frac{D_{total}}{D_{max}})$		
Eustress	Auxiliary	vas
$E_{eu} = (1 - w_{success,eustress}) \times \frac{N_{resilience} + T_{resilience}}{2} + w_{success,eustress} \times S_{interventions}$		

C.5.2. Input variables

Variable	Base	Unit	Low/High boundary
Normal increase of emotional distress $I_{emodist,norm}$	0.5	vas/Week	0/1
Initial emotional distress level $E_{distress,init}$	0.5	vas	0/1
Time for psychosomatic complaints to have effect on stress $T_{psych,effect}$	2	weeks	2/12
Coping with emotional distress through depersonalization $C_{emodist}$	0.1	dmnl/Week	0/1
Normal increase of depersonalization rate $I_{deperson,norm}$	0.8	vas/Week	0/1
Normal decrease of depersonalization $D_{deperson,norm}$	0.1	vas/Week	0/1

Variable	Base	Unit	Low/High boundary
Time that moral distress leads to depersonalization $T_{moral,deperson}$	8	weeks	2/12
Weight of ability to deliver safe care in workplace positivity $w_{safe,adversity}$	0.4	dmnl	0/1
Weight of team cohesion in positive interactions $w_{team,interact}$	0.7	dmnl	0/1
Interactions with colleagues outside of nursing team $I_{outnursingteam}$	0.7	vas	0/1
Weight of interactions outside team in positive interactions $w_{interact,outside}$	0.2	dmnl	0/1
Weight of ability to deliver safe care positive interactions $w_{safe,interact}$	0.1	dmnl	0/1
Preferred ratio of direct and indirect care time $R_{preferred}$	0.36	dmnl	0.1/2
Weight of job control in job satisfaction $w_{control,sat}$	0.2	dmnl	0/1
Weight of workplace positivity in job satisfaction $w_{positivity,sat}$	0.2	dmnl	0/1
Weight of psychosomatic complaints in job satisfaction $w_{psych,sat}$	0.4	dmnl	0/1
Weight of satisfaction with ratio in job satisfaction $w_{ratio,sat}$	0.8	dmnl	0/1
Career expectation fulfillment C_{met}	0.8	vas	0/1
Weight of career in intention to stay $w_{career,stay}$	0.1	dmnl	0/1
Weight of work life balance in intention to stay $w_{balance,stay}$	0.5	dmnl	0/1
Weight of job satisfaction in intention to stay $w_{sat,stay}$	0.4	dmnl	0/1
Time that stress turns into physical complaints $T_{stress,physical}$	8	Week	2/12
Percentage that resting reduces psychosomatic complaints $P_{rest,reduces}$	0.1	dmnl/Week	0/1
Normal increase of moral distress $I_{moral,norm}$	0.5	vas/Week	0/1
Weight of supportive leadership in affirmation for decisions $w_{lead,affirm}$	0.3	dmnl	0/1
Weight of eustress in total amount of distress $w_{eustress,distress}$	0.2	dmnl	0/1
Weight of success of interventions in eustress $w_{success,eustress}$	0.1	dmnl	0/1

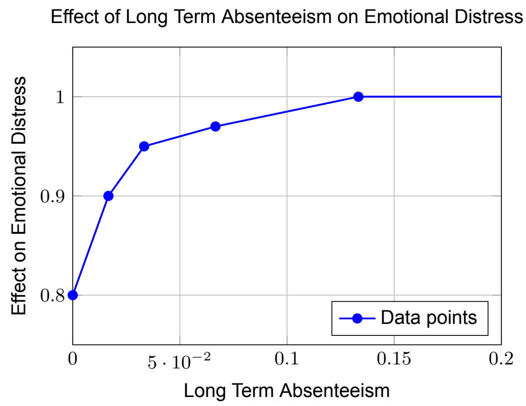
C.5.3. Lookups



Shift Balance	Emotional Distress Effect
0.0	1.00
1.0	1.00
2.0	0.88
3.0	0.75
4.0	0.40
5.0	0.10
5.1	0.00
10.0	0.00

