

A Service of

ZBW

Leibniz-Informationszentrum Wirtschaft Leibniz Information Centre for Economics

Latos, Benedikt et al.

Article — Published Version

Time autonomy in personnel planning: Requirements and solution approaches in the context of intelligent scheduling from a holistic organizational perspective

Zeitschrift für Arbeitswissenschaft

Suggested Citation: Latos, Benedikt et al. (2024) : Time autonomy in personnel planning: Requirements and solution approaches in the context of intelligent scheduling from a holistic organizational perspective, Zeitschrift für Arbeitswissenschaft, ISSN 2366-4681, Springer Berlin Heidelberg, Berlin/Heidelberg, Vol. 78, Iss. 3, pp. 277-298, https://doi.org/10.1007/s41449-024-00432-7

This Version is available at: https://hdl.handle.net/10419/316677

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.



http://creativecommons.org/licenses/by/4.0/

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



WWW.ECONSTOR.EU

WISSENSCHAFTLICHE BEITRÄGE



Time autonomy in personnel planning: Requirements and solution approaches in the context of intelligent scheduling from a holistic organizational perspective

Benedikt Latos¹ · Armin Buckhorst² · Peyman Kalantar¹ · Dominik Bentler³ · Stefan Gabriel⁴ · Roman Dumitrescu⁴ · Michael Minge¹ · Barbara Steinmann¹ · Nadine Guhr¹

Accepted: 5 August 2024 / Published online: 16 September 2024 © The Author(s) 2024

Abstract

Traditional work models often need more flexibility and time autonomy for employees, especially in manufacturing. Quantitative approaches and Artificial Intelligence (AI) applications offer the potential to improve work design. However, current research does not entirely focus on human-centric criteria that enable time autonomy. This paper addresses this gap by developing a set of criteria to evaluate intelligent personnel planning approaches based on their ability to enhance time autonomy for employees. Existing quantitative approaches are not sufficient to fully integrate the developed criteria. Consequently, a novel model approach is proposed in an attempt to bridge the gap between current practices and the newly developed criteria. This two-stage planning approach fosters democratization of time autonomy on the shopfloor, moving beyond traditional top-down scheduling. The paper concludes by outlining the implementation process and discusses future developments with respect to AI for this model approach.

Practical Relevance: In order to make working conditions on the shopfloor in high-wage countries more attractive, an alternative organization of shift work is needed. Intelligent planning approaches that combine traditional operations research methods with artificial intelligence approaches can democratize shift organization regarding time autonomy. Planning that takes both employee and employer preferences into account in a balanced way will strengthen the long-term competitiveness of manufacturing companies in high-wage countries and counteract the shortage of skilled labor.

Keywords Personnel Planning · Time Autonomy · Human-Centric Optimization · Artificial Intelligence · Manufacturing

Zeitautonomie in der Personaleinsatzplanung: Anforderungen und Lösungsansätze im Rahmen einer intelligenten Planung aus ganzheitlicher organisationaler Perspektive

Zusammenfassung

Flexible Schichtmodelle, die Zeitautonomie fördern, sind für Beschäftigte in der Produktion nur selten anzutreffen. Quantitative Ansätze und Anwendungen der Künstlichen Intelligenz (KI) haben das Potenzial, die Arbeitsgestaltung zu verbessern. In diesem Beitrag werden aktuelle Forschungsansätze anhand arbeitswissenschaftlicher Kriterien systematisiert und im Hinblick auf die Ermöglichung von Zeitautonomie auf dem Shopfloor bewertet. Es wird gezeigt, dass aktuell kein Ansatz die Kriterien umfassend erfüllt. Es wird ein zweistufiger Planungsansatz entwickelt, der über die traditionelle Top-down Planung hinaus geht und die Demokratisierung der Zeitautonomie in der Produktion fördert. Schließlich wird der Implementierungsprozess skizziert und ein Ausblick auf zukünftige Entwicklungen im Hinblick auf Erweiterungen durch KI gegeben.

- ² eleVate, Neue Eiler Straße 46, 51145 Köln, Germany
- ³ Universität Bielefeld, Universitätsstraße 25, 33615 Bielefeld, Germany
- ⁴ Fraunhofer IEM, Zukunftsmeile 1, 33102 Paderborn, Germany

Prof. Dr.-Ing. Benedikt Latos benedikt.latos@th-owl.de

¹ Technische Hochschule Ostwestfalen-Lippe, Campusallee, 12, 32657 Lemgo, Germany

Praktische Relevanz: Um die Arbeitsbedingungen auf dem Shopfloor in Hochlohnländern attraktiver zu gestalten, bedarf es einer alternativen Realisierung der Schichtarbeit. Mit intelligenten Planungsansätzen, die tradierte Methoden des Operations Research mit Ansätzen Künstlicher Intelligenz kombinieren, kann eine Demokratisierung der Schichtgestaltung im Hinblick auf die Zeitautonomie erfolgen. Durch eine Planung, die sowohl Beschäftigten- als auch Arbeitgeberpräferenzen ausgewogen berücksichtigt, wird die langfristige Wettbewerbsfähigkeit von produzierenden Unternehmen an Hochlohnstandorten gestärkt und dem Fachkräftemangel entgegengewirkt.

Schlüsselwörter Personaleinsatzplanung · Zeitautonomie · Menschenzentrierte Optimierung · Künstliche Intelligenz · Produktion

Introduction, research question and research approach

Employee retention is a significant challenge in today's global labor market. Especially in high-wage countries, such as Germany, demographic developments are creating a shortage of qualified workers, which forces companies to attract and retain a qualified workforce (Smit et al. 2020). This especially relates to manufacturing companies where rationalization topics need to be addressed simultaneously. Current work suggests that offering flexible work arrangements that grant employees more autonomy with regard to their working time might be a critical measure for organizations to retain their employees (cf. Sharma 2024).

Job autonomy—defined by Hackman and Oldham (1980) as "the degree to which the job provides substantial freedom, independence, and discretion to the individual in scheduling the work and in determining the procedures to be used in carrying it out" (Hackman and Oldham 1980, p. 162)—is a promising approach to leverage humanization and rationalization potentials in work design. Several factors contribute to employees' desire for autonomy, including a preference for uninterrupted time off, a need for work-life balance to manage personal commitments (e.g. childcare during specific hours) and even individual health considerations such as optimal sleep patterns (Garhammer 1994; Parker et al. 2017; Parker and Knight 2024; Schlick et al. 2018).

Since job autonomy is multidimensional, there is a need to distinguish between different dimensions of autonomy (De Spiegelaere et al. 2016; Morgeson and Humphrey 2006). According to De Spiegelaere et al. (2016), work time autonomy refers to the discretion of employees on

when to stop and start working. Flexible shifts and working patterns that offer time autonomy and promote work-life balance are, however, rarely evident for blue-collar workers in manufacturing companies so far (IG Metall 2017).

If such flexible shifts and working patterns are introduced in manufacturing companies, they need to be considered within the personnel planning process (Fig. 1).

According to Scherf (2005), personnel planning in production considers a long-term phase in which general personnel requirements as well as working time models (e.g. shift models in production) are defined. Subsequently, the required primary data (such as planned production volumes and planned employee absenteeism) is captured and employees are assigned to working hours and tasks. The latter process is referred to as "personnel scheduling" in literature and takes into account the given numbers of employees, their qualifications and the assigned tasks, working locations and times in production (cf. Günther 2010; Burgert et al. 2024). In a short-term phase, operational planning takes part in which the absence of employees needs to be considered within a rescheduling of staff to meet the required production targets (cf. Scherf 2005).

Overall, personnel scheduling links personnel and production planning, as the required production plan is realized with the available work persons with the required competencies (cf. Denkena et al. 2016, p. 489). On the one hand, personnel planning has a significant impact on developing the competencies of the employees (Denkena et al. 2016, p. 489) and offers the potential to promote human-centered work by incorporating key elements of work design into the planning rational (Burgert et al. 2024, p. 1573). On the other hand, personnel planning has a strong influence

Fig. 1 Workforce planning process according to Scherf (2005), adapted Gabriel et al. (2022) Abb. 1 Personalplanungsprozess nach Scherf (2005), adaptiert von Gabriel et al. (2022)



on the degree of flexibility and productivity in production (Denkena et al. 2016, p. 489).

