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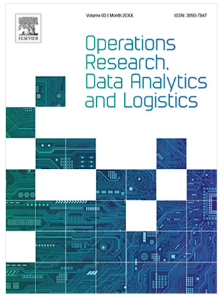

A roadmap for integrating fairness in personnel planning and scheduling in hospitals

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Highlights

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- Review of 97 personnel planning and scheduling papers in hospitals with a focus on operations research/management science.
- A discussion of the different fairness concepts applied.
- Organization of the literature by fairness metric and fairness measurement applied.
- Identification of promising research directions.

A roadmap for integrating fairness in personnel planning and scheduling in hospitals

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Abstract

The healthcare sector, and hospitals in particular, are confronted with an increasing challenge of staff shortages. To effectively address this issue, hospitals must enhance their workforce planning and scheduling processes in a manner that ensures fairness for employees. The application of operations research/management science methods offers significant promise for the integration of fairness into these processes. To assist researchers and practitioners in capitalizing on this potential, we present a comprehensive review of the extant literature. This review examines the current trends in the integration of fairness into workforce planning and scheduling in hospitals. It analyses 97 papers, providing insightful metadata and categorising the literature based on three key questions: what constitutes fairness, what metrics are crucial for assessing fairness, and how fairness can be quantitatively measured. By structuring our review around these questions, we identify gaps in existing research and suggest potential avenues for future research.

Keywords: OR in health services, personnel scheduling, personnel planning, fairness

1. Introduction

The healthcare sector represents a significant cost factor, with hospitals being the most prominent cost drivers (OECD, 2019; WHO, 2023). Within hospitals, employees are undeniably the most valuable yet most costly asset (Gross et al., 2018; Guo and Bard, 2022; Mansini and Zanotti, 2020). This is primarily due to their extensive specialization and the ongoing scarcity of qualified professionals (Gross et al., 2019). However, widespread dissatisfaction among highly skilled individuals often results in them leaving their employers and ultimately the healthcare sector prematurely (Goodare, 2017; CHAN et al., 2013). One significant source of this discontent stems from the burden of excessive and uneven workloads (Bruni and Detti, 2014; Kling et al., 2024). These imbalanced workloads are frequently a consequence of manual planning, where human planners face insurmountable challenges in resolving the issues of personnel planning satisfactorily (Schoenfelder and Pfefferlen, 2018). The application of Operations Research (OR) provides a promising pathway to tackle those intricate challenges associated with workforce planning in hospital settings (Kagerbauer et al., 2023; Seizinger and Brunner, 2023). OR methods not only enhance the efficiency of the planning process (Brunner et al., 2009; Brunner and Kolisch, 2010) but also offer an opportunity to integrate fairness into this critical aspect of healthcare management (Stolletz and Brunner, 2012). The inclusion of fairness considerations in planning serves to mitigate employee dissatisfaction (Baum et al., 2014). This is particularly relevant in countries where hospitals are unable to provide financial incentives to nurses (Seizinger and Brunner, 2023).

In this paper, we present a review of the current literature on integrating fairness into personnel planning and scheduling within hospitals. This study focuses on hospitals for two primary reasons: their pivotal role in the healthcare sector and the context-specific nature of fairness. By concentrating on this setting, we aim to provide a focused and valuable resource for researchers in the field. The extensive and expanding body of literature reviewed further supports the need for this targeted approach[1].

For readers seeking a more comprehensive and general overview of personnel planning and scheduling literature, we refer to (De Bruecker et al., 2015; Ernst et al., 2004a,b; Van den Bergh et al., 2013). For insights into the nurse scheduling problem within hospital settings, see (Cheang et al., 2003). Erhard et al. (2018) provide a well-structured overview of physician scheduling problems in hospitals. Our review narrows this focus further by concentrating on papers that integrate fairness into the personnel scheduling and planning process in hospitals. For a more general overview of how fairness is in-

[1]For a detailed meta-analysis of the papers included in this review, please refer to Appendix A.

tegrated into personnel scheduling, we refer readers to the broader overviews by Wolbeck (2019) and Xinying Chen and Hooker (2023), which discuss the implementation of fairness in mathematical decision models. In contrast to these general overviews, our goal is to present a structured overview of current practices and trends in the literature concerning the integration of fairness into hospital personnel scheduling. We will discuss various aspects that are important to integration of fairness into the personnel planning and scheduling process in hospitals. Using these aspects, we will organize the existing literature, rather than focusing on the technical details of implementation.

The primary objective of this literature review is to provide a comprehensive overview of how fairness is incorporated into personnel planning and scheduling within hospitals, as reported in the current literature. To do so we have focused on physician, residents and nurses in our initial structured search while expanding to other professions in the hospital through our extensive forward and backward searches. We intended for this review to serve as a roadmap for researchers, highlighting what has been accomplished and identifying areas for further investigation. We provide a comprehensive overview of the current literature, identifying 97 relevant papers according to our search criteria. Our review addresses three fundamental questions: what constitutes fairness, what metrics assess fairness, and how to measure fairness effectively. To illustrate how the literature addresses these questions, we will discuss the fairness concepts applied, the metrics used, and the measurement methods. Within these topics, we organize the literature by introducing distinct classifications, offering researchers a framework to contextualize their work and foster innovative ideas.

We have structured our work into the following sections: In the next section, we will expound on the criteria we have established for selecting pertinent literature and elucidate our methodology for identifying relevant publications. In Section 3, we will discuss how fairness is integrated into the personnel planning and scheduling process within the current literature. We will introduce classifications for the various aspects of fairness considered. This approach provides a comprehensive overview and assists future researchers in positioning their work within the scientific landscape. In Section 4, we will discuss our findings and offer potential avenues for future research. Finally, in Section 5, we will conclude with a summary of the most important results of our work.

2. Literature Scope

Our goal is to provide a comprehensive overview of how fairness is currently integrated into the personnel planning and scheduling processes in hospitals. At the same time, we aim to provide a useful guide for researchers wishing to incorporate fairness into their research. To achieve these objectives, we have developed a list of criteria for identifying relevant literature:

1. Published between 2013 and 2024.
2. Written in English.
3. Published in a peer-reviewed journal.
4. Problem setting within a hospital.
5. Comprehensive description of personnel planning or scheduling with focus on OR-Methods or Management Science.
6. Fairness is an integral component of the paper.

In the following, we will discuss these criteria to clarify their application and usefulness. We have limited the publication dates of the articles considered to ensure that we identify current trends. For consistency and accessibility, we included the criterion that papers must be written in English. To ensure the publication's quality, we limit inclusion to those records published within peer-reviewed journals. However, if we perceived a contribution as scientifically inadequate and not providing novel insights for our review, we excluded it. Based on this criterion, only six papers were excluded, which did not meaningfully change the body of literature identified. To ensure the discussed concepts are applicable in hospitals, we have focused on problems within hospital settings. Moreover, the comprehensive description of the personnel planning and scheduling process is a prerequisite for inclusion. This means the paper must convey how the specific personnel planning and scheduling process can be implemented. However, demonstrating its practical application in a real-world scenario is not required for the paper to be included in our review. Finally, papers are included only if the authors comprehensibly detail how they consider fairness and how their process contributes to fairness in the results of their approach. Applying the final criterion presents unique challenges due to the context-dependent nature of fairness, which can vary widely across studies. To avoid imposing a singular definition of fairness while ensuring that it is considered, we included only those papers that explicitly discuss fairness. This method allows us to showcase a diverse range of relevant approaches. By leveraging the authors' expertise, we gain insights into how their approaches effectively achieve fair personnel planning and scheduling within their specific contexts.

In the following, we describe the process used to identify the papers included in our review: Recognizing the diverse range of problem settings in hospital personnel planning and scheduling where fairness can be considered, we acknowledged the absence of standardized terminology. Therefore, we intentionally formulated search terms to encompass a wide spectrum of literature. These terms were systematically grouped into three categories: descriptors for primary employees in hospitals (physician*, nurse*, resident*), terms related to planning (schedul*, roster*), and terms associated with fairness (fair*, equit*, equal*, balanc*). A comprehensive overview of the terms is provided in Table 1. Instead of incorporating the term "hospital" or its synonyms in our search, we chose to focus on the primary professions working within hospitals. This decision was based on the lack of a single terminology to describe hospital settings. Additionally, not all papers studying hospital-related problems explicitly refer to the hospital; some refer to specific areas like the ward, the Emergency Department, or other departments relevant to their problem setting. By implementing a thorough forward and backward search, we ensure the comprehensive identification of relevant literature considering other professions in the hospital.
We created 24 search strings, encompassing all possible combinations, each including one term from each category linked with the "and" operator. Implementing all these strings in searches on Scopus, ScienceDirect and EBSCO, we identified 1,746 papers containing all the terms of at least one of the 24 strings in the abstract, title, or keywords.

profession	**planning**	**fairness**
physician*	schedul*	fair*
nurse*	roster*	equit*
resident*		equal*
		balanc*

Table 1: Search terms

In the subsequent refinement phase, we excluded papers based on their titles and language, dismissing those not written in English. This was done when it was evident from the title that the paper was unrelated to the problem setting under study. This criterion led to the exclusion of 1,551 papers, a significant portion of which pertained to energy distribution problems, a consequence of incorporating the term "resident" in our search. For the remaining 195 papers, we consulted the abstracts and, if necessary, the conclusions to pinpoint the relevant contributions. Throughout this phase, papers that did not address personnel planning and scheduling within a hospital were excluded. Applying these refined criteria resulted in the identification of 98 papers deemed potentially relevant. Each of these identified papers was read thoroughly and comprehensively. During this stage, we applied the additional criterion that fairness must be explicitly and adequately discussed. As a result, we excluded a further 48 papers. Conducting a thorough forward and backward search based on the 50 papers that remained after the initial screening, we identified an additional 47 papers to include in our review. To summarize the entire process, starting with 1,746 papers, we ultimately identified 97 papers to be included in our comprehensive review. A visual representation of this process can be found in Figure 1, and Table A.2 provide an overview of the included papers.

