Nursing Workload Balancing: Lean Healthcare, Analytics and Optimization in two Latin American University Hospitals

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Abstract

In most Latin American hospitals, the workload assignment of healthcare workers is a crucial process. These strategies seek to improve the level of patient care and safety while avoiding incurring unnecessary costs by hiring and maintaining excessive staff. The distribution of activities falls to the chief nurses in the hospital, taking as criteria for allocation the number of patients rather than the complexity of care that each individual carries. Specifically for the inpatient area and for nursing professionals, it is complex to determine an adequate distribution of human resources, considering the diagnosis of the patients and the number of tasks that a nursing professional must carry out throughout the day. Therefore, this work proposes the development of a strategy and a load-balancing model based on lean healthcare theory, analytics, and mathematical optimization, so that working hours do not result in the generation of stress and the presence of burnout in nurses. Likewise, mathematical modelling maximizes the use of the nursing staff's capacity, generating awareness based on the integration of continuous improvement theories so that the clinics can be updated to technological trends. Finally, this project is part of a macro-project for the development of technologies that support hospital nursing processes, carried out by the Universidad de La Sabana Clinic in Colombia and the Universidad de los Andes Clinic in Chile, so the results of this project impact two clinics in Latin America.

Key words: Hospital logistics, Nursing Scheduling Problem, Mixed integer linear programming, Lean Healthcare, Analytics.

Resumen

En la mayoría de los hospitales latinoamericanos, la asignación de carga laboral al personal de la salud es un proceso de vital importancia. Estas estrategias buscan mejorar el nivel de atención al paciente y la seguridad, sin tener que incurrir en gastos innecesarios por la contratación y manutención de un personal excesivo. Esto conlleva a la distribución de las actividades recae en los jefes de las áreas en el hospital, tomando como criterios de asignación la cantidad de pacientes y no la complejidad del cuidado que acarrea cada individuo. Específicamente para el área de hospitalización y para los profesionales de enfermería, resulta complejo determinar una distribución adecuada del recurso humano teniendo en cuenta el diagnóstico de los pacientes y la cantidad de tareas que debe realizar un profesional de enfermería a lo largo de su jornada. Por ello, este trabajo propone el desarrollo de una estrategia y un modelo de balanceo de carga a partir de la teoría lean healthcare, analítica y optimización matemática, de tal forma que las jornadas laborales no resulten en la generación de estrés y la presencia de burnout en los enfermeros. Así mismo, se logra maximizar el aprovechamiento de la capacidad del personal de enfermería, generando bases de concientización sobre la integración de teorías de mejora continua para que las clínicas puedan actualizarse a las tendencias tecnológicas. Por último, este proyecto se enmarcó en un macroproyecto para el desarrollo de tecnologías que soporten los procesos hospitalarios de enfermería, llevado a cabo por la Clínica Universidad de La Sabana en Colombia y la Clínica Universidad de los Andes en Chile, por lo que los resultados de este proyecto impactan dos clínicas en Latinoamérica.

Palabras Clave: Logística hospitalaria, Problema de programación de enfermería, Programación lineal entera mixta, Lean Healthcare, Analítica.

Table of contents

List of figures

List of tables

Chapter 1

INTRODUCTION

1.1 Problem definition and justification

Nursing, as well as many health and human care professions, is considered a major profession in safeguarding the optimal human condition and promoting good health care and healing processes. This profession also involves a greater sacrifice to be involved in the care and enhancement of the person, which results in the physical and psychological burnout of the professional [1]. According to the WHO, around 70% of the recovery activities fall on the nursing professional, and they are responsible for the process of accompanying patients once they have been assessed and/or diagnosed [2].

Over recent years, patient care has become a highly complex task, due to changes in the epidemiological profile with an increase in the number of patients with chronic conditions, in addition to the high cost of healthcare provided by institutions [3], [4]. Furthermore, this profession has been suffering a decline in the number of professionals prepared for the current challenges of care [5], [6], and a disparity in technological progress and the adoption of new methodologies for improvement in comparison to other fields that are more quantitative and futuristic in their focus [7], [8].

Nowadays, in Latin American clinics, there is no methodology or technology that enables the appropriate workload distribution for nurses, nor agreements that might allow the analysis of the challenges from a global perspective. In other words, a methodology applicable to diverse hospital contexts [2], [9]. Likewise, it is necessary to consider the long working shifts that can reach up to 12 continuous hours of work, which generate fatigue in the hospitals' human resources due to the high load level associated with a continuous increase in each patient's risk level [10], and which, jointly, ends up impacting the way patient care is provided and the level of effectiveness in the execution of the processes carried out by the nurses, such as change-of-shift, patient admission, patient assessment, medicines delivery, risk assessment, medication administration, medication registration, medical notes review, return of supplies and medicines, sharing, clinical history review, nursing notes, adverse events report, control and inventory of trolleys, basic needs assistance, specimen collection, patient discharge report, extemporaneous meals request, medical procedures assistance, attention to patients' or relatives' concerns, blood glucose monitoring, electrocardiography, vascular access, healing, management of medical requests, system patient discharge, fluid balance, preoperative preparation, nursing round, nursing discharge, patient, family or caregiver education [11], [12]. Apart from the consequences for the health system and the employees' condition, this represents cost overruns by generating reprocesses in the activities since most of them are manual and must be documented while being carried out [13], which gives a greater possibility of error if all the factors previously exposed are considered [14].

Considering the above, it is crucial to integrate disciplines such as nursing with engineering, as linking them enables new ideas to be explored and designed for the execution of intra-hospital processes, achieving the upgrading of techniques in clinics based on tools from industry and research. In addition, it makes it possible to implement continuous improvement strategies based on the identification of waste and critical activities, and the integration of optimization or predictive models for workload assignment within healthcare environments based on workload balancing using factors that disrupt the proper functioning of the hospital service [15], [16].

A multidisciplinary perspective can facilitate the approach and progress in the knowledge of these daily situations in healthcare institutions. Evidence of this can be found in a wide range of research, which, although it has not been possible to determine a suitable strategy for task assignment in hospitals, it has established a framework which, once integrated, can become a high-impact tool within a hospital system. Examples of this include: a) monitoring of the working environment and employee satisfaction for the generation of indicators and the assessment of staff turnover [17]; b) designing various cost models in specialties such as oncology. [18], pediatric [19], family health [20], etc., including staff-per-unit value calculations.

Additionally, it is important to bear in mind that in third world countries the adoption and implementation of these state-of-the-art methodologies is deficient, and thus represents a disadvantage compared to developed countries. On the other hand, it is possible to implement tools such as analytics, which make it possible to determine factors or attributes of great impact within a system, based on the historical behaviour of both nursing professionals and patients treated in the clinics. It also facilitates the detection of irregularities in the healthcare system based on the perceived workload of the professional nurse [21], in order to generate predictive models that incorporate clinical administrative management indicators and, at the same time, the level of care required by each patient in the facilities, as well as the nurse-to-patient ratio, aiming to follow the guideline suggested by the WHO.

Based on the previous information, the research question is: How to develop a workload assignment strategy in nursing, based on Lean Healthcare principles, mathematical and analytical programming, that reaches an adequate workload balance for nurses in the inpatient area, applicable to two Latin American hospitals?

1.2 Objectives

1.2.1 General Objective

To design a workload balancing strategy for nursing staff in the inpatient area, based on lean healthcare principles, optimization and analytics for two university hospitals in Latin America.

1.2.2 Specific Objectives

1. Explore 31 nursing care processes in the inpatient area from the Lean Healthcare and analytical methodology, identifying wastes, critical factors in care and the level of effectiveness in the activities carried out, based on the daily operational information of the nursing professionals in the inpatient area of the university hospitals analyzed.

2. Develop a mathematical model for labour time balancing in the inpatient service, based on wastes, activities and patient care factors identified as relevant, to support decision making in the management of nursing staff in the university hospitals analyzed.

3. Validate a workload assignment strategy for the execution of activities of nurses in the inpatient area of the university hospitals analyzed.

Chapter 2

CONCEPTUAL FRAMEWORK

The theory and methodologies proposed in the development of the project to propose a solution to the problem described above are presented below.

2.1 Theoretical Framework

2.1.1 Nursing Theory

According to the WHO, nursing is defined as the profession in charge of the primary, autonomous, and collaborative care of patients in a wide range of services offered by health institutions. Nurses have the ability to decide in some situations which do not suppose a risk to the patient's condition, in addition to being trained to teach their work and preventive services [2].

In the inpatient area, nurses act as the staff in charge of monitoring the patient's condition and performing in accordance with the medical orders issued during their medical evaluation. However, it should be noted that as there is a nursing assistant who supports the tasks carried out in the area, the main role of the nursing professional is to correctly manage the area to which he/she is assigned, establishing levels of prioritization in patient care, routes or plans for administering medication, monitoring incoming and discharged patients, and shift changes [22]. Therefore, although the professional's contact with the patient remains within the execution of the tasks, most of the contact falls to the nursing assistants, as they are directly responsible for attending to the basic needs of the patients and for carrying out constant monitoring, which is subsequently reported to the chief nurse.

2.1.2 Lean Healthcare

It is a methodology based on the adaptation of Lean theory to health systems (see figure 2.1), applying the principles of continuous improvement and reduction of waste generated or evidenced in the processes [23].
Such waste is defined as follows:

Fig. 2.1 Eight Wastes of Lean Theory [24]

- Overproduction: Doing more or earlier than necessary. In the service, this can be unnecessary tests or procedures, generation of additional reports, or graphs.
- Transportation: Movement of patients, samples, supplies, equipment, etc., that are not required.
- Inventory: Excess supplies, expired medicines, obsolete equipment.
- Waiting: Time for patient care, the release of beds and/or equipment, filling in documents, obtaining information, and consultation.
- Over-processing: Performing additional procedures that do not add any value to the execution of tasks.
- Defects: Medication errors, loss of supplies or equipment, missing or erroneous information, repetition of activities.
- Motion: Staff movements generated from any search, order, graph, medication, supply, or information.

- Human Potential: Non-use of staff's experience, knowledge, and creativity.

2.1.3 Workload Balance

Load balancing is defined as the allocation of a set of jobs to various agents acting on a system in order to complete various tasks that make up a production process or the operation of a service.

It also aims to guarantee the execution of activities in a continuous and connected flow, minimizing the stress that may be generated on any person in the process due to the excess or level of complexity of the programmed tasks [25].
This process is guided by 3 crucial conditions that will determine the way in which this analysis is approached:

- Quantity: The level of output or care required in a system to meet minimum standards of care within the system.
- Balance: The fairness between the times in which activities are carried out.
- Continuity: The uninterrupted flow of the system, which must be guaranteed by the correct management of inputs, schedules, locations, etc.

Once this has been established, cycle times, bottleneck detection, production rate and effectiveness, and other times considered important can be determined.

2.1.4 Mathematical Programming Modelling

Optimization is the activity in which a system or process is mathematically modeled on the basis of parameters, equations, restrictions, and variables, in order to find a configuration in which this process guarantees efficiency, in other words, using the least possible amount of resources (be they materials, time, equipment, personnel, etc.) and increasing its productivity to the maximum allowed [26].

There are several approaches in the planning of activities for production, services, and/or projects. These approaches must be aligned with the objectives of the company, in order not to perturb activities that are external to the mathematical modeling [27], [28]. Traditional approaches include mixed integer linear programming (MILP) as one of the most common.

Mixed integer programming models are a variation of conventional linear programming models, where the solutions constructed must take into account integer values in the resources, so it is conventional that their results are vectors or binary matrices where a given resource is used or not. These models usually involve task execution times, resource availability, working day limits and availability of professionals against a demanded level of clinical care [29]–[31].
There are also heuristic methods, which are based on making approximations to a solution, ensuring it is good or, at least, it satisfies all the constraints established. Generally, these problems are based on assumptions made by the researcher and are usually computationally faster, as a strategy for combinatorial or computationally demanding problems that exact methods cannot solve in a limited amount of time.

Among the most commonly used methods at present, we can find the following:

- Trajectory methods: These are algorithms based on the construction of an initial solution, which is subsequently perturbed to traverse the solution space by the intensification principle. These algorithms seek to identify the local minimum within the explored space, and once the solution is not improved, local optimality is determined [32]. Among the most widely used are GRASP, Variable Neighborhood Search or Descent (VNS/VND), simulated annealing, and tabu search [33], [34].

- Population methods: These algorithms are based on the consideration of working on a set, taking as a reference several points within it. From there, mutations in the characteristics of the solutions are generated and crossed between the selected points, to test whether the solutions obtained build a better solution than the one found by the initial points [35]. Several algorithms present in the literature are genetic algorithms, memetic algorithms, and sparse searches [33], [36].

2.1.5 Data Analytics

This technique is used to extract information from the organization, data filtering, and/or implementation of algorithms to a set of data taken from a real process or system. It allows to analyze the trends or behaviors of a system and possible interactions between various factors that are involved in its operation.
It is usually performed through the use of statistical software or mathematical methods and can be descriptive (past information), diagnostic (disaggregation and contrast of past data), predictive (anticipation of events or trends), or prescriptive (taking action on possible future events) depending on the level of analysis performed on the dataset [37]. These studies

generally try to establish the level of impact between direct or indirect factors during task execution [38].

2.2 Literature Review

In addition to the above information, a literature review of what has been developed so far in nursing programming and the advances aligned to continuous improvement and engineering strategies is carried out.

2.2.1 Lean Healthcare applied in nursing

In last years, there has been a significant advance in the application of Lean concepts to the internal processes of health institutions. The purpose of this is to enhance patient care and at the same time to investigate the perception of nursing professionals about their tasks and the way in which they could improve their performance.

A clear example of this has been the development of open and semi-structured perception interviews [39], [40], focused on the perception of the work performed by the nurses, in order to evaluate modifications made under the lean theory. The implementation of Liker's 4P model (philosophy, people & partners, problem-solving and processes) [41], [42] for measuring lean healthcare maturity in service as well as quality of care, the sampling of task execution times [43], [44] for preliminary standardization of the work and construction of confidence intervals, and process simulation from causal models [45] to outline the primary care service offered by the institutions and find gaps, bottlenecks, etc., which need to be prioritized to be solved. Furthermore, it is important to note that predicting human behavior is highly complicated. Taking some of these techniques and performing a full-time deployment in the service, however, can guarantee an adequate estimation of patient flow and care required in healthcare facilities.

Nonetheless, the studies developed to date have not been able to establish a strategy that enables estimates or predictions of an adequate workload assignment, taking as a principle the level of risk in each patient, their pharmacological treatment, and other activities carried out by the nurses, which are crucial in their daily work, so there is no guarantee of a decrease in the appearance of variables such as burnout, omitted care, adverse events, and uneven skill-mix.

2.2.2 Implementing Lean Healthcare Techniques in nursing processes

Even though significant progress has been made in process improvement through the implementation of Lean theory, this does not mean that everyone understands and wants to adopt this concept in the same way [12], [46]. Some people need to be made aware of the importance of using this knowledge in their daily work, and how it can contribute to facilitating their work [47], [48], since the great challenge is to design systems that allow the professional to spend more time at the patient's side and less time in front of a computer performing administrative tasks. This is because, although these tasks are important for keeping a detailed record of the care provided to the patient and the progress of their recovery process, they end up having a proportional inverse impact on the level of relationship that the professionals maintain with the patients and the empathy developed for each patient's condition.

2.2.3 Continuous improvement techniques in nursing processes

Several impact analysis studies have shown that people previously trained in some form of formal or complementary study are able to quickly understand and adopt the concepts of this theory in their daily work [44], [49]. Nevertheless, those who do not know about the methodology may be more unwilling to accept it, as they see it as more rigorous work procedures, and not as a tool that contributes to personal and professional development [40]. To this must be added the fact that health entities are not oriented towards developing processes that involve the co-creation of value, so orienting the process exclusively towards customer satisfaction limits the possibilities of response (based on the training provided to staff on the subject) that a nursing professional can provide to the requirements, either of their patient or of a family member, if they are in a situation of pressure or work stress [50].

The integration of continuous improvement systems is also considered as additional activity that, as if that were not enough, aims to subject the professional to an even greater level of stress than they are usually exposed to [51], and which, although they have been complex to adapt in hospital environments, have improved the effectiveness in the execution of tasks and reduced the workload in the tasks performed, this supervised by the role of the nursing manager and the support of courses and/or regular training that simplify the understanding of the Lean theory [52], [53].

2.2.4 Workload balancing for nurses

When performing activities in a hospital area, one of the most important problems is the equitable distribution of human resources, as these are the main resources involved in direct patient care [54], [55]. To identify the needs in a load balance within a hospital and its context, it is important to take into account that there are factors that define the trajectory of the study, such as the requirement when caring for a patient [56], the skills of the nursing professional and the focus under which he/she was trained [57].

Nowadays, statistical methodologies have been implemented to test the level of impact of the work performed on patient recovery [58], [59], as well as professional utilization, level of care, and task planning [54], [60]. However, these studies have mostly been conducted in areas such as intensive care units (ICU) or emergency rooms (ER), and not inpatients. In several countries around the world, different ways of assigning nurses to patients are proposed, where most seek to ensure a nurse-to-patient ratio that can be between 4 to 20 patients according to the service and the experience of the professionals [9], [61].

2.2.5 Optimization in nursing activities planning

Mathematical models and networks with work activities have also been used as another strategy for the correct management of nurses. The main objective of these methodologies has been to reduce the time and costs of the tasks carried out in order to minimise the impact of hiring many professionals in hospitals, as well as the lengthy time it can take to care for and recover patients. Linear programming models have been used to estimate the number of professionals required and their allocation over a period of time [29]. Other options have been the selection, optimization and compensation (SOC) model, which enabless estimating the level of cost versus professional capacity [62] and performing work assignment on a Gantt chart based on a workload minimisation model [63].

Nursing Scheduling/Rostering Problem

The problem of assigning shifts to nurses is a problem of operational research that has been studied since 1969 and that, to date, only reflects about 250 publications on the subject where it is estimated that 25% have developed mathematical models to address the problem of load balancing.

Among the most prominent are the NSP (Nurse Scheduling Problem), which proposes to minimise costs based on the genetic algorithm based on "survival of the fittest", where a feasible allocation of 80% was obtained on average, considering that there are penalties for the allocation and movement of resources [64]; the Physician Rostering Problem (PRP), where a mixed integer programming model based on work balancing for a week was carried out to maximise the number of tasks assigned, considering working days and weekends as constraints [65]–[67]. Finally, the implementation of greedy algorithms that sought to minimise costs and load imbalance (specifically the Greedy Constructive Heuristic) for the rotation of personnel vs. schedules in a shift scheduling matrix [68], subject to shift constraints, minimum and maximum working time, work shift schedules, assignments, etc.

Other researchers have studied the problem by implementing artificial intelligence techniques such as genetic and swarm algorithms [69], [70] to minimize deviations from service constraints such as unemployment, shift changes, overtime, etc., and advanced techniques as deep learning to predict the level of care required by patients based on their lifestyle habits [71]. Variable and top-down neighbourhood searches (VNS & VND) for the implementation of artificial intelligence techniques such as swarming and genetic algorithms [36] and nurse scheduling given their low implementation cost [72]. Tabu searches considering work factors or weights and collaborative dynamics during the service [73], [74]. Models based on column generation giving the problem various priority options such as costs [75], omitted care, type of shift carried out, etc. [76]. Modelling cyclic shift assignments and changes from heuristic techniques such as sudoku grids and 8-piece puzzles [77], [78] and branch-and-price or hybrid algorithms for planning care in institutions and home [73], [79].

Chapter 3

METHODOLOGY

This research is a work applied in the Universidad de La Sabana Clinic and Universidad de Los Andes Clinic in Chile, in the period 2022 - 2023, with which it is expected to contribute a workload assignment strategy that supports the administrative processes of nursing professionals and, in turn, enhance the nurse-patient care relationship in the Clinics. To ensure this, 5 phases are established in the project, as described below. Likewise, figure 3.1 illustrates the methodology followed in this project and the stages, as well as the inputs and outputs of each one.

