Master Surgery Scheduling in the Scope of Scheduling Literature

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Abstract

The increasing demand for health care alongside the ageing population has resulted in growing waiting lists for elective surgery. In Portugal, approximately 32% of patients enrolled in the surgery waiting list in 2020 exceeded the maximum guaranteed response time. Operating Room (OR) Planning and Scheduling problems, namely, the Master Surgery Scheduling (MSS) and Elective Case Scheduling (ECS), are crucial to tackle these issues and improve the quality of services provided to the overall population. Nevertheless, analysing the literature, it is possible to observe that only a few studies attempt to place these problems in the general scheduling literature. Thus, this dissertation's objective is to position the OR Scheduling problems in the scheduling literature. An overview of scheduling problems, such as Instructional Scheduling, Bed Assignment, Blood Collection, Appointment Scheduling, and Home Healthcare, is provided. Characteristics present in these problems were included in a descriptive and percentage analysis to visualize in which ones are those features present or not. In the MSS and ECS problems, the characteristics emphasized are patient prioritization, staff preferences and uncertainty. Patient preferences, clustering methods, and fairness aspects stand out as the characteristics that are barely mentioned in the setting of OR scheduling and are widely studied in other scheduling categories. Concluding, for the MSS and ECS, there are multiple opportunities to invest in further research and take advantage of the knowledge already existing in other scheduling categories to improve performance measures, for example, waiting time, quality of service, and patient satisfaction.

Keywords: Operating Room Planning and Scheduling, Master Surgery Scheduling, Elective Case Scheduling, Scheduling

1. Introduction

The demand for healthcare, due to the aging population, is gradually growing and waiting times for elective surgeries are a pivotal concern in several countries due to creating dissatisfaction for patients. According to the Organization for Economic Cooperation and Development, in Portugal, waiting times from specialist assessment to treatment in the past decade for different types of elective surgical procedures have been increasing, with some (e.g. cataract surgery) nearly doubling from 28% in 2010 to 58.9% in 2018 [1]. Hence, OR planning is a crucial activity to tackle these problems and improve the services provided to the overall population.

The OR is the unit within a hospital which requires the most planning and funding as it utilizes the majority of human resources, as well as indispensable and expensive equipment. This way, surgical activity has a substantial impact in the hospitals and its planning is necessary to improve the efficiency of the OR. To reduce the respective waiting lists and maximize resource utilization, effective scheduling strategies must be put into practice. The problem of OR Planning and Scheduling is often divided into three levels: the strategical level (long-term decisions), the tactical level (medium-term decisions), and the operational level (short-term decisions). Each one of these levels corresponds to a scheduling problem, respectively, Case Mix Planning, MSS and ECS [2]. These problems are of utmost importance to the flow and proper functioning of the OR. However, there have not been many attempts to position the MSS and ESC problems in the general scheduling literature. Positioning them in a broader scheduling setting and studying possible knowledge transfers will bring advantages to the OR planning. Therefore, this study has as principal aim to position the MSS and ECS problems in the scheduling literature by identifying the problems that are most closely related and clearly stating the differences and similarities. The lack of comparison between different models and problems in the OR planning and scheduling and general scheduling contexts and works of literature

motivates this research dissertation and justifies its objective.

2. Operating Room Planning

Health care demand is gradually increasing and waiting times for elective surgeries are a longstanding issue present in several countries. OR planning is a crucial activity to tackle these problems and improve the services provided to the overall population. The good performance and high efficiency of the OR have a pivotal role regarding the improvement of the hospitals' welfare standards and the quality of the service provided to the patients. This way, the effort put in by the hospital managers towards the improvement of the OR performance is considerably high.

The SIGIC, Sistema Integrado de Gestão para Inscritos na Cirurgia (Integrated System for the Management of Registered Patients for Surgery), was established within the scope of special programs for fighting the long waiting lists for surgery in Portugal. SIGIC regulates all surgical activities and covers every step involved in the management of its users, since their enrolment in the program up until after the surgery is performed [3].

Data indicating that SIGIC was successful in improving the efficiency of the OR management in Portugal is shown in Table 1.

