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Workforce scheduling approaches for supporting human-centered algorithmic management in manufacturing: A systematic literature review and a conceptual optimization model

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Abstract

Workforce scheduling is becoming increasingly complex and time-consuming as the number of influencing factors increases. Intelligent, algorithmic optimization approaches can support managers in mastering this complex task. Since workforce scheduling influences key elements of work design, it has the potential to promote human-centered work design and thus, e.g., reduce stress and increase job satisfaction. This paper presents a literature review of various factors considered by existing algorithmic scheduling approaches in manufacturing environments. The identified factors are classified based on the dimensions of human-centered work design. The results show that the identified approaches integrate various aspects that can support human-centered workforce scheduling. However, usually only specific aspects are considered (e.g. learning effects) and certain dimensions are not considered at all (e.g. feedback). In order to exploit the potentials of algorithmic management for the design of humane work, an exemplary optimization model is presented and discussed.

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1. Introduction

As a result of the demographic development, companies face an increasing shortage of skilled personnel [1] and an aging workforce [2]. At the same time, a growing number of product variants and shorter product life cycles lead to increasing complexity of work tasks in manufacturing companies [3]. These developments result in new challenges for workforce scheduling [3] as an important management task [4]. Typically, each worker is assigned to a workstation or task for a certain period of time [5]. Workforce scheduling entails making decisions regarding the specific number of employees with certain skills, their designated tasks, as well as the time and location at which they are assigned [6].

Workforce scheduling has been addressed in research, e.g. by operations researchers and computer scientists, over the past few decades [7,8]. As scheduling includes decisions about working time, place and content, key elements of work design are affected [9,10]. Workforce scheduling therefore has the potential to promote human-centered work design and support a transition to a human-centered, sustainable, and resilient production as it is envisioned in the various discussions surrounding the concept of Industry 5.0 [11,12]. A human-centered approach may aim to reduce stress and hazards, integrate complete work tasks, foster learning and development, or increase employee job satisfaction [13,14,15]. Recently, research increasingly focuses on considering the employees' individual needs in workforce scheduling [8]. Bentler et al. (2022) [9] suggest providing greater worker participation in scheduling by including individual preferences. An efficient workforce scheduling that takes individual requirements into account is seen as a potential key factor to face current challenges of the industrial environment to remain competitive [3].

The multitude of influencing factors increases the complexity of the scheduling problem [4]. Besides personnel factors, such as individual operational capabilities and preferences as well as personal disposition, also temporal factors, such as working time regulations and shift systems, technical factors, as well as social and economic factors (e.g. time and cost pressure) are relevant [4,6]. As a result of the growing complexity, the scheduling task, which is often still carried out manually by managers based on experience and knowledge [9,16], is becoming increasingly difficult and time-consuming [17]. In order to remain competitive, automated solutions are essential [18].

Workforce scheduling is a highly constrained and complex optimization problem [4,19]. The solution of such problems is addressed in operations research [20]. Intelligent, algorithmic optimization approaches offer great potential to support manufacturing managers in coping with the complex scheduling task (cf. [16]). Literature reviews on algorithmic approaches for workforce scheduling consider, e.g., application areas, solution methods, and objectives, but do not specifically focus on manufacturing and human-centered workforce scheduling (e.g. Özder et al. (2020) [17], Niknafs et al. (2013) [20], van den Bergh et al. (2013) [8], Ernst et al. (2004) [19]).

This paper addresses the research question to which extent existing algorithmic approaches for workforce scheduling in manufacturing address dimensions of human-centered work design. Therefore, a systematic literature review is conducted. First, the review procedure is outlined. Second, the results are presented and discussed. Finally, a mathematical optimization model is proposed to integrate various facets of worker preferences, such as preferences for the assignment to workstations, the number of station changes, and the deviation between worker skill level and required skill level, as well as further human-centered aspects.