3.1 Identification and description of nursing processes

A group of experienced professionals composed of service coordinators, researchers, and teachers, all of them linked to nursing and the processes carried out in the respective clinics involved, are involved in initiating this research. These professionals are asked to conduct several focus groups in order to identify common activities of the nursing role [1], and also to provide a detailed description of all activities listed in each of the clinics, including guidelines to identify: task start and end, step(s) involved, what staff, people, systems and supplies are involved, and at what point in care it is classified. The description of activities is standard for the clinics studied and is taken as a baseline for data collection (for more information, see the attached excel document).

3.2 Data collection for 31 nursing selected processes

Subsequently, the aim is to provide an overview of the process currently used in nursing for the daily workload assignment in the inpatient area. This allocation is mainly impacted by 31

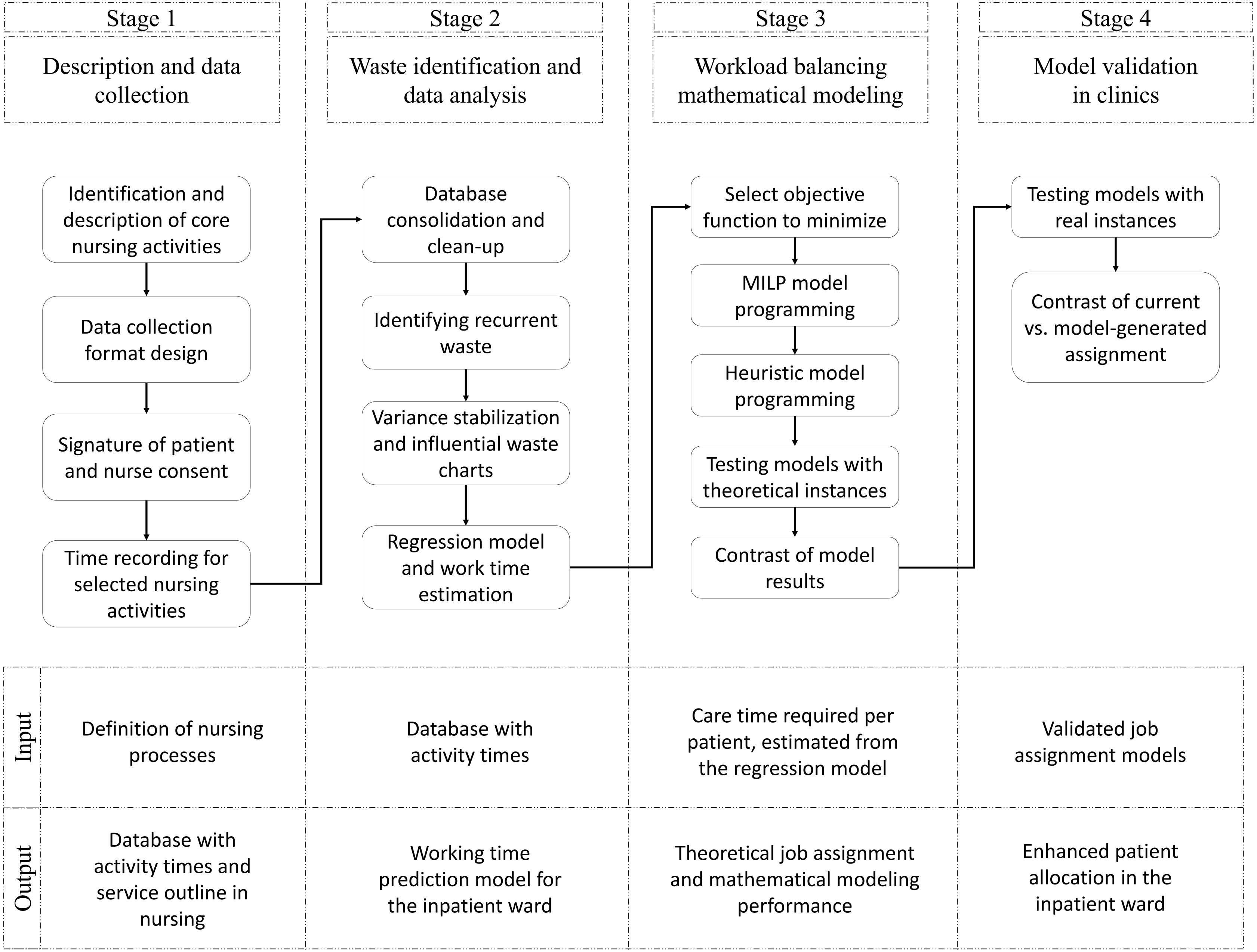


Fig. 3.1 Flowchart for the project methodology

activities mentioned below, which are part of the role of the nursing professionals:

- Change-of-shift
- Patient admission
- Patient assessment
- Medicine reception
- Risk assessment
- Medication administration
- Medication preparation
- Medication registration
- Medical notes review
- Return of supplies and medicines
- Nursing debriefing
- Clinical history review
- Nursing notes
- Adverse events report
- Control and inventory of crash carts
- Basic needs assistance
- Sampling for laboratory tests
- Patient discharge report
- Extemporaneous meals request
- Medical procedures assistance
- Attention to patients' or relatives' concerns
- Blood glucose monitoring
- Electrocardiography
- Vascular access
- Healing
- Management of medical requests
- System patient discharge
- Fluid balance
- Preoperative preparation
- Nursing round
- Nursing discharge
- Patient, family or caregiver education

Therefore, field observation of these activities was carried out based on the definition provided by nursing professionals, identifying recurrences, the waste found during their execution such as: nursing rotation, burnout, length of patient stay, adverse events: medication errors, falls, pressure injuries, among others, since their occurrence represents an increase in the operational cost of the area and does not add value.
The proposed data collection protocol is as follows:

1. Gathering of signed informed consent from nurses, explaining the objectives, risks of the project and the possibility of revoking consent. Records will be kept anonymously.

2. Drawing up a field diary to sketch an overview of the service and show its organization, flows and the dynamics involved in the processes. It will also consider emergent care or response to unforeseen events, the information systems and technologies used for recording information, methods of assigning work and shifts, staffing and working conditions.

3. Informed consent will be collected from SIGNED patients, explaining the objectives and risks of the project and the possibility of revoking consent at any time. Records

will be kept anonymously. This process can be implemented in patient admission activities if authorized by the patient.

4. Database update of patients and nurses who have approved and refused participation.
5. Completion of the abbreviated Pfeiffer mini-mental test (Test implemented to establish cognitive deterioration [80]).
6. Completion of the observation form, which will include information classified in 3 parts (This will be carried out by both nurses and the master's student and the whole process will be carried out confidentially, so no data will be recorded that would allow the identification of the participating professionals or patients):
    a Collection day information: Data such as date of observation, day/shift, clinic, caretaker and hospital area.
    b Patient information: Medical record information, age, gender, room, days inpatient, pharmacological treatment, dependency level, fall risk, pressure injury risk and mental status.
    c Process information: Activity name, description, nurse experience, start time, activity duration, end time, wastes identified.
7. Complete the nurses' survey on their physical and emotional state.

3.3 Analysis of the 31 processes based on waste identification

This phase aims to determine factors, types of waste and main activities that outline the functioning of the inpatient service:

1. To ensure that the sample collected for each activity is adequate, cumulative variance plots will be made to visualize the behaviour of the data. Once the variance has been stabilized or there is no significant variability, the data collection will stop.
2. Once the database has been consolidated and the time variance of each activity has been stabilised, Pareto diagrams by number of records, times recorded and waste per activity will be made to determine the main activities within the hospital service and those that need to be focused on.

3. In parallel to the above, an Ishikawa diagram will be drawn by applying the 6M theory, in order to carry out a quantitative-qualitative contrast with the previous diagrams and validate that the analytical deductions are in line with the observations in the hospital service.

4. Finally, a multiple linear regression model will be applied to predict the execution time of activities within the hospital service, based on the identification of activities and patient status factors.
   This model will be built under the equation:

   $$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... + \beta_n X_n \tag{3.1}$$

   This equation allows the estimation of the response variable Y (in this case the time of execution of the activity), from multiple recorded factors, which will be each item of information recorded in the first step (age, gender, falling risk, mental state, etc.) [60].

3.4 Mathematical workload balancing model design

Using the information collected and the results of the analysis of the variables, a mathematical model is built, taking as a reference the unrelated parallel machines scheduling, to determine the appropriate assignment of tasks to the professional nurses in a work period, during a workday.

The model have as input the critical activities determined from the regression model, as well as information on the patient's condition which is of vital importance and which impacts on the execution time of the activities.

It minimizes the makespan (time of completion of all work in the service) for each nurse, as well as an efficient sequencing of activities, following the steps:

1. First, a mixed integer optimization model (MILP) is developed in order to determine the performance that a classical programming model can reach for this type of problem, taking into account that there are more limiting conditions and, therefore, it can better constrain the solution space, speeding up the convergence to the optimal solution.
   This model integrates time window constraints for starting the execution of tasks, precedence between activities, and guarantees the traceability of the patient within a work shift, which means that the same professional should attend to all of its activities.

2. A heuristic model is then developed from random keys so that a random ordering can be made for each nurse of the tasks she has to perform throughout her day.

These keys also help to respect the existing precedence between activities, as well as the time in which they must start their execution.

Likewise, the criteria for assigning patients to nurses is based on randomly scanning the space, trying different combinations with a limit of attempts, in order to speed up the assignment process and obtain a good solution.

This model is required once the designed instances reach a considerable size of activities to be scheduled (for this problem, more than 70 jobs), as it facilitates obtaining solutions applicable to the nursing service, thereby reducing the waiting time for scheduling activities.

3.5 Testing the workload assignment model in nursing environment

Once the models are built, their problem-solving capability is tested by implementing theoretical instances. If adequate performance is achieved with these data, it will then be implemented directly in the inpatient services of the clinics involved in the project. Otherwise, a second model will be built based on heuristic methods as an alternative to obtaining suitable solutions that satisfy the conditions required for service planning.

From this it is possible to determine the differences between the actual assignment and the one proposed by the optimization model, in order to subsequently modify the general task assignment protocol where an efficient service level can be maintained, considering an adequate workload level for the nurses. In addition, this strategy can be evaluated with the respective indicators for each clinic, measuring the level of impact generated by the project results.

Chapter 4

ETHICAL CONSIDERATIONS

This research is carried out within the legal framework of Law 266 of 1996 and Law 911 of 2004, which establishes the regulations for the practice of nursing and its respective code. These laws establish that all research processes must guarantee the dignity, integrity, and rights of all human beings, as a fundamental ethical principle.

The terms of Resolution 008430 of 1993, which establishes the scientific, technical, and administrative standards for health research, are also contemplated [61]. Thus, in accordance with the regulations, this research project is conducted on the informed consent given to the participants. This will protect the privacy of the collaborators and will consider the principles of beneficence, non-maleficence, autonomy, justice, truthfulness, fidelity, and reciprocity. All information collected will be anonymous and protected in the private files of the principal investigator. No private or confidential information will be published.

This study has been approved by the ethics committees of the Universidad de La Sabana clinic in Colombia and the Universidad de Los Andes clinic in Chile. The informed consent of patients and participating nurses have been gathered and stored. If required, these can be requested and cross-checked against the information consolidated in the database to verify the veracity of the information recorded.

Chapter 5

ANALYSIS OF INPATIENT WARD DATA

Data collection was performed by a team formed of nursing and engineering students, in addition to the researchers. All of them are assisted by the nursing staff in the medical-surgical inpatient services. The collection process took place from October 2021 to June 2022, obtaining 1200 records of activities between both institutions (see figures 5.1 and 5.2).

Prior to these collections, the entire group was trained in time measurement for nursing processes, considering the description of activities previously made and validated in the nursing focus groups that initiated the research. Likewise, time measurement was done from room corridors and not by entering patient rooms, so as to avoid disturbances in the service or possible discomfort to the hospitalized patients.

Finally, this section provides a qualitative and quantitative analysis of the sample collected. The qualitative analysis demonstrates the justification for the occurrence of waste in the service, in addition to the increasing overload that nurses have in their shifts for performing diverse activities that can be considered not proper to their role.

Meanwhile, quantitative analysis explains the construction of models for estimates of nursing activity execution times, in order to determine how long it can take to care for a patient in the department according to the variables defined for analysis. These times calculated with the predictive models make it possible to simulate the behavior of the service with regular patient profiles and will be the input data for the subsequent mathematical workload balancing model.

Fig. 5.1 Data collection in clinics, nursing students

Fig. 5.2 Data collection in clinics, engineering students

5.1 Descriptive analysis

Initially, in the qualitative analysis generated from the Ishikawa - 6M diagram, most of the issues found in services are grouped into 3 groups (Materials, Machinery, and Methods), and these groups are the ones that determine firsthand how patient care tasks are to be performed in clinics.

Figure 5.3 lists the situations that are causal and have negative effects on the nursing processes, some of which have a high impact on the service as it generates time delays in the execution of tasks, such as shortages of supplies and medicines. Another example is the disruption of traceability by nurses in the system due to misalignment with established nursing protocols and non-improvement of information management systems within hospital services.

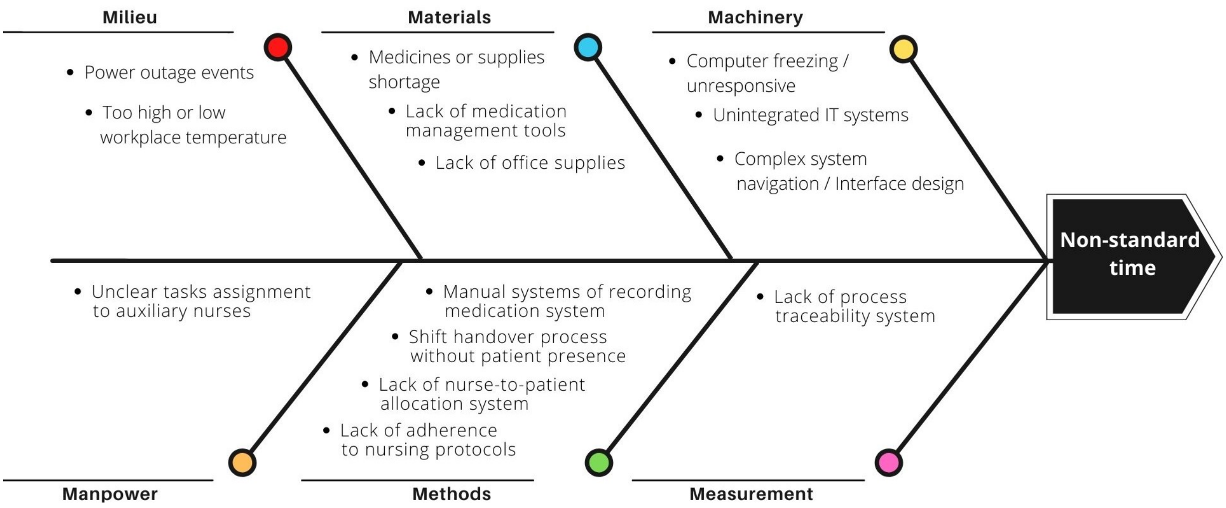


Fig. 5.3 6M Ishikawa Diagram for inpatient and MQ units - 6M Methodology

Subsequently, in the Pareto waste diagram (see Figure 5.4), it can be observed how the existence of the situations listed above leads to the appearance of waste in the service and results in the under-utilization of human resources in the clinics. In the Chilean clinic, there are mainly unnecessary movements, overproduction, and waiting times, which account for 80% of the total waste. In Colombia, on the other hand, there is a higher amount of waste, 80% of which is due to over-processing tasks and defects during their execution. This clearly illustrates a cause-effect correlation that sustains system failures and overloads nurses, as they have to work harder to obtain an adequate level of care that could be guaranteed if these circumstances were fixed.

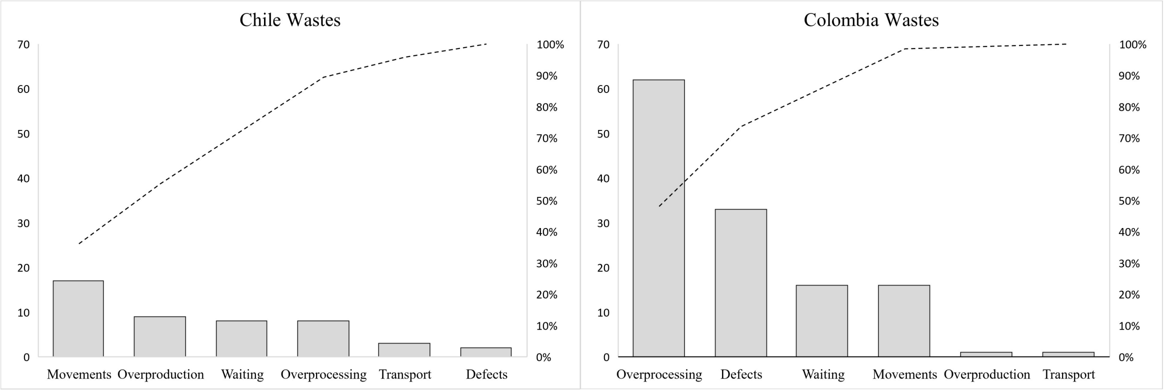
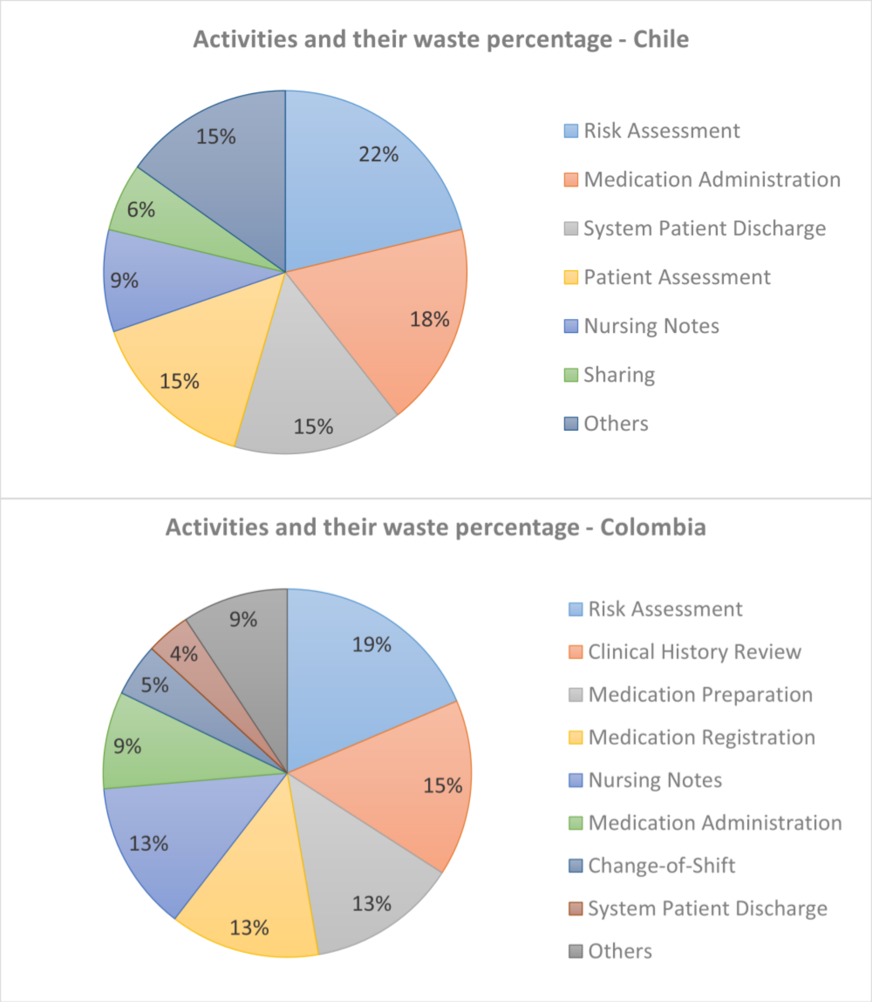


Fig. 5.4 Pareto diagram of waste in inpatient and MQ services

These figures also sketch a scenario in which there is no adequate management of nursing staff within the hospital services analyzed. On the contrary, their workload is being increased by reprocessing, errors, and waiting times. This ends up having a direct impact on the quality of patient care and the time a nurse can spend on care rather than administrative management, as shown in Figure 5.5, where most of the wasteful processes within the service are administrative processes (such as filling out scales, discharges, logs, etc.), and will therefore take longer than required to complete before delivering patient care.