Table 1. Demand Indicators from 2015 to 2019 **[3]**

Indicators	2015	2016	2017	2018	2019	Δ 2015/2019	Δ 2018/2019
No. of entries of patients in the SWL	662,642	670,913	699,132	706,103	724,324	9.3%	2.6%
No. of remaining patients in the SWL	197,401	210,906	231,250	244,501	242,949	23.1%	-0.6%
90-percentile of the SWL (months)	9.3	10.3	9.7	11.4	13.3	43.0%	17.0%
% of registered patients that exceed the MGRT	28.7%	28.4%	32.3%	30.0%	32.1%	11.8%	7.0%

2.1 Master Surgery Scheduling

In order for surgeries to be scheduled and performed efficiently, and subsequently reduce the respective waiting lists and maximize resources utilization, a master surgery schedule must be first developed. This schedule is a cyclic schedule (e.g. monthly) that attributes different medical disciplines to available ORs, which facilitates the decisions later made at the operational level. This schedule is also responsible for specifying the hours that rooms will be open and the surgeons or specialties which should be given priority at an OR [4].

Developing a master surgery schedule is of extreme importance in the scheduling process, since the MSS determines the surgical workload distribution. Hence, it presents a major influence on time and resource allocation, which then facilitates the decisions made at the operational level.

2.2 Elective Case Scheduling

Based on the previously discussed MSS Problem and the cyclic schedule derived from it, decisions to be made at the patient level are studied through the ECS Problem. This phase involves decisions whose aim is to support short-term goals, such as maximizing the surgical suites utilization and, in consequence, increasing the efficiency of the hospitals' operating theatre [5]. Subsequently, a specific OR, a day, and a starting time are given to a certain surgery included in the waiting list.

The principal aim of the ECS problem is to schedule the surgical procedures, based on the previously defined MSS, such that the workload is evenly distributed, resources are available and correctly allocated, and lastly, the proposed schedule for each day is practical and contributes to the proper functioning of the OR.

2.3 Importance of Positioning the OR Problems in the Scheduling Literature

As mentioned in the previous sections, the MSS and ECS problems result from important planning phases that can have an immense impact on the flow of an OR, as well as on the scheduling of resources and patients. Literature regarding these problems and on improving the flow of patients, reducing the OR costs, with uncertainty consideration and other capacity constraints, is somewhat extensive and it has been present throughout the years. However, there have been only a very small number of studies attempting to place these problems in the scheduling literature. Considering how vast the literature on scheduling problems is and the dimension of different settings, it would be expected that more studies would introduce and compare them to the health care context, specifically the OR management setting.

Some studies have been conducted where either an MSS or an ECS problem is formulated as a setting studied in the scheduling theory. For example, Fügener et al. [6] resort to a general assignment problem model, with the intent of minimizing downstream costs for a given master surgery schedule. The authors recognize the importance and practicability of using general scheduling problems and adapting them to other scenarios, and as in their

case to surgical scheduling. Thus, one can conclude that positioning the MSS and ECS problems in a broader scheduling environment and study possible transfers of knowledge can only bring advantages to the OR planning and scheduling.

3. Literature Review

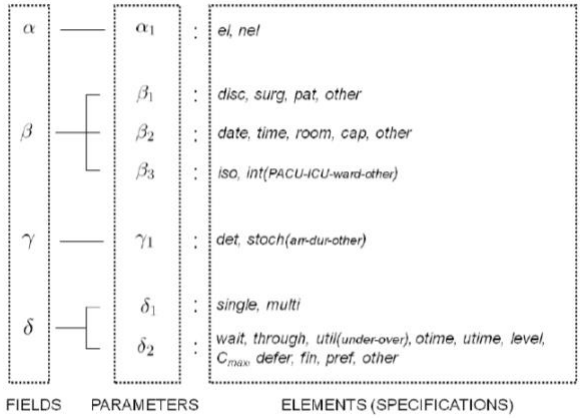

Figure 1. Overview of the Fields, Parameters, Elements that constitute a classification scheme for OR planning and scheduling **[7]**

Literature regarding the OR and subjects related to this matter has been growing over the last few decades. This stems from an increased interest of researchers as well as hospitals to improve efficiency in the OR and its utilization rate, and, subsequently, the number of patients in the respective waiting lists. Throughout this review, a classification scheme consisting of four descriptive fields will be followed (Figure 1): patient characteristics α, delineation of the decision β, uncertainty incorporation γ, and performance measures δ, [7].