The past decades of research on personnel planning in production have produced various optimization approaches to consider these complex interdependencies in the planning process. Intelligent algorithm-based optimization approaches are especially capable of supporting this complex task (Burgert et al. 2024, p. 1573.) Besides the traditional quantitative approaches, the last years of research have generated single applications of Artificial intelligence (AI) for personnel planning.

There is no single definition for the term artificial intelligence (Forschungsbeirat Industrie 4.0/acatech 2024): This is because the topic is complex and the understanding of what AI actually is varies greatly. Frequently mentioned capabilities of AI are learning, autonomous decision-making and action as well as independent handling of uncertainty. Mockenhaupt (2021) distinguishes between four development stages of AI. In stage 1, heuristic systems make it possible to draw conclusions with limited knowledge. In stage 2, knowledge-based systems enable machine-based knowledge processing with a manually created knowledge base. In stage 3, Machine Learning (ML) methods are used to process knowledge using an automatically created model. In level 4, hybrid cognitive systems combine machine learning methods and knowledge-based systems (Mockenhaupt 2021). This is a simplified categorization because the term "intelligence" is not uniformly defined in the context of technical systems and it is not possible to make a clear statement about which AI level is at the top of the pyramid (Forschungsbeirat Industrie 4.0/acatech 2024).

While the development stages of AI offer a framework for understanding its capabilities, a key challenge lies in ensuring transparency in these systems. Decision trees or knowledge bases of expert systems for humans follow a clearly comprehensible structure based on logical rules, features and object hierarchies. This is also referred to as symbolic models (cf. Döbel et al. 2018). Machine learning methods, unlike traditional programming, often function as black boxes, making it difficult for humans to understand the reasoning behind their outputs. This applies in particular to deep neural networks. This is why sub-symbolic models gain importance (Döbel et al. 2018). Hybrid cognitive systems are a combination of data-driven and knowledge-based components that promise great benefits due to the different strengths of the approaches (Kirchner and Schmid 2023; Forschungsbeirat Industrie 4.0/acatech 2024).

Both intelligent algorithm-based optimization and AI sub-symbolic models offer significant advantages for manufacturing firms and work design. However, a sole focus on the technical system is inadequate for systems intended to be used by employees and to be both successful and sustainable. Instead, the entire work system must be designed with a socio-technical system approach in mind (cf. Cummings 1978; Fraccaroli et al. 2024; Bentler et al. 2023a, b), considering the complex interrelationships of information systems-induced change and a radically changing working environment (Nolte et al. 2020). This facilitates the combination of human strengths with the benefits of intelligent systems (cf. Gabriel et al. 2022, p. 431).

The current technological developments open up new opportunities to strengthen democratization of time autonomy in personnel planning. This paper aims at exploring and analyzing these opportunities by answering the following research questions:

- 1. Which central criteria must a participatory personnel planning system fulfill from a work-science perspective?
- 2. How well do current solutions address these criteria?
- 3. Which strategies can be implemented in manufacturing to manage employee preferences?
- 4. To what extent can AI technologies make an additional contribution to increase time autonomy?

To address these research questions, the paper is structured as follows:

First, selection criteria for an approach of Artificial Intelligence and optimization for human-centric personnel planning to increase time autonomy are developed in Sect. 2 on the basis of the relevant literature on work science and ergonomics. Then, the results of a systematic literature research and market research on current approaches of intelligent, human-oriented personnel scheduling are presented in Sect. 3 and compared to the selection criteria. It is shown that currently, no solution exists that fully embraces relevant criteria from a work science perspective with respect to enhancing time autonomy (e.g. employee-specific preferences, qualification matrix-based competence development, work-life balance enhancement, flexible shift models). Section 4 proposes a novel concept for intelligent personnel planning. This concept integrates elements from the reviewed approaches and adapts them for a manufacturing environment, although the framework can be adapted to other contexts. Recommendations for the implementation are outlined to achieve an optimal level of workforce time autonomy.

The paper concludes with a critical discussion with respect to i.e. ethical and work psychological considerations. Future research questions are identified as well as conditions for further scalability in industrial practice are outlined.

2 Development of selection criteria for an intelligent personnel planning approach to increase time autonomy

When introducing an approach for intelligent personnel planning in production, two key objectives of work science need to be considered (Guest et al. 2022; cf. Schlick et al. 2018, p. 5). The objective of "*rationalization*" addresses the productive-related aspects—such as meeting the required production volumes within the planned time and cost. "*Humanization*," however, constitutes all aspects of designing work in a human-oriented manner. These two objectives need to be considered and balanced in order to successfully introduce a new approach of intelligent personnel planning with focus on increasing time autonomy in a producing company.

Furthermore, introducing an intelligent tool needs to be considered from a socio-technical point of view (cf. Gabriel et al. 2022, p. 342). Work systems, such as an assembly department within production, are regarded within industrial psychology as socio-technical systems (cf. Emery 1959; Emery and Thorsrud 1982). They consist of a social subsystem (e.g. the workgroups in production) and a technical subsystem (e.g. the intelligent personnel planning software tool) (cf. Ulich 2013, p. 4). The concept of socio-technical system design envisages a joint optimization of the use of technology and the organization (Ulich 2013, p. 4f.).

The HTO (human, technology, organization) concept, also known as MTO-concept (man, technology, organiza-



Fig. 2 HTO-concept according to Ulich (2013), adapted Gabriel et al. (2022)

Abb. 2 MTO-Konzept in Anlehnung an Ulich (2013), adaptiert von Gabriel et al. (2022)

tion) is based on this approach (see Strohm and Ulich 1997). The HTO concept by Ulich (2013) assumes that people, technology and organization must be considered in terms of their interdependences and interactions. It further provides a holistic analysis and design of these dimensions. The work task is considered as a link between these areas (Fig. 2; see Ulich 2013, p. 5 ff.).

To develop a holistic approach of increasing time autonomy in production with an intelligent personnel planning concept, the HTO concept is utilized as an overarching meta-criteria for developing detailed *criteria within the dimensions of human, organization and technology*, as well as in the intersections of these dimensions.

2.1 Human-oriented criteria

Early human-centered approaches from the tradition of work psychology considered how tasks, which link human, technological and organizational systems, should be designed to keep employees healthy and motivated and to foster their personal growth at work.

According to these early guidelines, tasks first have to be designed in a way that ensures harmlessness, feasibility and freedom from impairment. However, going beyond that, tasks should also provide opportunities for learning and personal development (Hacker and Richter 1980). Work settings, which grant employees decision latitude and scope for action (cf. Ulich 2005), or autonomy (cf. Hackman and Oldham 1976) and in which they may take responsibility for complete tasks (cf. Hacker 2006), are particularly important to let employees' personality develop. Complete tasks are high in task identity (Hackman and Oldham 1976), which means they provide jobs that involve a whole piece of work (Morgeson and Humphrey 2006)-from the setting of goals and the planning of resources, via the selection of means and actions to their implementation and control (cf. Hacker 2006). Employees may easily identify the results of their own effort while working on these tasks (Morgeson and Humphrey 2006). Complete tasks are more interesting to perform (Morgeson and Humphrey 2006), but also help workers to recognize how their own work contributes to the organization's overall goals and to see the importance and significance of the job they do (Ulich 2011). Moreover, they require a variety of skills from the worker and, therefore, provide meaningful learning opportunities (Ulich 2005).

If workers cannot be assigned complete tasks, rotating tasks and workplaces may still help achieve the positive effects associated with such tasks. Workers may understand how the different sub-tasks they fulfill at different points in time are intertwined and implement different skills for different sub-tasks. Based on that, they may more clearly see their own contribution to the big picture. Meta-analytic evidence suggests that *task rotation* particularly contributes to positive job attitudes, whereas learning and development as well as employees' subjective well-being and organizational performance profit more if entire jobs are rotated (Mlekus and Maier 2021).