Activities and their waste percentage - Chile

Activities and their waste percentage - Colombia

Fig. 5.5 Percentage of sampled activities with the highest waste presence

Once the processes with the greatest amount of waste in the system had been identified, we proceeded to verify whether the sample collected for each task showed stability in its variance, in order to have a stable sample for the construction of predictive models, avoiding in the first instance non-compliance with the validation assumptions involved in these models. It is calculated from the sample variance equation (see eq. 5.1). X_i variables are each a time recorded for the activities listed for sampling. Likewise, variables s_n^2 and $\overline{x}_n$ depend on the sample size for each activity sampled.

$$s_n^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x_n})^2}{n-1} \tag{5.1}$$

Figure 5.6 shows the behavior of the variance for the medication administration task, where its variability stabilizes on the red line from 100 records.

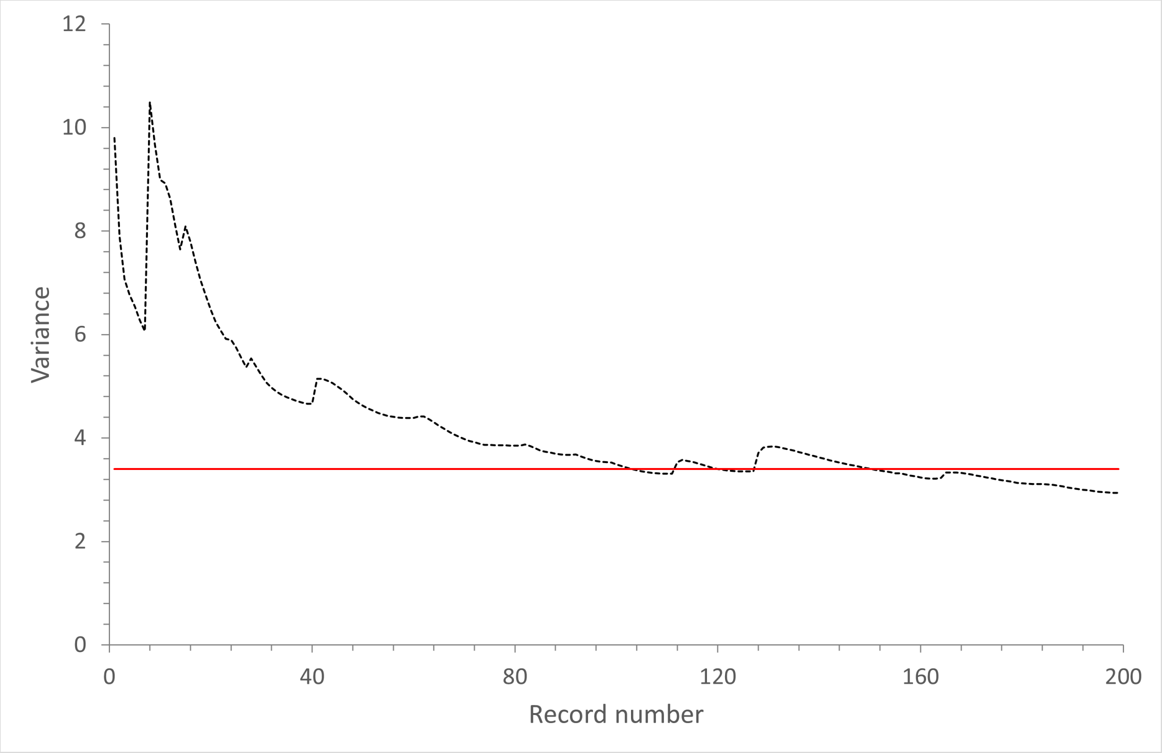


Fig. 5.6 Variance stabilization plot for the task medication administration

This process is carried out for each activity, showing that of the 31 processes proposed, 12 achieved stability and sufficient sample size. These were:

- Medication administration
- Medication preparation
- Risk assessment
- Medication registration
- Change-of-shift
- Nursing notes
- Clinical history review

- Nursing debriefing
- Patient assessment
- System patient discharge
- Return of supplies and medicines
- Attention to patients' or relatives' concerns

It is worth noting that, because the data come from a human activity, a normal distribution cannot be demonstrated. Thus, traditional methods for calculating outliers such as interquartile range are not reliable methods. No records were eliminated from the analysis and the difference between outlier and infrequent data cannot be justified because of the relationship with the patient's condition and the care required. Furthermore, these irregular data were consulted with the nursing professionals involved in the research, who appropriately justified the record, which resulted in it not being classified as outlier data, as is usually the case in production processes.

5.2 Multiple linear regression

When plotting the stabilized activity data on a Q-Q plot and histogram, it is found that the data is not normally distributed but exponentially distributed, so a natural logarithm is applied to the sample to achieve this distribution and to achieve a better fit in the regression models. The regression models were also constructed for the non-normalized data, since, if a better fit could be achieved with a generalized or robust regression technique, the equation would be adjusted according to the trend found.

The aim of developing these regression models is to correlate the time taken to perform jobs in the inpatient ward with the care variables that, according to nursing experts' comments, would be the predictors.

Thus, four regression models were generated considering first-order interactions for some of them, with the following equations (see Table 5.1):

	No Interactions	1st Order Interactions
Original Data	(1) $Y = \beta_0 + \sum_{i=0}^{13} \beta_i X_i$	(2) $Y = \beta_0 + \sum_{i=0}^{13} \beta_i X_i + \sum_{i=0}^{12} \sum_{j=1}^{13} \beta_{ij} X_i X_j$
Normalized Data	(3) $Ln(Y) = \beta_0 + \sum_{i=0}^{13} \beta_i X_i$	(4) $Ln(Y) = \beta_0 + \sum_{i=0}^{13} \beta_i X_i + \sum_{i=0}^{12} \sum_{j=1}^{13} \beta_{ij} X_i X_j$

Table 5.1 Multiple regression models generated from the sample

The response variable of the regression models is:

$$Y = \textit{Activity execution time}$$

The independent variables to be considered in the model were:

- X_1 = *Shift* *{0: Day, 1: Night}*
- X_2 = *Clinic* *{0: Chilean, 1: Colombian}*
- X_3 = *Age*
- X_4 = *Gender* *{0: Female, 1: Male}*
- X_5 = *Inpatient stay (In days)*
- X_6 = *Over-the-counter medicines (OTC)* *{0: No, 1: Yes}*

- X_7 = *Prescription-only medicines (Rx only)* *{0: No, 1: Yes}*
- X_8 = *Medication routes of administration* $\begin{cases} *Organized\ from\ simple\ to\ complex \\ Notation \\ (O: Oral, P: Parenteral, T: Topic, A: Other) \\ 0: O, 1: OA, 2: OP, 3: OPA \\ 4: OTP, 5: PA, 6: P, 7: TP, 8: TPA \end{cases}$
- X_9 = *Dependence level* *(0: Independent, 1: Low, 2: Moderate, 3: Severe, 4: Total)*
- X_{10} = *Fall risk* *(0: Low, 1: Medium, 2: High)*
- X_{11} = *Pressure sore risk* *(0: Low, 1: Medium, 2: High)*
- X_{12} = *Mental state distortion* *(0: None, 1: Low, 2: Moderate, 3:Severe)*
- X_{13} = *Waste type* *(0: Defects, 1: Overproduction, 2: Waiting, 3: Non-value added processing, 4: Transportation, 5: Inventory, 6: Motion, 7: Employees underutilized)*

For measuring the quality and fit of these models, the adjusted R^2, the Akaike (AIC), and Bayesian (BIC) information criteria were taken as a reference. Table 5.2 shows the results obtained for each of the models, where a difference and improvement are presented for models 3 and 4, which include the first-order interactions. For the selection of the best option between these 2 models, the 3 calculated parameters were taken as a reference, and although model 3 achieves a better fit (R^2), its AIC and BIC are high compared to those of model 4, since the lower the value of these information criteria, the better the selection of variables in the model. Therefore, it is decided to choose model 4 for variable selection. Note it is important to bear in mind this result may not perform as well as desired as in theoretical studies, as it involves direct human intervention in the care of other humans, which significantly increases the variability in the system studied.

Model	AIC	BIC	Adjusted R^2
1	10999.81	11291.38	0.178
2	2029.69	2321.26	0.255
3	10415.02	12981.84	0.658
4	1848.60	4415.41	0.510

Table 5.2 Performance indicators for regression models

Table 5.3 shows the variables which take relevance within the model, as well as their first-order combinations (Thus the interaction set is defined for each variable, where the interaction produces a significant effect, subject to a positive or negative coefficient, on the patient care response time, thereby generating the fit of the model to the working time).

The selection of significant variables within the model is done by applying the backward method subject to the Akaike criterion (AIC), which reduces the value calculated by the likelihood function to the most negative possible. Once this process has been carried out, it is determined that the number of significant variables and interactions for an optimized model goes from 169 to 58 (see Table 5.3).

Interactions	Significant Variables
None	$X_1, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}$
	Variable Interaction Set
First Order	- $X_1 : \{X_3, X_5, X_6, X_7, X_{11}\}$ - $X_3 : \{X_5, X_6, X_7, X_8, X_{10}, X_{11}, X_{12}, X_{13}\}$ - $X_4 : \{X_5, X_6, X_7, X_8, X_9, X_{10}\}$ - $X_5 : \{X_6, X_8, X_9, X_{10}, X_{11}\}$ - $X_6 : \{X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}\}$ - $X_7 : \{X_8, X_9, X_{10}, X_{11}, X_{12}\}$ - $X_8 : \{X_9, X_{10}, X_{11}, X_{12}\}$ - $X_9 : \{X_{10}, X_{11}\}$ - $X_{10} : \{X_{11}, X_{12}\}$ - $X_{11} : \{X_{12}\}$

Table 5.3 Significant variables for model 4 based on AIC - Backward Method

Subsequently, the multiple linear regression model assumptions are validated. Figure 5.7 is divided into 4 quadrants, where:

1. The upper left quadrant presents the random distribution of the errors, showing that there is no identifiable pattern in the sample and they can be considered independent. To corroborate the above, the Durbin-Watson test is applied, obtaining a p-value = 0.2216, which validates the assumption of independence of the errors.

2. The upper right and lower quadrant show the distribution of errors and data respectively, in order to ensure normality in the sample. To support the above, the Kolmogorov test with Lilliefors correction is applied. In this case the test yields a p-value = 0.0, which means that the sample would not behave normally.

   The reason is the tails in the Q-Q diagram deviate quite a lot from the trend line, which makes the assumption invalid, despite performing various transformations to the data they are usually used to normalize such as: logarithmic, exponential, box-cox.

3. Finally, for the validation of homoscedasticity, the Breusch-Pagan test is applied, obtaining a p-value = 0.7717, which means that the model complies with homoscedasticity.

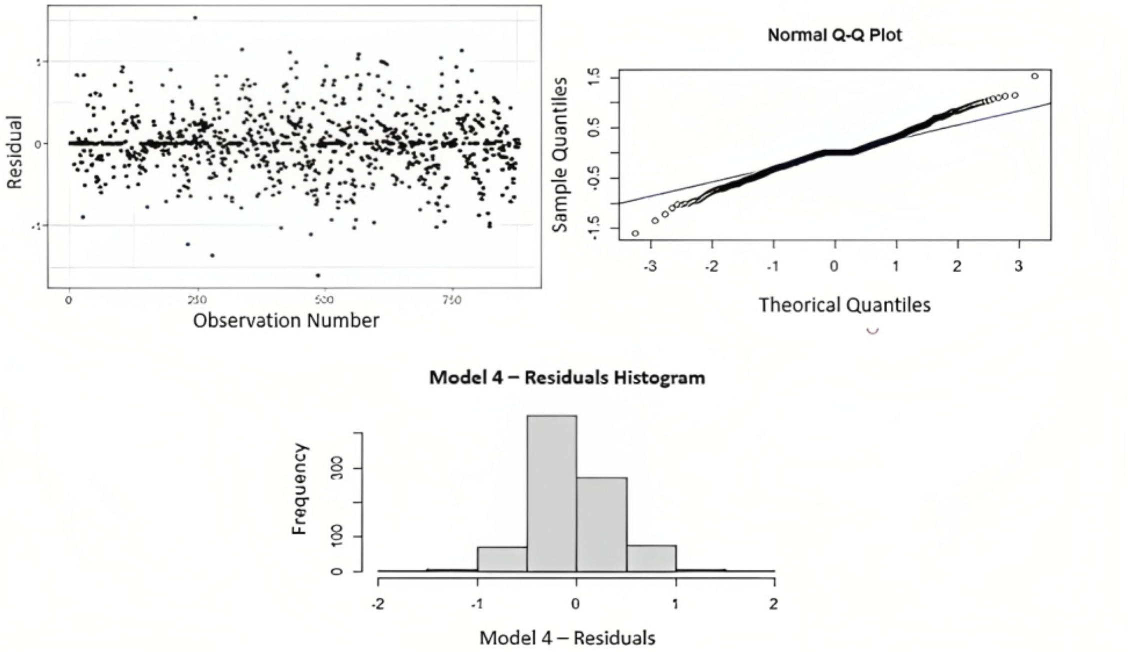


Fig. 5.7 Model 4 assumptions validation graph

5.3 Regression models per clinic

As a complementary study, and to corroborate that the previously obtained model has a better implementation within the study, new models are built under the same scenarios of table 5.1, but this time segregating the data by the clinic.

	Chile Clinic			Colombia Clinic (')		
New Model	AIC	BIC	Adjusted R^2	AIC	BIC	Adjusted R^2
A - A'	2606.65	2710.05	0.038	9032.43	9165.71	0.086
B - B'	588.75	692.15	0.116	1740.57	1873.85	0.069
C - C'	2538.01	2951.59	0.379	8987.55	9842.36	0.280
D - D'	595.08	1006.66	0.148	1812.61	2667.42	0.139

Table 5.4 Regression models with separation by clinic

In this way, table 5.4 is obtained, where the adjustment achieved for each of these models is not appropriate to be considered a response within the study and is due to the imbalance in the data collection performed since the occurrence of activities within the services in both clinics was not the same.

Chapter 6

MATHEMATICAL FORMULATION

By using the regression equation generated, it is possible to estimate the time required for a nurse to provide the necessary care to the patients in the service. Using the working times achieved per activity, the problem of scheduling patients to nurses based on the care time required for each patient is addressed. It seeks to balance the workload per nurse by considering the time spent on care patients, rather than the number of patients in the service. In this way, equal solutions can be generated regarding the task completion time and the occupation of the nurses' time.

Therefore, in order to guarantee that each professional achieves the completion of their administrative and care activities in a similar time as their colleagues, a model of unrelated parallel machines was proposed, minimizing the makespan, including time windows and precedences between jobs.

6.1 Problem definition

Workforce management within companies is a challenge in balancing the costs generated and the utilization of manpower. The aim of this type of problem is to assign each worker to an available hour on a work schedule, generally programmed on a time horizon. Nevertheless, due to the latent high patient turnover in hospital services (keeping in mind that hospitalization is the most stable), scheduling the personnel within a work shift becomes a priority, allowing them to react to the change of the service, enhancing patient care and decreasing the omitted care and the appearance of waste in the process.

This problem is addressed to allocate patients to nurses on a single shift. There is a requirement of activities $N = \{1,2,...,n\}$ for a set patient $P = \{1,2,...,n\}$, all these n activities must be scheduled within the same nurse $M = \{1,2,...,m\}$ to ensure traceability in the care provided, as well as patient comfort by not rotating their care staff to a large extent. In addition, the minimization of makespan is also considered an objective function, which intrinsically seeks to guarantee a balance at the end of the working day for each person or machine.

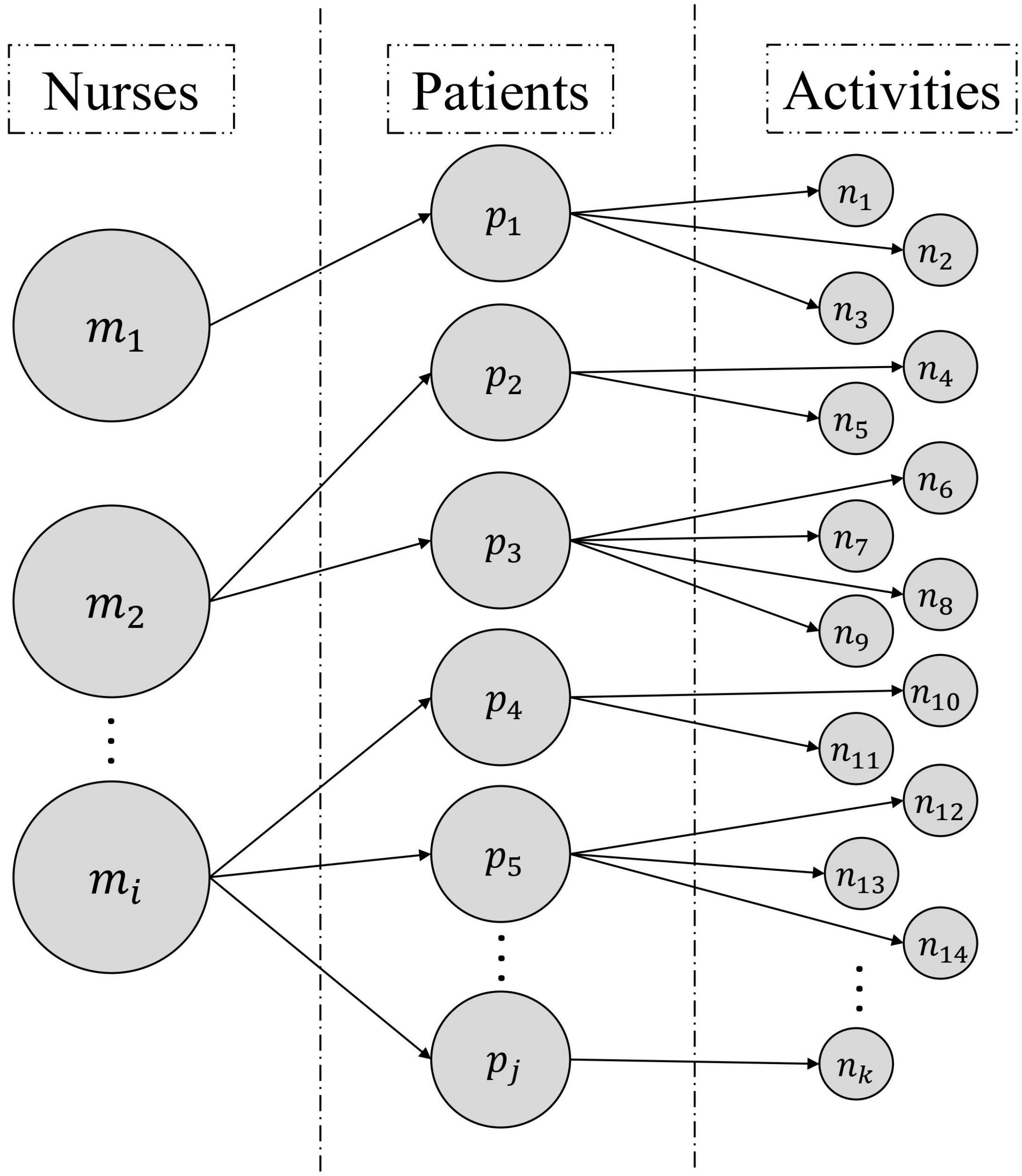


Fig. 6.1 Node diagram for nurse allocation problem

Furthermore, this mathematical model integrates specific conditions of the studied clinics, where it is assumed:

1. Any workday where this mathematical model is implemented shall be 12 consecutive hours, equivalent to one work shift.
2. There are time windows for certain activities, generally linked to medication, where the travel time between rooms and/or modules is considered insignificant.
3. This model considers only precedence between the activities of a single patient.
4. The preparation of certain procedures is considered an individual activity established by precedence.