By employing the previously described approach, we have cast a wide net to ensure a comprehensive overview of the current literature. Notably, we avoided the need to define fairness ourselves. This is particularly sensible given the diversity of personnel planning and scheduling problems found in the literature. As discussed earlier, we believe that authors are best positioned to judge whether they intended to introduce fairness into the personnel planning and scheduling process.

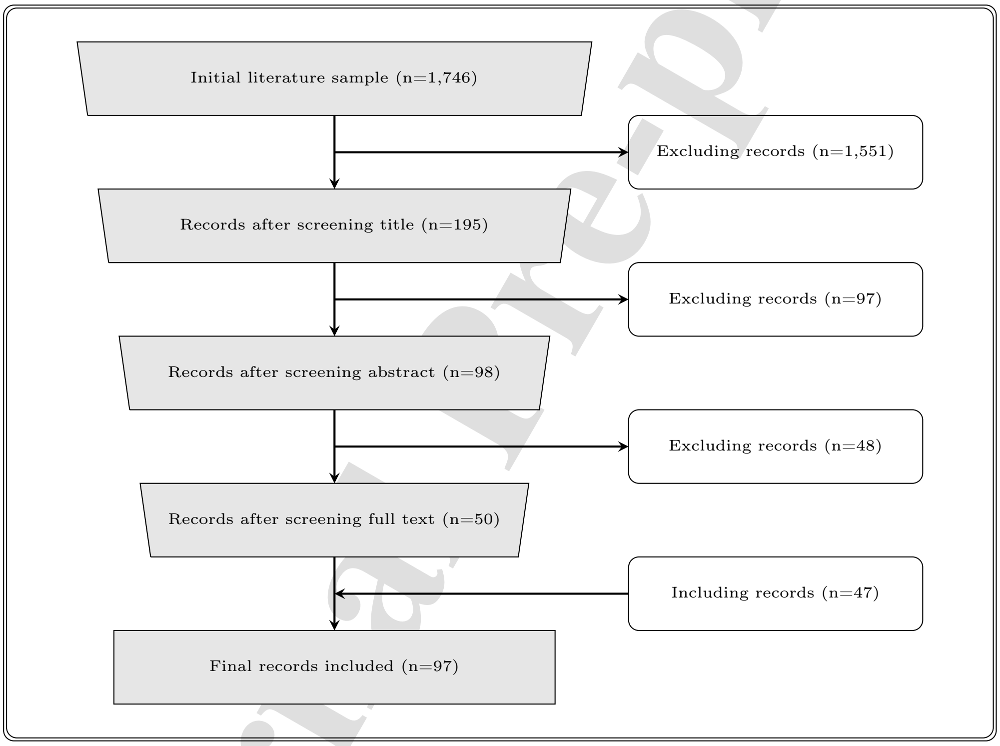

Figure 1: Process of the literature review

3. Fairness within the literature

3.1. Concepts of fairness: What constitutes Fairness?

In this section, we show how the literature answers the question: What constitutes fairness? We introduce and discuss the different interpretations of fairness applied by various authors in the context of personnel planning and scheduling in hospitals. We identified three overarching fairness concepts applied to classify the different approaches:

- The concept of **Equal fairness (EquaF)** refers to the principle of treating everyone equally. This concept is based on the assumption that there are no distinguishing factors among employees that would warrant different treatment. Consequently, fairness involves treating each employee anonymously and ensuring a uniform outcome in the planning and scheduling process.

- The concept of **equitable fairness (EquiF)** involves treating individuals based on their unique characteristics e.g., experience levels. There is no single correct method to achieve this. This concept acknowledges that employees have distinct traits and posits that fairness requires personnel planning and scheduling to be tailored to accommodate these differences.

- Building upon the two earlier principles, the concept of **harmonious fairness (HarF)** entails identifying distinct groups of comparable employees. Equitable treatment is applied between these groups, while equal treatment is maintained within each group. Unlike the equitable concept, HarF allows for the identification of various groups and criteria for their assignment without prior knowledge of individual employees.

We have derived these concepts through the analysis of approaches described in the literature. Our analysis focuses on how these concepts are applied to categorize employees. Notably, the concepts of equality and equity are prevalent in the broader fairness literature. For further reading, we direct interested readers to (Jain et al., 1984; Rawls, 1971; Sen, 1997). These concepts differ fundamentally in how they categorize employees. To illustrate this, we applied the different concepts to the same six employees, depicted in Figure 2. The EquaF approach is applied first, categorizing all employees uniformly, as shown in the first box. In contrast, the EquiF approach categorizes employees based on individual characteristics. In our example, employees are grouped by a combination of facial features and the hat they are wearing, as illustrated in the second box. In a hospital setting, an example of the EquiF approach might be using individual preferences as the basis for fair planning and scheduling processes. Lastly, the HarF approach categorizes employees based on an external characteristic. In our example, employees are grouped by the type of hat they are wearing, as shown in the third box. In a hospital context, an example of the HarF approach is grouping employees by seniority. These diverse categorizations allow for different interpretations of fairness, which we will explore in greater detail in the following section. The number of papers applying each concept is given in Figure 3. For an in-depth overview of which papers apply each approach, please refer to Table B.3. In the following paragraphs, we will discuss these concepts in more detail.

The first concept, EquaF, involves treating employees anonymously, without applying differentiation criteria to the employees under consideration, with an emphasis on treating each employee equally. Smet (2023) serves as a unique yet descriptive example, as he does not consider individual employees but instead assumes that fair treatment of each employee can be achieved by creating schedules of equal quality across different wards. This concept intuitively aligns with the principle of fairness, as it equates treating employees fairly with treating them equally. To illustrate this, consider the example of assigning 18 upcoming night shifts to the six physicians depicted in Figure 2. Applying the equal treatment idea means we do not differentiate between them, thereby arriving at the only fair solution: assigning each physician three shifts.

However, equating fairness with equal treatment relies on the critical assumption that all employees are equal and should therefore be treated equally. In a diverse hospital workforce, this assumption may not hold true. Consider-

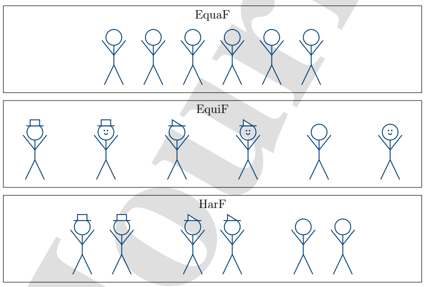

Figure 2: Fairness concepts

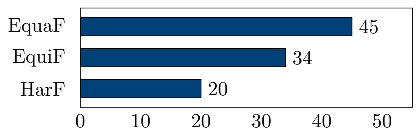

Figure 3: Number of papers by Fairness concept applied

ations such as an employee's profession, age, or maternity status (Thielen, 2018; Zanda et al., 2018) may be pertinent in personnel planning and scheduling. For example, some scholars argue that pregnant women or employees with children should be treated differently from young employees without family commitments (Cildoz et al., 2021; Zanda et al., 2018). These examples illustrate that treating employees equally does not necessarily equate to treating them fairly. Consequently, other concepts are required to ensure fair treatment of employees. One such concept is EquiF, which posits that each employee is unique and should be treated according to their individual characteristics. Within EquiF, employees are differentiated based on these characteristics, with the planner determining which ones are relevant in a given context. Fairness is achieved by setting rules that consider these characteristics within the context of the planning problem. For the example of assigning night shifts, individual preferences might serve as the relevant individual characteristics. Subsequently, a variety of assignments could be deemed fair based on these preferences and the established rules. This example illustrates that EquiF does not offer a single, definitive solution for what is fair. Instead, it provides flexibility, allowing planners to account for individual differences to enhance planning and scheduling outcomes while considering fairness. However, this flexibility poses a significant interpretive challenge for planners. Reconciling individual characteristics into a notion of fairness that is accepted by all or most employees can be challenging, if not impossible. Thus, applying this concept demands careful definition and clear communication of how fairness is integrated into the planning and scheduling process.