2. Methodology

2.1. Search and Selection Procedure

The systematic literature review was conducted and documented based on the STARLITE approach [21] and the PRISMA statement [22]. The STARLITE elements were determined as follows: The *sampling strategy* was selective in order to identify relevant publications within specific limits. No restriction was set regarding the *type of studies*. The *approach* was an electronic subject search complemented by a manual reverse search. The *range of years* was from January 2000 to June 2022. English and German-language publications were included as functional *limit*. As contextual restriction, publications with (optimization) models for workforce scheduling were *included*. Papers relating to health care were specifically *excluded*, as these are often represented in scientific publications on workforce scheduling, but are outside the chosen scope of manufacturing [17]. The *term* used as search query was: (*workforce OR staff OR personnel*) AND (*scheduling OR assignment OR rostering*) AND (*production OR manufacturing*) AND (*requirements OR constraints OR criteria OR performance OR classification OR motivation*) NOT (*healthcare OR*

medicine OR nurse) [23]. The databases selected as *electronic sources* were Scopus (Elsevier B.V.), IEEE Xplore (IEEE), and Web of Science (Clarivate).

Initially, the search led to a total of 1341 publications. After removing duplicates (n = 391) and non-German and non-English publications (n = 15), 935 papers remained. 611 publications were excluded based on title and keywords due to missing relevance for the given research context. Next, the abstracts of the remaining 324 papers were reviewed and 244 publications were further excluded especially due to missing reference to workforce scheduling (n = 130) or manufacturing (n = 60). After excluding nine publications that could not be retrieved, 71 publications as well as four additional publications found through a manual reverse search were finally examined on a full-text basis.

2.2. Classification Framework

The literature review is intended to indicate the extent to which approaches for workforce scheduling in manufacturing take into account different dimensions of work design. Therefore, the results were classified based on the dimensions addressed. For this purpose, the shell model of human-centered work design in companies by Mütze-Niewöhner et al. (2022) [14] was used. The shell model (Figure 1) provides an overview of influencing factors and design dimensions that need to be taken into account in work design at the individual, company and supra-company level and is therefore considered a suitable classification framework in this paper. As indicated in Figure 1, the workers themselves and several essential elements of work design are affected by workforce scheduling.

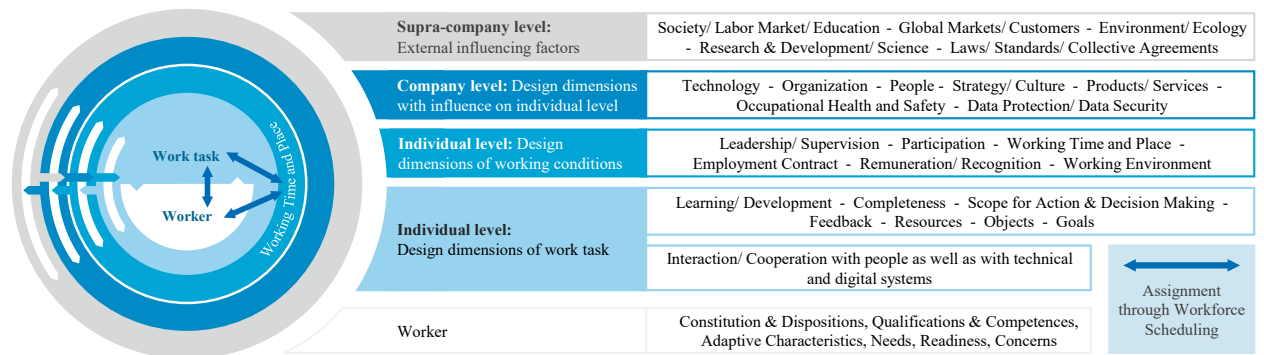


Fig. 1. Shell model of human-centered work design in companies adapted from Mütze-Niewöhner et al. (2022) [14].