6.2 Mixed Integer Linear Model

Based on the above, the mathematical model built is presented, also taking as input parameters the data previously collected in the hospitalization services of the clinics studied.

Sets

N	Jobs set $N = \{1, 2, ..., n\}$
M	Nurses set $M = \{1, 2, ..., m\}$
P	Patients set $P = \{1, 2, ..., p\}$

Parameters

P_{nm}	Processing time of the activity n by the nurse m (*Nurses are assumed as unrelated machines*).
PT_{np}	Identification matrix if jobs n belongs to patient p *{0: No, 1: Yes}*.
ET_n	Earliest start time for job n.
LT_n	Lastest start time for job n.
$Prec_{nu}$	Matrix of precedences from job n to job u *{0: No, 1: Yes}*.
PAT_n	Identifier of the patient p to which job n is assigned.

$$PAT_n = \sum_{p \in P} p * PT_{np} \qquad \forall n \in N \tag{6.1}$$

Variables

- Y_{num} $\begin{cases} 1 & \text{if job } n \text{ precedes job } u \text{ on nurse } m \\ 0 & \text{otherwise} \end{cases}$
- X_{nm} $\begin{cases} 1 & \text{if job } n \text{ is assigned to nurse } m \\ 0 & \text{otherwise} \end{cases}$
- ST_n Start time of job n.
- FT_n Completion time of the job n.
- $Cmax$ Makespan.

The objective function of the proposed model is indicated in equation 6.2, minimizing the time required to perform all the inpatient service jobs.

$$Min \text{ Cmax} \tag{6.2}$$

Subject to:

$$X_{nm} = X_{um} \qquad \forall\, m \in M\ n,u \in N/PAT_n = PAT_u \tag{6.3}$$

$$\sum_{m\in M} X_{nm} = 1, \qquad \forall\, n \in N \tag{6.4}$$

$$FT_n = ST_n + \sum_{m\in M} X_{nm} * P_{nm} \qquad \forall\, n \in N \tag{6.5}$$

$$FT_n \leq Cmax \qquad \forall\, n \in N \tag{6.6}$$

$$ST_u \geq FT_n \qquad \forall\, n,u \in N/Prec_{nu} = 1 \tag{6.7}$$

$$ET_n \leq ST_n \leq LT_n \qquad \forall\, n \in N \tag{6.8}$$

$$\sum_{m\in M} Y_{num} \geq Prec_{nu} \qquad \forall\, n,u \in N/n < u \tag{6.9}$$

$$\sum_{m\in M} Y_{num} \leq 1 - Prec_{un} \qquad \forall\, n,u \in N/n > u \tag{6.10}$$

$$Y_{num} \leq X_{mn} \qquad \forall\, m \in M\ n,u \in N/n < u \tag{6.11}$$

$$Y_{num} \leq X_{mu} \qquad \forall\, m \in M\ n,u \in N/n < u \tag{6.12}$$

$$ST_u \geq FT_n - BigM * (1 - Y_{num}) \quad \forall\, m \in M\ n,u \in N/n < u \tag{6.13}$$

$$ST_n \geq FT_u - BigM * (Y_{num}) - BigM * (2 - X_{nm} - X_{um}) \quad \forall\, m \in M\; n,u \in N/n < u \quad (6.14)$$

Constraint (6.3) ensures that two jobs *n* and *u* are done in the same nurse if they belong to the same patient *p*. Constraint (6.4) indicates that each job can only be placed in one nurse. Proper accumulation of nurse time, adding the processing time of each activity according to the completion time of the previous job, is shown in the equation (6.5). Constraint (6.6) dictates that all job completion times must be less than the makespan.

In (6.7) it is guaranteed that a job *u* does not start before job *n* if they precede each other. (6.8) sets the time window in which the start of activity *n* can begin, having a set time range throughout the shift. The equation (6.9) dictates that for every pair of jobs *n* and *u* there is a sequencing in the nurse *m* if they are precedent. By contrast, if the precedence of jobs goes from *u* to *n*, (6.10), the sequencing variable will take the opposite value to identify the scheduling order of such an inverse sequence. Constraints (6.11) and (6.12) ensure that if there is a sequencing from *n* to *u*, they must be assigned to the same nurse *m*.

Finally, in the equation (6.13) and (6.14) a correct flow of job times for each job is guaranteed, where (6.13) is enabled if there is a sequence of scheduled jobs from *n* to *u*. Otherwise, (6.14) is enabled only if there is a sequence from *u* to *n* and the jobs are assigned to the same nurse *m*.

6.3 Heuristic model - Biased random key based

Following the criteria of the first model, a heuristic model is developed based on random keys, a technique used in genetic algorithms to organize the chromosome and facilitate crossovers. In the problem studied it is used to perform chromosome ordering and correction based on randomized sequencing respecting precedences inherent to the care process, as well as the time windows in which they must be carried out [81].

The problem was divided into two sections, initially allocating patients to nurses (see algorithm 1). Subsequently, once the patients have a nurse assigned to them, tasks are ordered according to the care criteria required by the patient (see algorithm 2).

This procedure is iterative performed at each stage, enabling exploration of the solution space in both phases, guaranteeing a feasible solution that could be applied to the real service.

Algorithm 1 Nurse Scheduling Heuristic - Main Stage

```
Require: $N$, $M$, $P$, $PT_{np}$, $ET_n$, $LT_n$, $PAT_n$, $BigM$,
Require: $RandomNumber$, $SpaceSize$,
Ensure: Cmax, ExecutionTime, NumberTasksNurse, CompletionTimeNurse, NurseOccupationPercentage, PatientsNurse
$SampleService = \emptyset$
for $x = 1$ to $SpaceSize$ do
    $NursesOccupied = \emptyset$
    $PatientsAssignment = \emptyset$
    for $pa = 1$ to $P$ do
        $Nurse = RandomNumber(0, M-1)$
        $NurseAssigned = [pa, Nurse]$
        $PatientsAssignment \leftarrow NurseAssigned$
        $NursesOccupied \leftarrow Nurse$
    $Service = \emptyset$
    for $p = 1$ to $P$ do
        for $n = 1$ to $N$ do
            if $PT_{np} = 1$ then
                $Service \leftarrow$ [n,p]
    for $n = 1$ to $N$ do
        for $p = 1$ to $P$ do
            if $Service_{n,1} = PatientsAssignment_{p,0}$ then
                $Service_n \leftarrow PatientsAssignment_{p,1}$
    function ALGORITHM2($N$)
    $ServiceAssignment = \emptyset$
    for $i = 1$ to $NursesOccupied$ do
        $ServiceAssignment \leftarrow Algorithm_i$
    $SampleService \leftarrow ServiceAssignment$
    $ServiceAssignment = SampleService_0$
```

In the algorithm 1, the starting point is the creation of a space representing the service. This is empty and is carried out as many times as required to obtain an adequate solution to the problem. From line 3, a vector is created in which a random assignment of patients is made, including patient and nurse identifier.

Subsequently, from line 11 to 18 the extraction of patients by each professional is carried out, in order to carry out an ordering of activities assigned to each nurse, without the need to have the information of the whole service in the subproblem (function in line 19).
The distribution of patients is done randomly following a uniform distribution, also ensuring that all professionals must have at least 1 patient within the service. Likewise, due to the iterativity of the algorithm, it does not matter how bad the starting point is as long as it is feasible, which guarantees an exploration where, if due to resources it is not possible to have a high computational processing capacity, the initial solution can still be implemented in the service.

Finally, line 20 to 24 the entire service is grouped with the scheduled patients and the order of execution of activities for each nurse in their work shift. In line 24 a vector of solutions is stored, where the best one is selected based on the makespan. This vector also enables the service evaluation indicators to be calculated.

Algorithm 2 Nurse Scheduling Heuristic - Random Keys Based - Sub Stage

```
Require: $N, M, P, ShiftLimit, NumberCombinations, Service, PatientAssignment, Prec_{nu}, PT_{np}, P_{nm}$
Ensure: $Makespan$
$Makespan = \emptyset$
for $i = 1$ to $NumberCombinations$ do
    $Chromosome, TempPatient, TempChromo, TempJobs = \emptyset$
    for $j = 1$ to $PatientAssignment$ do
        if $PatientAssignment_{i,1} = Nurse$ then
            $TempPatient \leftarrow j$
    for $j = 1$ to $Service$ do
        if $Service_{i,1} = TempPatient$ then
            $TempChromo \leftarrow Service_j$
    for $j = 1$ to $TempChromo$ do
        $a = TempChromo_{j,0}$
        $b = TempChromo_{j,1}$
        $c = TempChromo_{j,2}$
        $d = RandomNumber(0.7, 1)$
        $h = [a, b, c, d]$
        $Chromosome \leftarrow h$
        $TempJobs \leftarrow TempChromo_{j,0}$
    $Precedences = \emptyset$
    for $i = 1$ to $Prec_{nu}$ do
        for $j = 1$ to $Prec_{nu}[0]$ do
            if $Prec_{i,j} = 1$ then
                $Brigde = [i, j]$
                $Prececendes \leftarrow Brigde$
    $Relations = \emptyset$
    for $i = 1$ to $N$ do
        $temp = \emptyset$
        for $j = 1$ to $Prececendes$ do
            if $Prececendes_{i,0} = i$ then
                $temp \leftarrow Prececendes_{i,1}$
            else if $Prececendes_{i,1} = i$ then
                $temp \leftarrow Prececendes_{i,0}$
        $Relations \leftarrow temp$
    $AuxService = \emptyset$
```

```
for $p = 1$ to $P$ do
    $Patient = \emptyset$
    for $n = 1$ to $N$ do
        if $PT_{np} = 1$ then
            $Patient \leftarrow n$
    $AuxService \leftarrow Patient$
$Correction = True$
while $Correction = True$ do
    $Correction = False$
    for $i = 1$ to $Precedences$ do
        if $Precedences_{i,0}$ & $Precedences_{i,1}$ in $TempJobs$ then
            $IndexPrec1 = TempJobs_{Precedences_{i,0}}$
            $IndexPrec2 = TempJobs_{Precedences_{i,1}}$
            if $Chromosome_{IndexPrec1,3} > Chromosome_{IndexPrec2,3}$ then
                $Correction = True$
                $Chromosome_{IndexPrec1,3} = RandomNumber(0, Chromosome_{IndexPrec2,3}$
$Chromosome = sort(Chromosome)$
$ShiftOccupied, ShiftAvailable, MinimumTimeValue = \emptyset$
for $i = 1$ to Chromosome do
    $MinimumTimeValue = [P_{Chromosome_{i,0}}, ShiftLimit]$
    if $ShiftAvailable = \emptyset$ then
        $e = MinimumTimeValue_0$
    else
        $MinimumTimeValue = [max(P_{Chromosome_{i,0}}), Chromosome_{i-1,6}, ShiftLimit]$
        if $MinimumTimeValue = \emptyset$ then
            $Infeasible$
    $e = MinimumTimeValue_0$
    $f = P_{Chromosome_{i,0}, Chromosome_{i,2}}$
    $g = e + f$
    if $e$ in $ShiftOccupied$ then
        for $j = 1$ to $MinimumTimeValue$ do
            if $MinimumTimeValue_j$ in $ShiftAvailable$ then
                $e = MinimumTimeValue_j$
                $g = e + f$
    $Chromosome_i \leftarrow e, f, g$
    $ShiftOccupied \leftarrow [e, g]$
    $ShiftAvailable = Shift \cap ShiftOccupied$
$Makespan \leftarrow Chromosome$
$Makespan \leftarrow \min(Makespan)$
```

In the algorithm 2, the input parameter is taken as the nurse to whom the task ordering will be generated, once a number of patients has been assigned. As a first step, sequencing is set to be performed a number of times to enable the algorithm to explore the solution space. Each of these solutions will be integrated into the makespan vector, which in the end will return the best of the solutions found (in this case the one with the lowest value).

Subsequently, lines 4 to 9 describe the extraction of the specific tasks for each patient and the linearization of the vector (since what is retrieved are tuples), integrating all the data into a one-dimensional vector. From row 10 to 17, the construction based on chromosomes with random keys is started, which enables a primitive sequencing to be obtained that can be improved without applying rules that increase the possibility of an infeasible solution. The first data inserted are the task identifier, patient, nurse and the random key (numeric value from 0 to 1).

Validation and correction of precedence in the service is performed between rows 18 and 49. Initially, this is validated with the random keys associated to each task, in such a way that, if a precedence is not validated, the predecessor key must take a lower value than the successor, independently of the tasks that may exist in between, since it is not required that the tasks are strictly performed one after each other.
As a complementary step, in row 24 there is a set of relations that has the purpose of registering the relations that exist between the tasks, whether predecessors or successors, so that if there is a sequence of tasks from n_a to n_b, a new validation of the relation in the inverse sense must not be performed, saving computational time when the precedence matrix is imported and read and it has a considerable size.

Once the sequence with the precedences has been configured, the time windows are validated to ensure that they are executed within the time established in the medical assessments. To do this, one of sets is made with a maximum length of the shift value. In this way, the solution will never go out of the real limits and its applicability can be guaranteed. From row 52, a fully available shift starts, which is occupied as each task is integrated. This process consists of two parallel vectors where one is in charge of blocking the places used by a task once it enters the scheduling, and the other one crosses the requested and the previously available, to give as an answer the new working time availability (Minimum Time Value vector).
It should be noted that each task must be able to be scheduled in its entirety, avoiding overlaps or crossings in the scheduling, in the available spaces. Otherwise, it will be sent to the end of the queue, which, although it significantly increases the makespan in the first solutions, it

decreases once new task configurations are found.
Finally, in rows 71 and 72, the recorded solutions are sorted and the one with the lowest value is selected.

6.4 Test and results

All tests and real instances for this problem were runned in Python on a ThinkVision PC with an Intel Xeon R W-2145 3.70 Hz processor, with 32GB RAM and a 64-bit operating system. The MILP problem instances were solved with IBM's CPLEX solver.

6.4.1 Instances generation

To test the model in hypothetical situations and, due to the characteristics of the problem which integrates precedence, time windows and activities subject to the patient epidemiological profile, the construction of instances generated under the assumptions is carried out:

1. Number of patients in the inpatient service must be greater than number of nurses.
2. A patient must not have more than 40 jobs assigned to their care condition, otherwise it is considered critical care and their care therefore relies on another area in charge of specialized care.
3. All patients in the inpatient service must have at least one activity related to their care.

Based on the above, the following instance sizes are proposed based on the proposed sizes of regular instances for unrelated machine problems (see table 6.1). The number of nurses and patients is taken from the clinics surveyed and from clinics for which reference is available, as well as from the WHO report [2], where nurse-patient ratios range from 6 to 1 to 20 to 1. Likewise, it is expected that for its application in the real service, the real planning of the work shift can be obtained within 30 minutes after the start of the service, so that an execution would be carried out at the end of the previous shift and the start of the next one, in parallel to the shift handover carried out by the nursing staff.

Additionally, for each combination we propose the construction of 21 instances where, 7 will have large time windows (between 1 to 4 hours to start job n), 7 will have small time windows (between 20 min to 1 hour to start job n) and the remaining 7 will have windows combined in half according to the number of jobs to be done.

Jobs	25	50	75	100	125
Nurses	2	4	6	8	10
Patients	5	10	15	25	30

Table 6.1 Proposed combinations for theoretical instances

Nonetheless, considering the problem's features, and given that the larger the combination, the greater the complexity, for the MILP model it was found that for combinations with a high number of jobs with a low number of nurses, the problem failed to converge to a solution. It was also noted that those combinations with larger or more diverse time windows (small, medium, and large), took longer to converge to optimality or a good solution, as the number of possibilities to configure the service increases (see tables A.1 & A.2).

6.4.2 Instances Run-Time vs Size & Time Windows

As the first factor to be evaluated, a contrast is made of the statistical parameters evidenced for each instance size, according to the time window implemented. The number of solved instances for the MILP model was a total of 1194, while for the heuristic model, it was 1537. For both models, instances of up to 100 jobs were solved in the service, so combinations with 125 jobs were excluded due to solution time and lack of convergence to a feasible solution.

In this study, the time windows show an effect on the solution time of the instances for the MILP model (see figure 6.2 left graph), demonstrating how, given the size configured for the service between patients and nurses available, the time window will be hard or will have no effect on the solution time, whereas, in the heuristic model, this has no effect on the solution time of the instances, leaving the latter only subject to the dependency on instance size.
The number of instance combinations (x-axis in figure 6.2) was calculated as the product of n, p, and m.

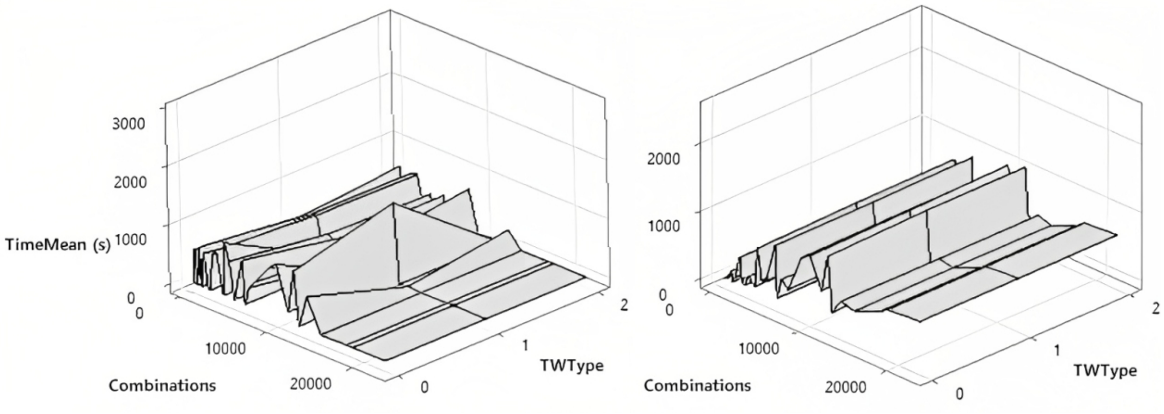


Fig. 6.2 Run time vs. size vs. time window plots (0: Small, 1: Large, 2: Mixed)

Figures 6.3 and 6.4 show in a clearer way the combinations for which the execution time increases. It should be noted that clear areas indicate greater facility in solving the instance with either of the two models and the greater the number in the combination, the greater the number of tasks, machines and patients in the service, so that, despite the greater possibility of accommodation, the system is not forced to make re-locations due to the time windows when it adds jobs to the schedule.

It is also confirmed that for the MILP model there are differences in the execution time for the same instance with different time windows, especially for small time windows, in which the execution time can be slightly increased as it is a hard constraint type.
The specific combinations in which the significant increase in debugging times is detected can be broken down in the tables A.1 & A.2.