The HarF combines elements of the equitable and equal concepts. It involves identifying groups of employees with similar characteristics. Within these groups, the goal is to treat employees equally, while between groups, equitable treatment is sought. Such groupings are often identified based on employees' qualifications or seniority, although a wider variety of groupings is feasible (Malekian et al., 2023; Smalley and Keskinocak, 2016; Thongsanit et al., 2016). The advantage of this approach is that it allows employees within the same group to have a reference for assessing their treatment, while still offering some flexibility in the treatment of employees within different groups. Deciding on how to cluster employees is context-dependent, and involving employees in this process can improve their perception of the fairness of the personnel planning system. Continuing the previous example, we could use seniority as the basis for grouping. By categorizing the physicians into senior, junior, and resident groups, and assigning zero shifts to each senior physician, four shifts to each junior physician, and five shifts to

each resident, we could achieve a fair solution. The difference in the number of night shifts between these groups results from applying the concept of equitable fairness. Utilizing the flexibility of this concept, the comparative treatment of the groups might vary significantly depending on the context of the planning problem. Additional grouping characteristics could be applied if necessary to further refine fairness.
The HarF concept is not an independent concept, but builds on the two previously discussed concepts. This is particularly evident when all employees are treated as a single group or each employee is viewed as an individual group. In these cases, the HarF concept is equivalent in function with the other concepts discussed. Nevertheless, the HarF concept is valuable for classifying literature, especially for understanding how planners perceive and prioritize fairness. It provides insight into whether planners are guided by the notion that all employees are the same, that everyone is different, or that there are groups of similar employees. This understanding helps reveal the underlying principles that drive fairness considerations in workforce planning and scheduling.
All these concepts of what constitutes fairness have their advantages and disadvantages. Bowers et al. (2016) demonstrate that different people prefer different concepts. They introduce both an equitable approach on an individual level and an equal approach, then allow employees to choose the approach they would like to be used for them. Among nine employees, six opt for the anonymous approach while three choose an individualized approach, thereby showing that no single approach is perceived as superior by all employees. Implementing a comprehensive feedback mechanism to assess employee perceptions of different fairness concepts could yield valuable insights into the contexts in which various approaches are most appropriately applied Mystakidis et al. (2024). Moreover, the choice of concept does not only rely on employee preferences but may also depend on the problem setting, as evident in the work of Smalley and Keskinocak (2016). They address both a resident rotation problem and a resident scheduling problem. In the long-term resident rotation problem, employees are differentiated according to their seniority, focusing on balancing the experience gained and ensuring fairness within groups. In contrast, for the short-term resident scheduling problem, they focus on first-year residents and assume that there are no differentiating criteria worth considering, thus treating employees equally.
In summary, when the workforce is homogeneous, applying EquaF ensures that all employees are treated uniformly. If there are distinct groups within the workforce, HarF can address the needs and characteristics of these groups in a balanced manner. In cases where the workforce is highly heterogeneous,

EquiF can cater to the specific needs and circumstances of each employee. The choice of the fairness concept lies within the planner's discretion.

3.2. Fairness metrics: What to measure?

Upon selecting one of the previously outlined fairness concepts, researchers need to establish a procedure for quantifying the effectiveness of their personnel planning and scheduling approach in accordance with the chosen concept. A crucial step in this process involves addressing the question: What to measure? The answer to this question is referred to as metric (M_{ij}). We identified two key aspects to consider when selecting a metric: the degree of employee involvement and the dimension being measured. To provide readers with insights into potential metrics, we will introduce two classification schemes that offer valuable guidelines for establishing a metric, forming the foundational basis for quantifying fairness.
The first classification categorizes articles based on the degree of involvement required from employees for the metrics:

- **Individual metrics** are the outcome of input provided by individual employees.
- **Anonymous metrics** are observable by a third party without requiring input from the employee.

The number of papers in each individual category is illustrated in Figure 4. For an in-depth overview of which degree of involvement is considered in each paper, please refer to Table B.3. In the following paragraphs, we will discuss these categories in more detail.
This classification parallels the previously discussed concepts of fairness but is not necessarily synonymous. Importantly, even when employing anonymous metrics, it is still possible to apply HarF or EquiF. This is accomplished by utilizing externally observable characteristics, such as age, qualification, or maternity status, to differentiate between employees. However, applying an EquaF using individual metrics is not feasible because employee distinctions are inherently integrated into the metrics used. The choice between employing anonymous or individual metrics hinges on the particular problem under consideration. Anonymous metrics are easy to apply and are typically straightforward for third parties to assess. Nevertheless, they may only capture individual differences to a limited extent. For example, in the pursuit of harmonious fairness, authors may consider the seniority level of the employee (Smalley and Keskinocak, 2016). While this approach allows for differentiation based on seniority, it lacks the capacity to accommodate individual

employees' preferences regarding working more or fewer shifts compared to the average employee of the same seniority. In such cases, considering individual metrics may enhance the perception of fairness among employees.
In contrast, individual metrics provide an opportunity to consider the personal desires and needs of each employee, actively leveraging the differences among employees. While involving employees in this process is generally viewed positively (Chow et al., 2015), it does require additional investment. Because these metrics cannot be observed directly, employees must provide input, which is time-consuming. Additionally, employees may be incentivized to misrepresent their characteristics for personal gain. Designing a system to mitigate this risk requires even further investment. Within the literature, some researchers actively attempt to prevent collusion or dishonesty within a system. For instance, coordinating shift preferences is prohibited in (Chow et al., 2015). Another strategy to prevent dishonesty is by restricting how employees can provide input (Chiang et al., 2019). However, there is no comprehensive study on the susceptibility of these systems to cheating or how effective these measures are. Consequently, it is difficult to evaluate how vulnerable individual metrics are to lying and collusion. Ultimately, the choice between anonymous and individual metrics should depend on the specific problem at hand. A discussion with employees can contribute to making an appropriate decision.
The second classification aids in distinguishing the metrics based on their dimension. We identified four dimensions commonly considered within the literature:

- Metrics quantifying the **personnel dimension** gauge the utility or satisfaction of individual employees, with many of them relying on input directly from the employees.
- The **financial dimension** category includes metrics that evaluate the financial consequences for employees stemming from the personnel planning and scheduling process.
- The **working time dimension** encompasses metrics that quantify employees' working hours. Within this metric, working hours may be weighted to account for their desirability.
- Metrics pertaining to the **quality dimension** quantify the quality of outcomes derived from the planning process, taking into account factors like shift arrangements, the quantity and severity of assigned patients, and the frequency of weekend work. Unlike metrics in the

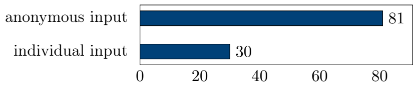

Figure 4: Number of papers classified by employee involvement

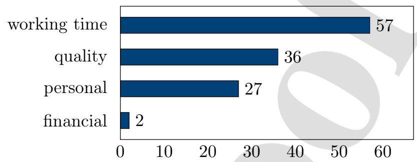

Figure 5: Number of papers by dimension

personnel dimension, quality dimension metrics are typically externally observable and not concerned with employees' perceptions. This category also functions as a repository for metrics not encompassed in prior categories.

The dimensions have been selected in order to effectively map the key objectives in personnel planning and scheduling problems within hospitals. The personnel dimension ensures that planning focuses on the perception of employees. The financial dimension is crucial for hospitals and is frequently considered in various problem settings. Working time is a significant factor due to regulatory requirements and its direct impact on employees. Finally, the quality dimension assesses the ergonomics of work schedules. Integrating these dimensions while addressing fairness in the planning and scheduling process is both practical and essential. The frequency of papers applying the different dimensions is illustrated in Figure 5. For a comprehensive overview of the dimensions used in each paper, please refer to Table B.3. In the following section, we will discuss these dimensions in more detail.
Metrics using the personnel dimension are designed to quantify employee satisfaction or utility, typically relying on individual employee input to calculate a personalized score (Chow et al., 2015; Gross et al., 2019; Rerkjirattikal et al., 2020). Given their individualized nature, reliant on subjective employee input, these metrics often pose challenges in objective measurement. Moreover, comparing these scores can be intricate due to variations in perceptions and the diverse ways employees express their preferences. In addition to preferences, self-generated schedules are a less frequently discussed input provided by employees (London et al., 2023; van der Veen et al., 2016). The challenge with these schedules lies in determining how to arrive at a feasible schedule fairly. Despite the challenges, the personnel dimension holds significant potential for improving efficiency by capitalizing on the distinctions in employee characteristics. Since metrics in this category typically rely on individual employee inputs, there is a potential for self-interested actors to manipulate the system. Therefore, the use of such metrics should always

be accompanied by safeguards to ensure the system's integrity and proper function.
Metrics capturing the financial dimension receive explicit attention in only two of the articles. Leksakul and Phetsawat (2014) attempt to equitably distribute paid overtime, while Baum et al. (2014) focuses on the fair allocation of compensation for honorary physicians. It is unclear why the financial dimension is considered so little within the literature. One explanation is that employees usually work on fixed salaries. Financial implications are then often downstream consequences of working hours. Consequently, fairly assigning working time might lead to fair payments. Therefore, financial considerations should be incorporated to promote overall fairness when applicable.
Working time metrics, appearing in diverse forms, are widely employed in the literature. These metrics involve various methodologies for quantifying employees' working time. Notably, some metrics incorporate weighting to align with the differing burdens resulting from assigned working hours. For instance, night shifts are commonly perceived as less attractive than other shifts (Gross et al., 2018), and weekend working hours are generally considered less appealing (Camiat et al., 2021; Cappanera et al., 2022; Ito et al., 2018). Recognizing and accounting for these distinctions by appropriately weighing working hours is paramount for accurately assessing the fairness of the assigned working time. In specific instances, focusing on a subset of total working hours, while disregarding others by assigning them weights of zero, may suffice to capture the planners' idea of fairness (Chiang et al., 2019; Fügener et al., 2015). Consequently, appropriately considering the attractiveness of working hours is paramount to achieving a fair result.
Within the final category, the quality of the planning and scheduling outcome is measured. Since ultimately everything contributes to the perceived quality, this category is designed to encompass all metrics with dimensions that diverge from those in the preceding categories. Illustrative examples within this category involve evaluating the prevalence of unfavorable shift sequences (Camiat et al., 2021; Wang et al., 2014; Hong et al., 2019b), monitoring the frequency of weekends worked (Cappanera et al., 2022; Devesse et al., 2023), and quantifying the workload arising from patient assignments (Adams et al., 2019; Sir et al., 2015; Jiang et al., 2023). Please note that when discussing the frequency of weekends worked, we focus solely on the number of weekends worked and not the actual time spent working on weekends. Therefore, papers measuring this dimension are included in the quality category rather than the working time category.
A notable degree of variation in content and terminology is observed across

these categories, largely attributable to the distinctive characteristics of each problem. No metrics of a single category are inherently superior for ensuring fairness in personnel planning and scheduling. This variability may explain why authors frequently employ metrics drawn from multiple categories (Proano and Agarwal, 2018; Senbel, 2021; Wickert et al., 2021). The selection of the number of metrics, the nature of employee input—whether anonymous or individual—and the specific dimension of the metrics should be context-dependent. Given employees' individualized and multifaceted perceptions of fairness, selecting appropriate metrics should involve a collaborative process between planners and employees. This collaboration helps ensure that the chosen metrics effectively reflect employees' perceptions of fairness.