Figure C.12: Effect of Shift Balance on Emotional Distress Lookup

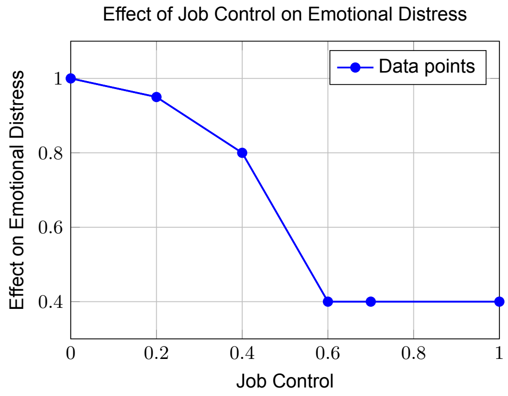
The shift balance variable reflects the ratio of positive to negative shifts and its influence on emotional distress. The lookup function is constructed such that no additional emotional distress occurs when there is a ratio of at least 5 positive shifts for every 1 negative shift. Beyond this threshold, the function follows an upward-sloping trajectory, indicating that a worsening balance—i.e., an increasing proportion of negative shifts—leads to a progressively larger increase in emotional distress. This approach captures the cumulative emotional toll of repeated negative experiences at work, particularly when not buffered by a sufficient number of positive shifts.



Long Term Absenteeism	Emotional Distress Effect
0.0000	0.80
0.0167	0.90
0.0333	0.95
0.0666	0.97
0.1333	1.00
1.0000	1.00

Figure C.13: Effect of Long Term Absenteeism on Emotional Distress Lookup

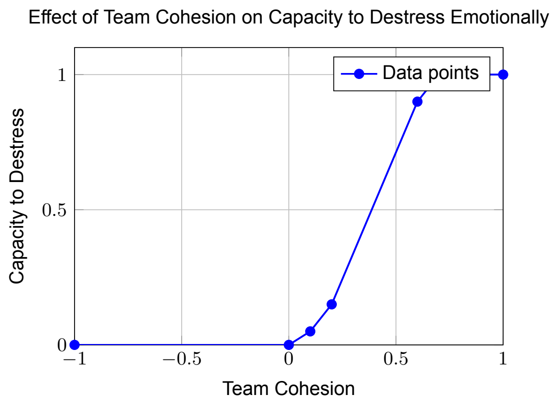
This effect is modeled as a mild influence, intended to represent an increase in self-awareness rather than a direct rise in emotional distress. The lower bound is set at 0.8, reflecting that only at relatively high levels does this factor begin to affect emotional outcomes. Rather than contributing to heightened distress, the effect slightly dampens the overall increase in emotional strain. This reflects the idea that nurses may not initially be fully conscious of the implications of their stress levels, and that a growing awareness may actually cause more feelings of stress.



Job Control	Emotional Distress Effect
0.0	1.00
0.2	0.95
0.4	0.80
0.6	0.40
0.7	0.40
1.0	0.40

Figure C.14: Effect of Job Control on Emotional Distress Lookup

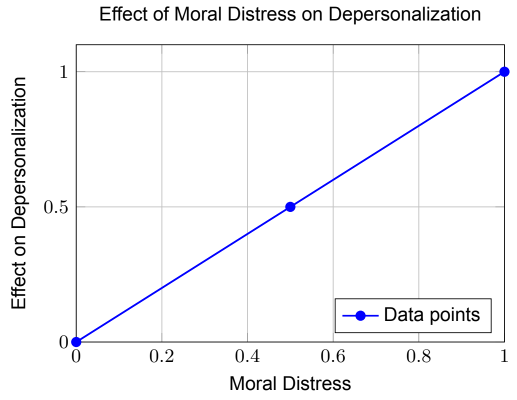
This lookup models the effect of job control on emotional distress, framing job control as a psychological buffer. When job control is absent or very low, there is a substantial increase in emotional distress, reflecting the detrimental impact of perceived helplessness in the work environment. However, once job control exceeds the threshold of 0.6, it steadily mitigates emotional distress. In this way, job control functions as a moderating factor, where greater autonomy and decision-making capacity help protect against the emotional consequences of workplace stressors.



Team Cohesion	Capacity to Destress
-1.0	0.00
0.0	0.00
0.1	0.05
0.2	0.15
0.6	0.90
0.7	1.00
1.0	1.00

Figure C.15: Effect of Team Cohesion on Capacity to Destress Emotionally Lookup

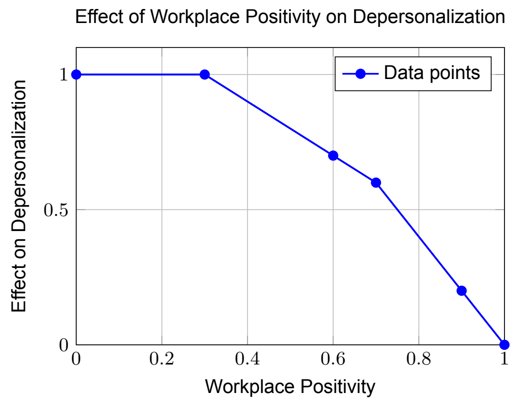
This lookup represents the effect of team cohesion on the capacity to destress, modeled as an S-shaped curve. A threshold is set at 0.7, above which increases in team cohesion significantly enhance the ability of nurses to recover from stress. Below this threshold, the effect is minimal, suggesting that only sufficiently cohesive teams provide the psychological safety and interpersonal support necessary for effective stress recovery. This formulation captures the role of social connectedness as a facilitator of emotional resilience within the workplace.