Task identity, task variety and autonomy regarding decisions as well as work schedules and methods are central design features in the Job Characteristics Model (JCM; Hackman and Oldham 1976) and its extensions (Humphrey et al. 2007; Morgeson and Campion 2003; Morgeson and Humphrey 2008; Parker et al. 2001). The JCM has longtime been the most influential model in work design and it still has a major impact on the field (Parker et al. 2017). Its motivational job characteristics are the design features most studied in research (Morgeson and Humphrey 2006) and the importance of the five work characteristics the JCM promotes for jobs to be intrinsically motivating and satisfying, have empirically been acknowledged to relate to a variety of affective and behavioral outcomes (e.g. Humphrey et al. 2007). Apart from these traditional and further (e.g. specialization or task identity) motivational design features, the newer models highlight social characteristics like interdependence and feedback from others as important design features. If workers may choose their tasks on a daily or weekly basis and tasks are rotated among workers, the task one fulfills is inevitably contingent on the work of others. Moreover, if workers select their shifts and tasks according to their preferences, they may align their work setting with that of close colleagues with whom they collaborate effectively. This could be realized with a marketplace tool approach of preference setting and shift swapping (cf. Gabriel et al. 2023). As social characteristics are closely related to employees' turnover intentions and commitment (Humphrey et al. 2007), they need to be considered when jobs are designed. Another aspect that needs to be considered is the team composition, as well-established teams may be torn apart by an intelligent planning tool (cf. Gabriel et al. 2023). Further, human-oriented aspects were found in a qualitative interview study at a manufacturer of white goods (see Gabriel et al. 2023), where it was stated that a stable *long-term planning fixation* is appreciated for compatibility with private activities. Moreover, early transparency about attendance and absences facilitates the adaption to short-term changes. The (current and future targeted) competencies and qualifications of the employees need to be taken into account and *personal* (physical and cognitive) limitations need to be considered in planning (cf. Gabriel et al. 2023; Burgert et al. 2024).

2.2 Organization-oriented criteria

With respect to the dimension of organization, the planning tool needs to consider the planned *production programme* in

terms of variants and quantity to meet the production targets as well as the corresponding planned *production processes* and forms of *work organization* (cf. Burggräf et al. 2021).

On the one hand, the organization requires *long-term planning stability* to enable purchasing or manufacturing processes within the upstream production steps and supply chain. On the other hand, the planning tool must be able to adapt to *short-term changes* (e.g. because of unplanned absenteeism of employees).

Furthermore, the planning rational needs to take into account the *shift models, working times* and *composition of the workforce* (permanent and temporary employees) as well as *holiday planning* and *time accounts* need to be considered (cf. Burgert et al. 2024; Gabriel et al. 2022). The working conditions, such as the *working environment* (e.g. noise exposures) and aspects of *production ergonomics*, need to be considered and interlinked to the individual personal limitations (cf. Gabriel et al. 2023; Burgert et al. 2024).

In order to understand and adequately represent the needs of stakeholders in the organization, it is essential to follow a *participatory approach* when introducing such planning tools into the organization. Simonsen and Robertson (2013) have pointed out that one of the most important advantages of participatory design is "[...] to support mutual learning between multiple participants in collective reflectionin-action" (Simonsen and Robertson 2013, p. 2). This is of particular importance for developing and implementing a digitized support tool for personnel planning, as implicit and informal ways of communication can be uncovered. Participatory design gives a voice to people who remain otherwise invisible and it enables them to take responsibility for their own work environment (Van der Velden and Mörtberg 2015). Therefore, it offers a democratic way to "moralize technology" and to find a solution that takes user values seriously into account (Verbeek 2011).

2.3 Technology-related criteria

Concerning the dimension of technology, it can be stated that traditional human criteria of work design, which focus only on the interaction between the employees and the work activity, are no longer sufficient. The use of artificial intelligence adds another element to this field, which must be taken into account in the interaction of human-centered design of work and technology. Recent work (Parker and Grote 2022) highlights that these human-centered criteria should be considered proactively when algorithms are designed and implemented. Current approaches attempt to meet this challenge by proposing that socio-technical systems must be designed in a deficit-oriented, data-reliabilityoriented, protection-oriented and potential-oriented manner to meet the needs of employees (Kluge et al. 2021; Parker and Boeing 2023).

As mentioned by Latos et al. (2024), most studies of use and acceptance of innovative products and technologies are based on the Technology Acceptance Model (TAM) (Davis 1989), Theory of Planned Behaviour (TPB) (Ajzen 1991) and Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003), which have undergone a large number of further developments and modifications (e.g. Mlekus et al. 2020; Gursoy et al. 2019; Venkatesh et al. 2016). Despite the existence of many empirical technology acceptance studies in various contexts, such as the social context (Dwivedi and Williams 2008; Hossain et al. 2018), the organizational context (Martins et al. 2016) and the private context of use (Kizgin et al. 2018), as well as various research fields, e.g. intelligent healthcare systems (Fan et al. 2020; Chen et al. 2017) or intelligent robots (Liang and Lee 2017), little work has been done so far to synthesize existing evidence (especially quantitatively) to provide a comprehensive picture of relationships between antecedent variables and AI acceptance (Sohn and Kwon 2020).

Based on the published literature, Kelly et al. (2023) identified factors fitting with the most common theories that influence the acceptance of AI, such as perceived usefulness (see also perceived value (Huang et al. 2019), perceived quality (Kim and Kim 2021), perceived ease of use, effort expectancy, performance expectancy and attitudes). These task-oriented interaction qualities are in line with the ISO definition of usability, to which a distinction is made between effectiveness (i.e., accuracy and completeness of goal achievement), efficiency (the resources expanded in relation to effectiveness) and satisfaction (ISO 9241-210 2019). Beyond task-oriented interaction qualities such as perceived usefulness and perceived ease of use, hedonic aspects, such as identification, stimulation and attractiveness, are increasingly being discussed as relevant influencing factors for technology acceptance and intention to use (Gursoy et al. 2019; Hornbæk and Hertzum 2017; Hassenzahl 2003). For example, Mlekus et al. (2020) integrate stimulation and novelty in an extended version of TAM, the so-called User Experience TAM. Hedonic aspects not only affect intention to use, but they also explain significant variance in perceived usefulness and perceived ease of use.

With respect to artificial intelligence, there is an increasing effort to investigate the perceived use of algorithms in the context of human-computer interaction. For a typical user, algorithms are non-tangible and the underlying process can be physically perceived only to a limited extent. Shin et al. (2020) refer to this experience as Algorithmic Experience (AX) and they propose the Algorithm Acceptance Model (AAM). Here, the central antecedent of *perceived trust* (see also Fan et al. 2020; Gefen et al. 2003; Lee 2009) is the system's *algorithmic credibility*, which is composed of three aspects: *transparency*, *accountability and fairness*.

Moreover, trust is strongly associated with *data security*. Park and Jones-Jang (2023) highlight the importance of prioritizing data security measures to enhance user trust and confidence in AI systems. Furthermore, they found that AI security concerns negatively impact perceived ease of use and perceived usefulness, ultimately leading to decreased AI acceptance. For the purpose of personnel planning, each component plays an important role: Results should contain no biases or discriminatory outcomes (fairness), algorithms must produce solutions that are comprehensible for users with clear recommendations for action (transparency) and firms should be held accountable for the outcomes of their algorithms (accountability).

Overall, the studies show the importance of psychological factors related to the acceptance of AI across different industries (Kelly et al. 2023). According to the value sensitive design (VSA) approach of Friedman et al. (2006), autonomy, human welfare, trust, privacy and informed consent are 5 of 13 basic human values that are of ethical importance in the design of computer software. Taking them into account seems particularly relevant when processes become increasingly less transparent and comprehensible for typical users through the use of artificial intelligence and machine learning.

In addition to these, numerous studies have investigated other potential determinants of TAM and upstream antecedents, such as the *subjective norm*, as a consequence of the caregivers' expectations and the individual need to fulfill them (Eichner 2021; Venkatesh et al. 2003), the *perception of external control* (Venkatesh and Bala 2008), facilitating conditions (Kuberkar and Singhal 2020) and *support* (Igbaria et al. 1997).

A crucial aspect of technological implementation that needs to be considered is that the planning tool must fit into the IT architecture of a company and, therefore, must be linkable to traditional lead systems, such as MES or ERP systems, in manufacturing companies with *suitable IT interfaces*. Alternatively, the tool can be conceptualized as a *single solution* (e.g. in a cloud application) with certain input and output possibilities. Since the employees should be able to change preferences from home to enhance time autonomy when needed, *mobile usage options* (e.g. via an app and a smartphone) should be implemented as well.