3. Results

In this section, the results of the literature review are presented. The identified factors considered by existing workforce scheduling approaches were aggregated and related to the dimensions of human-centered work design. Factors considered include parameters used in the approaches as well as decision and auxiliary variables, and restrictions that are considered as constraints and/ or in objective functions. Publications in which the implementation of the respective aspect is described comprehensibly are listed in the following tables as exemplary references. A complete list of the publications examined can be obtained from the authors.

Table 1 shows which external influencing factors at the supra-company level are addressed by identified workforce scheduling approaches. Laws and collective agreements are considered in terms of working time regulations, such as a maximal daily work duration [24] or regulations for occupational health and safety [25]. Regarding customer-related aspects, Attia et al. (2014) [26] propose a model to minimize delay penalties for late product completion among others.

Table 1. Consideration of external influencing factors at the supra-company level.

Influencing factor	Consideration in workforce scheduling approaches	Reference (exemplary)
Laws/ standards/ collective agreements	Regulations for working time	[24]
	Regulations for occupational health and safety	[25]
Global markets/ customers	Delay penalties for late product completion	[26]

In Table 2, the consideration of design dimensions at the company-level with influence on the individual level is presented. With regard to costs, overtime costs are considered in addition to salary costs, training costs, and costs resulting from hiring and firing. For example, Rerkjirattikal and Olapiriyakul (2021) [25] consider regular and overtime shifts with resulting overtime wages. Othman et al. (2012) [27] integrate hiring and firing of workers in their scheduling approach. The objective is to minimize the costs resulting from hiring and firing as well as from training and overtime [27]. Work demand is addressed in terms of tasks (e.g. time demand required to complete each task [28]), related to workers (e.g. required number of workers per workstation [29]), or related to products (e.g. required production volume [30]). Regarding occupational health and safety, threshold values or limits are considered, such as a limit for the daily permissible noise exposure [31].

Table 2. Consideration of dimensions at the company level.

Design dimension	Consideration in workforce scheduling approaches	Reference (exemplary)
Organization/ people	Salary costs	[28]
	Overtime costs	[25]
	Training costs	[27,32]
	Hiring and firing costs	[27,32]
	Work demand related to tasks	[28]
	Work demand related to number of workers	[29]
Products/ services	Work demand related to products	[30]
Occupational health and safety	Limit for ergonomic stress	[5]
	Limit for noise exposure	[31]
	Limit for physical workload	[33]
	Threshold value for mental stress	[3]

Table 3 shows aspects related to the design dimensions of the working conditions at the individual level. Supervision is only considered by Asgari et al. (2017) [34] in the context of product quality by assigning inspectors in addition to workers. The working environment is considered in terms of workstation-related characteristics, such as an ergonomic stress value related to ergonomic exposures [5]. In addition to working time, break time, overtime and unavailability are considered. For example, Azmat and Widmer (2004) [35] integrate constraints to ensure a certain number of vacation weeks per year as well as a certain number of days off per week.

Table 3. Consideration of dimensions of working conditions.

Design dimension	Consideration in workforce scheduling approaches	Reference (exemplary)
Leadership/ supervision	Inspector required for workstations	[34]
Participation	Consideration of preferences	[36]
Employment contract	Hiring and firing of workers	[27,32]
Working environment	Workstation-related ergonomic values	[5,37]
	Workstation-related mental stress	[3]
	Workstation-related noise exposure levels	[25,31]
	Workstation-related learning and fatigue rates	[38]
	Workstation/ machine-related COVID-19 risk levels	[39]
Working time and place	Working time	[25]
	Break time	[24]
	Overtime	[25]
	Unavailability/ vacation/ day off	[35,40]