3.1 Patient Characteristics α

This field is usually divided into two main groups, namely, elective patients (el) or non-elective patients (nel). A patient is integrated into the elective class if it does not have to be treated immediately. The latter class includes patients whose surgery is not planned and should be performed as soon as possible. Additionally, many researchers distinguish between urgent non-elective patients (i.e. patients whose surgery can be postponed for a short time) and emergency non-elective patients (i.e. surgery needs to be performed as soon as possible). Some studies differentiate between inpatients (i.e. require an overnight stay) and outpatients (i.e. leave the hospital the same day of their arrival [8]. Concerning the MSS problem, Beliën et al. [9] developed a decision support system that only accounts for elective cases, with the justification for this simplification being that it is not possible to plan non-elective cases beforehand. Considering non-elective patients would significantly increase the amount of uncertainty and variability in bed occupancy. Moosavi & Ebrahimnejad [10] also study the OR planning problem at a tactical level and consider elective and emergency patients. Wullink et al. [11] study a framework where it shows that reserving elective OR capacity for emergency surgery leads to an improvement in waiting times, a reduction in overtime work, and overall the OR utilization increased.

3.2 Delineation of the Decision β

This field concerns the type of decisions that are necessary to make in a certain OR scheduling problem. For the subject of decision, β_1 , the elements considered are: medical disciplines (disc), surgeons (surg), patients or patient types (pat), and other subjects (other), for example, hospitals. Astaraky & Patrick [12] present a model to contribute to the problem of allocating OR capacity (i.e. specific daily allocations) to different medical specialties. Doulabi et al. [13] study the integrated OR planning and scheduling with a focus on surgeons. They take into account the surgeons' maximum daily working hours and aim to prevent the overlapping of surgeries performed by the same surgeon.

Type of decision, β_2: the decisions that have to be taken are regarding the assignment of a date (date), a time indication (time), an OR (room), capacity (cap), as well as other decisions (other) which may contemplate the pairing of patients with surgeons. Molina-Pariente et al. [14] study the OR planning problem with an objective of assigning an intervention date and an OR to a set of surgeries on the waiting list. Penn et al. [15] address the MSS problem and develop a model that assists in the creation of master theatre timetables. The capacity of ORs is studied along with the maximum number of beds required and the number of surgeons available.

Degree of integration, β_3: the problem can either study the OR in an isolated (iso) or in an integrated way (int). In the latter case, both upstream and downstream facilities can be considered. Agnetis et al. [16] study the OR planning problem in an isolated setting, focusing only on determining the MSS on a weekly basis, by assigning the different surgical specialties to the available sessions. Latorre-Núñez et al. [17] address the MSS problem while simultaneously considering the post anaesthesia

care unit and resources required by surgery and for recovery.

3.3 Uncertainty Incorporation γ

The environment where surgery scheduling is placed is considered to have several factors contributing to consistent uncertainty. Problems concerning uncertainty can be classified either as deterministic (det) or stochastic (stoch), based on the approach the authors used to incorporate uncertainty. Deterministic planning approaches ignore uncertainty. Contrarily to this, stochastic approaches explicitly try to incorporate it.

In the literature, different types of stochasticity in the form of uncertainty are addressed, namely, duration (dur) and arrival uncertainty (arr). Khaniyev et al. [18] aim to determine the starting and finishing time of a certain surgery included in a sequence of non-identical procedures. The objective is to minimize the weighted sum of expected patient waiting times, room idle time, and overtime. Soudi et al. [19] formulate a weekly scheduling of an integrated surgical procedure as a hybrid flow shop scheduling problem, with capacity constraints on ward beds and ORs. The authors consider the arrival uncertainty of emergency patients and the impact it has on the elective schedule.

Resource uncertainty and care requirement uncertainty are addressed as well in some studies. Hooshmand et al. [20] study the MSS problem and intend to develop a cyclic allocation table in which blocks are assigned to surgeons. The authors consider the number of available beds in hospitalization units and the length of stay of patients to be uncertain and their objective is to minimize the expected bed shortage in the ICU and wards.

3.4 Performance Measures δ

The problems in question can address single (single) or multiple (multi) objectives. Cardoen et al. [7] distinguish between the main performance measures: waiting time (wait), throughput (through), utilization (util), overtime (otime), undertime (utime), levelling (level), makespan (C_{max}), deferrals (defer), financial measures (fin), preferences (pref), and others (other). Due to the variety in stakeholders and their objectives, researchers, more often than not, opt to include more than one criterion in their studies to try and adapt to real-life problem settings. These settings may have multiple objectives, such as minimizing the patient waiting times [18], maximizing the OR utilization [21], minimizing the overtime [10], minimizing the makespan [17], and levelling the utilization of different resources, for example, the up and downstream units of the OR [6].