Figure 3 provides an overview of the criteria suggested in this paper. It maps these criteria to the corresponding pillars and sub-dimensions of the HTO framework. The numbers correspond to the individual criteria explained in this section for each HTO sub-dimension. **Fig. 3** Developed HTO criteria (the numbers correspond to the number of individual criteria developed for each HTO sub-dimension)

Abb. 3 Entwickelte MTO-Kriterien (die Zahlen stellen die Anzahl der jeweils entwickelten Kriterien pro MTO Subdimension dar)



3 Literature review on personnel planning approaches of artificial intelligence and traditional optimization

This section investigates how current solutions for personnel planning consider the criteria across the dimensions of human, organization and technology. A systematic review approach was employed to achieve this. Two recent and relevant literature reviews by Burgert et al. (2024) and Özder et al. (2020) were selected as a foundation to assess whether the criteria within the three dimensions have been addressed. These specific reviews were chosen because they conducted extensive literature reviews on personnel planning. The two reviews were complemented by an additional targeted literature review to capture further research approaches that were not included in the two reviews due to their focus. This approach ensured a comprehensive understanding of how current research integrates human, organizational and technological considerations into algorithmic and AI-based solutions for personnel planning. A summary table is developed to outline how different criteria within the three dimensions have been addressed in the identified literature (cf. Table 1). This analysis is complemented by a market review of currently available personnel planning software. The section concludes by synthesizing the findings from both the literature analysis and the market review. This synthesis allows for the identification of research gaps in the current state-of-the-art and reveals to which extent AI is used in the existing solutions.

The literature review was conducted using the procedure of Fink (2014) to answer research question 2. ScienceDirect and IEEE Xplore were chosen as databases due to their extensive coverage of peer-reviewed academic literature in relevant fields of computer science, engineering and management. The literature review was conducted in two parts to expand the literature pool and prevent a narrow and restrictive search.

In the first part, the initial keywords selection aimed to capture the core elements in personnel planning using algorithmic solutions, artificial intelligence and machine learning (AI/ML). The terms "workforce," "staff," "employee," and "personnel" were employed to encompass the human aspect. The Keywords "scheduling," "problem," "assignment," and "timetabling" targeted the specific tasks

Table 1 Sys Tab. 1 Syste	stematization of person smatisierung der Person	nel planning approaches with respect to the criteria nalplanungsansätze im Hinblick auf die Kriterien	
OTH	Sub-dimension	Criteria	Exemplary references
Human	Task and	Complete tasks or task rotation	Drezet and Billaut (2008)
	personal factors	Task/skill variety	Annear et al. (2023), Li et al. (2017)
		Decision latitude/scope for action/autonomy (time & methods)	Farahani et al. (2022)
		Competencies and qualifications	Annear et al. (2023), Bocewicz et al. (2023), Rinaldi et al. (2022), Katiraee et al. (2021), Ast et al. (2021), Guastaroba et al. (2021)
		Physical and cognitive limitations	Bocewicz et al. (2023), Rinaldi et al. (2022), Berti et al. (2021), Katiraee et al. (2021), Akbari et al. (2013)
	Social	Task autonomy (preferences)	Katiraee et al. (2021), Ruiz-Torres et al. (2017)
	characteristics	Time autonomy (long term shift preferences)	Akbari et al. (2013)
		Time autonomy (short term worktime preferences within shift)	Farahani et al. (2022)
		Team composition	Behnia et al. (2021), Çakırgil et al. (2020), Guastaroba et al. (2021), Li et al. (2017)
		Long-term planning fixation for the employees	Wang et al. (2023), Borgonjon and Maenhout (2022a)
		Adaption to short-term changes of employees	Bocewicz et al. (2023), Wang et al. (2023), Wu et al. (2023), Vahedi-Nouri et al. (2022)
Organi-	Process	Production program (QTY)	Annear et al. (2023), Katiraee et al. (2021)
zation		Production program (variant)	Annear et al. (2023)
		Production process	Annear et al. (2023), Katiraee et al. (2021)
		Form of work organization	Annear et al. (2023), Xiong and Li (2022), Gürsoy et al. (2023), Othman et al. (2012)
	Time and	Long-term planning stability (production view)	Wang et al. (2023), Borgonjon and Maenhout (2022a)
	workforce	Short-term adaption to changes (production view)	Annear et al. (2023)
		Shift model	Wang et al. (2023), Annear et al. (2023)
		Working times	Wang et al. (2023), Annear et al. (2023)
		Composition of the workforce	Behnia et al. (2021)
		Holiday planning	Annear et al. (2023)
		Time accounts	Annear et al. (2023), Wang et al. (2023)
		Working environment	Rerkjirattikal and Olapiriyakul (2021)
		Production ergonomics	Battini et al. (2022), Rinaldi et al. (2022), Katiraee et al. (2021)
	Introduction	Participatory introduction process	Gabriel et al. (2022)

Table 1(CorTab. 1(Forts)	ntinued) etzung)		
HTO	Sub-dimension	Criteria	Exemplary references
Technology	Output	Perceived usefulness	
		Completeness	Mansini et al. (2023), Battini et al. (2022), Borgonjon and Maenhout (2022a)
		Accuracy	Annear et al. (2023), Annear et al. (2023), Borgonjon and Maenhout (2022b), Ast et al. (2021), Kati- raee et al. (2021)
	Usage	Perceived ease of use	1
		Attractiveness (global)	Wang et al. (2023)
		Stimulation and novelty	Annear et al. (2023), Akl et al. (2022)
	Trust	Perceived trust	1
		Transparency	1
		Accountability	1
		Fairness	1
		Data security	1
	Context	Subjective norm	1
		External control	1
		External support	1
	Technical	Suitable IT interfaces	1
	integration	Single technical solution	Wang et al. (2023)
		Mobile mode of operation	Gabriel et al. (2023)

involved in personnel planning. Moreover, "optimization," "algorithm," "model," and "modeling" addressed the technique of solving the problem.

In the second part, since the focus of the study was to identify the use of AI, the next set of keywords ("AI" OR "Artificial intelligence" OR "Machine Learning" Or "ML") was used in a full-text search with the condition that the keywords that address the human aspect and personnel planning were also included in the title of the articles.

The search, which was conducted in March 2024, resulted in 135 articles, comprising both journal and conference papers. Following a practical screening process, a subset of the initial literature pool was retained. This screening process involved excluding articles published prior to 2014 and those with titles that demonstrably lacked relevance to the research topic of personnel planning and non-English papers. The final selection resulted in 90 papers for further analysis.

After a methodological quality screen to identify research directly relevant to personnel planning, with an emphasis on employee time autonomy, several categories of papers were excluded: those not explicitly addressing personnel planning and scheduling; studies proposing algorithms or methods tailored to specific use cases; research primarily focused on the challenges of personnel planning during the COVID-19 pandemic; papers with abstracts that indicated a lack of emphasis on time autonomy for employees, exemplified by studies solely focused on weekend nurse scheduling. 29 papers were selected and—with the manual addition of 7 sources—a total of 36 sources were chosen for the detailed review.

In addition to our own literature review, we drew on Burgert et al.'s (2024) work. They dedicated their research to reviewing and identifying different dimensions of work design in personnel scheduling considerations based on the shell model of human-centered work design of Mütze-Niewöhner et al. (2022). The shell model is used as a basis to understand how workforce scheduling interacts with work design. This framework primarily focuses on the human and organizational factors in personnel scheduling that influence work design across individual, company and even industry levels. One aspect reviewed is the human factor in work design and time autonomy, categorized under worker characteristics such as needs, readiness and concerns (Farahani et al. 2022).

In total, the review shows that all aspects of the shell model have been partially addressed. However, no approach fully considers all areas of the model. Additionally, it is stated that employees' autonomy is not entirely addressed in the literature. When discussing job satisfaction, Burgert et al. (2024, p. 1581) point out a research gap exists because the approaches addressing this have the assumption that satisfying employees' preferences will result in higher job satisfaction (cf. Akbari et al. 2013). They suggested that quantifying the variables' impact on job satisfaction and relating them to model parameters is needed before integrating employees' perceived job satisfaction and mental and physical health into optimization models. They encourage the use of AI and machine learning algorithms to do so.

The second review from Özder et al. (2020), which was used as a foundation for this paper, focuses on parameters and problems in personnel scheduling. Planning problems introduce many constraints that can be differentiated into hard and soft constraints that would increase the complexity of the problem (Volland et al. 2017). Özder et al. (2020, p. 2) explain that including "requests and demands of the personnel"—what can be referred to as time autonomy—in scheduling problems increases the complexity of the problem. Even though some companies have shown interest in including employee preferences in scheduling, there is no algorithm that can effectively address this requirement (Özder et al. 2020, p. 19).