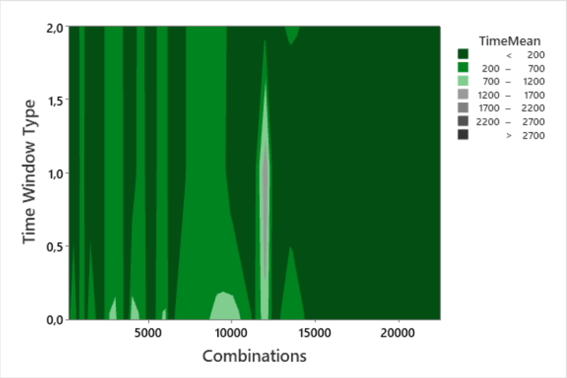


Fig. 6.3 Contour plot for MILP model run-time

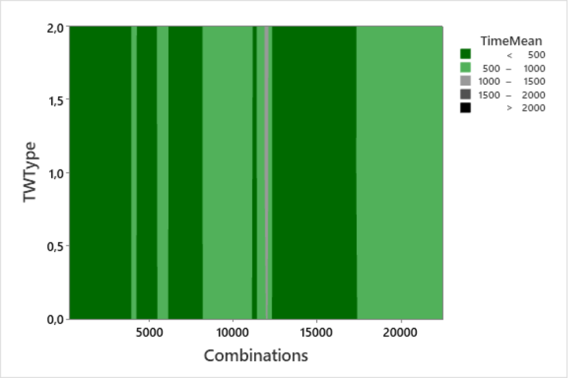


Fig. 6.4 Contour plot for heuristic model run-time

Additionally, to compare the performance of each instance, 4 indicators were exported which are:

- Activities Per Nurse (APM):

$$\begin{cases} Count(n) & \text{if job } n \in \text{Service}_p \\ 0 & \text{otherwise} \end{cases} \tag{6.15}$$

- Nurse Occupation Percentage (NOP):

$$\frac{\sum_{n=1}^{N} P_{nm}}{Cmax} \qquad \forall\, m \tag{6.16}$$

- Completion Time per Nurse (CTM):

$$\max(FT_n) \qquad \forall\, m \tag{6.17}$$

- Patients Per Nurse (PPM):

$$\begin{cases} Count(p) & \text{if patient } p \notin \text{Service}_p \\ 0 & \text{otherwise} \end{cases} \tag{6.18}$$

Each of these indicators was calculated for each instance, where it is demonstrated that, while a considerable imbalance in nurse utilization can be obtained given a scenario where some patients require more care than others, it is guaranteed to minimize the difference in shift completion times for each nurse (see tables A.1 & A.2).

6.4.3 Sample solved instances MILP vs Heuristic models

In order to perform a more explicit contrast between the scheduling models, some solutions exported by the MILP and heuristic model are taken randomly from various instance sizes and time windows.

Table 6.2 presents the results for instances from the combination n, m and p being 25, 4, and 5 respectively until combinations of 100, 10, and 10.
It can be seen that, although the problem may converge optimally in most cases with the MILP model, the heuristic model manages to find solutions for small instances, and for large ones, it achieves a good solution in less time, so it could be easily implemented within the

daily operation considering its ease of implementation compared to traditional optimization models.

	MILP				Heuristic			
Size	**Cmax**	**Status**	**Time**	**GAP**	**Cmax**	**Status**	**Time**	**GAP**
25x4x5	267	Optimal	0.46	0.00	267	Optimal	12.55	0.00
50X4X10	318	Optimal	13.03	0.00	318	Optimal	66.282	0.00
100X4X10	327	Optimal	1813.545	0.00	419	Best found	1253.219	0.28
100x2x5	572	Best found	539.706	0.18	619	Best found	520.317	N/A
100x6x10	310	Optimal	1806.288	0.00	340	Best found	2262.532	0.10
100x10x10	283	Optimal	2198.694	0.00	288	Best found	1805.548	0.02

Table 6.2 Table with sample results generated by MILP and heuristic models (Run-time in seconds).

Figures 6.5 and 6.6 present the diagrams corresponding to the solutions of the 6.2 table, showing the distribution of the tasks for the evaluated instances.

First, it is observed that for the small instances of 25 and 50 jobs there are large gaps in the service because they are test instances to evaluate the speed of the model in small environments. However, for the 100-job instances with different numbers of patients and nurses, we can see that the service reaches a considerable level of occupancy, with almost all the free spaces disappearing when the number of nurses available for primary care in hospitalization is reduced.

From the presented solutions, it can be stated that the size of the instance relatively affects the solution time as the time windows are flexible, as strict windows only allow two configurations, 1) a solution with room for jobs exactly aligned to the scheduled space or 2) infactibility due to the inability to configure jobs within the set window.

Also, it is corroborated that the completion time of activities can be equalized in the service for nursing professionals if the necessary information is available to estimate the time of care required by patients, as this information enables patients to be located within the service in a better way and work is not assigned according to the number of patients since it reflects a significant bias within the service and operationally impacts the quality of care provided (see tables 6.3 & 6.4).

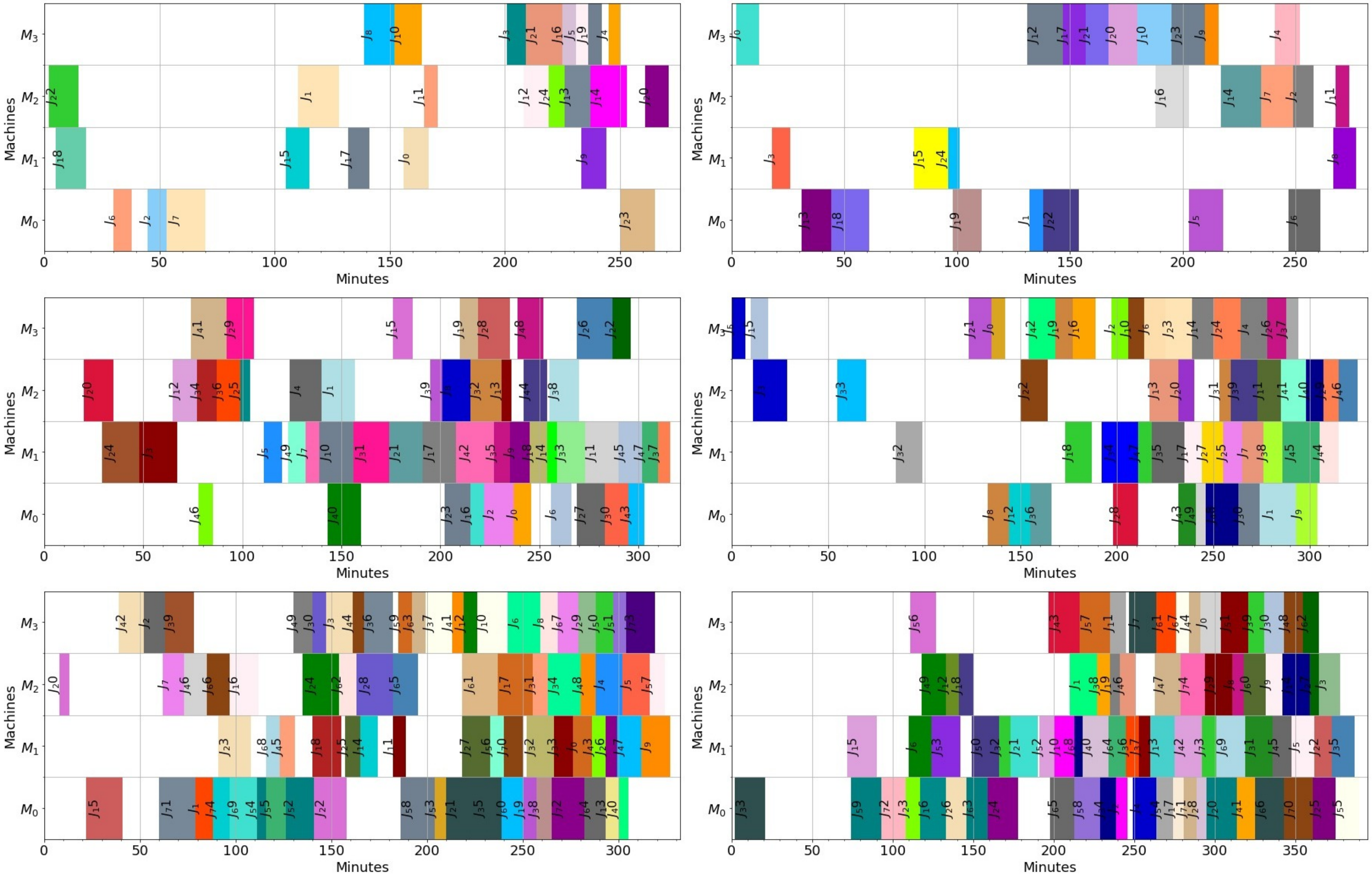


Fig. 6.5 Gantt chart solutions for MILP vs Heuristic models for instances with jobs $n = 25, 50, 100$, machines $m = 4$ and patients $p = 5$ 10

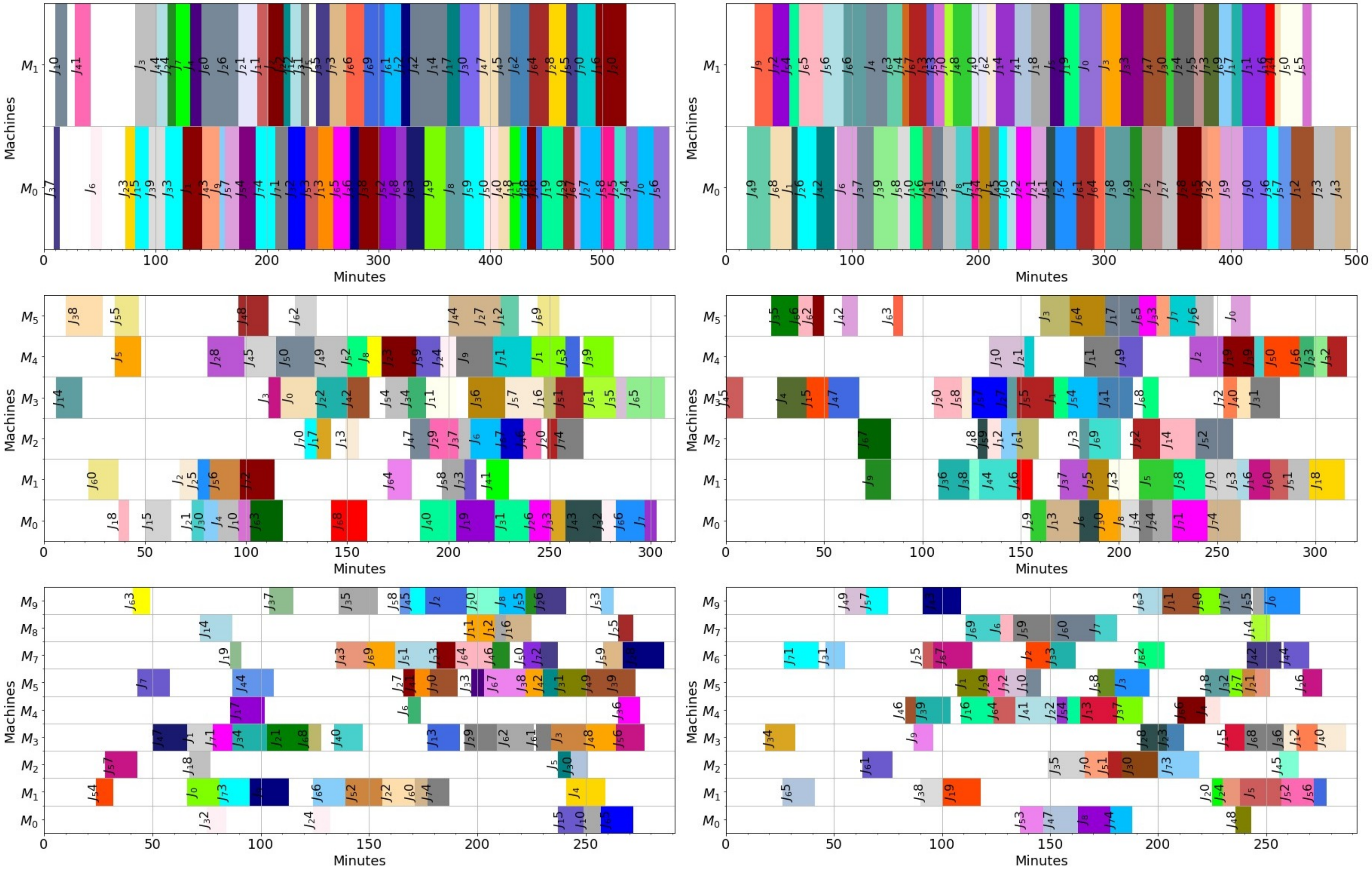


Fig. 6.6 Gantt chart solutions for MILP vs Heuristic models for instances with jobs $n = 100$, machines $m = 2, 6, 10$ and patients $p = 5$ 10

Size	MILP			
	APM	CTM	NOP	PPM
25x4x5	[8, 8, 5, 4]	[250, 267, 248, 265]	[0.17, 0.48, 0.25, 0.31]	[1, 2, 1, 1]
50X4X10	[8, 13, 19, 10]	[296, 260, 318, 305]	[0.48, 0.62, 0.88, 0.13]	[2, 4, 3, 1]
100X4X10	[20, 29, 24, 27]	[326, 327, 315, 324]	[0.79, 0.97, 0.83, 0.94]	[2, 3, 2, 3]
100x2x5	[48, 52]	[509, 531]	[0.93, 0.97]	[2, 3]
100x6x10	[19, 19, 13, 18, 19, 12]	[273, 273, 310, 265, 310, 285]	[0.33, 0.65, 0.56, 0.71, 0.80, 0.55]	[2, 2, 1, 2, 2, 1]
100x10x10	[16, 6, 13, 14, 7 , 14, 8, 13, 9]	[250, 263, 283, 266, 268 , 270, 251, 258, 261]	[0.45, 0.15, 0.42, 0.43, 0.08 , 0.57, 0.12, 0.39, 0.07]	[2, 1, 1, 1, 1 , 1, 1, 1, 1]

Table 6.3 Calculation of indicators for sample MILP model instances.

Size	Heuristic			
	APM	CTM	NOP	PPM
25x4x5	[9, 5, 4, 7]	[240, 264, 267, 261]	[0.30, 0.20, 0.10, 0.30]	[1, 1, 1, 2]
50X4X10	[15, 13, 12, 10]	[291, 318, 308, 302]	[0.61, 0.41, 0.39, 0.37]	[3, 2, 3, 2]
100X4X10	[26, 30, 19, 25]	[419, 384, 321, 361]	[0.74, 0.81, 0.52, 0.72]	[3, 3, 2, 2]
100x2x5	[48, 52]	[471, 503]	[0.93, 0.98]	[2, 3]
100x6x10	[24, 17, 24, 9, 13, 13]	[312, 338, 340, 255, 245, 336]	[0.81, 0.54, 0.77, 0.29, 0.39, 0.52]	[2, 2, 3, 1, 1, 1]
100x10x10	[7, 11, 9, 12, 14, 14, 12, 9, 12]	[245, 277, 265, 288, 238, 265, 260, 251, 257]	[0.09, 0.15, 0.12, 0.16, 0.46, 0.39, 0.28, 0.22, 0.30]	[1, 1, 1, 1, 1, 2, 1, 1, 1]

Table 6.4 Calculation of indicators for sample Heuristic model instances.

Tables 6.3 & 6.4 show in detail the information in the diagrams presented in figures 6.5 & 6.6. From this table, it can be seen that the most important indicators are the NOP (eq. 6.16) and the CTM (eq. 6.17), which show that the staff is being used appropriately within the service, making the most of their availability, as well as guaranteeing them an equitable completion of their shift, since the number of tasks associated with a patient does not define their condition of care.

	MILP		**Heuristic**	
Size	**Mean**	**SD**	**Mean**	**SD**
25x4x5	257.50	9.88	258.00	12.25
50X4X10	294.75	24.86	304.75	11.30
100X4X10	323.00	5.48	371.25	41.12
100x2x5	520.00	15.56	487.00	22.63
100x6x10	286.00	19.66	304.33	43.41
100x10x10	263.33	10.15	260.67	15.48

Table 6.5 Summary table for the CTM indicator (min).

Furthermore, table 6.5 presents summary statistics for both models, demonstrating for the majority, the deviation is between 15 to 20 min of deviation in the completion of the activities execution (CTM). Bearing in mind that in a 12-hour shift, 20 minutes represents 2% of the working day and that the models showed that they did not use the entire working day (720 minutes), this is considered insignificant and supports the assumption that the non-existence of waste, as shown in the previous chapter, significantly improves the exclusive dedication to care and traceability in the same.

On the other hand, for the NOP indicator, no statistical calculation is made, as it can be seen firsthand that there is a considerable imbalance in the use of each nurse (see tables 6.3 and 6.4). This is due to two reasons: 1) the number of activities subject to patients and the time in which these should be performed because traceability in personal mixed patient care should not be interrupted and if there are activities that can be performed in a common time window by the same nurse, it is most appropriate to assign them to the same nurse; 2) the size of the implemented instances is based on an ideal representation of the hospital service, because in reality, there are not many nurses in the same shift, so they are usually loaded than they should be (an example would be the graphs in the first line in figure 6.6, which could be a real instance).

Chapter 7

EXPERIMENTATION WITH REAL DATA

In the previous chapter, it was proven that both models developed achieve solutions that are compliant and applicable to the reality of the service in both hospitals. It remains to be verified, however, whether good solutions can also be achieved and whether they are improved compared to the current allocation of these services.

This analysis is based on the historical data collected in the first phase of the study since we have records of the activities carried out during a working day over several days, as well as the workload distribution and the patient number in the inpatient service.

This comparison was done by taking 4 instances and running the MILP and heuristic models to be contrasted with the original allocation observed on the day of collection. In addition to the run-time, GAP and makespan of the solution, this contrast is made on the basis of the proposed indicators. Contrast order for the Gantt charts in figures 7.1 and 7.2 is done vertically, in the order of real situation, MILP model and heuristic model.

Selection of instances was based on the highest amount of jobs evidenced in the database developed. In all the selected instances the service had two professional nurses, who were monitored throughout the day at different times of the day, taking into account a 12-hour (720 min) working day from 7 am to 7 pm. It is also necessary to mention that, given the conditions of the service and the presence of adverse events during the service, the solutions presented do not reflect the totality of the work carried out by the staff due to insufficient equipment and personnel to carry out complete monitoring.

Size (Jobs)	Cmax (min)			Status		GAP		Time (s)	
	Real	MILP	Heuristic	MILP	Heuristic	MILP	Heuristic	MILP	Heuristic
125	616	598	610	Optimal	Best Found	0.00	0.02	1805.30	774.67
88	579	550	559	Optimal	Best Found	0.00	0.02	1806.49	799.20
73	718	590	654	Optimal	Best Found	0.00	0.11	1803.35	195.15
73	453	407	427	Optimal	Best Found	0.00	0.05	1803.27	200.70

Table 7.1 Summary table of the debugging of real instances.

Size (Jobs)	APM			CTM		
	Real	MILP	Heuristic	Real	MILP	Heuristic
125	[56, 69]	[61, 64]	[62, 63]	[604, 616]	[598, 516]	[610, 503]
88	[37, 51]	[43, 45]	[43, 45]	[537, 579]	[541, 550]	[570, 559]
73	[45. 28]	[37, 36]	[48, 25]	[660, 718]	[587, 590]	[691, 654]
73	[36, 37]	[39, 34]	[32, 41]	[453, 305]	[353, 407]	[427, 325]
Size (Jobs)	NOP			PPM		
125	[0.64, 0.90]	[0.84, 0.69]	[0.83, 0.71]	[22, 21]	[19, 24]	[20, 23]
88	[0.35, 0.47]	[0.41, 0.41]	[0.40, 0.41]	[15, 16]	[18, 13]	[18, 13]
73	[0.58, 0.52]	[0.51, 0.60]	[0.63, 0.48]	[18, 20]	[23, 15]	[21, 17]
73	[0.38, 0.43]	[0.41, 0.40]	[0.33, 0.48]	[18. 17]	[21, 14]	[20, 15]

Table 7.2 Table of proposed indicators obtained from the debugging of real instances.