Aringhieri et al. [22] study the MSS and ECS problems to optimize both patient and hospital utilities by reducing the waiting time and production costs corresponding to the number of weekend stay beds required by the surgery planning. Kamran et al. [23] also have the objective of minimizing the patient waiting time, along with the number of cancelations, the block overtime, and the number of surgeon's surgery days within the planning horizon. Another common objective is the minimization of overtime. Zhang et al. [24] study the ECS problem with consideration of ORs and downstream units with the objective of minimizing the overtime and the associated costs, and the number of open ORs.

4. Research Methodology

The methodology consists of four stages (Figure 1):

Stage 1. Scheduling Problems Review: The aim of this stage is to acquire a deeper understanding of the existing research and studied applications relevant to scheduling problems. Additionally, a classification of these problems will also be made, depending on the focused features used.

Stage 2. Positioning the MSS and ECS Problems: This stage has as the main purpose to position these two problems in the review and classification of the general scheduling problems provided in the previous stage.

Stage 3. Identification of the Problems Most Closely Related: To perform the intended identification, a percentage analysis of the different characteristics in each scheduling category, including every paper covered in both reviews is performed. This allows to better understand the possible similarities and differences between general scheduling and OR planning problems.

Stage 4. Discussion of Possible Knowledge Transfer: By addressing the existing research gaps in the OR planning problems and analysing the differences and similarities between both matters, one can conclude if it is possible to discuss whether or not knowledge transfer between the problems defined and addressed in the previous stage, namely, the general scheduling problems, and the MSS and ECS, is feasible.

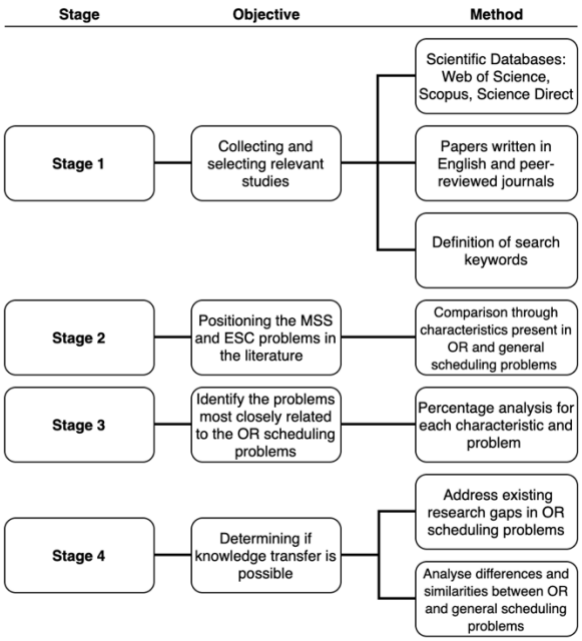

Figure 1. Proposed research methodology

5. Scheduling Problems Review

Among the literature, one can find several scheduling problems, that consider multiple and diverse criteria, depending on the type of industry the problem is inserted in. Different scheduling problems, that deal with limited capacity and resources, divided into five categories, specifically, Instructional Scheduling, Bed Assignment, Blood Collection, Appointment Scheduling, and Home Healthcare, were reviewed.

Since the activity of scheduling is present in multiple sectors globally, the academic setting, as expected is no exception. The large scale scheduling problems in higher institutions, such as universities can be denominated as instructional scheduling. This involves the development of a course schedule, in other words, the booking of a free time slot for both students and lecturers, as well as the assignment of suitable classrooms, while taking into consideration the different types of classes taught and the existing courses in each institution. Adding to the complexity of this scheduling problem is the number of students and teachers that are part of a university. This way, a well-rounded course schedule will lead to an optimization of the allocation of resources in addition to the efficient use of the available infrastructures.

Beds are one of the most important resources medical centres possess. If this particular resource is lacking, for example in a downstream unit, the flow of patients coming from that unit is blocked, and as a result, other surgical activities are impacted. Additionally, as a consequence of the increased demand for health care, the request for hospital beds grows as well. For this reason, an efficient management and assignment of beds is essential to minimize the number of internal movements within a unit and to maximize the bed usage, improving the overall performance of a hospital and the quality of care delivered.