The consideration of design dimensions related to the work task at the individual level is presented in Table 4. Learning and forgetting effects are considered, e.g., by Attia et al. (2014) [26] in the form of efficiency variables for each worker and skill. The efficiency increases if the worker practices the skill without interruption and depends, e.g., on the worker's learning speed [26]. Attia et al. (2014) [26] integrate the overall change of the average skills into the

objective function. Fidanova et al. (2018) [40] consider a minimum time a worker must perform a task to be efficient. Regarding task completeness, Drezet and Billaut (2008) [24] consider a maximum number of task changes during a day in order to enhance productivity and provide good working conditions. According to Wang et al. (2020) [41], switching between tasks leads to efficiency gains as it is assumed that switching can prevent boredom. Regarding work resources and objects, e.g., a minimum number of workers required to perform a task [42], physical work effort [33], or risk impact and probability [28] are considered. To integrate fatigue and recovery, Othman et al. (2012) [32] assume linear fatigue accumulation and recovery curves. Additionally, workers have a maximum time they can perform a task without becoming fatigued as well as a task-specific maximum fatigue load [32]. A task-related risk level for each worker is considered by Krynke et al. (2021) [28] with the objective to minimize costs and risks.

Table 4. Consideration of dimensions of the work task.

Design dimension	Consideration in workforce scheduling approaches	Reference (exemplary)
Learning/ development	Task completion time/ efficiency change due to learning and forgetting	[26,38]
	Worker training for higher skill level	[27,32]
	Minimum time for performing a task efficiently	[40]
Completeness	Maximum number of task changes during a day for a worker	[24]
Scope for action and decision making	Switching between different tasks leading to an increase in efficiency	[41]
	Task-sequence-dependent processing time of workers	[43]
Resources/ objects	Task-related number of workers required (e.g. due to technical reasons)	[42]
	Task-related physical effort	[33]
	Task-related fatigue and recovery effects	[32]
	Task-related risk impact and risk probability	[28]
Goals	Task release time and due date	[24]
Interaction/ cooperation	Teamwork preferences	[44]

Table 5 shows the results related to worker characteristics. Worker competences are integrated related to tasks or stations (e.g. [45]) or shifts. For example, Akbari et al. (2013) [46] integrate a number of hours certain skills are needed for a shift. Ruiz-Torres et al. (2017) [36] consider qualifications in the form of certifications for workers and task types. Task types which should be assigned to a worker can be set in order to prevent the loss of certifications [36]. Akbari et al. (2013) [46] model fatigue effecting worker productivity. Productivity is related to worker and skill and decreases if a worker is assigned to sequential shifts a day [46]. Boenzi et al. (2015) [37] consider worker-specific task completion time as a function of a skill factor and an endurance function to account for effects such as age-dependent physical fatigue.

Table 5. Consideration of worker characteristics.

Worker characteristics	Consideration in workforce scheduling approaches	Reference (exemplary)
Constitution and dispositions	Physical status of a worker for each workstation	[33]
	Worker-related risk impact and risk probability	[28]
	COVID-19-related vulnerability level of a worker	[39]
Qualifications and competences	Worker competency/ skill (level) required for station/ task/ shift	[45,46]
	Worker qualification (level) required for station/ task/ shift	[36]
	Worker seniority	[46]
	Worker-related learning index	[38]
Adaptive characteristics	Worker-related fatigue (and recovery) parameters	[37,38,46]
	Worker capabilities influencing human error probability	[34]
Needs, readiness, concerns	Preferences for task/ station assignment	[36]
	Preferences for shift assignment	[46]
	Preference for start time of work	[39]
	Preferences for team assignment	[44]
Including several characteristics	Worker personality and skill levels related to capacity and willingness	[27]
	Worker productivity for each task	[47]

Preferences are considered for tasks or stations (e.g. [36]), shifts (e.g. [46]), working time (e.g. [39]), or team assignment (e.g. [44]). Typically, the objective is to maximize the overall preference consideration (e.g. [46]). Similarly, satisfaction parameters, for instance in relation to task allocation, are used (e.g. [42]). Additionally, the consideration of preference or satisfaction parameters can be kept to a minimum [48], or be evenly distributed [36].

Othman et al. (2012) [27] group workers according to personality levels and skill levels. For each group, parameters for the ability to conduct a task and for the willingness to work on a machine are introduced [27]. It is suggested that these should be measured in a real production environment [27]. In their numerical example, Othman et al. (2012) [32] assume a smaller recovery allowance for workers with a higher personality level.