3.3. Fairness measures: How to measure fairness?

After deciding on the fairness concept to apply and selecting the appropriate metric, one crucial question remains: How to measure fairness? To sufficiently address this question, we identified three key aspects to be considered: The timeframe in which fairness is to be ensured, the approach used to ensure fairness, and the measurement applied to quantify fairness. We will introduce three classification schemes for these aspects in this section.
Starting with the temporal aspect of measuring fairness, we have identified two distinct approaches within the literature:

- If fairness is maintained within the planning period of the underlying problem, the approaches are classified as **within-period approach**.
- Within the **continuous approach**, fairness is ensured over a time frame that extends beyond the current planning period. This approach relies on information from previous or future planning periods to achieve fairness.

Figure 6 provides an overview of the number of papers categorized by their approach to the temporal aspect of fairness. For a detailed examination of which approach is applied in which paper, please refer to Table B.3. The prevailing approach in the literature typically focuses on achieving fairness within the time frame of the planning problem. Finding a solution that is perceived as fair by employees is often impossible. This is partly because fairness is not the sole objective in most problems (Cildoz et al., 2021; Jiang et al., 2023; Zanazzo et al., 2024). Moreover, these problems are often highly constrained, making it challenging to identify feasible solutions (Bruni and Detti, 2014; Schoenfelder and Pfefferlen, 2018). Consequently, ensuring fair treatment for each employee may not always be possible within the time frame of the planning problem being examined. Conversely, fairness may be achievable over time by considering fairness beyond the planning problem's time horizon. Consequently we will in detail discuss the importance of continuous fairness and how this approach is implemented in the literature. The effects of implementing continuous fairness considerations were studied by Senbel (2021). Their study indicated that incorporating long-term fairness measurements will significantly enhance fairness in the long run. Gross et al. (2019) conducted a similar study, showing that a single-period approach to ensuring fairness can disproportionately burden a single employee. The results of both papers highlight the importance of incorporating continuous fairness considerations when fairness is a significant concern.

Considering the limited attention to continuous fairness in existing literature, our objective is to provide an overview of how different studies address this issue. Typically, these papers introduce a score that tracks the treatment of employees across one or more previous planning periods, often reflecting how well employee preferences were fulfilled. This score is then used to weigh the employees' preferences in the current planning period within the objective function of the models (Lin et al., 2014; Gross et al., 2019; Huang et al., 2016b,a; Lin et al., 2015a,b; Mystakidis et al., 2024; Pahlevanzadeh et al., 2021; Senbel, 2021). If the score is calculated each planning period anew it is not possible to track fairness over more then two periods (Mystakidis et al., 2024). Therefore updating the score using the last score aswell helps track fairness continously.

Wolbeck et al. (2020) additionally normalize this score to ensure its comparability with other parts of the objective function. By applying this approach, the preferences of previously disadvantaged employees are more likely to be considered in the current planning period. The scores are typically updated after the completion of planning to be taken into account in the subsequent planning period. Various mechanisms are employed for score updates, all aiming to adjust the score based on the treatment of employees in the previous planning periods. Notably, Gross et al. (2019) stands out as the only paper specifically addressing the timing of the updating of the weights. They compare updating the weights after each planning period versus updating it directly within the planning period. Their computational study demonstrates a significant increase in the fairness of the distribution of accepted preferences within a planning period by incorporating the updating of the satisfaction factor in their model. These findings are further supported by Wolbeck et al. (2020), who explicitly acknowledge that their updating strategy after each planning period leads to unfair solutions within that specific period but is considered acceptable in order to prioritize long-term fairness.

Alternatively, Malekian et al. (2023) do not use scores but instead partition nurses into fairly and unfairly treated groups based on the last planning period. Subsequently, only the requests of unfairly treated nurses are considered in the current planning period. Similar to the previous approach, this method makes it impossible to keep track of fairness for more than two periods. Additionally, there is no easy way to differentiate the presented nurses. It is rather the responsibility of the planner, which might add an additional burden.

In contrast to the previously described papers, London et al. (2023), Bhutiani et al. (2018) and Turner et al. (2013) ensure fairness not in the objective function of the mathematical decision model. London et al. (2023) propose a rotational system for self-scheduling shifts, wherein the order of selection from available shifts is rotated among employees during planning periods. Additionally, the assignment of major holidays is tracked separately, and these assignments are made based on historical data. Bhutiani et al. (2018) sort employees by their working time above contractual hours. This information is used by the planner to make scheduling decisions. Similarly, Turner et al. (2013) attempt to balance the learning experiences of residents by creating suggestions based on prior accumulated imbalances. Senior physicians then use these suggestions to create what they consider to be fair plans. In both methods, the final decision rests with the planner. Turner et al. (2013) explicitly mention that their approach did not help improve equality, as planners regularly ignored their suggestions.

In conclusion, the literature shows that considering fairness beyond the immediate planning horizon is a promising idea. However, there is very little research on this topic beyond the use of weights within the objective function. Additionally, updating strategies for these weights are only superficially studied. Therefore, the question of how to incorporate continuous fairness offers ample opportunity for further research.

After determining the appropriate timeframe for considering fairness, the next step is to select a structure for the planning and scheduling process. There are various methods to integrate fairness into workforce planning, which can be broadly categorized into three main approaches:

- Integrating fairness into the planning process occurs through the choice of a suitable **planning structure**, without ensuring fairness within a mathematical decision model.
- The introduction of **hard constraints** in a mathematical decision model can be employed to integrate fairness into the planning process.

- Fairness is integrated into the planning process by incorporating it within the **objective function** of the mathematical decision model, utilizing variables defined through soft constraints.

Figure 7 provides an overview of the frequency with which different approaches are applied in the literature. For a detailed overview of the approaches used in each paper, please refer to Table B.3. In the following section, we will discuss these approaches in greater detail. For those approaches that utilize a mathematical decision model, we will illustrate the general concept using the notation provided in Table C.4.

One significant advantage of incorporating fairness into the structure of the personnel planning and scheduling process is the considerable flexibility it provides. As a result, the literature presents numerous distinct concepts within this context. An illustrative example can be found in (Hong et al., 2019a), where models are used to generate a spectrum of Pareto-optimal plans from which the planner can choose. Consequently, it is within the purview of the planner to select a fair plan. We have also discussed the examples of Bhutiani et al. (2018) and Turner et al. (2013), who offer suggestions to the planner by sorting employees based on suitable criteria. Alternatively, fairness can be incorporated into heuristic algorithms (Chen et al., 2022; Chow et al., 2015; Guo and Bard, 2022). For instance, Sun et al. (2023) utilize an iterative heuristic that sequentially improves the schedule for the most disadvantaged employee. Saad et al. (2023) introduce two different sorting algorithms to balance the patient acuity that nurses deal with during a workday. In addition to these approaches, several other strategies exist for addressing fairness within a specific planning framework. The commonality among all these approaches is that fairness is frequently not precisely quantified, and achieving an optimal solution is not always the primary objective. Consequently, it might be challenging to transparently communicate to employees how fairness is ensured.

In contrast, using mandatory constraints within mathematical decision models to ensure fairness facilitates clear and transparent communication with employees about what constitutes fairness and how it is achieved. To effectively formulate these constraints, planners need a fundamental understanding of what makes a plan fair and how this fairness is reflected in the outcomes. For instance, a planner might establish the range of a metric that is considered fair. By setting minimum ($minV_{ij}$) and maximum ($maxV_{ij}$) values for a given metric j and each employee i, as illustrated in Equation 1 the planner ensures that fairness is achieved for each employee within these bounds. If the planner does not have a predefined range for what is con-

$$minV_{ij} \leq M_{ij} \leq maxV_{ij} \qquad \forall i, j \tag{1}$$
$$M_{ij} - M_{kj} \leq thr_{ikj} \qquad \forall i, k, j \tag{2}$$

sidered fair, they might focus on controlling the disparity between metrics for different employees. This can be done by defining a maximum allowable difference (thr_{ikj}) between the same metric j for two employees i and k, as shown in Equation 2. Examples of such constraints in the literature encompass ensuring that each employee works an identical number of shifts (Bowers et al., 2016; Zaerpour et al., 2022), is guaranteed a minimum probability of being able to take their planned break Kraul et al. (2024) or that the discrepancy in the shifts worked by employees does not surpass a certain threshold (Klyve et al., 2021; Otero-Caicedo et al., 2023; Senbel, 2021). By choosing appropriate parameters the planner can exert significant control over the solution space through constraint formulation. Striking the right balance is paramount because overly rigid constraints can render the mathematical problem infeasible, while more lenient ones may lead to fairness not being discernible in the final results. This presents a significant drawback of the approach, as knowing what constitutes a fair solution is rarely apparent before the planning process. This makes it difficult to formulate effective constraints. Furthermore, enabling a trade-off between fairness and other objectives within the planning is not feasible when mandatory constraints are employed.