Moral Distress	Depersonalization Effect
0.0	0.00
0.5	0.50
1.0	1.00

Figure C.16: Effect of Moral Distress on Depersonalization Lookup

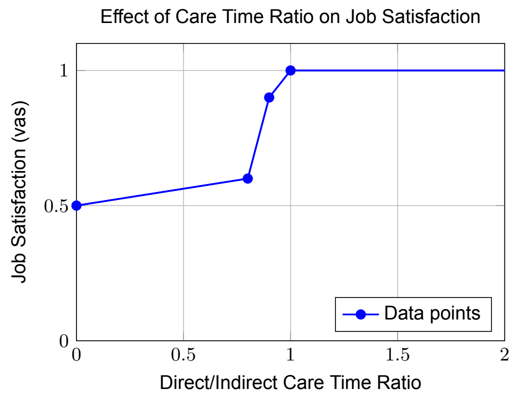
This effect is modeled as linear and is included to allow for a potential lookup sensitivity analysis.



Workplace Positivity	Depersonalization Effect
0.0	1.00
0.3	1.00
0.6	0.70
0.7	0.60
0.9	0.20
1.0	0.00

Figure C.17: Effect of Workplace Positivity on Depersonalization Lookup

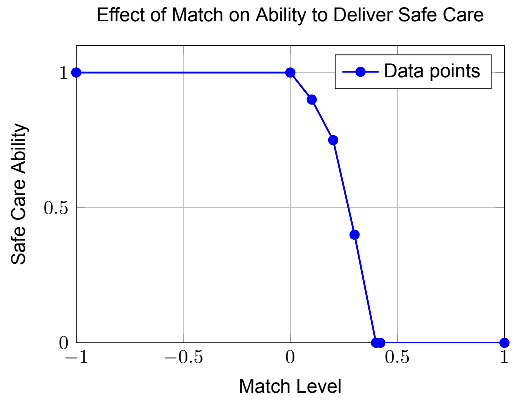
Workplace positivity has a strong effect on depersonalization, reflecting the importance of positive interactions for staying connected to oneself. Below a threshold of 0.3, this effect remains constant. However, once depersonalization drops below 1, the effect rapidly declines, showing that as nurses become more disconnected, workplace positivity has less of an impact.



Care Time Ratio	Job Satisfaction
0.0	0.50
0.8	0.60
0.9	0.90
1.0	1.00
6.0	1.00

Figure C.18: Effect of Ratio of Direct and Indirect Care Time on Job Satisfaction Lookup

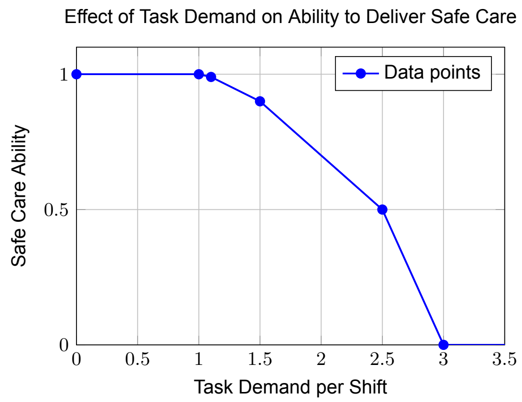
This lookup shows a sharp S-curve for the effect of the ratio of direct to indirect care time on job satisfaction. When the ratio approaches 0, the score levels off at 0.5. The biggest decline in satisfaction occurs between a ratio of 1.0 and 0.8. Beyond this point, the imbalance is considered so extreme that the marginal effect on job satisfaction becomes smaller. Nurses are happiest when the ratio is 1:1, with equal amounts of direct and indirect care time.