Blood is a crucial component used in multiple medical interventions, and consequently having a major role in the health care systems worldwide. Moreover, it cannot be stored for long periods of time due to its short shelf life, which means the time between donation and utilization is bounded. The Blood Donation system is responsible for providing suitable amounts of blood units to supply the demand from hospitals and transfusion centres. The number of donations has to be great enough not only to provide reliable blood units, and therefore meet demand requests, but also to maintain the throughput of the Blood Donation system in the following steps.

The Appointment Scheduling Problem is present in multiple service settings, such as airlines, notarial services, health care, among others. This problem mainly arises when it is customary to serve the customers sequentially, service times are uncertain, and most commonly, when it is necessary to assign time slots for booking customers beforehand. In the health care setting, appointment scheduling is an activity with extreme importance, as it is vital to ensure the good performance of the medical centre along with patient satisfaction, the high quality of the care and the high rates of resource utilization.

By definition, home healthcare is any sort of care given to a patient at his own home instead of in a hospital or medical centre. This type of service is rapidly becoming one of the most important in the healthcare sector, due to alleviating the flow in hospitals. Moreover, the standard of living of the patients is greater, as they are able to reside in the comfort of their own homes, and unnecessary hospitalizations are avoided. Home healthcare managers provide the nurses and caregivers with an effective route and schedule to minimize total travel time and costs and deliver high quality care to the patients [25].

The reason for choosing these categories was mainly based on the possibility of parallelism with the MSS and ECS problems. This possibility was assessed through the features of the problems researched. Among these features are the scheduling of dates and time slots, the allocation of resources, the development of an optimal schedule

under various objectives, such as minimization of waiting times and improvement of patient satisfaction, and lastly, the simultaneous presence of these features. The main features in common between each problem presented are capacity constraints, limited resources, and time slots determination. Other elements present are patient preferences and patient prioritization. Lastly, none of the problems studied in this review has adapted or compared the respective different methodologies and solutions with the MSS and ECS problems.

6.Positioning the MSS and ECS Problems

A critical analysis will be performed to determine in which problems are features, such as patient preferences, patient prioritization, workload balance, clustering, fairness, staff preferences, and uncertainty, present or not, and in the case that they are, where are they most common.

6.1 Patient Preferences

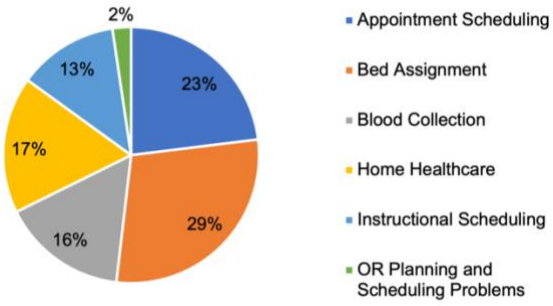

Figure 2. Distribution of Patient Preferences within the groups of scheduling problems

Patient preferences can be understood as the decisions between different options patients have to make regarding their treatment in healthcare, for example, preference for a certain surgeon. Patient preferences are not usually included in the OR scheduling problems even though taking them into consideration when planning an OR schedule increases patient satisfaction and continuance in treatments. In Figure 2, it is possible to observe how Patient Preferences are distributed in the different groups of scheduling problems. Appointment Scheduling and Bed Assignment are two categories in which this feature is widely considered and studied, whereas, in the groups of Blood Collection and OR scheduling problems, it is not as thoroughly contemplated

6.2 Patient Prioritization

When constructing a master surgery schedule and, determining the details for several surgeries, there is a priority order of patients. Not incorporating priorities regarding patients can lead to inefficient schedules and, consequently, reduce patient satisfaction [26]. Figure 3 illustrates the presence of Patient Prioritization as a feature in the scheduling problems. In the MSS and ECS problems, researchers frequently study how different patient priority rules affect patient satisfaction and the overall performance and efficacy of the developed surgical schedules. In the Appointment Scheduling and Bed Assignment frameworks, patient prioritization is also often taken into account. On the other hand, in Instructional Scheduling, the priority of patients, which, in this case, are the students, is not a characteristic observed in the respective problems. However, in this context, students should not have priority over others.