Özder et al. (2020, p. 19) further point out another research gap in the literature that is specifically relevant for manufacturing applications: The inclusion of a master schedule in personnel scheduling that has not been addressed yet. The Master Production Schedule (MPS) acts as a bridge, translating broad production plans into specific, detailed schedules. These schedules pinpoint the exact production timelines for individual end items or models, allowing for the prioritization of critical items (Kiran 2019).

From the literature review, that was conducted for the purpose of this paper, the following findings can be stated:

If Artificial Intelligence (AI) is used for planning purposes, it is essential to determine how and to which level it can make decisions. Shrestha et al. (2019) introduce a framework for how human decision-making-combined with AI-based decision-making-can be utilized as starting point for creating a concept. Gabriel et al. (2022) discuss AI's potential to support humans and, in the case of personnel scheduling, planners. However, the main challenges in using AI for scheduling are: gathering the required data, expertise and complexity. Hence, their work presents a concept of how AI can be used. Rischmeyer (2021) presents a general idea of the possibility of using AI for automated workforce planning and explains the challenges and the advantages of having an AI tool for planning. It further recognizes real-time, user-friendliness and safety as the success factors of an AI planner and explains how an implementation project should be managed.

Out of 37 articles, where AI was mentioned, only 11 included an own AI implementation. However, no ML approach could be identified in the review, that specifically tackled the focus of this paper. Instead, it has been ap-

plied to other problems. For example, Denkena et al. (2017) used deep learning to determine the employee influence on setup and processing time in a manufacturing setup. Mo et al. (2020) used natural language processing techniques in construction to prioritize the tasks and assign them to the correct employee with the right skill. Due to the nature of the use case, the action and timing of work should be covered here. Patel et al. (2023) leveraged a Support Vector Machines (SVM) classifier to categorize employee activities based on data collected in an office environment. This classification is used to measure employee performance and to manage workload and scheduling as input. Technology acceptance and ease of use are further points that remain unexplored in literature.

According to Grinter et al. (2023), the current commercial solutions for workforce planning have gaps that need to be addressed, such as compliance, data collection and the need for transparency about automation. Further investment is made in trying to improve the human factor's consideration in the applications and to address the gaps in skill management capabilities. To compare the state of research with the state of commercial tools, an additional market research on available commercial personnel scheduling tools was conducted in the InTime Research Project (https://arbeitswelt.plus/leuchtturmprojekte/miele/). In total, 18 software solutions were identified, which are used in a wide range of fields, from production to logistics, services and healthcare. Exemplary tools that covered several criteria were Getaiplan, Quinyx, gfos., Workforce, ShyftPlan and Q-Planner.

The evaluation of the tools is associated with a certain degree of uncertainty. This is mainly due to the limited information available, which is mainly on the providers' respective websites. In particular, little information can be found about the technical functionality of the tools. Only a few other publications exist. For instance, the implementation of Getaiplan, powered by artificial intelligence, significantly minimized planning time and boosted productivity and efficiency at Sägewerk Schwaiger enabling more accurate customer and delivery scheduling (Bauer et al. 2019). The tool from the company p.l.i. solutions uses live location data, among other things, to deploy the nearest employee and thus implement intelligent planning (Johannhörster et al. 2024). In total, none of the assessed tools fulfilled the range of criteria entirely since they often focussed on particular tasks of personnel planning, such as shift swapping in a mobile app. Furthermore, the first approaches to using artificial intelligence could only be found in a few of the available tools.

The current research highlights the gap in the potential of technological advancements and the actual use of AIpowered solutions in personnel planning as evidenced by the absence of any AI-based approaches. Furthermore, there is a lack of comparative analysis of different techniques to achieve scheduling objectives.

The literature review suggests that the shell model provides a valuable foundation for exploring how scheduling decisions impact these dimensions. Table 1 summarizes the key findings from the literature review. Within each sub-category, the table highlights the most recent studies that met the HTO criteria for relevance. Notably, any blank spaces in the table indicate a lack of existing research that addressed specific criteria within that sub-category.

To sum up, research gaps in the consideration of human factors, such as employee satisfaction and preferences and the use of AI as a solution method, were identified in the literature reviews. The inclusion of master scheduling in personnel scheduling for manufacturing applications and the effects of differentiating constraints into hard and soft constraints on scheduling problem complexity also requires further exploration. To address these gaps, a humancentered approach to personnel planning and the use of machine learning algorithms may be necessary to optimize employee satisfaction and resource use.

Furthermore, in the context of production, an overarching scheme for intelligent personnel planning to enhance time autonomy on the shopfloor is needed, since there are different stages in which time autonomy can be realized for the employees. Therefore, different time horizons (long-, mid- and short-term) need to be considered in the process.

4 Development of an intelligent personnel planning approach to enhance time autonomy on the shopfloor

In this section, an overarching personnel planning approach is developed to overcome the identified gap in the literature review. The duration of fixed work schedules is initially established by weighing the level of flexibility desired by both employers (e.g. predictability for planning) and employees (e.g. time autonomy).

The employer's perspective is not one-sided though, as recent economic factors imply extending the classic production triangular of cost, time and quality by flexibility. Flexibility is the ability of a system to adapt reversibly to changing circumstances within the framework of a fundamentally preconceived scope of characteristics and their specification (Wiendahl 2002). External market factors requiring flexibility involve volatility, periodicity, materialand personnel availability (Oertig and Zölch 2020; cf. also Sects. 1 and 2).

It is important to recognize that employee motives for autonomy are not about seeking infinite temporal flexibility, as this can also lead to additional stress. Instead, they desire a work environment that offers plannability, safety

Therefore, modern approaches to personnel planning and scheduling need to address this inherent duality between long-term planning stability for employers and employee time autonomy. Existing practical tools for personnel planning and scientific optimization approaches do not entirely consider this.

Although surveys show that shift models are among the most undesirable work time models (Statista 2023), they are common in production settings because they offer high plannability for employers. According to the German workers' union IG Metall, every third member of the union works in shifts (IG Metall 2017). Time autonomy ranks as a significant factor in attracting employees (Gallup-Institut 2022) and shift models restrict time autonomy for employees.

Generally, a work time system is a bundle of rules for controlling labor input regarding temporal distributions and durations within a (sub-)period (Sager 2007; Hess 1988). When companies design and implement such shift approaches, recognized flexibility dimensions are referred to as chronometric and chronological dimensions. The chronometric dimension corresponds to the daily, weekly and total work duration within the period. The chronological dimension corresponds to the temporal location of work time, e.g. at a day or various days within a week as well as the distribution of the total time within the planning period (cf. Bauer 1999; Fergen et al. 2022; Schlick et al. 2018).

For shift models, the duration and temporal location are fixed. From an employee's perspective, there is minimum variability and autonomy, as shifts may be switched with colleagues, or free shifts are defined within a planning period. The rate of change is identified as medium-term. From an employer's perspective, the total operations time of the production system, daily working time, working days, number of shifts per week, number of shifts per day as well as shift regulation and shift organization are fixed long-term.

The following work time concept enhances flexibility and time autonomy levels for both employers and employees. It acknowledges that complete employee autonomy might be impractical, but it prioritizes increased freedom and co-determination for workers while maintaining a necessary level of predictability for planning.

This is achieved by raising the typical long-term fixation to the level of medium-term fixation and including averaged worker preferences, especially for the definition of the location of daily work time based on a suggestion of Buckhorst (2023; cf. Fig. 4).

This approach must be considered when developing a suitable personnel planning pipeline. Furthermore, this concept should address the criteria identified in the HTO dimensions. The planning pipeline is presented in Fig. 5. This two-step approach leverages optimization algorithms to create production schedules that consider both employee preferences for flexible working times and employer requirements for efficient personnel planning. By incorporating employee qualifications, legal constraints and company agreements, the system aims to create a balanced and feasible production schedule that satisfies all stakeholders.



Fig. 4 Shift in the planning dimension from long-term towards medium-term variability for employee preferences Abb. 4 Verschiebung der Planungsdimension von der langfristigen zur mittelfristigen Variabilität der Beschäftigtenpräferenzen



Fig. 5 Concept of a democratic shift in a multi-level approachAbb. 5 Konzept der demokratischen Schicht in einem Multi-Level-Ansatz

Based on employee voting regarding individual preferences, the work time location is decided on, e.g. for each workday in the first planning period, and is fixed (step 1). The assignment of operators to shifts is executed afterwards (step 2). It is recommended that this be done based on the same voting results. This time, this is not done by determining an average preference but by the individual preference for the assignment. The approach is denoted as a "democratic shift." Both steps will be executed by parameterizable algorithms, either from operations research or artificial intelligence.