Match Level	Safe Care Ability
-1.0	1.00
0.0	1.00
0.1	0.90
0.2	0.75
0.3	0.40
0.4	0.00
0.42	0.00
1.0	0.00

Figure C.19: Effect of Match on Ability to Deliver Safe Care Lookup

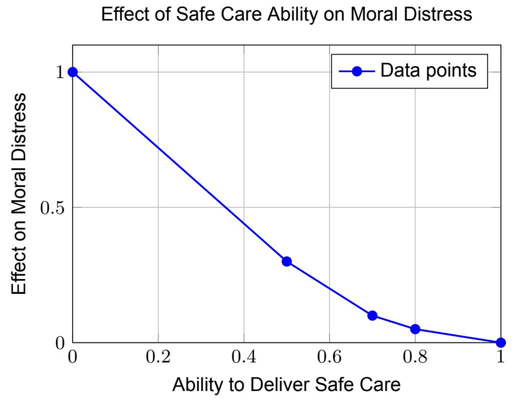
A negative value indicates that nurses are more competent than the complexity of care requires. However, once the value becomes positive, the ability to deliver safe care declines quickly, reaching zero at a level of 0.4. Beyond this point, the ability to deliver safe care is considered to be zero.



Task Demand	Safe Care Ability
0.0	1.00
1.0	1.00
1.1	0.99
1.5	0.90
2.5	0.50
3.0	0.00
40.0	0.00

Figure C.20: Effect of Task Demand per Shift on Ability to Deliver Safe Care Lookup

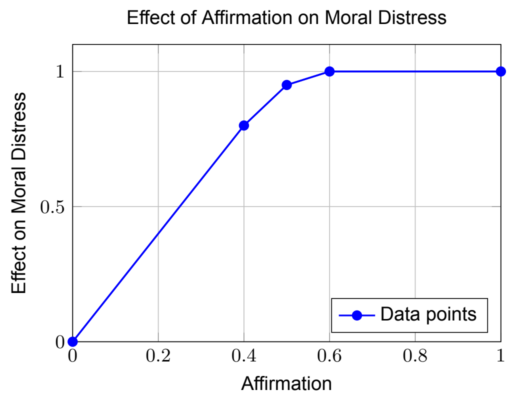
The effect of task demand has a threshold of 1, meaning that the hours of work align with the expected workload. This lookup shows that nurses are willing to work hard and take on extra tasks, as reflected by the low impact of 1.5 times the expected task demand—especially when it comes to patient safety. However, once task demand exceeds this point, it becomes increasingly difficult to deliver safe care, causing the effect to drop sharply



Safe Care Ability	Moral Distress Effect
0.0	1.00
0.5	0.30
0.7	0.10
0.8	0.05
1.0	0.00

Figure C.21: Effect of Ability to Deliver Safe Care on Moral Distress Lookup

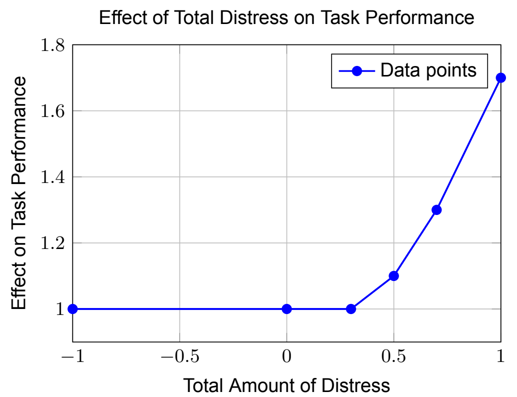
The effect of the ability to deliver safe care is modeled as a downward-sloping curve (if you flip the graph). When the ability to deliver safe care is high, the impact on moral distress is low. However, as the ability to deliver safe care decreases, moral distress increases more sharply.



Affirmation	Moral Distress Effect
0.0	0.00
0.4	0.80
0.5	0.95
0.6	1.00
1.0	1.00

Figure C.22: Effect of Affirmation on Moral Distress Lookup

Affirmation from the team helps reduce moral distress, with a threshold set at 0.6. This indicates that nurses don't require constant affirmation. Beyond this threshold, the effect steeply declines, showing that a lack of team support causes significant stress. However, nurses don't need excessive affirmation to maintain lower levels of distress.



Total Distress	Task Performance Effect
-1.0	1.00
0.0	1.00
0.3	1.00
0.5	1.10
0.7	1.30
1.0	1.70

Figure C.23: Effect of Total Amount of Distress on Task Performance Lookup

The total amount of distress has a strong impact on a nurse's individual task performance. A threshold of 0.3 is set for any effect to occur, and after 0.5, task performance declines sharply as distress increases.