4. Exemplary Mathematical Optimization Model

As part of the research and development project AKzentE4.0, a basic, exemplary mathematical optimization model was developed, which is intended to provide a starting point for further developments that exploit the potentials of algorithmic management for human-centered work design. The results of the literature review served as a basis for potential aspects to be integrated into the optimization model. The initial focus was on the integration of various preference-related aspects, as this is considered a promising approach for human-centered workforce scheduling [9].

First, worker preferences for the assignment to stations are integrated into the mathematical model based on Ruiz-Torres et al. (2015) [48]. Second, preferences for the number of station changes are included. Whilst a maximum number of changes per day to promote productivity and good working conditions had already been considered in existing approaches (e.g. [24]), corresponding preferences to address individual worker needs have not been considered so far. Third, preferences for the deviation between worker and required skill level are integrated as an attempt to address the reduction of under-demanding tasks. Last, the equal consideration of preferences among workers (based on [36]) as well as a minimum overall preferences consideration (based on [48]) are integrated. Besides preference-related aspects, basic aspects on the company level, i.e. salary costs and work demand related to workstations, and on the individual level, i.e. worker availability and a required skill level, are included. Also, the model integrates a minimum and a maximum time a worker should spend at a station if assigned to it (based on e.g. [40]). For the sake of simplicity, the model does not yet integrate the dimensions of shift work and teamwork. Therefore, related preferences identified in the literature review were not applied at this point. The model is based on the operations research problem of the travelling salesman [49]. The schedule of each worker is modeled as a tour between stations, including workstations and virtual stations for break and rest time. The following assumptions are made:

- Parameters such as the number of workstations, worker availability, work demand, worker costs, required skill level, or worker skill levels are given.
- Worker preference values are given. A smaller preference value indicates a higher preference. All preferences from all workers are indicated on the same scale.
- The weighting factors of the different preferences in the objective function are equal for all workers.
- The overall preferences consideration is based on the preferences that are satisfied by the schedule.
- The equal distribution of preferences consideration is based on minimizing the difference between the maximum and minimum overall worker preference consideration.
- The work demand can be fulfilled with the available worker capacities.

4.1. Indices, Sets and Parameters

P, R	Index for the virtual pause station, index for the virtual rest station
W	Set of all workers
S	Set of all workstations, $S = \{1, \dots, K\}$
S^P / S^{PR}	Set of all stations including P ($S^P = S \cup \{P\}$) / including P and R ($S^{PR} = S \cup \{P, R\}$)
$T \subset \mathbb{N}_0$	Set of all points in time of the planning period, $T = \{0, \dots, \tau\}$
$t_{ij}^{min} / t_{ij}^{max}$	Minimum/ maximum duration that worker i should spend at workstation j

$Z^{max} \in \mathbb{N}_0$	Maximum permitted working time of a worker in the planning period in time units
$s_i \in \mathbb{R}_0^+$	Available working time of worker i in time units for the planning period, $s_i \leq Z^{max}$
$C_i \in \mathbb{R}_0^+$	Salary costs for worker i per time unit
$d_j \in \mathbb{N}_0$	Work demand at workstation j in time units
$A_j \in \mathbb{N}_0$	Minimum required skill level at workstation j
$F_{ij} \in \mathbb{N}_0$	Skill level of worker i at workstation j
$e_{ij} \in \mathbb{N}_0$	Difference between the worker's skill level and the required skill level for worker i at workstation j , $e_{ij} = F_{ij} - A_j \forall i \in W, \forall j \in S$
$U^{max} \in \mathbb{N}_0$	Minimum overall preferences consideration (Index max due to minimization problem)
$P1_{ij} \in \mathbb{N}$	Preference of worker i to be assigned to station j
$P2_i \in \mathbb{N}$	Preference of worker i regarding the number of station changes
$P3_i \in \mathbb{N}$	Preference of worker i regarding the overall difference between the worker's skill level and the required skill level
$P1^g / P2^g / P3^g \in \mathbb{R}_0^+$	Weighting factor for preferences 1/ 2/ 3
$Pt^g \in \mathbb{R}_0^+$	Weighting factor for violation of working time limit related to workstation and worker
$F^g \in \mathbb{R}_0^+$	Weighting factor for equal distribution of preferences consideration among workers
$C^g \in \mathbb{R}_0^+$	Weighting factor for total salary costs for all workers
M	Big-M, choose large number $M \geq S^{PR} T $