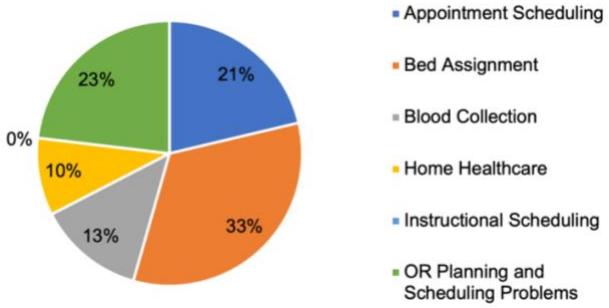

Figure 3. Distribution of Patient Prioritization within the groups of scheduling problems

6.3 Workload Balance

A well though-out master surgery scheduling is of extreme importance in the OR scheduling process, since it is responsible for determining the workload distribution. In Figure 4 it is summarized the distribution of Workload Balance throughout the different groups of scheduling problems. OR scheduling problems and Appointment Scheduling are the two categories with the higher concentration of problems considering workload balance. The remaining categories also incorporate this characteristic into the respective problems, however, not as frequently as the mentioned above.

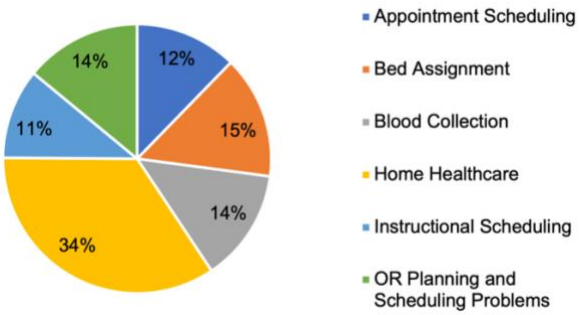

Figure 4. Distribution of Workload Balance within the groups of scheduling problems

6.4 Clustering

Within the MSS and ECS problems, clustering is not very present, however, in recent years, interest has been growing. In these studies, the researchers cluster surgical activities mainly according to the types of surgery and surgery duration. Figure 5 represents the distribution of which scheduling categories have clustering incorporated as an element in their respective problems. In the Home Healthcare, Bed Assignment, and Instructional Scheduling frameworks, clustering methods are often applied to achieve the objectives of a certain problem.

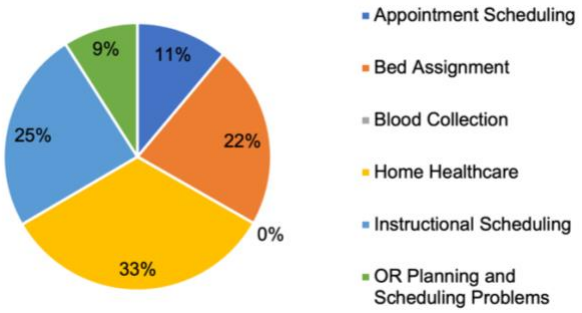

Figure 5. Distribution of Clustering within the groups of scheduling problems

6.5 Fairness

Fairness can be defined as the equality of characteristics among numerous individuals in a certain situation. In the literature of OR problems, some authors study fairness regarding the order that patients are treated, while others focus on fairly scheduling the nurses and other medical staff, based on their preferences [27]. In Figure 6 is possible to observe that Home Healthcare is the category in which fairness is most often considered by researchers. Appointment and Instructional Scheduling problems also integrate the fairness component, however, not as regularly. It is possible to observe that in Bed Assignment and Blood Collection problems, fairness is not a considered criterion.

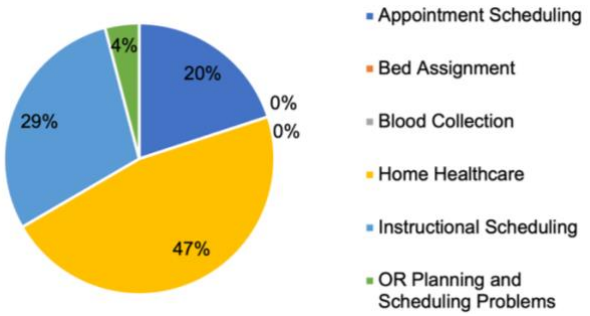

Figure 6. Distribution of Fairness within the groups of scheduling problems

6.6 Staff Preferences

In the OR setting, surgeons and nurses have time slots and particular days of the week they prefer to work and additionally, they both prefer to work continuously in the same OR. Surgeons may present a preference for specific ORs where it is possible to work back-to-back, as well as for the same surgical team [28]. Respecting and fulfilling these preferences contributes positively to staff satisfaction and improves staff retention. Figure 7 illustrates the presence of Staff Preferences as a feature in the scheduling problems. In the OR planning problems, researchers incorporate staff preferences into their models very frequently. In the Appointment Scheduling, Bed Assignment, and Blood Collection frameworks, staff preferences are, for the most part, not taken into account. On the other hand, in Instructional Scheduling and Home Healthcare problems, fairness is frequently considered by researchers.