C.6. Team subsystem

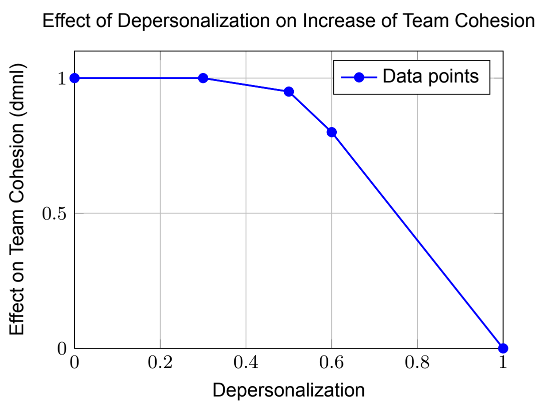
C.6.1. Main variables

Variable	Type	Unit
Team cohesion	Stock	vas
$T_{cohesion} = \int_0^t (I_{cohesion} - D_{cohesion})\, dt + T_{trust}$		
Increase in team cohesion	Inflow	vas/Week
$I_{cohesion} = R_{cohesion,norm} \times Eff_{deperson,cohesion} \times (1 - \frac{T_{cohesion}}{V_{max}})$		
Effect of depersonalization on increase of team cohesion	Auxiliary	dmnl
$Eff_{deperson,cohesion} = Eff_{deperson,cohesion,lookup}(\frac{D_{person}}{V_{max}})$		
Decrease in team cohesion	Outflow	vas/Week
$D_{cohesion} = T_{cohesion} \times L_{cohesion} \times (A_{long,flow} + N_{leave})$		
Team resilience	Auxiliary	vas
$T_{resilience} = w_{team,resilience} \times \max(T_{cohesion}, 0) + (1 - w_{team,resilience}) \times L_{support}$		
Team psychological safety	Auxiliary	vas
$T_{safety} = w_{team,safety} \times \max(T_{cohesion}, 0) + (1 - w_{team,safety}) \times L_{support}$		
Consultation opportunities with the team	Auxiliary	vas
$O_{consult} = T_{safety} \times \frac{M_{meet}}{T_{meet,max}}$		
Communication and training tasks	Auxiliary	minutes/patient
$T_{comm} = M_{meet} + T_{prof} + T_{students}$		
Time for professional development	Auxiliary	minutes/patient
$T_{prof} = Eff_{dev,time,lookup}(\frac{T_{develop}}{V_{max}})$		
Job control	Auxiliary	vas
$J_{control} = \frac{w_{consult,control} \times O_{consult} + w_{auto,control} \times D_{auto} + w_{skill,control} \times S_{comp}}{w_{consult,control} + w_{auto,control} + w_{skill,control}}$		
Decision making autonomy	Auxiliary	vas
$D_{auto} = w_{skill,auto} \times S_{comp} \times Eff_{exp,auto} + (1 - w_{skill,auto}) \times T_{safety}$		
Training and development	Auxiliary	vas
$T_{develop} = Eff_{lead,train,lookup}(\frac{L_{support}}{V_{max}})$		
Professional development	Inflow	vas/Week
$D_{prof} = \frac{\text{DELAY1}(T_{develop}, T_{train})}{T_{train}} \times (1 - \frac{S_{comp}}{V_{max}})$		
Skill mix and competency of nursing team	Stock	vas
$S_{comp} = \int_0^t (D_{prof} - D_{comp})\, dt + E_{edu}$		
Decrease of competency	Outflow	vas/Week
$D_{comp} = S_{comp} \times C_{lost} \times (A_{long,flow} + N_{leave})$		
Success of interventions	Auxiliary	vas
$S_{interventions} = S_{comp} \times S_{success} + (V_{max} \times S_{success})$		
Nurse resilience	Auxiliary	vas
$N_{resilience} = S_{comp} \times Eff_{exp,resilience} \times A_{destress}$		
Effect of experience on resilience	Auxiliary	dmnl
$Eff_{exp,resilience} = Eff_{exp,resilience,lookup}(\frac{E_{avg}}{E_{max}})$		
Effect of experience on decision making autonomy	Auxiliary	dmnl
$Eff_{exp,auto} = Eff_{exp,auto,lookup}(\frac{E_{avg}}{E_{max}})$		
Task efficiency from team organisation	Auxiliary	vas
$T_{efficiency} = w_{skill,efficiency} \times S_{comp} + (1 - w_{skill,efficiency}) \times O_{consult}$		