4.2. Decision Variable and Auxiliary Variables

$x_{kjit} \in \{0,1\}$	Equals 1 if worker i transfers from station k to station j in t , else 0 (<i>decision variable</i>)	$\forall k, j \in S^{PR}, \forall i \in W, \forall t \in T \cup \{\tau + 1\}$
$y_{ji} \in \{0,1\}$	Equals 1 if worker i is assigned to workstation j during the planning period, else 0	$\forall i \in W, \forall j \in S$
$z_i \in \{0,1\}$	Equals 1 if worker i is assigned to any workstation during the planning period, else 0	$\forall i \in W$
$w_i \in \mathbb{N}_0$	Number of station changes of worker i	$\forall i \in W$
$p_{ij} \in \mathbb{R}^+$	Time limits violation of worker i at workstation j in time units	$\forall i \in W, \forall j \in S$
$p^{min} / p^{max} \in \mathbb{N}_0$	Minimum/ maximum overall preferences consideration of all workers who are assigned during the planning period	

4.3. Mathematical Optimization Model

$$\begin{aligned}
 \text{Min } & \sum_{k \in S^{PR}} \sum_{i \in W} \sum_{t \in T} (\sum_{j \in S^P} x_{kjit} (C_i C^g + P1_{ij} P1^g) + \sum_{j \in S} x_{kjit} e_{ij} P3_i P3^g) \\
 & + \sum_{i \in W} ((w_i P2_i P2^g) + \sum_{j \in S} p_{ij} Pt^g) + (p^{max} - p^{min}) F^g \\
 \text{s.t.: } & \sum_{k \in S^P} \sum_{t \in T} x_{kRit} \leq 1 \quad \forall i \in W \quad (2) \\
 & \sum_{k \in S^{PR}} x_{kRi \tau+1} = 1 \quad \forall i \in W \quad (3) \\
 & \sum_{k \in S^{PR}} x_{kjit} = \sum_{k \in S^{PR}} x_{jk i \tau+1} \quad \forall j \in S^{PR}, \forall i \in W, \forall t \in T \quad (4) \\
 & \sum_{k \in S^{PR}} \sum_{j \in S^{PR}} x_{kjit} = 1 \quad \forall i \in W, \forall t \in T \quad (5) \\
 & \sum_{k \in S^{PR}} \sum_{i \in W} x_{kjit} \leq 1 \quad \forall j \in S, \forall t \in T \quad (6) \\
 & \sum_{k \in S^{PR}} \sum_{j \in S^P} \sum_{t \in T} x_{kjit} \leq s_i \quad \forall i \in W \quad (7) \\
 & \sum_{k \in S^{PR}} \sum_{i \in W} \sum_{t \in T} x_{kjit} \geq d_j \quad \forall j \in S \quad (8) \\
 & \sum_{k \in S^{PR}} \sum_{t \in T} x_{kjit} + (1 - y_{ji}) M \geq t_{ij}^{min} - p_{ij} \quad \forall j \in S, \forall i \in W \quad (9) \\
 & \sum_{k \in S^{PR}} \sum_{t \in T} x_{kjit} \leq t_{ij}^{max} + p_{ij} \quad \forall j \in S, \forall i \in W \quad (10) \\
 & \sum_{k \in S^P} \sum_{j \in S^P, j \neq k} \sum_{t \in T} x_{kjit} = w_i \quad \forall i \in W \quad (11) \\
 & \sum_{k \in S^{PR}} x_{kjit} A_j \leq F_{ij} \quad \forall i \in W, \forall j \in S, \forall t \in T \quad (12) \\
 & \sum_{k \in S^{PR}} \sum_{t \in T} x_{kjit} \leq y_{ji} M \quad \forall j \in S, \forall i \in W \quad (13)
 \end{aligned}$$