Table 7.1 summarises the testing performed for the instances, where it is shown that the MILP model achieves the best possible solution, guaranteeing an adequate allocation in the service, which meets the patients' requirements and workflow. However, achieving this solution takes a significant amount of time during the workday and can generate delays at the start of work depending on the speed with which the shift is delivered, so implementing the heuristic solution is an acceptable alternative as it demonstrates a reduction of between 50% to 80% of the MILP model solution time, obtaining a GAP under 10% in the majority of solutions.

It should be noted that with both models it is possible to achieve a significantly balanced distribution of the work completion time, balancing the workload within the service based on the task difficulty. Table 7.2 records findings for the proposed indicators, demonstrating that an adequate balance in the workload in the department is subject to the condition of the patients (by not distributing them in half, as well as dividing the number of jobs equally). Rather, the distribution is in accordance with the execution time of the activities, enabling the service to reduce its makespan and, therefore, increase the spaces where professionals can take active breaks to help them reduce burnout, or to take advantage of patient traceability work.

For the purposes of this analysis, the CTM and NOP indicators are considered to be of greater importance (see table 7.2), as they reflect equality in the completion of work and intrinsically the balancing of the workload within the service, and the percentage of occupancy of the service (bearing in mind that the totality of activities could not be monitored).
The CTM indicator shows a variability of between 1% and 16% maximum between the completion of work by professionals, clearly subject to the traceability that must be observed when caring for them so that their activities cannot be transferred to another nurse.
On the other hand, the NOP indicator is found in a percentage of occupancy for the different instances between 38% and 84%, which indicates an addition to the existence of unregistered work for some days, the crucial thing to guarantee within the service is not to reach 100% occupancy, but rather an adequate balance between the two percentages. Figures 7.1 and 7.2 illustrate the distribution of tasks and the occupancy of the service in a work shift, showing a high load at the beginning of the shift and a decrease in activities after 6 hours of the shift.

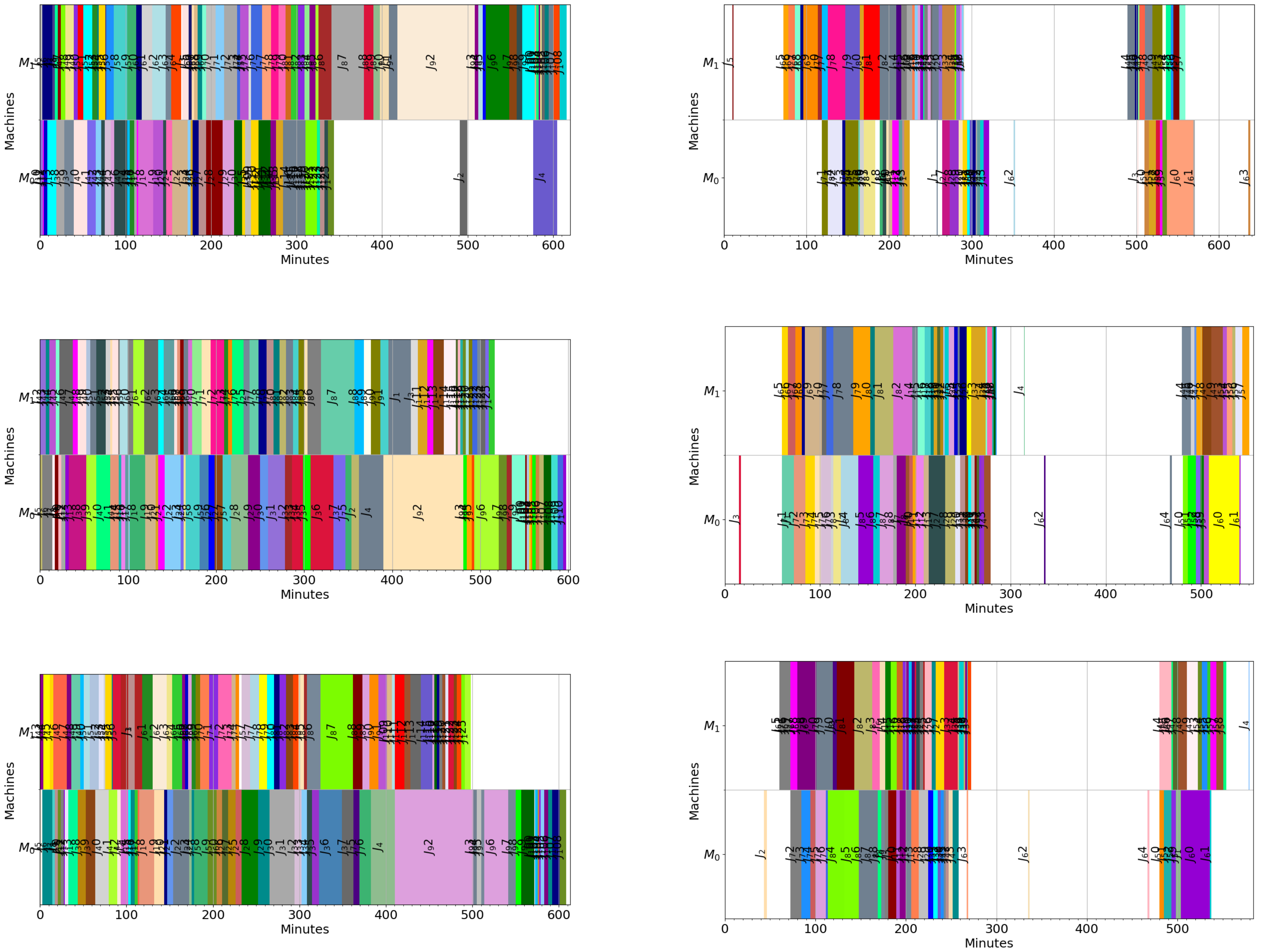


Fig. 7.1 Gantt chart solutions for Real vs MILP vs Heuristic models for instances with jobs n = 125, 88 and machines m = 2

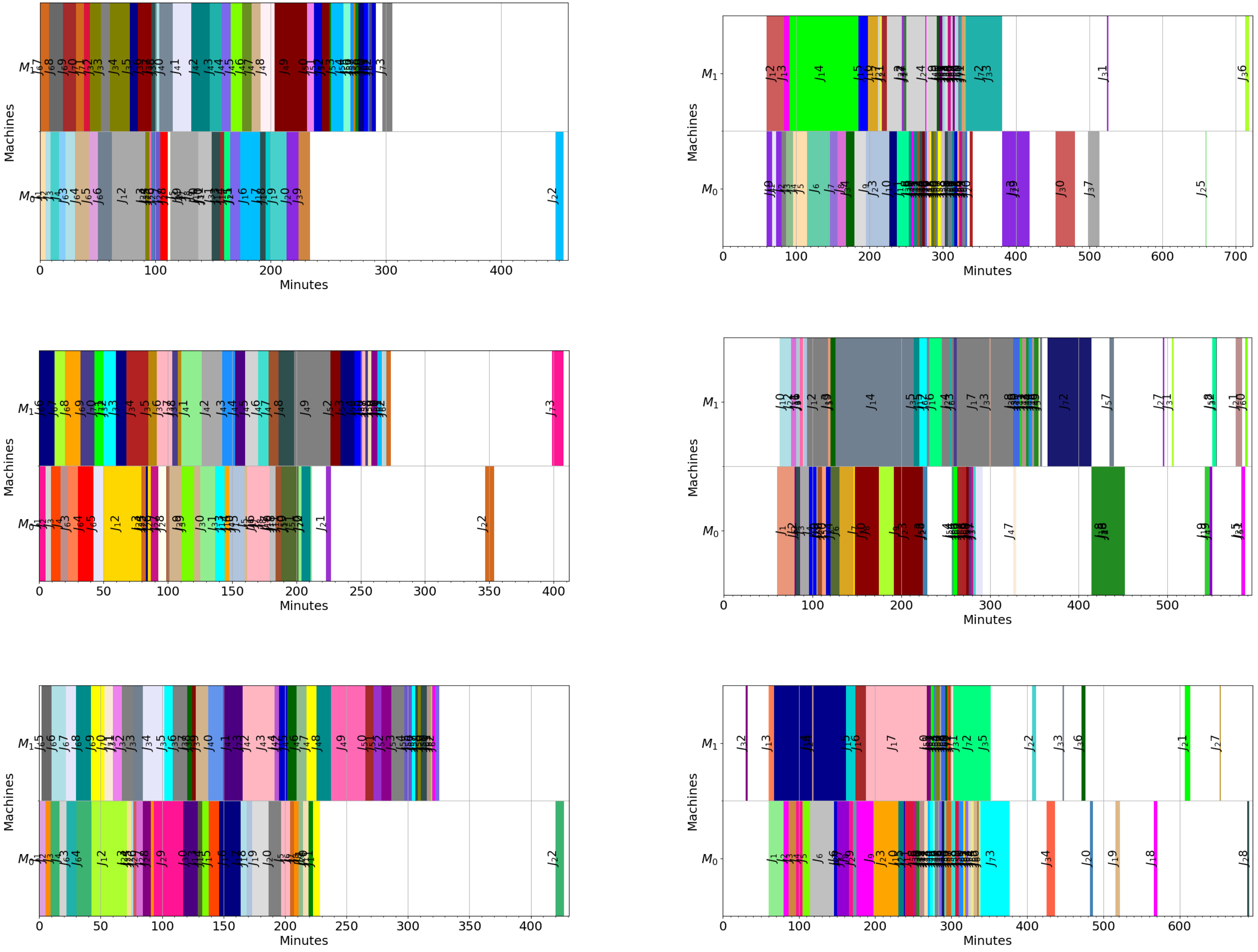


Fig. 7.2 Gantt chart solutions for Real vs MILP vs Heuristic models for instances with jobs n = 73 and machines m = 2

Chapter 8

CONCLUSIONS AND FUTURE WORK

This thesis studied the nurse-to-patient allocation problem based on the real problem observed in two Latin American clinics. To solve it, two strategies for solving the problem were formulated, the first one, with mixed integer programming MILP, obtained good results with small and some medium-sized instances, proving to be a tool that could be implemented in decisions that can be delegated to auxiliary personnel. Nonetheless, the implementation of tools such as professional solvers for NP-hard problems within non-academic institutions results in a significant investment both in the implementation of the software and in the training of personnel and the adaptation of these tools to internal systems.

On the other hand, the second option proposed is a heuristic algorithm based on local search and genetic algorithms with random keys (technique used to order a dataset, in a random or guided way by generating random numbers assigned to an activity and subsequently sorted), enabling the construction of a solution that is easy to process and apply in the hospital systems available to clinics. This heuristic model also enables obtaining good solutions, not far from the optimal solution, with a variation between 2% to 15% on average, but demonstrating a significant reduction in the execution times of the instances by up to 25% when these exceed 75 scheduled jobs. For the performance evaluation of the developed models, randomly generated data were used, taking into account the essential characteristics of the problem, in addition to real data previously collected in several observation days carried out in both clinics.

Regarding the study of lean healthcare and the evaluation of the execution of activities in hospital services, it is essential to have a larger sample of hospitals, as well as budget and personnel, to complement this study and to be able to converge to a common point in which it is easier to replicate these workload predictor models.

Measuring the condition of a patient requires a large investment in both technology and care itself, so as not to generate inconveniences in hospital stays, but bearing in mind that a measurement of the greatest number of variables involved in the environment can lead to a better understanding of care.
This should also apply to the staff themselves because although questionnaires or interviews can be conducted with the personnel about their willingness to work, there is information that can be omitted or biased by the observer or the personnel themselves.

For statistical analysis and construction of predictive models in working times, it is recommended to implement robust models and epidemiological models that are not sensitive to variability when validating assumptions, since in this problem we tried to predict with different techniques to detect patterns such as random forests, Gaussian distributions, generalized regressions, but none of them is effective for the detection of patterns.

As future work, it is expected to carry out enhancements to the models built, especially to the heuristic algorithm developed, eliminating randomization in several of its stages and obtaining a greater diversification in the solutions generated, which would lead to an improvement in the execution time of the algorithm.

Implementing stochastic process times is an important aspect to consider, as it would more adequately model the behavior of hospital services, integrating latent adverse events. This requires more rigorous sampling, preferably 24/7, where all service routine is evidenced.
Moreover, the application of advanced programming and modelling techniques such as dynamic programming and meta-heuristics would enable a better solution time for the problem, or techniques such as preemptive scheduling, which reflects the reality of the service, but requires a large number of restrictions to reduce the computational processing time in which a solution is achieved.

Finally, and as complementary findings in this research, it is important to consider the future development of applied technologies in nursing, such as software for decision-making, as is the purpose of the macro-project to which this study was subjected, that its development should be parallel and always under consultation with the nursing staff.
This is mentioned because many systems are migrated from the industry and although they manage to adapt to a great extent to the general hospital requirements, it is not possible to guarantee their immediate adaptation to the evolution of the patient's profile, falling back on

complementary developments that sometimes are not connected to the main system, and this generates repetition of work and losses in traceability.

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Appendix A

Size	TW Type	Optimal Instances	GAP		Cmax		Solution Time		Nurse Occupation		Task per Nurse	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
25x2x5	Small	6	0.00	0.00	271.17	17.19	0.39	0.12	0.55	0.05	12.50	0.00
	Large	7	0.00	0.00	267.29	5.74	0.34	0.04	0.52	0.04	12.21	0.76
	Mixed	6	0.00	0.00	282.17	1.60	0.35	0.03	0.52	0.05	12.50	0.00
25x2x10	Small	7	0.00	0.00	265.71	20.01	0.46	0.18	0.54	0.05	12.50	0.00
	Large	7	0.00	0.00	268.29	6.60	0.35	0.11	0.55	0.05	12.50	0.00
	Mixed	7	0.00	0.00	269.71	11.60	0.34	0.10	0.53	0.07	12.50	0.00
25x2x15	Small	7	0.00	0.00	270.86	13.26	0.63	0.48	0.55	0.05	12.50	0.00
	Large	7	0.00	0.00	263.29	17.34	0.39	0.09	0.56	0.05	12.50	0.00
	Mixed	7	0.00	0.00	260.00	10.34	0.39	0.15	0.57	0.05	12.43	0.19
25x2x25	Small	7	0.00	0.00	271.71	11.28	0.50	0.17	0.52	0.02	12.29	0.39
	Large	7	0.00	0.00	272.71	6.45	0.51	0.27	0.53	0.06	12.29	0.57
	Mixed	7	0.00	0.00	267.14	18.99	0.49	0.22	0.58	0.05	12.50	0.00
25x4x5	Small	7	0.00	0.00	272.14	6.96	0.48	0.10	0.32	0.03	7.44	1.11
	Large	7	0.00	0.00	263.29	18.11	0.48	0.07	0.33	0.08	6.55	0.79
	Mixed	7	0.00	0.00	264.86	10.98	0.39	0.06	0.37	0.05	8.03	0.79
25x4x10	Small	7	0.00	0.00	274.00	2.77	0.45	0.10	0.34	0.07	7.14	1.11
	Large	7	0.00	0.00	259.29	14.14	0.42	0.06	0.44	0.09	7.80	0.92
	Mixed	7	0.00	0.00	273.71	9.46	0.42	0.12	0.38	0.07	6.84	1.01
25x4x15	Small	7	0.00	0.00	264.71	9.52	0.48	0.08	0.46	0.20	6.84	1.01
	Large	7	0.00	0.00	263.57	7.39	0.49	0.10	0.38	0.13	6.48	0.84
	Mixed	7	0.00	0.00	269.71	5.53	0.44	0.08	0.56	0.14	7.14	1.11
25x4x25	Small	7	0.00	0.00	270.57	4.16	0.47	0.14	0.45	0.16	6.25	0.00
	Large	7	0.00	0.00	268.86	6.54	0.42	0.04	0.30	0.09	6.25	0.00

	Mixed	7	0.00	0.00	265.14	6.79	0.44	0.11	0.54	0.17	6.25	0.00
25x6x10	Small	7	0.00	0.00	262.29	17.09	0.58	0.23	0.35	0.11	6.01	1.70
	Large	7	0.00	0.00	271.14	4.22	0.60	0.07	0.32	0.09	5.54	1.37
	Mixed	7	0.00	0.00	255.86	11.87	0.50	0.08	0.32	0.06	6.19	1.64
25x6x15	Small	7	0.00	0.00	263.86	9.48	0.77	0.31	0.51	0.15	6.31	1.49
	Large	7	0.00	0.00	267.43	10.42	0.57	0.06	0.38	0.15	5.83	1.73
	Mixed	7	0.00	0.00	268.86	3.89	0.60	0.08	0.53	0.18	5.77	1.47
25x6x25	Small	7	0.00	0.00	261.00	9.73	0.63	0.21	0.46	0.08	6.01	2.94
	Large	7	0.00	0.00	268.71	6.50	0.54	0.03	0.31	0.10	4.41	0.40
	Mixed	7	0.00	0.00	265.71	8.83	0.60	0.08	0.46	0.09	5.66	1.57
25x8x10	Small	7	0.00	0.00	256.57	13.59	0.69	0.08	0.30	0.08	4.53	0.44
	Large	7	0.00	0.00	270.71	8.24	0.82	0.13	0.37	0.08	4.10	0.98
	Mixed	7	0.00	0.00	270.29	7.61	0.75	0.11	0.38	0.12	5.01	1.26
25x8x15	Small	7	0.00	0.00	259.57	21.32	0.65	0.28	0.35	0.11	3.90	0.68
	Large	7	0.00	0.00	260.86	9.53	0.73	0.10	0.37	0.12	4.32	0.51
	Mixed	7	0.00	0.00	265.29	6.78	0.58	0.07	0.32	0.09	4.33	0.99
25x8x25	Small	7	0.00	0.00	271.29	5.35	0.66	0.13	0.47	0.05	4.68	0.58
	Large	7	0.00	0.00	264.14	7.27	0.57	0.11	0.46	0.06	3.76	0.41
	Mixed	7	0.00	0.00	263.00	8.37	0.65	0.12	0.46	0.05	4.43	0.98
25x10x10	Small	7	0.00	0.00	265.57	7.63	0.92	0.19	0.29	0.09	4.09	0.72
	Large	7	0.00	0.00	267.00	5.54	0.89	0.06	0.36	0.07	4.47	1.04
	Mixed	7	0.00	0.00	264.86	10.84	0.87	0.11	0.36	0.07	4.15	0.64
25x10x15	Small	7	0.00	0.00	261.29	15.30	0.96	0.05	0.39	0.12	4.01	1.93
	Large	7	0.00	0.00	270.71	5.47	0.91	0.13	0.40	0.11	3.71	0.75

	Mixed	7	0.00	0.00	257.14	24.82	0.75	0.13	0.35	0.14	5.00	0.93
25x10x25	Small	7	0.00	0.00	269.29	5.31	0.96	0.22	0.45	0.11	3.56	0.51
	Large	7	0.00	0.00	266.29	7.76	0.58	0.04	0.40	0.09	2.79	0.18
	Mixed	7	0.00	0.00	265.14	8.82	0.66	0.07	0.39	0.06	2.96	0.39
50x2x5	Small	7	0.12	0.04	330.43	15.54	1803.64	1.19	0.85	0.09	24.00	2.65
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
50x2x10	Small	7	0.10	0.03	312.29	11.18	1803.85	1.32	0.90	0.08	24.50	1.32
	Large	3	0.00	0.00	312.00	5.29	1372.76	741.23	0.86	0.06	24.00	1.73
	Mixed	3	0.05	0.02	311.33	13.65	1804.78	2.84	0.93	0.02	25.00	0.00
50x2x15	Small	7	0.12	0.03	321.14	13.70	1803.71	0.94	0.89	0.07	24.36	0.94
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
50x2x25	Small	7	0.11	0.02	310.57	6.02	1804.46	0.82	0.91	0.03	24.64	0.48
	Large	4	0.09	0.02	307.75	10.87	1801.98	0.47	0.92	0.02	25.00	0.00
	Mixed	4	0.10	0.09	312.00	26.80	1759.19	87.98	0.91	0.05	25.00	0.00
50x2x30	Small	7	0.09	0.06	308.14	24.85	1803.18	1.48	0.91	0.04	25.00	0.00
	Large	4	0.04	0.02	291.00	4.90	1801.59	0.35	0.90	0.02	25.00	0.00
	Mixed	4	0.10	0.04	306.50	15.59	1804.28	0.38	0.90	0.05	24.25	0.65
50x4x5	Small	7	0.00	0.00	277.43	14.58	160.51	414.49	0.54	0.06	13.10	1.58
	Large	7	0.00	0.00	282.29	5.77	4.17	0.37	0.54	0.06	13.10	1.58
	Mixed	7	0.00	0.00	273.43	7.87	7.28	4.32	0.53	0.02	12.50	0.00
50x4x10	Small	7	0.00	0.00	274.57	7.32	4.88	2.93	0.55	0.06	13.10	1.58
	Large	7	0.00	0.00	276.43	6.63	3.81	1.58	0.51	0.03	12.29	0.57