To address the challenges associated with mandatory constraints, fairness can be integrated into the objective function of a mathematical decision model. When paired with suitable soft constraints, this approach ensures that problems remain feasible. Moreover, it facilitates a trade-off among diverse elements within the objective function. The opportunities for integrating fairness into the objective function of a mathematical decision model are highly diverse. For clarity, we will refer to the calculation rules used to quantify fairness as measurements. The choice of measurement applied in the objective function significantly impacts the output of the mathematical decision model. As a result, the various approaches within the objective function will be explored and categorized in more detail in the following.

In conclusion, different methods for addressing fairness in personnel planning each have their own strengths and weaknesses. While integrating fairness into the objective function presents unique opportunities for balancing multiple objectives, it is important to explore and understand the various

approaches to find the most suitable solution for each specific context. Further research will be essential in refining these techniques and improving their implementation.
In the following discussion, we explore how fairness can be incorporated into the objective function of mathematical models. Numerous studies incorporate multiple objectives within their objective functions, frequently emphasizing a trade-off between fairness and efficiency or overall quality (Fügener et al., 2015; Wolbeck et al., 2020; Zanda et al., 2018). A limited number of papers also addresses the trade-off between various aspects or metrics of fairness (Acar and Butt, 2016; Pahlevanzadeh et al., 2021; Rea et al., 2021). To adequately consider these diverse objectives, the most prevalent approach is to employ a weighted sum within the objective function (Chiang et al., 2019; Thielen, 2018; Wickert et al., 2021). This method facilitates the weighting of different objectives in accordance with the problem context. In extreme cases, these weights can result in lexicographic approaches where either efficiency (Guo and Bard, 2022) or fairness (Gross et al., 2019) may be the primary objective, while other objective aspects are secondary. Bin Obaid (2024) apply their model twice, initially using efficiency and subsequently optimizing for fairness, rendering their approach lexicographic. In contrast, only a few studies utilize approaches to identify a set of non-dominated solutions or the Pareto frontier (Heidari et al., 2021; Huang et al., 2021; Mahdizadeh Sarami et al., 2024; Otero-Caicedo et al., 2023; Smet, 2023; Sun et al., 2023). For instance, Smet (2023) employs the balanced box method to identify a set of non-dominated solutions for presentation to the planner. Similar to the work of Hong et al. (2019a), these studies have the advantage of enabling the planner to select outcomes they deem fair or of high quality. Explicitly considering fairness in the objective function allows for the provision of well-informed suggestions regarding the fairness aspect. Given that only a few papers explicitly address multi-objective modeling and fairness does not alter their approach to multi-objective modeling from standard methods, we will not delve deeper into this topic here. In the following discussion, we assume that the measurements we discuss could be integrated within multi-objective approaches. For ease of understanding and clarity, we present the measurements in isolation. Given the diverse measurements to quantifying fairness within the objective function found in the literature, we will classify these measurements in the following paragraph.[2] We introduce

[2]The categorized measurements discussed here rely on different metrics utilizing different dimensions, as elaborated in Subsection 3.2. Describing the functionality of different

a two-dimensional classification scheme:

1. We differentiate measurements according to the **number of observations** in the objective function.
   - Exactly **one** employee is considered in the measurement.
   - **Two** employees are considered in the measurement.
   - **All** employees are considered in the measurement.
2. We distinguish the **types of measurement** utilized in the objective function, aiming to differentiate based on functionality.
   - **Spread measurements** quantify fairness by measuring the disparities in specific metrics across different employees – e.g., discrepancies in assigned working hours.
   - **Position measurements** quantify fairness based on the absolute values of specific metrics – e.g., the number of working hours each employee is assigned.

Both dimensions are simultaneously applied to categorize the papers. This results in six distinct categories of the format "number of observations/type of measurement". For a snapshot of how frequently measurements of each category appear in the literature, see Figure 8. For a comprehensive overview of the measurements employed by each papers, please refer to Table B.3. In the following section, we will delve into these categories in more detail.
In the "one/Spread" category, the objective function is designed to minimize the maximum (absolute, positive, or negative) difference between a target and the actual assignment for a single employee (Bard et al., 2017; Klyve et al., 2021; Kraul, 2020) — such as the difference between a target working time and the working time of the employee with the most substantial deviation. A general formulation of the measurements used in the "one/Spread" category is formally outlined in Equation 3. The choice of an appropriate function (f_p) depends on the type of spread being considered.establish[3] However, this approach is limited in that it exclusively focuses on one employee,

measurements using a generic dimension can be challenging to comprehend. Since the specific dimensions considered are not critical to the functionality of the measurement, we will use working time as a representative metric. It is important to note that working time is not the only dimension considered in the literature.

[3]Examples of spread functions utilizing a target value tgt_{ij} for metric j and employee i commonly found in the literature include the following: $f_p(M_{ij}) := \{(M_{ij} - tgt_{ij})^2; \max\{M_{ij} - tgt_{ij}; 0\}\}$.

while failing to consider the distribution of the metrics of the remaining employees. As a result, much of the information about fairness in the planning and scheduling process is lost.

$$f_p(M_{ij}) \leq Z_j \qquad \forall i, j \tag{3}$$

Within the "one/Position" category, a similar approach is employed, with the objective of optimizing the results for the most disadvantaged employee (Akbarzadeh et al., 2022; Dumrongsiri and Chongphaisal, 2018; Thongsanit et al., 2016) – e.g., minimizing the working hours of the employee who has to work the most hours. This concept is generally formulated in Equation 4. Similar to the measurements in the "one/Spread" category, the measurements in this category solely focus on one employee. Both of these approaches draw inspiration from the Rawlsian fairness principle, which emphasizes the maximization of benefits for the least advantaged individual (Rawls, 1971). While these methods are relatively straightforward to implement within a mathematical decision model, considering only one employee limits the potential for achieving fairness and efficiency. Bin Obaid (2024) expands on this idea by integrating his mathematical model into a structured framework for fairness considerations. In his work, the working hours of the employee with the highest workload are minimized sequentially until the working time of no employee can be further reduced. Thus, each employee is incorporated into the fairness considerations.

$$M_{ij} \leq Z_j \qquad \forall i, j \tag{4}$$

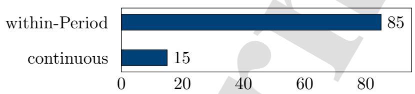

Figure 6: Number of papers by time frame

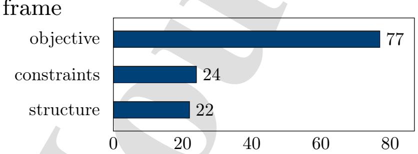

Figure 7: Number of papers by approach used

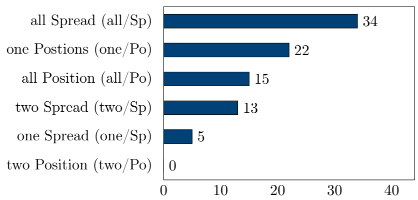

Figure 8: Number of papers by measurement

In the "two/Spread" category, the objective function aims to minimize the disparity between the most advantaged and the least advantaged employee (Adams et al., 2019; Böðvarsdóttir et al., 2022; Sir et al., 2015) – e.g., minimizing the difference in working hours between the employee working the most and the employee working the least. A formal description of the measurements in this category is depicted in Equation 5. The core idea is to narrow the range between the employees benefiting the most and the least from the outcome of the planning and scheduling process. This measurement, more so than the previous ones, incentivizes equal treatment of all employees. However, this can come at the cost of the overall quality of the resulting plan, meaning that everyone might receive worse plans compared to a less equitable solution. Consequently, while this approach achieves equality, it raises questions about whether employees perceive it as practical or fair. Generally, by solely applying spread measurements, we neglect the overall quality of the entire working plan, which might lead to unsatisfactory outcomes.

$$M_{ij} - M_{kj} \leq Z_j \qquad \forall i, k, j \tag{5}$$

For the "two/Position" category, no papers have been identified that apply a corresponding measurement. Furthermore, our broader examination of the fairness literature has not yielded any measurements that align with this category. Consequently, we conclude that this category offers very limited potential for the quantification of fairness.

In the "all/Spread" category, the primary objective is to minimize the sum of deviations (absolute, positive, or negative) in the final assignments for all employees – e.g., this could involve summing the absolute differences in working hours for every pair of employees. Within this category there are two general approaches to choose from. In Equation 6, the functions f_p are used to calculate deviations from a target value, while in Equation 7 the functions f_g[4] are used to calculate the difference in metrics between two different employees. Measurements of this category consider all employees and their respective deviations within the objective function. The prevailing approach in this category seeks to minimize the sum of all absolute deviations (Fügener et al., 2015; Lan et al., 2019; Olya et al., 2022). There are also papers that consider only negative or only positive deviations (Fügener et al.,

[4] Examples of spread functions based on the metrics of two employees i and k, as found in the literature, include the following: $f_g(M_{ij} \circ M_{kj}) := \{\max\{M_{ij} - M_{kj}, 0\}; |M_{ij} - M_{kj}|\}$.