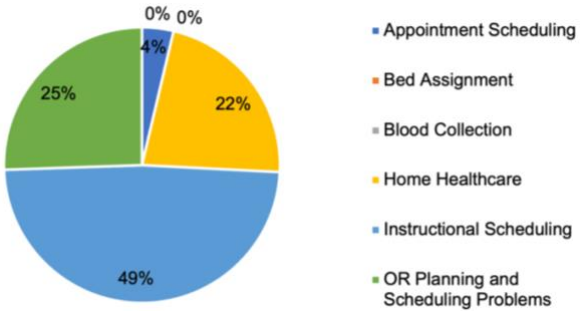

Figure 7. Distribution of Staff Preferences within the groups of scheduling problems

6.7 Uncertainty

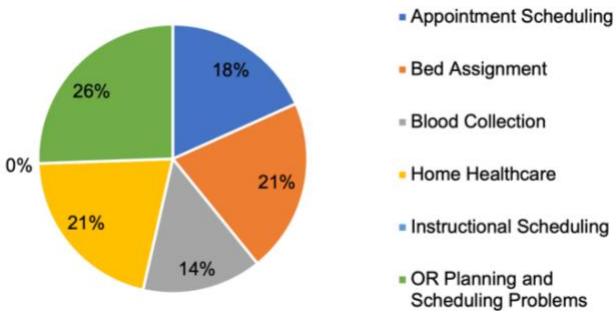

Figure 8. Distribution of Uncertainty within the groups of scheduling problems

Finally, Figure 8 summarizes the distribution of Uncertainty throughout the different groups of scheduling problems. According to what was previously explained in Chapter 3, the MSS and ECS problems incorporate a significant amount of uncertainty-based features. Appointment Scheduling, as well as Bed Assignment and Home Healthcare are categories that also consider

uncertainty in their respective problems. On the contrary, in Instructional Scheduling problems hardly any researchers regard uncertainty.

7. Discussion of Possible Knowledge Transfer

As demonstrated in the previous chapter, within the MSS and ECS problems certain characteristics are more contemplated than others. Each characteristic has a different relevance and is integrated into a problem depending on the objective of the researchers.

Patient satisfaction is extremely important in the sector of healthcare, as it indicates the quality of the services being delivered. One way to increase patient satisfaction is to incorporate patient preferences in the decisions involved when scheduling surgeries [29]. On the basis of the problems addressed in the review of Chapter 3, this characteristic is rarely studied. However, Appointment Scheduling, regularly account for the patient preferences, regarding physician and time slot, when booking appointments. This opens opportunities to transfer knowledge from one group to another.

Within the contexts of surgery waiting lists and surgery scheduling problems, patient prioritization has a significant influence on the patient waiting times and the urgency with which the required surgical procedure is performed, as well as patient satisfaction [3]. In OR planning problems, researchers frequently include this characteristic into the developed models.

Workload balance influences the quality of the service delivered by the medical staff to the patients. Consequently, if the workload is not evenly distributed and well-organized, patient satisfaction may be negatively impacted. This characteristic has been regularly contemplated in the MSS and ECS problems throughout the years. However, in the framework of home healthcare problems, its presence is more significant since the number of activities to be conducted by nurses is substantial and dispersed throughout different locations. This provides a link between the OR scheduling and home healthcare frameworks allowing for knowledge transfer among both problems.

Another feature not very represented in the MSS and ECS problems is clustering. The activity of clustering medical specialties and their respective surgical procedures is capable of maximizing the benefits of a master surgery schedule and, as a result, reducing surgery waiting lists [30]. Once again, in home healthcare problems, clustering methods are frequently applied when constructing schedules. Clusters are formed according to the type of task to be performed and its corresponding duration. Methods applied in these circumstances could be explored in the context of OR scheduling problems.