	Mixed	7	0.00	0.00	273.43	7.55	5.31	3.98	0.53	0.04	12.50	0.00
50x4x15	Small	7	0.00	0.00	270.14	10.17	7.41	6.15	0.50	0.03	12.43	0.19
	Large	7	0.00	0.00	275.86	4.14	3.05	1.01	0.50	0.03	12.50	0.00
	Mixed	7	0.00	0.00	274.29	5.09	2.29	0.38	0.50	0.04	12.50	0.00
50x4x25	Small	7	0.00	0.00	275.29	2.36	3.47	1.75	0.47	0.02	12.50	0.00
	Large	7	0.00	0.00	273.14	4.88	4.68	2.28	0.49	0.04	12.50	0.00
	Mixed	7	0.00	0.00	272.00	2.38	8.96	16.59	0.48	0.04	12.29	0.57
50x4x30	Small	7	0.00	0.00	277.14	5.27	5.32	4.21	0.45	0.04	12.50	0.00
	Large	7	0.00	0.00	271.57	5.62	3.38	0.91	0.47	0.03	12.50	0.00
	Mixed	7	0.00	0.00	274.14	5.27	3.76	1.87	0.46	0.03	12.36	0.28
50x6x10	Small	7	0.00	0.00	271.00	3.16	4.51	2.02	0.41	0.12	9.40	1.58
	Large	6	0.00	0.00	275.33	7.26	5.49	2.32	0.40	0.03	8.61	0.68
	Mixed	6	0.00	0.00	271.00	2.76	4.23	0.99	0.35	0.01	8.61	0.68
50x6x15	Small	7	0.00	0.00	276.00	5.51	5.52	5.08	0.39	0.08	8.33	0.00
	Large	7	0.00	0.00	272.43	4.28	4.21	2.82	0.39	0.06	9.05	0.89
	Mixed	7	0.00	0.00	274.57	2.64	3.21	0.82	0.34	0.02	8.57	0.63
50x6x25	Small	7	0.00	0.00	270.00	8.04	2.40	0.42	0.37	0.10	8.33	0.00
	Large	7	0.00	0.00	274.43	3.15	3.87	1.08	0.34	0.04	8.33	0.00
	Mixed	7	0.00	0.00	273.14	5.43	2.60	0.39	0.36	0.10	8.57	0.63
50x6x30	Small	7	0.00	0.00	271.86	5.08	2.60	0.47	0.33	0.05	8.33	0.00
	Large	7	0.00	0.00	271.29	3.90	3.09	0.57	0.33	0.07	8.33	0.00
	Mixed	7	0.00	0.00	270.14	7.58	2.33	0.92	0.34	0.07	8.33	0.00
50x8x10	Small	7	0.00	0.00	273.57	5.86	5.71	1.50	0.33	0.05	8.30	1.28
	Large	7	0.00	0.00	265.43	8.46	5.65	2.40	0.34	0.04	7.48	0.58

	Mixed	7	0.00	0.00	272.14	2.34	5.58	2.73	0.38	0.10	7.59	1.22
50x8x15	Small	7	0.00	0.00	275.57	6.24	4.41	0.91	0.34	0.06	7.52	0.82
	Large	7	0.00	0.00	274.43	4.54	4.44	0.82	0.33	0.10	7.80	1.35
	Mixed	7	0.00	0.00	275.14	8.13	4.19	1.43	0.29	0.04	7.40	0.95
50x8x25	Small	7	0.00	0.00	268.14	3.67	3.72	0.70	0.33	0.07	6.38	0.34
	Large	7	0.00	0.00	269.71	4.50	4.41	0.72	0.28	0.03	6.25	0.00
	Mixed	7	0.00	0.00	270.43	4.12	4.53	1.67	0.33	0.07	6.25	0.00
50x8x30	Small	7	0.00	0.00	272.14	2.97	3.36	0.44	0.38	0.08	6.50	0.43
	Large	7	0.00	0.00	275.43	4.28	4.36	1.48	0.33	0.08	6.38	0.34
	Mixed	7	0.00	0.00	273.00	9.66	3.67	1.35	0.29	0.07	6.38	0.34
50x10x10	Small	7	0.00	0.00	272.71	3.30	6.20	2.03	0.34	0.08	7.40	0.95
	Large	7	0.00	0.00	272.71	5.38	9.04	2.04	0.34	0.08	6.77	1.19
	Mixed	7	0.00	0.00	271.43	3.95	6.96	1.93	0.32	0.07	7.18	0.60
50x10x15	Small	7	0.00	0.00	268.43	5.71	6.04	2.25	0.31	0.05	5.82	0.77
	Large	7	0.00	0.00	268.86	4.38	6.04	0.78	0.31	0.05	5.90	0.70
	Mixed	7	0.00	0.00	270.57	4.35	4.57	0.91	0.34	0.08	5.60	0.51
50x10x25	Small	7	0.00	0.00	270.43	3.82	4.76	1.29	0.33	0.07	5.63	0.72
	Large	7	0.00	0.00	270.86	3.08	5.16	0.79	0.31	0.04	5.32	0.30
	Mixed	7	0.00	0.00	273.71	3.04	4.98	1.14	0.32	0.09	5.32	0.30
50x10x30	Small	7	0.00	0.00	272.86	4.67	4.47	0.79	0.36	0.07	5.55	0.76
	Large	7	0.00	0.00	272.29	3.68	4.95	1.29	0.36	0.06	5.18	0.47
	Mixed	7	0.00	0.00	272.86	5.05	4.76	1.45	0.33	0.11	5.32	0.30
75x2x5	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									

	Mixed	0	NO CONVERGENCE									
75x2x10	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
75x2x15	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
75x2x25	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
75x2x30	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
75x4x5	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
75x4x10	Small	7	0.05	0.05	293.86	19.83	1802.78	0.64	0.74	0.04	18.75	0.00
	Large	7	0.02	0.02	287.29	12.07	1231.91	767.71	0.71	0.03	18.29	1.23
	Mixed	7	0.02	0.04	285.57	12.16	1113.68	862.71	0.75	0.04	18.75	0.00
75x4x15	Small	7	0.04	0.03	282.14	14.74	1786.65	44.95	0.74	0.05	18.43	0.59
	Large	7	0.01	0.02	284.00	8.14	921.01	825.67	0.74	0.05	18.75	0.00
	Mixed	7	0.02	0.02	281.14	8.95	919.51	856.09	0.73	0.05	18.50	0.66
75x4x25	Small	7	0.03	0.03	281.57	9.54	1712.56	237.27	0.75	0.04	18.75	0.00
	Large	7	0.01	0.02	278.71	5.38	1113.93	695.62	0.78	0.03	18.75	0.00

	Mixed	7	0.01	0.01	276.29	6.78	1089.95	766.51	0.76	0.05	18.75	0.00
75x4x30	Small	7	0.00	0.01	276.14	7.17	1469.83	587.75	0.74	0.02	18.75	0.00
	Large	7	0.00	0.00	271.43	5.65	834.35	649.70	0.78	0.04	18.71	0.09
	Mixed	7	0.01	0.01	276.29	5.31	959.05	825.42	0.74	0.03	18.71	0.09
75x6x10	Small	7	0.00	0.00	277.14	7.38	91.45	141.08	0.52	0.05	12.86	0.94
	Large	7	0.00	0.00	277.00	5.29	239.97	549.65	0.51	0.02	12.50	0.00
	Mixed	7	0.00	0.00	278.00	6.88	93.64	90.70	0.51	0.03	12.50	0.00
75x6x15	Small	7	0.00	0.01	279.14	4.81	316.03	659.03	0.50	0.03	12.50	0.00
	Large	7	0.00	0.00	275.57	4.20	32.86	26.23	0.51	0.03	12.50	0.00
	Mixed	7	0.00	0.00	276.14	4.38	28.28	16.63	0.50	0.03	12.50	0.00
75x6x25	Small	7	0.00	0.00	274.57	2.82	52.15	46.90	0.49	0.03	12.50	0.00
	Large	7	0.00	0.00	275.29	2.29	33.91	26.91	0.50	0.03	12.50	0.00
	Mixed	7	0.00	0.00	274.43	3.10	29.47	19.04	0.50	0.03	12.50	0.00
75x6x30	Small	7	0.01	0.01	276.00	3.87	566.27	846.41	0.50	0.06	12.50	0.00
	Large	7	0.00	0.00	273.29	5.53	24.71	21.21	0.48	0.02	12.50	0.00
	Mixed	7	0.00	0.00	273.14	4.49	275.93	673.60	0.48	0.03	12.50	0.00
75x8x10	Small	7	0.00	0.00	271.71	4.03	46.89	39.21	0.44	0.08	10.44	2.07
	Large	7	0.00	0.00	274.14	3.63	26.68	9.99	0.48	0.05	11.48	0.96
	Mixed	7	0.00	0.00	279.86	6.09	47.34	26.56	0.45	0.05	10.84	1.28
75x8x15	Small	7	0.00	0.00	276.29	6.05	29.01	18.67	0.45	0.09	9.95	0.71
	Large	7	0.00	0.00	276.71	3.95	25.63	7.86	0.42	0.06	10.36	1.18
	Mixed	7	0.00	0.00	275.86	7.60	30.42	14.46	0.41	0.07	9.76	0.65
75x8x25	Small	7	0.00	0.00	274.71	2.36	12.09	2.52	0.36	0.05	9.38	0.00
	Large	7	0.00	0.00	275.14	7.43	19.72	6.60	0.36	0.03	9.57	0.50

	Mixed	7	0.00	0.00	270.57	7.00	18.73	13.05	0.38	0.05	9.38	0.00
75x8x30	Small	7	0.00	0.00	274.14	2.54	16.99	11.57	0.35	0.04	9.38	0.00
	Large	7	0.00	0.00	274.71	2.56	16.89	6.96	0.34	0.03	9.38	0.00
	Mixed	7	0.00	0.00	276.57	4.04	13.01	3.54	0.38	0.06	9.57	0.50
75x10x10	Small	7	0.00	0.00	276.29	8.64	128.01	223.99	0.42	0.07	10.59	1.05
	Large	7	0.00	0.00	272.57	6.24	43.81	20.87	0.36	0.03	9.08	0.51
	Mixed	7	0.00	0.00	272.86	7.43	68.25	74.75	0.42	0.06	10.46	1.47
75x10x15	Small	7	0.00	0.01	276.71	6.82	290.58	668.38	0.36	0.04	8.51	0.67
	Large	7	0.00	0.00	276.14	6.49	34.93	17.85	0.37	0.06	8.12	0.69
	Mixed	7	0.00	0.00	272.29	4.27	21.65	4.88	0.34	0.03	8.39	0.77
75x10x25	Small	7	0.00	0.00	274.00	2.83	15.11	5.39	0.35	0.08	8.01	0.72
	Large	7	0.00	0.00	270.29	7.80	21.43	6.38	0.39	0.06	7.74	0.40
	Mixed	7	0.00	0.00	274.29	6.45	17.88	6.98	0.35	0.06	7.62	0.31
75x10x30	Small	7	0.00	0.00	271.86	5.08	19.24	9.91	0.32	0.04	7.62	0.31
	Large	7	0.00	0.00	272.86	4.74	18.49	3.88	0.32	0.06	7.62	0.31
	Mixed	7	0.00	0.00	272.43	3.82	13.85	3.47	0.32	0.06	7.74	0.40
100x2x5	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x2x10	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x2x15	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									

	Mixed	0	NO CONVERGENCE									
100x2x25	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x2x30	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x4x5	Small	0	NO CONVERGENCE									
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x4x10	Small	7	0.21	0.06	357.00	25.03	1812.81	4.33	0.81	0.05	24.82	0.47
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x4x15	Small	7	0.19	0.03	346.00	12.01	1816.08	4.59	0.81	0.04	24.75	0.66
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x4x25	Small	6	0.18	0.07	339.50	24.79	1818.59	8.82	0.83	0.03	24.58	0.58
	Large	0	NO CONVERGENCE									
	Mixed	0	NO CONVERGENCE									
100x4x30	Small	7	0.17	0.04	333.43	18.11	1817.48	4.87	0.84	0.04	24.89	0.28
	Large	2	0.12	0.02	324.50	14.85	2712.30	1273.39	0.86	0.01	24.63	0.53
	Mixed	0	NO CONVERGENCE									
100x6x10	Small	7	0.02	0.01	286.29	7.27	1802.32	8.68	0.68	0.02	16.67	0.00
	Large	7	0.03	0.03	287.00	13.90	1607.79	449.37	0.65	0.04	16.46	0.57

	Mixed	7	0.03	0.02	291.57	12.25	1574.73	611.45	0.66	0.06	16.48	0.51
100x6x15	Small	7	0.02	0.02	284.86	6.84	1603.75	369.01	0.65	0.06	16.24	1.13
	Large	6	0.01	0.01	279.00	2.53	1051.93	722.59	0.67	0.03	16.67	0.00
	Mixed	6	0.03	0.01	284.83	5.64	1805.73	0.69	0.69	0.03	16.67	0.00

Table A.1 Table results for MILP model

Size	TW Type	Optimal Instances	GAP		Makespan		Solution Time		Nurse Occupation		Task per Nurse	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
25x2x5	Small	1	0.04	0.04	280.43	14.33	8.43	0.15	0.52	0.03	12.50	0.00
	Large	0	0.06	0.04	283.57	13.35	8.38	0.12	0.51	0.04	12.50	0.00
	Mixed	1	0.05	0.05	295.00	11.99	8.90	0.79	0.48	0.03	12.50	0.00
25x2x10	Small	0	0.10	0.04	292.00	22.38	9.94	0.49	0.51	0.05	12.50	0.00
	Large	0	0.08	0.04	290.29	16.34	9.88	0.43	0.50	0.02	12.50	0.00
	Mixed	3	0.07	0.08	288.43	24.86	9.85	0.22	0.50	0.06	12.50	0.00
25x2x15	Small	0	0.08	0.04	291.71	19.04	10.99	0.04	0.51	0.03	12.50	0.00
	Large	0	0.08	0.05	284.43	22.90	10.92	0.05	0.51	0.06	12.50	0.00
	Mixed	0	0.09	0.03	282.71	16.14	11.12	0.33	0.51	0.03	12.50	0.00
25x2x25	Small	0	0.08	0.05	293.71	18.62	14.07	1.68	0.51	0.03	12.50	0.00
	Large	0	0.11	0.05	303.29	13.30	13.67	0.48	0.49	0.06	12.50	0.00
	Mixed	0	0.12	0.07	299.00	12.57	13.73	0.42	0.50	0.03	12.50	0.00
25x4x5	Small	3	0.01	0.01	274.86	10.54	12.68	1.04	0.34	0.08	6.84	1.01
	Large	3	0.01	0.01	266.29	18.71	12.71	1.04	0.29	0.04	6.55	0.79
	Mixed	5	0.01	0.02	268.00	13.99	12.29	0.18	0.32	0.09	6.55	0.79
25x4x10	Small	5	0.01	0.01	275.43	3.64	16.51	0.34	0.28	0.04	6.55	0.79
	Large	5	0.00	0.00	259.57	14.36	17.83	2.13	0.35	0.11	6.25	0.00
	Mixed	4	0.01	0.01	276.29	7.57	17.39	1.27	0.28	0.05	6.55	0.79
25x4x15	Small	4	0.01	0.01	266.29	10.77	23.00	3.41	0.30	0.06	6.25	0.00
	Large	2	0.02	0.02	267.57	10.15	20.09	0.34	0.31	0.08	6.25	0.00
	Mixed	4	0.00	0.01	271.00	6.40	21.07	2.25	0.26	0.02	6.25	0.00
25x4x25	Small	4	0.00	0.01	271.86	4.26	25.22	0.61	0.27	0.02	6.25	0.00
	Large	3	0.01	0.01	270.57	7.41	25.44	1.27	0.27	0.02	6.25	0.00

	Mixed	5	0.00	0.00	265.57	7.00	26.01	1.97	0.29	0.07	6.25	0.00
25x6x10	Small	5	0.00	0.01	263.14	17.81	22.00	0.34	0.33	0.09	4.64	0.44
	Large	5	0.01	0.01	272.86	6.31	23.33	2.40	0.29	0.14	4.88	0.31
	Mixed	4	0.00	0.01	256.86	11.84	23.38	2.33	0.40	0.13	4.53	0.44
25x6x15	Small	6	0.00	0.00	264.00	9.66	28.95	2.86	0.33	0.07	4.17	0.00
	Large	6	0.00	0.00	267.71	9.81	27.83	0.79	0.33	0.08	4.53	0.44
	Mixed	4	0.01	0.01	270.57	5.13	28.57	1.31	0.32	0.06	4.29	0.31
25x6x25	Small	6	0.00	0.01	261.57	10.11	38.49	2.41	0.22	0.07	4.17	0.00
	Large	6	0.00	0.00	269.00	7.00	37.27	0.94	0.30	0.09	4.29	0.31
	Mixed	5	0.00	0.00	266.29	8.46	37.35	0.74	0.25	0.06	4.17	0.00
25x8x10	Small	5	0.00	0.01	257.43	14.14	25.59	0.79	0.33	0.09	4.41	0.94
	Large	3	0.00	0.01	272.00	8.81	27.03	1.57	0.32	0.08	3.66	0.23
	Mixed	6	0.00	0.00	270.71	7.48	26.94	0.72	0.34	0.12	3.88	0.62
25x8x15	Small	5	0.00	0.00	260.00	21.17	33.96	0.48	0.29	0.10	3.86	0.55
	Large	4	0.01	0.01	262.86	11.26	34.85	0.89	0.31	0.06	3.70	0.48
	Mixed	7	0.00	0.00	265.29	6.78	34.36	0.89	0.29	0.06	3.46	0.38
25x8x25	Small	5	0.00	0.00	271.86	5.34	47.80	0.79	0.30	0.06	3.18	0.17
	Large	5	0.00	0.00	264.71	7.52	47.77	1.28	0.34	0.09	3.38	0.24
	Mixed	6	0.00	0.00	263.29	8.04	49.16	2.71	0.33	0.10	3.25	0.22
25x10x10	Small	5	0.00	0.01	266.86	8.40	30.93	4.69	0.34	0.06	3.44	0.55
	Large	5	0.00	0.01	268.29	6.73	28.37	0.56	0.36	0.07	3.80	0.61
	Mixed	5	0.00	0.00	265.29	10.92	28.96	1.97	0.30	0.11	3.83	0.32
25x10x15	Small	7	0.00	0.00	261.29	15.30	41.18	2.66	0.34	0.07	3.15	0.32
	Large	6	0.00	0.00	270.86	5.61	40.67	1.72	0.35	0.08	2.98	0.25