C.6.2. Input variables

Variable	Base	Unit	Low/High boundary
Normal rate of team cohesion $R_{cohesion,norm}$	0.3	vas/Week	0/1
Loss of team cohesion from nurses leaving $L_{cohesion}$	0.05	dmnl/nurse	0/0.1
Trust in other colleagues T_{trust}	0.9	vas	0/1
Weight of team cohesion in team resilience $w_{team,resilience}$	0.8	dmnl	0/1
Supportive leadership $L_{support}$	0.9	vas	0/1
Weight of team cohesion in team psychological safety $w_{team,safety}$	0.7	dmnl	0/1
Meetings M_{meet}	5	minutes/patient	1/15
Training students $T_{students}$	5	minutes/patient	2/10
Weight of consultation opportunities in job control $w_{consult,control}$	0.1	dmnl	0/1
Weight of decision making autonomy in job control $w_{auto,control}$	0.3	dmnl	0/1
Weight of skill mix and competency in job control $w_{skill,control}$	0.6	dmnl	0/1
Weight of skill mix and competency in decision making autonomy $w_{skill,auto}$	0.7	dmnl	0/1
Time before training is completed T_{train}	16	weeks	6/52
Education level of nurses E_{edu}	0.7	vas	0/1
Competency lost by nurses leaving C_{lost}	0.01	dmnl/nurse	0/0.1
Success of intervention determined by competency $S_{success}$	0.3	dmnl	0/1
Average experience of nurses E_{avg}	5	years	0/25
Weight of skill mix and competency in task efficiency $w_{skill,efficiency}$	0.6	dmnl	0/1

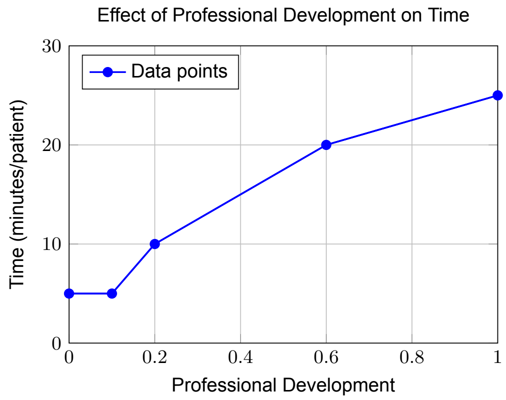
C.6.3. Lookups



Depersonalization	Effect on Team Cohesion
0.0	1.0
0.3	1.0
0.5	0.95
0.6	0.8
1.0	0.0

Figure C.24: Effect of Depersonalization on Increase of Team Cohesion Lookup

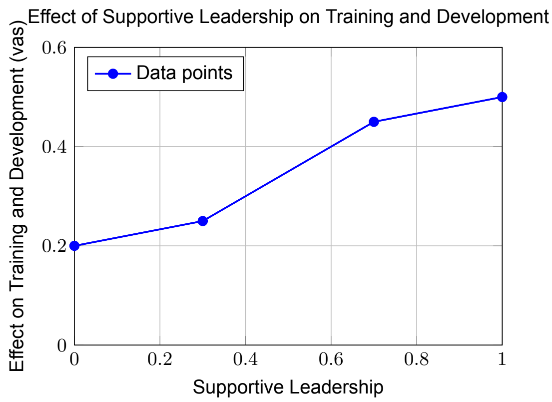
This lookup shows the effect of depersonalization on team cohesion. The threshold is set at 0.3—below that, the effect is still pretty minor. But once depersonalization really starts to build up, team cohesion drops off quickly. It reflects the idea that when emotional distance gets too strong, it starts to seriously affect how the team functions together.



Professional Development	Time (minutes/patient)
0.0	5
0.1	5
0.2	10
0.6	20
1.0	25

Figure C.25: Effect of Professional Development on Time Lookup

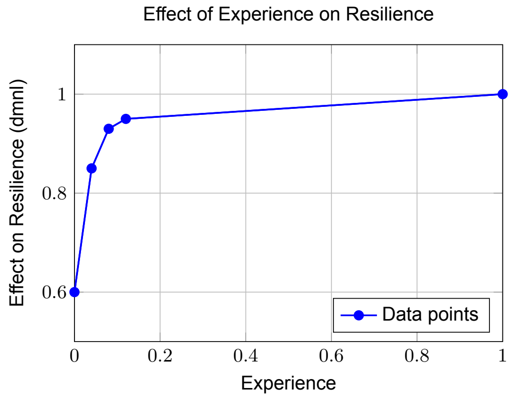
This lookup shows how Professional Development builds up into time spent per patient. It's mainly used to translate the level of Professional Development into objective task demand, as well as a slight curve in time it takes more in the low values of Professional Development.