2015; Gross et al., 2018). Nevertheless, a notable challenge emerges with this method, as it fails to distinguish between equitably distributing deviations among all employees and permitting uneven distribution. This discrepancy often contradicts the fairness principles outlined within the same research papers employing this objective function. In response to this challenge, some authors propose objective functions that accord greater weights to larger deviations, frequently accomplished by squaring the deviation (Devesse et al., 2023; Rea et al., 2021) or applying a linearized exponential function (Devesse et al., 2023). These modifications can help enforce a fairer solution. However, such adjustments tend to amplify the model's complexity.

$$\sum_i f_p(M_{ij}) = Z_j \qquad \forall j \tag{6}$$

$$\sum_i \sum_k f_g(M_{ij} \circ M_{kj}) = Z_j \qquad \forall j \tag{7}$$

In the "all/Position" category, the primary goal is to optimize fairness by considering the assignments of all employees. To address fairness considerations, weights can be applied to either the employees or their assignments – e.g., squaring the working hours of all employees. Generally, the planner must assign a weight ($wght_i$) to each employee i and decide on a power (n) to apply to the value of the metric. A depiction of the measurements used in this category can be found in Equation 8. The most commonly adopted approach in this category quantifies fairness by summing the product of the working hours assigned to each employee and the respective weight assigned to them (Gross et al., 2019; Pahlevanzadeh et al., 2021; Wolbeck et al., 2020). These weightings must be carefully selected to achieve a balanced and fair work plan. It's important to emphasize that the resulting distribution may not consistently align with fairness principles proclaimed within the respective article within one planning period. Therefore this approach is arguably most suitable when fairness is achieved over multiple planning periods where weights can be adjusted. To achieve fairness within a single planning period, some papers opt for a power $n = 2$ to weigh longer working hours more heavily (Martin et al., 2013), or they use a linearized exponential function (Guo and Bard, 2022; Punnakitikashem et al., 2013).

$$\sum_i wght_i \cdot (M_{ij})^n = Z_j \qquad \forall j \tag{8}$$

In general, the objective functions used to consider fairness in mathematical models, the use of hard constraints, or even structural approaches may only serve as approximations of the more fundamental goal of achieving fairness. For example, in the work of Elomri et al. (2015), fairness is ensured by minimizing the deviation from the target duties worked for each employee. However, in scenarios that do not allow for a fair distribution of work duties, the objective function does not differentiate between the deviation borne by one employee or shared among all. Consequently, the objective value may not be an adequate indicator of the solution's fairness. Some papers introduce a fairness indicator independent of the objective function to address this limitation. For instance, Sun et al. (2023) utilize standard deviation to assess various objective functions. Their findings indicate that the various measurements can lead to significantly disparate outcomes related to standard deviation. Martin et al. (2013) provide an in-depth analysis of different measurements by employing Jain's Fairness Index. They find that various approaches result in solutions of differing quality in terms of fairness. Yasmine et al. (2024) similarly demonstrate that different measurements in the objective function produce varying results. They utilize both the standard deviation and the range from least to most working time to assess the fairness of the results. Cappanera et al. (2022) introduce six different indicators to assess fairness, although not all of them are included within their model. They evaluate results by studying deviations from these key performance measurements, distinct from their model approach. Gross et al. (2019) also introduce an independent fairness measurement. While fairness is ensured by a weighted sum within the mathematical decision model, they evaluate results by examining the variance of the granted preferences. The rationale for utilizing such independent fairness measurements is multifaceted. Firstly, the measurements used in the objective function often serve as approximations and may not fully capture the fairness concept introduced within the problem setting. Employing tailor-made measurements for assessing fairness enhances the robustness of result interpretation. Secondly, using a consistent measurement across different papers facilitates more effective comparisons, enhancing the evaluation of the quality of various approaches. Additionally, calculating such measurements using the results of the planning process does not introduce additional complexity, requiring no extra effort to enhance solution algorithms or simplify model complexity. In essence, employing an independent fairness measurement provides an opportunity to assess the strengths and weaknesses of different approaches more precisely at negligible cost. Most literature does not introduce an independent fairness measure, making this a relatively unexplored research field with considerable potential. An easily applicable example used in (Martin et al., 2013) and widely recognized in the literature (Jain et al., 1984; Hoßfeld et al., 2017) is the Jain Index. Another example of a measure used in the literature is the variance or standard deviation Bin Obaid (2024); Koruca et al. (2023); Smet (2023). However, there are many other measurements that can be used to measure fairness. For further exploration, we refer interested readers to (Cowell, 2000; De Maio, 2007).

4. Future Research Directions

In this section, we highlight the key findings of our review and identify opportunities for further research. To contextualize our findings appropriately, it is essential to acknowledge the limitations of our approach. By limiting our review to English-language publications, we may have overlooked valuable insights from non-English sources. Similarly, focusing on publications from 2013 to 2024 may result in the exclusion of relevant studies conducted at an earlier date. Nevertheless, the risk of missing crucial research findings is mitigated by the fact that contemporary research frequently builds upon previous work, thereby indirectly incorporating it into our overview. Furthermore, the introduced time frame allows us to present a more coherent snapshot of recent developments in the literature. By limiting ourselves to peer-reviewed journals, we might miss insights gained from conference papers and PhD theses. However, considering that the scientific standards and accessibility of these publications vary significantly, and that these findings often make their way into journals, we believe our work provides a comprehensive literature overview. The focus of this study is on hospital environments, and as a result, the review addresses only a subset of potential approaches to integrate fairness in personnel planning and scheduling. While the identified trends and methods are highly relevant to hospital settings, they may not fully represent related issues in other sectors. However, this focused approach enables us to provide a detailed and concise overview of the literature that is particularly valuable for researchers in hospital settings. In our approach to identifying literature that integrates fairness into personnel scheduling and planning, we defer to the authors of the respective studies to define what fairness entails in their problem setting. Accordingly, we refrain from imposing our own definition of fairness. This method necessitates that authors address the issue of fairness in their work. However, the lack of standardized terminology necessitates some degree of interpretation. Consequently, we may exclude papers where authors aim to ensure fairness but do not discuss it in detail or use terminology that we may not interpret correctly. Despite this, we are confident that our overview remains robust due to the large number of papers identified. Furthermore, this approach also allows us to cover a variety of papers and perspectives, enhancing our understanding of the current literature. While our review offers valuable insights into current practices and emerging research questions, we acknowledge the limitations of our methodological choices. These limitations should be considered when interpreting our findings' implications for both further research and practical applications in healthcare settings. In the following, we will highlight the most promising fields for further research:

- **Continuous Fairness:** Few papers consider continuous approaches to ensure fairness. In those instances where fairness is addressed, it is typically achieved by sequentially solving decision models and adjusting weights over time. Only three papers discuss integrating multi-period fairness structurally, highlighting a gap in the literature. More research is needed on achieving long-term fairness through constraints, structural approaches or different measurements in the objective function. Additionally, the temporal aspect of fairness is rarely addressed, and the difference between ensuring continuous and within-period fairness, as well as employees' perceptions of these concepts, is superficially discussed. Addressing these topics could enhance workforce planning efficiency and employee satisfaction.

- **Application of Different Metrics:** The literature discusses different dimensions of metrics, each capturing different aspects of fairness. The choice of dimensions often depends on the specific problem context, but the rationale for selecting appropriate dimensions is seldom discussed, and employee perceptions are rarely examined. For example, financial aspects are considered in only two papers, leaving the appropriateness of this focus undetermined. Thoroughly investigating different dimensions and their impact on employees might help to establish a suitable framework for further research.

- **Measuring Fairness:** The literature offers different ways to measure fairness, particularly regarding the design of objective functions. Few papers explain why specific measurements were chosen and their associated advantages and disadvantages. Most papers limit their evaluation to metrics used in the objective function, without employing metrics specifically developed for measuring fairness in results evaluation. A standardized approach to evaluating fairness would enhance comparability among articles and enable more informed result interpretations. This opens a promising field for analyzing various approaches' strengths and weaknesses using external fairness measures and examining employee perceptions of different measurements.

- **Inclusion of Employees in the Planning Process:** Understanding how different measures align with employees' perceptions of fairness is crucial. Regardless of the technical outcomes, if employees do not feel being treated fairly, the goal of fairness in planning is not achieved. Therefore, actively involving employees in the planning process is essential. However, this involvement introduces the risk of collusion among employees. Researching strategies to prevent collusion and identifying which fairness measures are robust against such behavior is vital for improving the scheduling process and ensuring the effective integration of employees' input.

- **Integration into the broader literature:** A substantial body of literature addresses the concept of fairness in the allocation of indivisible resources, which encompasses all the problems discussed in this review. Within this framework, two primary strands of fairness are prominently examined: proportionality and envy-freeness[5]. However, neither of these principles can be guaranteed in the context of indivisible goods. As a result, numerous relaxed concepts have emerged for assessing fairness in the division of such resources. Exploring how the approaches utilized in the healthcare sector correspond with the established concepts in the broader literature presents an intriguing direction for further research. In particular, the concept of envy is noteworthy for two reasons. First, it is not addressed at all within the healthcare literature. Second, in healthcare settings where employees can frequently compare their schedules, envy may significantly influence their perceptions of the planning and scheduling processes.

[5]Proportionality describes the principle that each employee receives at least the proportion of utility they would be guaranteed if they were solely responsible for dividing the resources, yet had to choose the package that provides the least utility. The concept of envy-freeness suggests that no employee would prefer to trade their assigned resources—or, in our case, their schedule—with another person. For readers interested in further discussions on fairness in the assignment of indivisible goods, we refer to Amanatidis et al. (2023).