	Mixed	6	0.00	0.00	257.29	24.47	39.17	1.11	0.34	0.08	2.97	0.18
25x10x25	Small	6	0.00	0.00	269.43	5.26	57.32	3.08	0.41	0.10	2.62	0.15
	Large	6	0.00	0.00	266.43	7.44	59.10	3.19	0.31	0.05	2.71	0.23
	Mixed	5	0.00	0.00	265.57	8.89	57.83	3.66	0.39	0.09	2.73	0.39
50x2x5	Small	0	0.17	0.06	385.86	29.85	32.51	1.01	0.77	0.05	25.00	0.00
	Large	0	N/A	N/A	388.71	12.24	32.78	0.83	0.75	0.02	25.00	0.00
	Mixed	0	N/A	N/A	383.43	14.29	32.39	0.46	0.74	0.02	25.00	0.00
50x2x10	Small	0	0.25	0.07	391.14	30.25	35.77	1.16	0.73	0.05	25.00	0.00
	Large	0	0.35	0.05	405.57	21.70	35.45	0.30	0.70	0.03	25.00	0.00
	Mixed	0	0.29	0.03	402.43	19.62	35.95	0.47	0.72	0.04	25.00	0.00
50x2x15	Small	0	0.28	0.07	409.14	20.00	38.80	0.92	0.71	0.03	25.00	0.00
	Large	0	0.43	N/A	401.57	16.33	37.81	0.54	0.71	0.05	25.00	0.00
	Mixed	0	0.37	N/A	407.57	8.14	38.12	0.95	0.68	0.03	25.00	0.00
50x2x25	Small	0	0.34	0.05	415.57	18.30	44.79	3.47	0.69	0.02	25.00	0.00
	Large	0	0.41	0.04	430.14	10.09	44.14	0.85	0.68	0.04	25.00	0.00
	Mixed	0	0.34	0.12	424.86	18.42	44.51	0.90	0.67	0.05	25.00	0.00
50x2x30	Small	0	0.37	0.08	419.86	17.81	47.48	0.54	0.70	0.03	25.00	0.00
	Large	0	0.42	0.03	406.43	12.39	47.31	1.60	0.69	0.04	25.00	0.00
	Mixed	0	0.37	0.07	420.71	11.57	46.34	0.54	0.70	0.03	25.00	0.00
50x4x5	Small	0	0.06	0.04	293.71	15.57	47.77	1.99	0.52	0.03	12.50	0.00
	Large	0	0.09	0.08	306.43	23.47	48.62	1.20	0.48	0.03	12.50	0.00
	Mixed	0	0.10	0.06	299.86	15.73	53.16	5.94	0.50	0.03	12.50	0.00
50x4x10	Small	0	0.13	0.04	310.29	16.62	62.70	1.98	0.49	0.03	12.50	0.00
	Large	0	0.14	0.03	314.29	8.92	62.52	2.90	0.48	0.02	12.50	0.00

	Mixed	0	0.10	0.04	301.29	10.48	63.46	1.81	0.49	0.03	12.50	0.00
50x4x15	Small	0	0.16	0.08	312.57	11.57	71.14	2.30	0.46	0.03	12.50	0.00
	Large	0	0.11	0.04	305.86	9.46	73.41	5.62	0.50	0.04	12.50	0.00
	Mixed	0	0.09	0.04	299.14	9.96	74.13	4.16	0.48	0.03	12.50	0.00
50x4x25	Small	0	0.12	0.02	307.43	8.46	82.78	2.47	0.49	0.03	12.50	0.00
	Large	0	0.15	0.04	315.43	11.28	83.94	2.81	0.46	0.04	12.50	0.00
	Mixed	0	0.12	0.05	304.57	12.61	86.92	5.13	0.49	0.02	12.50	0.00
50x4x30	Small	0	0.13	0.06	312.14	12.88	87.69	1.15	0.48	0.03	12.50	0.00
	Large	0	0.17	0.03	316.43	5.80	93.70	9.52	0.47	0.01	12.50	0.00
	Mixed	0	0.16	0.05	319.43	16.60	90.94	4.17	0.45	0.03	12.50	0.00
50x6x10	Small	0	0.07	0.02	289.43	8.40	86.51	4.85	0.36	0.03	8.81	0.81
	Large	0	0.09	0.03	294.86	15.08	88.03	3.12	0.40	0.05	9.40	1.58
	Mixed	0	0.08	0.03	291.14	7.29	87.11	3.07	0.39	0.06	9.05	0.89
50x6x15	Small	0	0.04	0.03	286.57	11.69	103.98	4.17	0.39	0.04	8.81	0.81
	Large	0	0.05	0.04	287.00	6.93	106.41	7.21	0.37	0.06	8.33	0.00
	Mixed	0	0.06	0.03	290.86	9.58	105.95	6.31	0.37	0.05	8.33	0.00
50x6x25	Small	0	0.04	0.02	281.00	11.60	126.83	5.73	0.38	0.07	8.33	0.00
	Large	0	0.08	0.02	295.57	5.74	126.46	6.26	0.34	0.05	8.33	0.00
	Mixed	2	0.04	0.04	283.71	11.46	124.90	3.42	0.35	0.02	8.33	0.00
50x6x30	Small	0	0.05	0.03	285.14	11.51	137.43	6.12	0.33	0.01	8.33	0.00
	Large	0	0.07	0.03	290.71	12.05	135.20	4.33	0.34	0.02	8.33	0.00
	Mixed	0	0.06	0.03	285.29	15.73	136.91	4.13	0.35	0.05	8.33	0.00
50x8x10	Small	1	0.02	0.01	278.86	5.76	107.90	4.26	0.31	0.04	7.06	0.70
	Large	0	0.04	0.03	277.43	15.65	108.31	2.90	0.36	0.05	7.35	0.74

	Mixed	1	0.04	0.04	281.71	10.78	107.54	1.04	0.34	0.06	7.76	1.23
50x8x15	Small	0	0.02	0.01	281.14	6.84	134.00	5.76	0.33	0.07	6.89	0.43
	Large	2	0.02	0.04	280.71	9.74	134.90	4.69	0.35	0.05	6.76	0.48
	Mixed	1	0.02	0.01	281.00	6.83	134.59	5.48	0.31	0.06	6.50	0.43
50x8x25	Small	0	0.03	0.01	275.43	5.47	170.38	9.39	0.32	0.06	6.50	0.43
	Large	1	0.02	0.01	274.71	6.42	173.50	3.47	0.32	0.06	6.25	0.00
	Mixed	0	0.03	0.01	278.57	4.83	169.33	7.66	0.30	0.05	6.25	0.00
50x8x30	Small	1	0.04	0.02	282.43	5.71	182.79	6.98	0.35	0.04	6.25	0.00
	Large	0	0.03	0.02	284.14	9.21	183.25	2.80	0.30	0.07	6.38	0.34
	Mixed	2	0.01	0.01	275.71	10.06	191.71	9.30	0.31	0.06	6.38	0.34
50x10x10	Small	1	0.02	0.02	278.14	4.34	131.68	7.27	0.32	0.07	6.66	0.64
	Large	0	0.03	0.02	281.00	7.68	129.17	2.60	0.30	0.05	6.58	0.90
	Mixed	3	0.01	0.01	273.71	5.88	132.23	4.12	0.30	0.05	7.10	0.93
50x10x15	Small	1	0.02	0.01	273.86	5.93	162.36	3.96	0.29	0.06	5.76	0.34
	Large	0	0.01	0.01	272.86	3.76	161.42	4.12	0.32	0.04	5.70	0.57
	Mixed	3	0.02	0.02	275.29	7.57	163.50	3.59	0.28	0.04	5.48	0.21
50x10x25	Small	1	0.01	0.01	274.00	2.45	208.43	6.39	0.34	0.08	5.16	0.27
	Large	2	0.01	0.01	274.57	7.00	208.19	3.73	0.32	0.03	5.34	0.48
	Mixed	1	0.01	0.01	276.86	4.38	213.40	6.29	0.33	0.08	5.58	0.36
50x10x30	Small	2	0.01	0.01	275.71	4.86	229.98	3.78	0.32	0.07	5.08	0.21
	Large	0	0.01	0.01	276.29	3.99	238.37	11.84	0.31	0.08	5.16	0.27
	Mixed	2	0.02	0.02	278.43	7.55	234.85	2.41	0.32	0.05	5.08	0.21
75x2x5	Small	0	N/A	N/A	498.14	17.32	139.59	2.74	0.90	0.03	37.50	0.00
	Large	0	N/A	N/A	519.43	27.45	141.43	2.11	0.87	0.03	37.50	0.00

	Mixed	0	N/A	N/A	498.00	10.80	145.15	3.13	0.91	0.03	37.50	0.00
75x2x10	Small	0	0.08	N/A	511.71	17.75	153.02	2.42	0.85	0.03	37.50	0.00
	Large	0	N/A	N/A	525.43	40.48	155.32	3.26	0.84	0.07	37.50	0.00
	Mixed	0	N/A	N/A	512.43	27.49	162.67	3.77	0.85	0.04	37.50	0.00
75x2x15	Small	0	0.22	N/A	534.00	20.56	167.12	3.05	0.82	0.02	37.50	0.00
	Large	0	N/A	N/A	544.57	29.97	175.07	6.36	0.82	0.03	37.50	0.00
	Mixed	0	N/A	N/A	523.71	20.48	172.33	6.73	0.82	0.02	37.50	0.00
75x2x25	Small	0	0.23	0.05	545.57	24.83	184.69	2.62	0.80	0.03	37.50	0.00
	Large	0	N/A	N/A	564.29	11.28	189.97	4.10	0.79	0.02	37.50	0.00
	Mixed	0	N/A	N/A	543.00	15.33	189.50	3.30	0.82	0.05	37.50	0.00
75x2x30	Small	0	N/A	N/A	559.29	7.25	198.77	3.32	0.78	0.02	37.50	0.00
	Large	0	N/A	N/A	553.86	28.88	204.58	4.84	0.79	0.03	37.50	0.00
	Mixed	0	N/A	N/A	571.86	15.61	210.07	1.81	0.76	0.02	37.50	0.00
75x4x5	Small	0	0.14	0.04	345.00	19.66	214.44	4.15	0.65	0.03	18.75	0.00
	Large	0	0.09	N/A	369.86	27.81	215.38	3.57	0.60	0.05	18.75	0.00
	Mixed	0	N/A	N/A	338.57	15.12	218.19	5.75	0.65	0.04	18.75	0.00
75x4x10	Small	0	0.22	0.10	357.71	20.20	246.34	2.63	0.61	0.05	18.75	0.00
	Large	0	0.35	0.06	388.43	11.15	252.05	2.51	0.58	0.03	18.75	0.00
	Mixed	0	0.27	0.05	362.86	12.73	254.28	6.32	0.60	0.03	18.75	0.00
75x4x15	Small	0	0.26	0.03	355.86	17.02	272.97	14.59	0.62	0.04	18.75	0.00
	Large	0	0.31	0.08	371.86	25.00	272.16	4.73	0.58	0.05	18.75	0.00
	Mixed	0	0.30	0.06	365.86	14.51	277.83	4.84	0.59	0.02	18.75	0.00
75x4x25	Small	0	0.32	0.04	371.00	9.57	295.65	5.63	0.58	0.03	18.75	0.00
	Large	0	0.39	0.03	388.29	8.06	302.31	3.65	0.58	0.02	18.75	0.00

	Mixed	0	0.33	0.04	367.00	13.32	298.90	2.33	0.61	0.04	18.75	0.00
75x4x30	Small	0	0.35	0.06	372.29	10.27	310.45	2.38	0.60	0.03	18.75	0.00
	Large	0	0.38	0.07	374.71	12.32	320.37	8.23	0.60	0.04	18.75	0.00
	Mixed	0	0.35	0.04	373.86	13.77	316.63	4.01	0.60	0.03	18.75	0.00
75x6x10	Small	0	0.19	0.05	330.86	15.81	315.61	5.70	0.52	0.07	14.82	2.10
	Large	0	0.18	0.06	327.00	16.00	321.99	6.54	0.48	0.06	13.21	1.22
	Mixed	0	0.16	0.06	321.71	14.86	325.47	4.26	0.49	0.05	13.21	1.22
75x6x15	Small	0	0.17	0.04	326.86	13.15	365.14	8.03	0.45	0.02	12.50	0.00
	Large	0	0.20	0.08	329.29	23.26	360.07	6.21	0.46	0.02	12.86	0.94
	Mixed	0	0.17	0.06	324.00	14.75	365.10	2.57	0.47	0.04	12.86	0.94
75x6x25	Small	0	0.15	0.02	316.71	6.05	401.42	6.51	0.46	0.03	12.50	0.00
	Large	0	0.21	0.06	333.71	16.84	408.14	6.37	0.44	0.03	12.50	0.00
	Mixed	0	0.16	0.06	319.57	12.95	408.70	8.15	0.46	0.02	12.50	0.00
75x6x30	Small	0	0.24	0.04	341.14	13.57	430.63	9.00	0.44	0.02	12.50	0.00
	Large	0	0.20	0.04	327.00	13.22	429.44	4.22	0.44	0.01	12.50	0.00
	Mixed	0	0.21	0.04	331.86	12.25	436.69	5.57	0.45	0.02	12.50	0.00
75x8x10	Small	0	0.11	0.03	302.71	8.56	388.63	6.01	0.42	0.04	10.52	0.50
	Large	0	0.14	0.04	311.86	11.47	393.09	5.03	0.41	0.04	10.78	0.91
	Mixed	0	0.09	0.07	305.43	21.00	394.63	8.75	0.44	0.05	11.29	1.23
75x8x15	Small	0	0.09	0.03	302.43	8.36	441.77	6.23	0.41	0.06	9.95	0.71
	Large	0	0.12	0.04	309.00	12.29	449.11	8.95	0.40	0.05	9.95	0.71
	Mixed	0	0.11	0.04	305.00	13.39	446.73	6.95	0.41	0.04	10.14	0.71
75x8x25	Small	0	0.10	0.04	301.43	12.25	511.37	7.44	0.37	0.02	9.38	0.00
	Large	0	0.11	0.03	306.43	8.94	520.19	9.66	0.38	0.04	9.38	0.00

	Mixed	0	0.10	0.03	298.29	10.58	515.39	7.21	0.38	0.04	9.57	0.50
75x8x30	Small	0	0.12	0.02	306.86	4.81	543.97	6.72	0.38	0.05	9.38	0.00
	Large	0	0.10	0.02	302.14	5.76	547.70	4.84	0.38	0.05	9.38	0.00
	Mixed	0	0.07	0.03	297.00	7.68	550.77	6.57	0.42	0.06	9.83	1.18
75x10x10	Small	0	0.09	0.04	302.14	7.31	455.18	5.97	0.40	0.06	10.21	1.19
	Large	0	0.11	0.02	301.14	5.40	453.54	8.35	0.40	0.05	10.25	1.35
	Mixed	0	0.06	0.02	290.29	10.37	458.09	7.20	0.43	0.06	10.31	1.65
75x10x15	Small	0	0.07	0.06	297.14	16.93	520.26	14.21	0.34	0.03	8.36	0.55
	Large	0	0.09	0.05	300.57	17.46	523.82	8.44	0.40	0.03	8.66	0.73
	Mixed	0	0.09	0.04	296.86	13.43	537.52	15.04	0.34	0.03	8.39	0.77
75x10x25	Small	0	0.04	0.02	284.29	6.45	608.23	7.58	0.35	0.06	7.86	0.44
	Large	0	0.08	0.03	292.71	11.61	616.63	15.23	0.35	0.04	7.62	0.31
	Mixed	0	0.08	0.05	296.29	13.65	626.80	5.58	0.33	0.03	7.74	0.40
75x10x30	Small	0	0.09	0.04	297.29	12.49	655.66	9.50	0.35	0.05	7.50	0.00
	Large	0	0.07	0.04	292.14	10.06	660.71	8.29	0.33	0.03	7.86	0.44
	Mixed	0	0.06	0.03	288.43	7.63	668.19	16.73	0.34	0.03	7.50	0.00
100x2x5	Small	0	N/A	N/A	647.14	30.84	529.50	10.67	0.92	0.04	50.00	0.00
	Large	0	N/A	N/A	660.29	37.18	537.66	11.20	0.89	0.05	50.00	0.00
	Mixed	0	N/A	N/A	643.00	45.61	553.66	13.43	0.92	0.05	50.00	0.00
100x2x10	Small	0	N/A	N/A	643.86	24.85	581.56	13.69	0.92	0.03	50.00	0.00
	Large	0	N/A	N/A	644.57	19.45	575.88	9.07	0.90	0.02	50.00	0.00
	Mixed	0	N/A	N/A	628.43	24.87	595.24	10.16	0.92	0.03	50.00	0.00
100x2x15	Small	0	N/A	N/A	644.86	22.06	621.47	14.26	0.91	0.03	50.00	0.00
	Large	0	N/A	N/A	673.29	30.44	624.76	7.99	0.87	0.04	50.00	0.00

	Mixed	0	N/A	N/A	643.43	27.01	642.79	14.05	0.91	0.02	50.00	0.00
100x2x25	Small	0	N/A	N/A	663.14	21.11	709.45	11.61	0.86	0.01	50.00	0.00
	Large	0	N/A	N/A	673.14	30.85	725.54	10.09	0.86	0.02	50.00	0.00
	Mixed	0	N/A	N/A	665.43	24.01	746.46	17.49	0.88	0.02	50.00	0.00
100x2x30	Small	0	N/A	N/A	664.14	18.18	784.79	16.90	0.87	0.02	50.00	0.00
	Large	0	N/A	N/A	670.86	23.09	816.31	10.72	0.86	0.02	50.00	0.00
	Mixed	0	N/A	N/A	660.86	12.12	817.62	24.71	0.87	0.03	50.00	0.00
100x4x5	Small	0	N/A	N/A	412.71	25.03	989.31	17.46	0.72	0.04	25.00	0.00
	Large	0	N/A	N/A	428.29	31.46	997.58	33.32	0.69	0.07	25.00	0.00
	Mixed	0	N/A	N/A	407.71	29.55	1021.92	20.83	0.72	0.07	25.00	0.00
100x4x10	Small	0	0.16	0.10	410.86	17.37	1218.58	46.37	0.72	0.04	25.00	0.00
	Large	0	N/A	N/A	441.57	14.22	1292.45	37.96	0.68	0.03	25.00	0.00
	Mixed	0	N/A	N/A	417.71	15.90	1325.52	39.99	0.71	0.04	25.00	0.00
100x4x15	Small	0	0.19	0.09	412.43	33.23	1408.16	31.92	0.73	0.06	25.00	0.00
	Large	0	0.31	N/A	426.29	15.88	1456.40	36.93	0.69	0.03	25.00	0.00
	Mixed	0	N/A	N/A	429.43	18.67	1515.62	64.38	0.69	0.03	25.00	0.00
100x4x25	Small	0	0.25	0.09	422.00	5.48	1632.15	65.79	0.70	0.01	25.00	0.00
	Large	0	N/A	N/A	425.86	16.81	1690.52	54.55	0.70	0.03	25.00	0.00
	Mixed	0	N/A	N/A	419.57	17.17	1778.32	73.20	0.69	0.03	25.00	0.00
100x4x30	Small	0	0.26	0.06	417.71	11.10	1830.49	57.37	0.70	0.03	25.00	0.00
	Large	0	0.37	0.12	435.57	15.74	1922.10	74.56	0.67	0.02	25.00	0.00
	Mixed	0	0.22	N/A	424.14	17.64	1923.68	56.64	0.71	0.04	25.00	0.00
100x6x10	Small	0	0.18	0.02	338.00	8.60	2090.32	123.02	0.60	0.04	17.15	1.26
	Large	0	0.30	0.07	371.29	18.59	2104.33	70.73	0.56	0.04	17.15	1.26

	Mixed	0	0.19	0.06	346.00	13.75	2188.14	102.14	0.60	0.04	17.15	1.26
100x6x15	Small	0	0.25	0.07	357.29	19.77	2353.64	133.26	0.56	0.03	17.15	1.26
	Large	0	0.34	0.04	368.57	15.99	2429.37	102.18	0.54	0.03	16.67	0.00
	Mixed	0	0.20	0.08	345.86	19.89	2463.56	59.38	0.59	0.07	16.67	0.00

Table A.2 Table results for heuristic model