4.1 Step one: Democratic work time

In the following, *step one* is explained and the required inputs for the planning pipeline are outlined, which are depicted in Fig. 5.

Input: Legal requirements need to be taken into account when planning work time. For example, in Germany:

- The working day of employees may not exceed eight hours. However, it can be extended to up to ten hours if an average of eight hours per working day is not exceeded within six calendar months or within 24 weeks (ArbZG n.d. § 3).
- The rest breaks may be divided into periods of at least 15 min each. Employees may not be employed for longer than six consecutive hours without a rest break. Work must be interrupted by predetermined rest breaks of at least 30 min if the total working time is between six and nine hours and 45 min if the total working time is more than nine hours (cf. ArbZG n.d. § 4).

The work time regulations are not only set by law but also driven by collective agreements, company agreements and individual employment contracts. The principle of favorability has to be respected from an employee's point of view (Schuhmann and Wagner 2022). Changes regarding these input parameters must be allowed in an implemented pipeline for a superuser.

Vacations and planned absences should also be considered, with individuals voting for a planning period. For employers, several factors can be adjusted within an optimization model that connects to step 1. The following factors, as identified by Hesseln and Zander (2005) and Schlick et al. (2018), act as constraints for the model:

- Minimum and/or maximum of fixed system operation time in the period or on a week level
- Minimum and/or maximum of daily target system operations time
- Minimum and/or maximum of workdays per week or planning period
- Minimum and/or maximum of shifts per day
- Minimum and/or maximum of shift count per day/week
- Type of shift organization (overlapping, separate and flush)

The voting itself is intended not to be too overcomplicated by involving too many preference levels. A primitive but sufficient variant would be a 1—preferred time slot of work on a given day and a 0—undesired time slot approach (in analogy to the task assignment of Burgert et al. 2024). Absences and illnesses are tracked by the system. In case absences on a specific day for an individual are known, the vote is associated with a weight of zero.

Each employee is asked to provide the preference voting for every day and every time slot. The individual preference in a set denoted by:

 $\psi_{m,h_t} \in \{0,1\}.$

This preference allows for an averaging over all involved employees regarding the work times, which is calculated by:

$$\overline{\psi}_{h_t} = \frac{\sum\limits_{m \in \widetilde{M}_t} \psi_{m,h_t}}{\left| \widetilde{M}_t \right|}$$

With

 $t \in P$ Days in a planning period $h_t \in H_t$ Steps per day t(resolution) $m \in M$ Set of Employees

 $\widetilde{M}_t \subseteq M$ Subset of employees without holiday on a given day t

The averaged preferences for an entire, possible shift τ_t on a day t are calculated by:

$$\overline{\pi}_{\tau_t} = \frac{\sum\limits_{h_t \in \{\tau_t, \dots, \tau_t + d - 1\}} \overline{\psi}_{h_t}}{d}$$

additionally with

$d \in N_{\leq 10}$ The duration of the shift is given in the steps and the size of the temporal steps per day

Based on $\overline{\pi}_{E,\tau_l}$, the maximum preferred start time may be selected if the planning period involves only one day and one shift per day. When two shifts per day are desired, a simple operations research model will suffice with a constraint indicating whether two shifts on a given day should have an overlap (due to handover times), should be directly connected to each other, or maybe allocated freely without intersection. The chosen modelling of time works well for one or two-shift organizations, though it requires a more continuous approach for a three-shift production.

While the presented formulas provide the employeebased voting perspective, employer preference voting may be adjoined and executed simultaneously for practical reasons. The calculus is similar. Assuming the averaged employer preference is denoted by $\overline{\pi}_{E,\tau_t}$. In the optimization model, the weight of the two perspectives (w_e for employees and w_E for employers) can be set as a parameter in an objective function. Of course, the employer preferences should not equal 1; otherwise, the overall system will be reduced to absurdity. Further, the weights are normalized such that:

 $w_e + w_E = 1.$

A corresponding objective z for a maximization approach with an integer decision variable $x_{\tau_t} \in \{0, 1\}$ is:

$$z = \sum_{\tau_t \in T_t, t \in P} \left(w_e \overline{\pi}_{\tau_t} + w_E \overline{\pi}_{E, \tau_t} \right) x_{\tau_t}$$

Deciding on shift-locations for a planning period in this way, other departments or trades considered as support services in the value stream should be informed about the resulting shift times for awareness and coordination with the primary value-creating workstream. Since step 1 is modeled as an extended knapp-sack model, its overall complexity is limited and decision-making is objective and explainable.

Meaningful and empirical established rulesets may be appended to this simple preference voting procedure:

- Minimum number of "1" votes per day
- Minimum number of connected "1" votes per day



Fig. 6 Heatmap of exemplary modelling results of individual and average preferencesAbb. 6 Heatmap der beispielhaften Modellierungsergebnisse der individuellen und durchschnittlichen Präferenzen

- Minimum number of "1" votes per week (in accordance with individual contract)
- Minimum number of "1" votes per planning period (in accordance with individual contract)

Output: Fig. 6 shows the intended planning results of step 1. The daily planned work time is the output based on a time discretization modeling approach. The design parameters include whether the succeeding shift requires an overlap time for handover and, therefore, a connection of the first and the second shift per day.

4.2 Step 2: Shift scheduling

The *second step* refines the initial production schedule (established in step 1) by assigning specific employees to shifts and stations. It has to be executed at least once right after the first step. However, it might be repeated when new information, e.g. work absences or sickness or priority to specific stations or lines in the corresponding production environment, is changed. In the following, the required input and the output of the second step will be outlined.

Input: To allow staffing in line with employee qualification profiles, this information needs to be made available accordingly, e.g. by a qualification matrix (skills vs. operators). Further previous input from step 1 is relevant, especially rule sets from law, company agreements and individual labor agreements are to be respected when deciding an individual employee schedule. Ultimately, they are complex though as "if—then—else" clauses and therefore can be formulated as mixed integer programming (MIP) problem constraints.

Output: The result of the second step is the production schedule, which is the assignment of operators to the previously fixed shifts and the assignment to a station or line within the production system under consideration of their qualification levels. This involves two perspectives: (1) Employee Perspective—details each employee's assigned shifts and working times in this period; (2) Employer Perspective—specifies which operator is assigned to each station or line, ensuring the production system is staffed with qualified personnel to maintain productivity.

A meaningful goal for optimization is the minimization of changes made to the previously provided plan, since significant changes negatively affect motivation as well as perceived usefulness. The update rate should not be too high and not frustrate people with new but shortly afterwards invalid information. The updates should be based on the following factors:

- Limit the total number of allowed schedules before the actual shift (e.g. directly after period planning, one week before the corresponding shift, and a short update at the shift itself to respect absences ultimately)
- Limit the allowed number and types of changes within an update (e.g. do only consider preferences for the first schedule, minimize changes and maximize preferences of employees for the one-week-before schedule, and lastly, only shift scheduled people to corresponding lines or stations according to their qualification and the given no-show rate at the day or shift respectively)

In addition to updates, a general shift-swap database should be provided for the employees to enhance their autonomy and allow for last-minute changes in their personal plans. Obviously, qualification profiles and rulesets for shift assignment are to be maintained constraints for shift swaps. As Sect. 3 highlighted, ready-made solutions for such are available in marketplaces. For the entire approach to function effectively, a seamless exchange of information between the shift-swap database and the step 2 model (responsible for updating schedules) is crucial. Hence, a robust data model is required, allowing for a streamlined integration. Here, the design of a shift planning ontology is suggested to facilitate a standardized information exchange (e.g. Vegetti and Henning 2022).

The following section discusses how the presented concept can be implemented and which technical optimization approaches for the models in steps one and step two could be adapted from current approaches in the literature. Practical implications and future research questions are outlined.

5 Discussion, practical implications, and outlook

The literature review showed that sufficient optimization models are available that address both steps of the planning pipeline in Sect. 5, especially the second step. However, they usually follow a specific goal under consideration of certain constraints from a practitioner's perspective. Therefore, the presented concept focused on the meta-level of how to integrate additional time autonomy in highly distributed shift models in production with a necessary voting procedure. The core concept is applicable to numerous personnel planning challenges across different industries. For instance, in service sectors like healthcare or customer service fixing time slots from an employer's perspective can ensure adequate staffing during peak hours. However, the system could also offer employees autonomy in scheduling their remaining work hours within the framework potentially improving employee satisfaction and reducing absenteeism. This adaptability makes the approach valuable for creating efficient and employee-centric personnel planning across various organizational contexts.