5. Conclusion

This literature review demonstrates that integrating fairness into personnel planning and scheduling is an issue of global relevance that is gaining increasing importance. Addressing this multifaceted problem requires comprehensive consideration of various aspects. We introduced different classifications to address the essential questions—what constitutes fairness, what to measure, and how to measure fairness—that researchers should ponder when incorporating fairness into their methodologies. The answers to these questions can vary significantly depending on the specific problem setting. Our classifications are intended to help researchers to contextualize their ideas and problem settings.
We have also identified several avenues for further research. Notably, these include considering the temporal aspect of fairness, evaluating different dimensions of fairness, applying a standardized approach for evaluating fairness, incorporating new concepts on how to measure fairness, analyzing fairness within multi-objective models, and involving employees more in the planning and scheduling process.
In conclusion, integrating fairness and developing efficient workforce planning and scheduling strategies are critical steps in addressing the challenges faced by the healthcare sector. We believe this review is particularly useful as it provides a comprehensive framework for understanding the current state of research on fairness in hospital personnel planning and scheduling. By highlighting key trends, methods, and gaps in the literature, our review serves as a valuable resource for researchers and practitioners aiming to improve working conditions, enhance employee satisfaction, and ultimately deliver better healthcare outcomes. Continued research in this field is essential to ensure sustained progress and innovation in addressing these vital issues.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Use of generative AI

During the preparation of this work the authors used ChatGPT and Le Chat in order to improve readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Appendix A. Meta-Analysis

In order to provide a more comprehensive understanding of the literature under review, a meta-analysis was conducted. The papers were initially clustered according to their publication date, as illustrated in Figure A.9. The continuous number of publications supports our thesis on the importance of this topic. Moreover, at least one publication was identified from authors on each continent, which underscores the global relevance of this issue. Due to the selection of search terms, the identified literature predominantly addresses physicians, residents, and nurses. (see Figure A.11 for an overview). With regard to the time horizon addressed, most papers focus on operational or tactical issues, with only a few considering strategic problem settings. Additionally, there is considerable variation in the approach to problem settings. Some papers, like Akbarzadeh and Maenhout (2021a), emphasize solution approaches, while others, such as Thielen (2018), focus more on in-depth problem modeling. This diversity is reflected in the range of journals publishing relevant research, including the *European Journal of Operational Research*, the *Journal of Scheduling*, and *Health Care Management Science*. Notably, *Operations Research for Health Care* has the highest number of included papers, with nine featured in this review. This extensive diversity of journals provides opportunities for a wide range of researchers. For a detailed overview of the papers and their characteristics, see Table A.2. In conclusion, the subject of fairness in personnel planning and scheduling is becoming increasingly prominent on the global academic stage. Researchers are primarily concerned with integrating fairness into the scheduling and planning of nurses, residents, and physicians. Their findings are disseminated across a diverse range of academic journals and predominantly address tactical or operational planning issues.

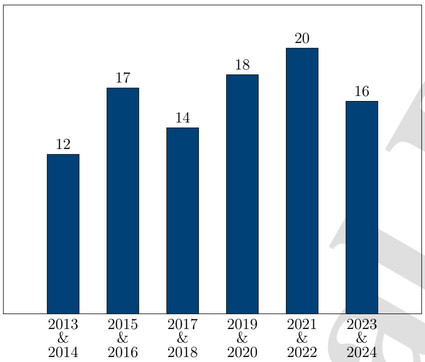

Figure A.9: Number of papers by year

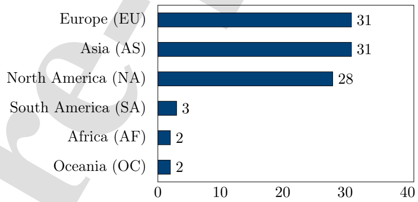

Figure A.10: Number of papers published by continent

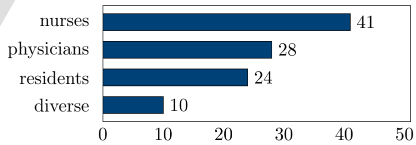

Figure A.11: Number of papers considering different professions

Reference	Publication Year	Continent	Journal
Acar and Butt (2016)	2016	NA	Journal of Biomedical Informatics
Achmad et al. (2021)	2021	AS	International Journal for Simulation and Multidisciplinary D
Adams et al. (2017)	2017	OC	BMJ Innovations
Adams et al. (2019)	2019	OC	Operations Research for Health Care
Agyei et al. (2015)	2015	AF	International Journal of Scientific & Technology Research
Akbarzadeh and Maenhout (2021b)	2021	EU	Computers & Operations Research
Akbarzadeh and Maenhout (2021a)	2021	EU	European Journal of Operational Research
Akbarzadeh et al. (2022)	2022	EU	INFORMS Journal of Applied Analytics
Bard et al. (2014)	2014	NA	Operations Research for Health Care
Bard et al. (2017)	2017	NA	IISE Transaction on Healthcare Systems Engineering
Baum et al. (2014)	2014	NA	Academic Radiology
Beck Dallaghan et al. (2022)	2022	NA	Medical Education Online
Becker et al. (2019)	2019	EU	Health Care Management Science
Bhutiani et al. (2018)	2018	NA	Anesthesia and Analgesia
Bin Obaid (2024)	2024	AS	Journal of Engineering Research
Böðvarsdóttir et al. (2022)	2022	EU	Journal of Scheduling
Bowers et al. (2016)	2016	NA	Interfaces
Bruni and Detti (2014)	2014	EU	Operations Research for Health Care
Camiat et al. (2021)	2021	NA	Health Systems
Cappanera et al. (2022)	2022	EU	Flexible Services and Manufacturing Journal
Lin et al. (2014)	2014	AS	Mathematical Problems in Engineering
Chawasemerwa et al. (2018)	2018	AF	International Journal of Research in Industrial Engineering
Chen et al. (2022)	2022	AS	Technology and Health Care
Chiang et al. (2019)	2019	AS	International Journal of Engineering Business Management
Chow et al. (2015)	2015	NA	Journal of Graduate Medical Education
Cildoz et al. (2021)	2021	EU	Applied Soft Computing
Damcı-Kurt et al. (2019)	2019	NA	Omega
Leksakul and Phetsawat (2014)	2014	AS	Mathematical Problems in Engineering
Devesse et al. (2023)	2023	SA	Journal of the Operational Research Society
Dumrongsiri and Chongphaisal (2018)	2018	AS	Songklanakarin Journal of Science & Technology
Elomri et al. (2015)	2015	AS	International Journal of Supply Chain Management
Fügener et al. (2015)	2015	EU	International Journal of Production Research
Gross et al. (2018)	2018	EU	Flexible Services and Manufacturing Journal
Gross et al. (2019)	2019	EU	Health Care Management Science
Guo and Bard (2022)	2022	AS	Computers & Operations Research
Heidari et al. (2021)	2021	AS	Scientia Iranica
Hong et al. (2019a)	2019	NA	Operations Research for Health Care
Hong et al. (2019b)	2019	NA	Journal on Applied Analytics
Howard et al. (2020)	2020	NA	PLOS ONE
Huang et al. (2014)	2014	AS	Neural Computing and Applications
Huang et al. (2016b)	2016	AS	Journal of Industrial and Production Engineering
Huang et al. (2016a)	2016	AS	Journal of Industrial and Production Engineering
Huang et al. (2021)	2021	AS	Complexity
Jiang et al. (2023)	2023	NA	Decision Support Systems
Klyve et al. (2021)	2021	EU	Operations Research for Health Care
Koruca et al. (2023)	2023	AS	Annals of Operations Research

With: Africa (**AF**), Asia (**AS**), Europe (**EU**), North America (**NA**), Oceania (**OC**), South and Central America (**SA**), diverse (**d**), nurses (**n**), physic

Reference	Publication Year	Continent	Journal
Kraul (2020)	2020	EU	Flexible Services and Manufacturing Journal
Kraul et al. (2024)	2024	EU	Omega
Lan et al. (2019)	2019	AS	Applied Soft Computing
Lin et al. (2015a)	2015	AS	International Journal of Distributed Sensors
Lin et al. (2015b)	2015	AS	Journal of Industrial and Production Engineering
London et al. (2023)	2023	NA	Journal of the American College of Emergency Physicians Op
Maenhout and Vanhoucke (2013)	2013	EU	Omega
Mahdizadeh Sarami et al. (2024)	2024	AS	Advances in Industrial Engineegin
Malekian et al. (2023)	2023	AS	Journal of Industrial and Systems Engineering
Mansini and Zanotti (2020)	2020	EU	Journal of Scheduling
Ito et al. (2018)	2018	AS	Journal of Japan Industrial Management
Martin et al. (2013)	2013	EU	Expert Systems With Applications
Michael et al. (2015)	2015	NA	Annals of Operations Research
Mohammadian et al. (2019)	2019	AS	International Journal of Engineering
Mohd Nasir et al. (2021)	2021	AS	Journal of Computing Research and Innovation
Rerkjirattikal et al. (2020)	2020	AS	Mathematical Problems in Engineering
Mystakidis et al. (2024)	2024	EU	Healthcare (Switzerland)
Özcan et al. (2019)	2019	AS	Sigma Journal of Engineering and Natural Sciences
Olya et al. (2022)	2022	NA	Expert Systems With Applications
Otero-Caicedo et al. (2023)	2023	SA	Operations Research for Health Care
Pahlevanzadeh et al. (2021)	2021	AS	RAIRO - Operations Research
Proano and Agarwal (2018)	2018	NA	Health Care Management Science
Punnakitikashem et al. (2013)	2013	NA	IIE Transactions
Razamin et al. (2020)	2020	AS	International Journal for Simulation and Multidisciplinary D
Rea et al. (2021)	2021	NA	Production and Operations Management
Saad et al. (2023)	2023	EU	Sustainable Computing: Informatics and Systems
Schaus and Régin (2014)	2014	EU	European Journal on Computational Optimization
Schoenfelder and Pfefferlen (2018)	2018	EU	Service Science
Seizinger and Brunner (2023)	2023	EU	European Journal of Operational Research
Senbel (2021)	2020	NA	Asia-Pacific Journal of Operational Research
Sir et al. (2015)	2015	NA	Journal of Biomedical Informatics
Smalley and Keskinocak (2016)	2016	NA	Health Care Management Science
Smet (2023)	2023	EU	Operations Research for Health Care
Sulak and Bayhan (2016)	2016	AS	Journal of Research in Business, Economics and Managemen
Sun et al. (2023)	2023	NA	Production and Operations Management
Thielen (2018)	2018	EU	Operations Research for Health Care
Thongsanit et al. (2016)	2016	AS	Science, Engineering and Health Studies
Tohidi et al. (2019)	2019	NA	Journal of Operational Research Society
Turner et al. (2013)	2013	NA	Interfaces
van der Veen et al. (2016)	2016	EU	Annals of Operations Research
Vermuyten et al. (2018)	2018	EU	Expert Systems With Applications
van de Vrugt et al. (2018)	2018	EU	Operations Research for Health Care
Wang et al. (2014)	2014	AS	Journal of Industrial and Production Engineering
Wickert et al. (2021)	2021	SA	Annals of Operations Research
Wolbeck et al. (2020)	2020	EU	European Journal of Operational Research
Wu et al. (2015)	2015	AS	Computers & Operations Research
Yasmine et al. (2024)	2024	EU	Socio-Economic Planning Sciences