Fairness is a relevant aspect to consider when constructing schedules. It ensures that the quality of service is consistent and homogeneous, contributing to patient satisfaction, and influences the workload distribution of the medical staff while simultaneously helping to avoid conflicts [31]. Both in instructional and appointment scheduling, fairness from the perspective of the patients, is often associated with and formulated as the average patient waiting time. Therefore, patient satisfaction can be improved when considering fairness. This way, there is an opportunity to invest in new research and to adapt the constraints used to model fairness in the latter scheduling groups to the methods applied in OR problems.

Staff preferences is very often incorporated into the MSS and ECS problems since it positively impacts the staff satisfaction and retention and, therefore, the continuity of the care delivered [28]. In the remaining categories, such as appointment scheduling, bed assignment, and blood collection, there is an evident lack of work incorporating this aspect into the derived models. Researchers could take advantage of the significant number of OR scheduling studies that include staff preferences and have as objective to maximize affinities among members of a surgical team, as well as minimize overtime hours.

Within the context of OR planning, uncertainty is majorly present. Therefore, disregarding this element distances the problem being studied from the reality in hospitals experienced by medical staff and patients. Uncertainty is widely studied in the MSS and ECS problems throughout multiple scenarios.

In Figure 10, presented below, the lack of studies incorporating characteristics, such as Patients Preferences, Fairness, and Clustering, in the MSS and ECS problems is demonstrated. Including these characteristics increases patient satisfaction significantly, hence, a research opportunity to consider these features is established. Nevertheless, Patient Prioritization, Uncertainty, and Staff Preferences have been extensively studied throughout the years.

Table 2. Summary Table

Characteristic	Presence in OR Planning Problems	Possible Knowledge Transfer	Advantages
Patient Preferences	Insignificant	Bed Assignment Appointment Scheduling	Increased patient satisfaction Improved adherence and continuity of treatments
Patient Prioritization	Very Significant	—	—
Workload Balance	Significant	Home Healthcare	Improved quality of service Increased patient satisfaction
Clustering	Insignificant	Instructional Scheduling Home Healthcare	Facilitate the scheduling of surgeons Respect for staff preferences
Fairness	Insignificant	Instructional Scheduling Appointment Scheduling Home Healthcare	Homogenous quality of service Increased patient satisfaction
Staff Preferences	Very Significant	Bed Assignment Blood Collection Appointment Scheduling	Maximize staff retention and care continuity Minimize overtime hours
Uncertainty	Very Significant	—	—

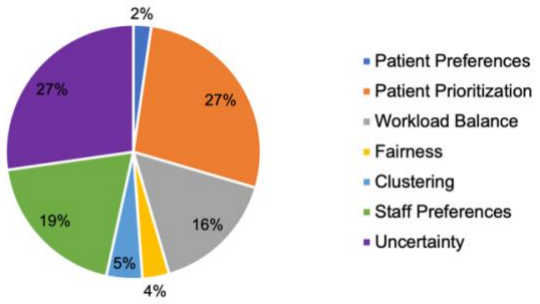

Figure 10. Characteristics treated in OR Planning and Scheduling Problems

In Table 2, presented above, the significance of specific characteristics in OR Planning and Scheduling problems is listed. Additionally, the problems with which knowledge transfer is possible are stated along with the advantages of including more frequently the respective characteristic.

8. Conclusions and Future Work

The main goal of this dissertation is to position the MSS and ECS problems in the scheduling literature. Due to the importance of these problems, there is a need to position them in a larger framework and take advantage of the dimension of the existing literature on scheduling problems. Patient preferences stands out as the only characteristic that is frequently incorporated in bed assignment and appointment scheduling respective studies and is barely mentioned in the setting of OR scheduling. This leaves scope for future research where this characteristic can be included in the MSS and ECS problems and utilized to increase patient satisfaction. There is also space for higher incorporation of clustering methods and fairness aspects to maximize the benefits of a master surgery schedule, minimize the surgery waiting lists, increase the quality of the service delivered. Concluding, in the OR setting and for these characteristics, there are multiple opportunities to invest in further research and take advantage of the knowledge already existing in other scheduling categories to improve performance measures, for example, waiting time, quality of service, and patient satisfaction.

This research clearly showed that there are research gaps concerning the OR scheduling problems. It is shown that other scheduling categories present more knowledge of these features. This way, for future research, other scheduling problems can be studied, as well as different characteristics than the ones included in this research to expand this analysis. Furthermore, a comparison of operational research methods and solutions applied both in general scheduling and the MSS and ECS problems could be performed.

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