$$\sum_{j \in S} y_{ji} \leq z_i M \quad \forall i \in W \quad (14)$$

$$\sum_{k \in S^{PR}} \sum_{t \in T} (\sum_{j \in S^P} x_{kjit} P1_{ij} + \sum_{j \in S} x_{kjit} e_{ij} P3_i) + w_i P2_i \leq P^{max} \quad \forall i \in W \quad (15)$$

$$\sum_{k \in S^{PR}} \sum_{t \in T} (\sum_{j \in S^P} x_{kjit} P1_{ij} + \sum_{j \in S} x_{kjit} e_{ij} P3_i) + w_i P2_i + (1 - z_i) M \geq P^{min} \quad \forall i \in W \quad (16)$$

$$P^{max} \leq U^{max} \quad (17)$$

The objective function (1) aims to minimize the considered preference values in order to maximize the consideration of preferences. It also minimizes the total salary costs, the violation of the time boundaries for the duration a worker should spend at a workstation, and the gap between maximum and minimum overall worker preference consideration. Constraints (2) and (3) ensure that each worker can transfer to the rest station only once and transfers to the rest station at the end of the planning period. Constraint (4) ensures that each worker can only transfer from one station to another if the worker was assigned to that station at the previous point in time. Constraint (5) guarantees that each worker is assigned to exactly one workstation or virtual station at any time. Constraint (6) provides that each workstation is occupied by at most one worker at any time. Constraint (7) ensures that the available working time of each worker for the planning period is not exceeded. Constraint (8) ensures that the working demand of each workstation is fulfilled. Constraints (9) and (10) provide a link between the working time boundaries and the working time violation for each worker and workstation. Constraint (11) calculates the number of station changes for each worker. Constraint (12) denotes that the assigned worker meets the minimum skill requirements at a workstation. Constraints (13) and (14) provide a link between the decision variable and the auxiliary variables y_{ji} and z_i . In constraints (15) and (16), the boundaries of the overall preferences considerations are calculated. Constraint (17) ensures that the minimum overall preferences consideration is met.

5. Discussion

Overall, the results of the literature review indicate that various dimensions of work design are already addressed by existing workforce scheduling approaches. In addition to economic parameters such as costs or work demand, the identified approaches consider various human aspects on the individual level (design dimensions of working conditions, work task, and worker characteristics) with regard to the shell model of human-centered work design by Mütze-Niewöhner et al. (2022) [14]. Less consideration in the approaches is given to aspects at the supra-company level (i.e. society/ labor market/ education, environment/ ecology, and research and development/ science) and company level (i.e. technology, strategy/ culture, and data protection/ data security).

One of the central goals of human-centered work design is to consider human needs and capabilities in order to promote employees' mental health, physical health, and satisfaction (cf. [13,14]). Taking the *Work Design Questionnaire* according to Morgeson and Humphrey (2006) [15] as established work design measure as reference, work task characteristics, such as autonomy, task variety, and task completeness, knowledge characteristics (e.g. skill variety and job complexity), social characteristics (e.g. feedback), and the work context (e.g. ergonomics and physical demands) can positively affect employees' health and satisfaction [50]. Although the results of the literature review indicate that these aspects are already partially addressed in the approaches, they are not yet fully covered. For example, a broader consideration of feedback or social interaction is not explicitly addressed by the identified approaches as, e.g., leadership is only considered with respect to the presence of an inspector (e.g. [34]). The dimension of individual remuneration and recognition is also not explicitly considered. Some approaches, such as the approach of Othman et al. (2012) [27], integrate workforce costs into the objective function. Also, the employees' autonomy (in the shell model: scope for action and decision making) is only partially addressed by the approaches. As another example, qualifications or competences are considered by some of the reviewed approaches but typically limited to the integration of a minimum required qualification or competence level for an assignment. The reduction of under-demanding or over-demanding tasks (cf. [14]) is not comprehensively considered. In addition to required qualifications and competences, task characteristics such as complexity or the requirements for problem solving, which generally have a positive effect on workers but can also indicate overload (cf. [50]), are not considered so far.