Supportive Leadership	Effect on Training (vas)
0.0	0.2
0.3	0.25
0.7	0.45
1.0	0.5

Figure C.26: Effect of Supportive Leadership on Training and Development Lookup

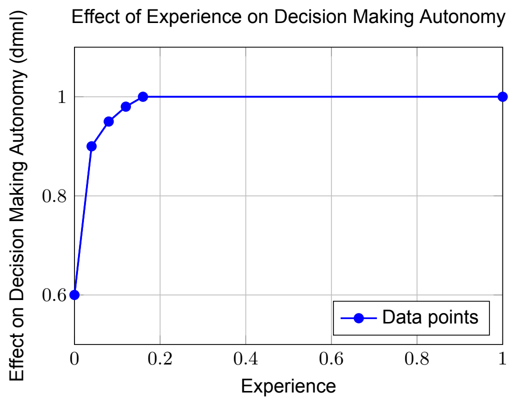
This lookup shows the slight S-curve effect of supportive leadership on training and development. The biggest impact happens in the middle—when leadership is mediocre, even a small change makes a difference. But if a leader is already very supportive or not supportive at all, it doesn't change the time spent on training and development much either way.



Experience	Effect on Resilience
0.0	0.6
0.04	0.85
0.08	0.93
0.12	0.95
1.0	1.0

Figure C.27: Effect of Experience on Resilience Lookup

This lookup shows how resilience builds quickly based on years of experience. As a nurse, you have to adapt fast—there's no slow buildup or soft landing. That's why we've used a steep curve that rises quickly and then flattens out near 1. It reflects how resilience becomes part of the job early on, as indicated by the nurses in the Group Model Building sessions.



Experience	Effect on Decision Autonomy
0.0	0.6
0.04	0.9
0.08	0.95
0.12	0.98
0.16	1.0
1.0	1.0

Figure C.28: Effect of Experience on Decision Making Autonomy Lookup

This lookup shows a minimal effect of experience on decision-making autonomy after the early years, with full autonomy reached around the 4-year mark. As was mentioned in the sessions, nurses are expected to start making decisions early in their careers, so autonomy builds up fast in this environment. That's why we chose a steep curve at the start that quickly levels off at 1.

C.7. Ability to destress subsystem

C.7.1. Main variables

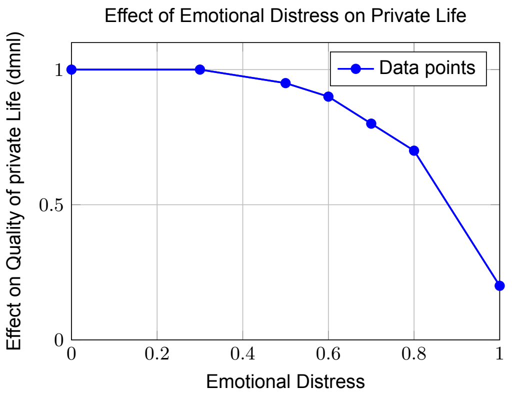
Variable	Type	Unit
Work life balance	Auxiliary	vas
$W_{balance} = L_{private} \times Eff_{emodist,priv}$		
Effect of emotional distress on private life	Auxiliary	dmnl
$Eff_{emodist,priv} = Eff_{emodist,priv,lookup}(\frac{E_{distress}}{D_{max}})$		
Effect of work life balance on ability to destress	Auxiliary	dmnl
$Eff_{balance,destress} = Eff_{balance,destress,lookup}(\frac{W_{balance}}{V_{max}})$		
Ability to destress	Stock	dmnl
$A_{destress} = \int_0^t (I_{destress} - D_{destress})\, dt + I_{destress,init}$		

Variable	Type	Unit
Increase in ability to destress	Inflow	dmnl/Week
$I_{destress} = A_{destress,norm} \times Eff_{balance,destress} \times (1 - A_{destress})$		
Decrease in ability to destress	Outflow	dmnl/Week
$D_{destress} = A_{destress,norm} \times Eff_{short,destress} \times A_{destress} \times Eff_{psych,destress}$		
Effect of psychosomatic complaints on ability to destress	Auxiliary	dmnl
$Eff_{psych,destress} = Eff_{psych,destress,lookup}(\frac{P_{complaints}}{D_{max}})$		
Effect of short term absenteeism on ability to destress	Auxiliary	dmnl
$Eff_{short,destress} = Eff_{short,destress,lookup}(\frac{A_{short}}{N_{sched,init}})$		

C.7.2. Input variables

Variable	Base	Unit	Low/High boundary
Quality of private life $L_{private}$	0.8	vas	0/1
Initial ability to destress $I_{destress,init}$	0.8	dmnl	0/1
Normal ability to destress $A_{destress,norm}$	0.1	dmnl/Week	0/1