With: Africa (**AF**), Asia (**AS**), Europe (**EU**), North America (**NA**), Oceania (**OC**), South and Central America (**SA**), diverse (**d**), nurses (**n**), physic

Reference	Publication Year	Continent	Journal
Zaerpour et al. (2022)	2022	NA	Production and Operations Management
Zanazzo et al. (2024)	2024	EU	Journal of Scheduling
Zanda et al. (2018)	2018	EU	Computers & Industrial Engineering
Zhong et al. (2017)	2017	NA	IISE Transaction on Healthcare Systems Engineering

With: Africa (**AF**), Asia (**AS**), Europe (**EU**), North America (**NA**), Oceania (**OC**), South and Central America (**SA**), diverse (**d**), nurses (**n**), physic

Table A.2: Meta information of the different papers

Appendix B. Paper classification at a glance

Reference	Concept			Input		Dimension				Time		Where			Measurement				
	EquaF	HarF	EquiF	ind	anon	qual	time	per	fin	within-period	continuous	objective	structure	constraints	one/Po	two/Sp	all/Sp	one/Sp	all/Po
Acar and Butt (2016)	•			•	•	•				•		•			•				
Achmad et al. (2021)	•				•		•			•			•						
Adams et al. (2017)		•			•	•				•		•				•			
Adams et al. (2019)		•			•	•				•		•				•			
Agyei et al. (2015)	•				•	•	•			•		•					•		
Akbarzadeh and Maenhout (2021b)			•	•				•		•		•			•				
Akbarzadeh and Maenhout (2021a)			•	•				•		•		•			•				
Akbarzadeh et al. (2022)			•	•				•		•		•			•				
Bard et al. (2014)	•				•	•				•				•					
Bard et al. (2017)		•			•		•			•		•						•	
Baum et al. (2014)			•	•	•			•	•	•		•		•	•				
Beck Dallaghan et al. (2022)	•				•	•				•		•			•				
Becker et al. (2019)	•				•	•	•			•		•	•	•	•				
Bhutiani et al. (2018)	•				•		•				•		•						
Bin Obaid (2024)	•				•		•			•		•	•		•				
Böðvarsdóttir et al. (2022)			•		•	•	•			•		•				•			
Bowers et al. (2016)	•		•	•	•		•	•		•		•		•				•	
Bruni and Detti (2014)		•		•	•		•	•		•		•			•				
Camiat et al. (2021)	•				•		•			•		•	•				•		
Cappanera et al. (2022)	•				•	•	•			•		•			•	•			
Lin et al. (2014)			•	•				•			•	•							•
Chawasemerwa et al. (2018)	•				•		•			•			•						
Chen et al. (2022)	•				•	•				•			•						
Chiang et al. (2019)			•	•	•		•	•		•		•		•					•
Chow et al. (2015)			•	•				•		•			•						
Cildoz et al. (2021)		•			•		•			•		•				•			
Damcı-Kurt et al. (2019)		•			•		•			•		•					•		
Leksakul and Phetsawat (2014)	•				•				•	•		•					•		
Devesse et al. (2023)			•		•	•	•			•		•		•			•		
Dumrongsiri and Chongphaisal (2018)		•			•	•				•		•			•				
Elomri et al. (2015)	•				•	•	•			•		•					•		
Fügener et al. (2015)		•			•	•	•			•		•		•			•		
Gross et al. (2018)	•				•		•			•		•					•		
Gross et al. (2019)	•			•				•			•	•							•
Guo and Bard (2022)	•				•	•	•			•		•	•			•			•

Reference	Concept			Input		Dimension				Time		Where			Measurement				
	EquaF	HarF	EquiF	ind	anon	qual	time	per	fin	within-period	continuous	objective	structure	constraints	one/Po	two/Sp	all/Sp	one/Sp	all/Po
Heidari et al. (2021)			•		•		•			•		•							•
Hong et al. (2019a)	•				•		•			•			•	•					
Hong et al. (2019b)		•			•		•			•				•					
Howard et al. (2020)			•	•				•		•			•						
Huang et al. (2014)	•				•		•			•		•					•		
Huang et al. (2016b)			•	•				•			•	•							•
Huang et al. (2016a)			•	•				•			•	•							•
Huang et al. (2021)		•			•	•				•		•					•		
Jiang et al. (2023)	•				•	•				•		•	•				•		
Klyve et al. (2021)		•			•		•			•		•		•		•		•	
Koruca et al. (2023)			•	•			•	•		•		•		•	•				
Kraul (2020)	•				•	•				•		•						•	
Kraul et al. (2024)	•				•	•				•				•					
Lan et al. (2019)	•				•		•			•		•					•		
Lin et al. (2015a)			•	•				•			•	•							•
Lin et al. (2015b)			•	•				•			•	•							•
London et al. (2023)			•	•				•			•		•						
Maenhout and Vanhoucke (2013)	•				•	•	•			•		•					•	•	
Mahdizadeh Sarami et al. (2024)	•				•		•			•		•					•		
Malekian et al. (2023)		•		•				•		•	•	•							•
Mansini and Zanotti (2020)			•		•		•			•				•					
Ito et al. (2018)	•				•		•			•		•					•		
Martin et al. (2013)	•				•		•			•		•			•	•	•		•
Michael et al. (2015)			•	•				•		•			•						
Mohammadian et al. (2019)	•				•		•			•		•					•		
Mohd Nasir et al. (2021)	•				•		•			•		•					•		
Rerkjirattikal et al. (2020)			•	•	•		•	•		•		•					•		
Mystakidis et al. (2024)			•		•		•				•	•							•
Özcan et al. (2019)	•				•		•			•		•					•		
Olya et al. (2022)		•			•	•				•		•					•		
Otero-Caicedo et al. (2023)		•		•	•		•	•		•		•		•	•				
Pahlevanzadeh et al. (2021)			•	•				•			•	•							•
Proano and Agarwal (2018)			•	•	•	•	•	•		•			•						
Punnakitikashem et al. (2013)			•		•	•				•		•							•
Razamin et al. (2020)	•				•		•			•			•						
Rea et al. (2021)			•		•		•			•		•		•			•		
Saad et al. (2023)	•				•	•				•			•						

Reference	Concept			Input		Dimension				Time		Where			Measurement				
	EquaF	HarF	EquiF	ind	anon	qual	time	per	fin	within-period	continuous	objective	structure	constraints	one/Po	two/Sp	all/Sp	one/Sp	all/Po
Schaus and Régin (2014)	•				•	•				•		•					•		
Schoenfelder and Pfefferlen (2018)	•				•		•			•		•				•			
Seizinger and Brunner (2023)		•			•	•				•			•						
Senbel (2021)			•	•	•		•	•		•	•	•		•	•				
Sir et al. (2015)	•		•	•	•	•				•		•		•		•			
Smalley and Keskinocak (2016)		•			•		•			•		•		•	•	•			
Smet (2023)	•				•	•				•		•			•				
Sulak and Bayhan (2016)	•				•		•			•		•					•		
Sun et al. (2023)			•		•	•				•		•	•	•	•		•		
Thielen (2018)		•	•	•	•		•			•		•	•	•			•		
Thongsanit et al. (2016)		•			•		•			•		•			•				
Tohidi et al. (2019)		•		•	•		•	•		•		•			•	•			
Turner et al. (2013)	•				•	•					•		•						
van der Veen et al. (2016)	•				•	•				•			•						
Vermuyten et al. (2018)			•		•		•			•		•		•			•		
van de Vrugt et al. (2018)			•		•		•			•		•					•		
Wang et al. (2014)		•			•	•	•			•		•					•		
Wickert et al. (2021)			•	•	•	•	•	•		•		•		•			•		
Wolbeck et al. (2020)	•				•	•					•	•							•
Wu et al. (2015)	•				•		•			•		•					•		
Yasmine et al. (2024)			•		•	•	•			•	•	•			•	•	•		
Zaerpour et al. (2022)	•				•		•			•				•					
Zanazzo et al. (2024)	•			•	•	•		•		•		•			•				
Zanda et al. (2018)					•		•			•		•		•			•		
Zhong et al. (2017)	•				•		•			•		•					•		

Table B.3: Classification of the papers

Appendix C. Notation

Sets	
i, k	Set of employees
j	Aspect measured using metric j
Parameters	
$minV_{ij}$	Minimum value of metric j for employee i
$maxV_{ij}$	Maximum value of metric j for employee i
thr_{ikj}	Maximum allowed difference for metric j between employees i and k
$wght_i$	Weight assigned to the metrics of employee i
tgt_{ij}	Target value for metric j for employee i
Decision variables	
M_{ij}	Metric measuring aspect j for employee i
Z_j	Objective contribution to measuring fairness in aspect j

Table C.4: Notation used in the formulation.

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