Although various dimensions of work design are already covered by the reviewed scheduling approaches, most approaches are limited to the consideration of only a few work dimensions. No approach was identified that covers a multitude of different dimensions in the sense of a holistic, human-centered workforce scheduling.

It can also be noted that although the identified approaches consider factors influencing employees' mental and physical health and satisfaction, the actual perceived magnitudes of these factors are not integrated as a quantitative measure. For example, Akbari et al. (2013) [46] introduce a scheduling optimization model with the aim of maximizing worker satisfaction. However, the model is based on maximizing the consideration of preferences rather than maximizing an actual satisfaction measure. The influence of other aspects of the schedule on satisfaction, apart from the consideration of preferences, is thus neglected. In order to integrate the overall perceived satisfaction, mental and physical health into optimization approaches, a quantification of the perceived variables in relation to implemented schedules would be required. One approach might be to survey the perceived level of these variables and relate them to parameters of the schedule using artificial intelligence methods like machine learning algorithms. These relations could then be incorporated into optimization models to further support human-centered workforce scheduling.

To support worker participation in workforce scheduling, the presented optimization model for algorithmic workforce scheduling focuses on integrating various facets of worker preferences, such as preferences related to workstation and the number of station changes, and an equal preference consideration among workers. In addition to preferences and typical aspects such as work demand or a maximum working time, further aspects are integrated, such as time boundaries for worker and workstation or the reduction of assignments to under-demanding tasks.

In interpreting the results, it is important to acknowledge the limitations inherent in the results of the literature review, primarily stemming from the subjective interpretation and categorization of data by the researchers. Furthermore, not all identified aspects could be clearly sorted into the shell model according to Mütze-Niewöhner et al. (2022) [14]. For example, Ast et al. (2021) [47] consider several worker characteristics in their approach to determining worker productivity. Future research should capitalize on the insights presented in this study and delve deeper into human-centered considerations that can be incorporated into algorithmic management approaches. This could involve conducting surveys among workers and managers to gain a more comprehensive understanding. Additionally, it is crucial to investigate the impact on individuals directly affected by these approaches and to explore avenues for further enhancing the proposed optimization model. Finally, the model, in particular the selection of the included factors, must undergo rigorous evaluation and validation, utilizing data obtained from real manufacturing environments.

6. Conclusion and Outlook

In workforce scheduling, workers are assigned to working time and place as well as to work tasks [6]. Since this affects key elements of work design, workforce scheduling has the potential to support human-centered work design. This paper contributes a systematic literature review to investigate to which extent existing workforce scheduling approaches for manufacturing address dimensions of human-centered work design. Therefore, the identified aspects were classified using the shell model of human-centered work design in companies by Mütze-Niewöhner et al. (2022) [14]. Overall, various dimensions of work design are already addressed by existing workforce scheduling approaches. However, certain dimensions are not considered at all, and the focus of the identified approaches is usually limited to specific aspects. Based on the results, an exemplary mathematical optimization model for algorithmic workforce scheduling was presented that attempts to integrate various facets of worker preferences as well as further human-centered aspects. It is evident that there are numerous additional factors that could prove pivotal and warrant consideration in future human-oriented algorithmic management approaches. As we look towards the future of work, innovative solutions and a growing understanding of the intricate dynamics between humans, technologies and organizational factors are needed to harmonize organizational goals with the well-being and fulfillment of employees, thus fostering an environment in which both individuals and businesses can thrive.

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