The choice of optimization models for each planning step ultimately needs to be considered individually for a company. The selection would have to be based on the planning steps according to available work time, company and operating agreements. The challenge is to establish a standardized data-model to consolidate input and output information. For solving the two steps, operations research approaches are generally preferred to AI and Machine Learning methods because of objectivity, planning result explainability, transparency and fairness from an employee's perspective. However, such model designs are tedious expert work and time consuming, since they need to undergo debugging and integration phases. In addition to the expert knowledge required to develop such one model, they are tailored to a unique use case. Therefore, with external and significant changes in law or in trade unions' negotiated set of rules, previous optimization models need to be adopted, which means that it could change the objective function and impose new constraints on the elaborately developed model. However, there is a risk that the problem might not be transferable or even solvable altogether when incorporating additional constraints and new objectives.

Despite the limitations discussed regarding explainability and employee acceptance, machine learning methods remain a potential avenue for solving personnel planning problems altogether. However, the accuracy and consistency of ML solutions compared to established Operations Research (OR) methods for the same problem have not been extensively investigated. A promising area for future research would be to implement and compare various ML techniques in solving a generalized personnel planning model. This research could evaluate the accuracy and fairness of these ML solutions against established OR methods.

This paper proposes incorporating Machine Learning techniques into the existing Operations Research framework for personnel planning to develop sub-symbolic hybrid models. Generative AI can be used to automate or accelerate the process of building OR models for specific personnel planning scenarios. Further suitable artifacts to be developed and based on artificial intelligence are:

- Neural Networks suggesting a pre-filled voting for the employees based on the learned preferences of the individuals to speed up the procedure and potentially improve voting accuracy.
- Neural Network suggesting meaningful weights of the employee and employer voting results based on external market circumstances. This could be a way to factor in external factors like labor market trends or skill shortages. However, careful consideration is needed to ensure fairness and transparency in the weighting process.
- AI for analyzing the generated schedules and verifying their adherence to the current or even simulated new rulesets. This allows for a proactive assessment of the impact of rule changes before implementation.

The growing interest in AI-powered scheduling solutions motivates further research on integrating them with established optimization models. While the proposed model leverages mixed integer programming for its meta-level nature, future research should explore linking this model with AI for scheduling. It is essential to acknowledge that the successful development of ML/AI methods in this area depends on having specific use cases and relevant data which were not available at this conceptual stage. However, several aspects of the concept can already be assessed and discussed with respect to the above-established evaluation criteria. All in all, the concept covers multiple criteria in the HTO dimensions and therefore offers the potential to enhance time autonomy on the shopfloor with a humancentric personnel planning approach:

Regarding the human-oriented criteria, the complete task, rotation and task variability are fundamental components of the concept. The same applies for the consideration of individual skills and task qualification following a qualification matrix scheme. For time autonomy, an employeefocused preference voting is the central element of the approach, including a potential extension for the integration of an employer perspective. Time autonomy has a community and individual dimension as well as long- and shortterm timelines. According to the self-determination theory (Ryan and Vansteenkiste 2023), people have a need for autonomy-but the extent of this need varies from person to person. Employees should therefore be able to influence the system as to how much autonomy they want. This is possible, as the voting procedure accounts for the individual time autonomy preferences. However, preferences with respect to the team composition have not been considered yet. Studies have shown that the desired flexibility through intelligent systems in the area of personnel planning can lead, in particular, to changes in the composition of teams, which can have an impact on the psychological well-being of employees (Cummings 1978; Hagemann et al. 2023). This aspect should be considered in future studies.

For the organization-oriented criteria, no superordinate interface to the production program was focused on due to the resources and skill-based personal planning. This implies that the research gap pointed out by Özder et al. (2020, p. 19), the inclusion of the master schedule in personnel scheduling, is still valid and needs to be considered in future research. A production-oriented long- and short-term stability is ensured through the weighted sum with the preferences of the employers next to the employees' preferences in the model. For the overall principle, the classic shift is extended by time democratization. Individual time accounts and holiday planning are part of all scheduling models in the pipeline as well as short-term, skill-based changes for short-term absences and illnesses. General time constraints of working times and shift models are also considered. As the qualification matrix is already used to ensure that the persons with the right qualifications are assigned to specific tasks, the concept can be further developed to account for the criteria of production ergonomics. A matrix with the ergonomic assessment of all workstations can be considered within task assignments to ensure that production ergonomic requirements are met. However, the interconnection between task assignment and ergonomic assessment is not trivial when considering task rotations and alternating ergonomic scores. Future research should focus on integrating time and ergonomic assessments-e.g. with the process language Human Work Design (MTM-HWD®) (see Faber et al. 2019)----into personnel scheduling algorithms in or-der to not only assign qualified employees to tasks but also assigning ergonomically acceptable tasks sequences to the employees. The scores should be evaluated for the whole task sequence of an assigned shift and not only for single workstations.

Finally, the participatory approach could not yet be applied because, at this stage, a concept was presented. This also applies to most of the *technology-oriented criteria*. Without an implementation in practice, a meaningful evaluation with respect to all criteria is not possible. However, the criteria give valuable guidelines for future research and applications in industrial practice.

If a participatory approach is applied, the output-related criteria (perceived usefulness, completeness, accuracy) can be evaluated at early stages. Early improvement iterations may lead to better acceptance of the solution through the employees. Also, a participatory approach helps to build trust in the assigned criteria. Of course, a careful technical implementation must ensure that aspects of data security, transparency etc. are implemented—but acceptance will be mainly reached, if the underlying principles are explained and discussed with the employees during a participatory pilot phase.

Furthermore, the introduction phase and underlying change management will significantly impact how the

criteria of subjective norm, external control and external support will be perceived. Finally, the concept considers the technical integration aspect of mobile modes of operations. Suitable IT interfaces and options as single technical solutions depend on the situation and requirements of the companies where such a concept would be implemented.

In the context of Mockenhaupt's AI development stages, the solution approach presented in this article can be assigned to stage 1 or 2 (see Mockenhaupt 2021). In order to take into account the numerous other factors influencing workforce scheduling, which have been published as part of a target concept in the InTime project, higher AI development levels promise significant benefits, e.g. to evaluate historical data using machine learning methods (cf. Gabriel et al. 2023). In the context of the target concept published as part of the InTime project, the approach presented in this paper can be seen as a central building block for meeting the requirements for taking employee preferences and flexible working hours into account. The process model for AI-supported decision-making, according to Bentler et al. (2023a) can help to translate the criteria identified in Sect. 3 into requirements for an intelligent workforce scheduling tool.

In total, the implementation and introduction of such intelligent personnel planning tools into manufacturing companies should be part of the digital transformation journey on the shopfloor: The transformation includes changes in mindset, work practices, and information systems (cf. Nolte et al. 2020)—which relate to the overall HTO dimensions. To overcome the outlined research gaps, multi- and transdisciplinary research initiatives need to be set up to cover the multifaceted criteria in a holistic implementation approach.

Acknowledgements The article is based on preliminary work of the research and development project "InTime", which is funded by the Federal Ministry of Education and Research (BMBF) within the "Kompetenzzentrum Arbeitswelt.Plus" (FKZ: 02L19C104, 02L19C107) and supervised by the Project Management Agency Karlsruhe (PTKA). The responsibility for the content of this publication lies with the authors.

Funding Open Access funding enabled and organized by Projekt DEAL.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4. 0/.