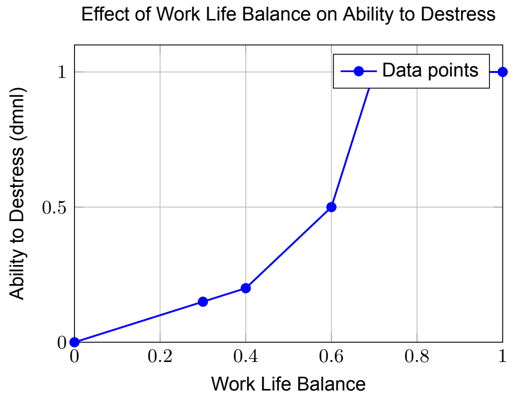
C.7.3. Lookups



Emotional Distress	Effect on Quality of private Life
0.0	1.0
0.3	1.0
0.5	0.95
0.6	0.9
0.7	0.8
0.8	0.7
1.0	0.2

Figure C.29: Effect of Emotional Distress on Quality of private Life Lookup

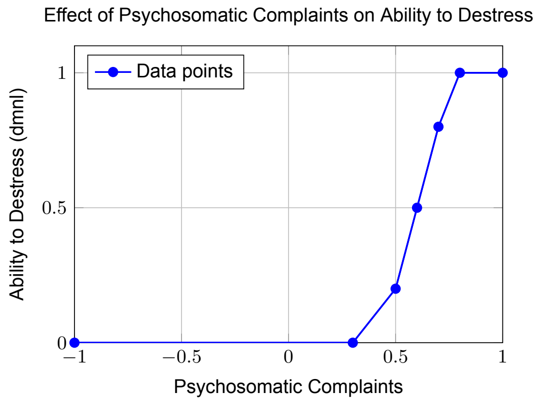
This relationship between emotional distress and the ability to leave work stress at work comes from what nurses shared during the sessions. When emotional distress is low, it's usually manageable and doesn't carry over into home life. But once it builds up, it quickly becomes harder to shake off. That's why we set a threshold at 0.3 and made the curve drop off steeply after distress hits 0.8.



Work Life Balance	Ability to Destress
0.0	0.0
0.3	0.15
0.4	0.2
0.6	0.5
0.7	1.0
1.0	1.0

Figure C.30: Effect of Work Life Balance on Ability to Destress Lookup

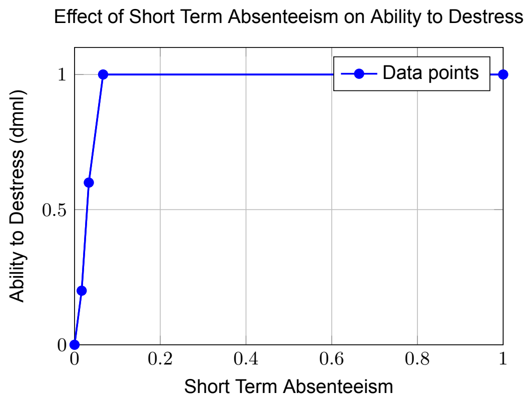
Work life balance was highlighted as an important factor in how well nurses are able to destress during their time off. We set a threshold at 0.7, and after that point, the curve drops sharply. This reflects the strong effect that was mentioned—when work life balance starts to fall apart, it quickly gets harder for nurses to recover outside of work.



Psychosomatic Complaints	Ability to Destress
-1.0	0.0
0.3	0.0
0.5	0.2
0.6	0.5
0.7	0.8
0.8	1.0
1.0	1.0

Figure C.31: Effect of Psychosomatic Complaints on Ability to Destress Lookup

Psychosomatic complaints start to affect the ability to destress once they pass a threshold of 0.3. The curve has a steep S-shape and reaches 1 at around 0.8, showing that a high number of complaints really hinders recovery. This shape reflects that physical symptoms are often a result of sustained distress—and once they show up, they make it much harder to actually unwind and recover, both mentally and physically.



Short Term Absenteeism	Ability to Destress
0.0	0.0
0.01666	0.2
0.03333	0.6
0.06666	1.0
1.0	1.0

Figure C.32: Effect of Short Term Absenteeism on Ability to Destress Lookup

Short-term absenteeism has a strong effect on the ability to destress, mainly because the work app often goes off during time off, asking nurses to fill in shifts. As a result, even low levels of absenteeism cause a sharp decrease in the ability to truly unwind.