References

- Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50:179–211
- Akbari M, Zandieh M, Dorri B (2013) Scheduling part-time and mixed-skilled workers to maximize employee satisfaction. Int J Adv Manuf Technol 64(5–8):1017–1027. https://doi.org/10.1007/ s00170-012-4032-4
- Akl AM, El Sawah S, Chakrabortty RK, Turan HH (2022) A joint optimization of strategic workforce planning and preventive maintenance scheduling: a simulation–optimization approach. Reliab Eng Syst Saf 219:108175. https://doi.org/10.1016/j.ress. 2021.108175
- Annear LM, Akhavan-Tabatabaei R, Schmid V (2023) Dynamic assignment of a multi-skilled workforce in job shops: an approximate dynamic programming approach. Eur J Oper Res 306(3):1109–1125. https://doi.org/10.1016/j.ejor.2022.08.049
- Arbeitszeitgesetz (ArbZG) § 3 Arbeitszeit der Arbeitnehmer. https:// www.gesetze-im-internet.de/arbzg/__3.html
- Arbeitszeitgesetz (ArbZG) § 4 Ruhepausen. https://www.gesetze-iminternet.de/arbzg/__4.html
- Ast J, Wasseghi R, Nyhuis P (2021) A comparison of methods for determining performance based employee deployment in production systems. Prod Eng Res Devel 15(3–4):335–342. https://doi.org/ 10.1007/s11740-021-01019-5
- Battini D, Berti N, Finco S, Zennaro I, Das A (2022) Towards industry 5.0: A multi-objective job rotation model for an inclusive workforce. Int J Prod Econ 250:108619. https://doi.org/10.1016/j.ijpe. 2022.108619
- Bauer T (1999) Betroffene beteiligen. Pers Sonderh Arbeitszeit (10):12–17
- Bauer W, Ganz W, Hämmerle M, Renner T (2019) Künstliche Intelligenz in der Unternehmenspraxis. Fraunhofer, Stuttgart
- Behnia B, Shirazi B, Mahdavi I, Paydar MM (2021) Nested Bi-level metaheuristic algorithms for cellular manufacturing systems considering workers' interest. Rairo Oper Res 55:S167–S194. https:// doi.org/10.1051/ro/2019075
- Bentler D, Gabriel S, Latos B, Maier GW (2023a) Prozessmodell personalorientierter Entscheidungsgestaltung einer künstlichen Intelligenz. PERSONAL Q 23(02):18–23
- Bentler D, Gabriel S, Latos B, Dietrich O, Dumitrescu R, Maier GW (2023b) Partizipatives Gestaltungsvorgehen bei der Einführung Künstlicher Intelligenz in produzierenden Unternehmen. In: GfA (ed) Frühjahrskongress – Nachhaltig Arbeiten und Lernen – Analyse und Gestaltung lernförderlicher und nachhaltiger Arbeitssysteme und Arbeits- und Lernprozesse. GfA Press, Sankt Augustin
- Berti N, Finco S, Battaïa O, Delorme X (2021) Ageing workforce effects in dual-resource constrained job-shop scheduling. Int J Prod Econ 237:108151. https://doi.org/10.1016/j.ijpe.2021.108151
- Bocewicz G, Smutnicki C, Jasiulewicz-Kaczmarek M, Wójcik R, Banaszak Z (2023) Competence-based robust scheduling of cyclic workforce relocation. IFACPapersOnLine 56(2):132–137. https:// doi.org/10.1016/j.ifacol.2023.10.1558
- Borgonjon T, Maenhout B (2022a) A two-phase Pareto front method for solving the bi-objective personnel task rescheduling problem. Comput Oper Res 138:105624. https://doi.org/10.1016/j.cor. 2021.105624
- Borgonjon T, Maenhout B (2022b) An exact approach for the personnel task rescheduling problem with task retiming. Eur J Oper Res 296(2):465–484. https://doi.org/10.1016/j.ejor.2021.03.047
- Buckhorst A (2023) Flexible work time organization and classic line-based assembly systems—a contradiction? Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Aachen (Doctoral viva. 17.08.2023)

- Burgert FL, Windhausen M, Kehder M, Steireif N, Mütze-Niewöhner S, Nitsch V (2024) Workforce scheduling approaches for supporting human-centered algorithmic management in manufacturing: A systematic literature review and a conceptual optimization model. Procedia Comput Sci 232(2024):1573–1583
- Burggräf P, Dannapfel M, Esfahani ME, Pulz C, Attig P (2021) Fertigungsmittel- und Personaleinsatzplanung. In: Burggräf P, Schuh G (eds) Fabrikplanung – Handbuch Produktion und Management, 2nd edn. vol 4. Springer Vieweg, Berlin, pp 273–364 https://doi.org/10.1007/978-3-662-61969-8
- Çakırgil S, Yücel E, Kuyzu G (2020) An integrated solution approach for multi-objective, multi-skill workforce scheduling and routing problems. Comput Oper Res 118:104908. https://doi.org/10.1016/ j.cor.2020.104908
- Chen Y, Le D, Yumak Z, Pu P (2017) EHR: A sensing technology readiness model for lifestyle changes. Mob Networks Appl 22(3):478–492
- Cummings TG (1978) Self-regulating work groups: a socio-technical synthesis. Acad Manage Rev 3(3):625–634. https://doi.org/10. 2307/257551
- Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. MISQ 13(3):319–340
- De Spiegelaere S, Van Gyes GG, Van Hootegem G (2016) Not all autonomy is the same. Different dimensions of job autonomy and their relation to work engagement & innovative work behavior. Human Fac Ergon Manuf Serv Ind 26(4):515–527
- Denkena B, Dittrich MA, Winter F, Wagener C (2016) Simulationbased planning and evaluation of personnel scheduling in knowledge-intensive production systems vol 10. Springer, pp 489–496 https://doi.org/10.1007/s11740-016-0693-4
- Denkena B, Dittrich MA, Winter F (2017) Competence-based personnel scheduling through production data. Procedia CIRP 63:265–270. https://doi.org/10.1016/j.procir.2017.03.114
- Döbel I, Leis M, Vogelsang M, Neustroev D, Petzka H, Riemer A, Rüping S, Voß A, Wegele M, Welz J (2018) Maschinelles Lernen – Eine Analyse zu Kompetenzen, Forschung und Anwendung. Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V, München
- Drezet LE, Billaut JC (2008) A project scheduling problem with labour constraints and time-dependent activities requirements. Int J Prod Econ 112(1):217–225. https://doi.org/10.1016/j.ijpe.2006.08.021
- Dwivedi YK, Williams MD (2008) Demographic influence on UK citizens' e-government adoption. Electron Gov Int J 5(3):261–274
- Eichner FA (2021) Der Einfluss des wahrgenommenen Alterns auf die Akzeptanz von Smart-Home-Technologien Wirkung der Future Time Perspective auf das Technology Acceptance Model. Schriften aus der Fakultät Sozial- und Wirtschaftswissenschaften der Otto-Friedrich-Universität Bamberg, vol 39
- Emery FE (1959) Characteristics of socio-technical systems. Document 527. Tavistock Institute of Human Relations, London
- Emery FE, Thorsrud E (1982) Industrielle Demokratie. Bericht über das norwegische Programm der industriellen Demokratie. Schriften zur Arbeitspsychologie, vol 25. Huber, Bern
- Faber M, Przybysz P, Latos B, Mertens A, Brandl C, Finsterbusch T, Härtel J, Kuhlang P, Nitsch V (2019) Empirical validation of the time accuracy of the novel process language Human Work Design (MTM-HWD[®]). Open Access J. https://doi.org/10.1080/ 21693277.2019.1621785
- Fan W, Liu J, Zhu S, Pardalos PM (2020) Investigating the impacting factors for the healthcare professionals to adopt artificial intelligence-based medical diagnosis support system (AIMDSS). Ann Oper Res 294:567–592
- Farahani A, Farahani H, Farahani G, Mousavi S (2022) Flexible personnel scheduling in large multi-product unpaced asynchronous assembly lines. In: 2022 27th International Conference on Au-

tomation and Computing (ICAC) Bristol, 01.09.2022–03.09.2022 IEEE, pp 1–6

- Fergen A, Schulte-Meine E, Vetter S (2022) Schichtarbeit. In: Schuhmann DHW (ed) Handbuch Arbeitszeit, pp 232–306
- Fink A (2014) Conducting research literature reviews, 4th edn. SAGE, Thousand Oaks (From the internet to paper / Arlene Fink, University of California at Los Angeles, The Langley Research Institute)
- Forschungsbeirat Industrie 4.0, acatech (2024) Künstliche Intelligenz und industrielle Arbeit – Perspektiven und Gestaltungsoptionen. Deutsche Akademie der Technikwissenschaften https://doi.org/ 10.48669/fb40_2024-1
- Fraccaroli F, Zaniboni S, Truxillo DM (2024) Challenges in the new economy: a new era for work design. Annu Rev Organ Psychol Organ Behav 11(1)
- Friedman B, Kahn PH, Borning A (2006) Value sensitive design and information systems. In: Zhang P, Galetta D, Zwass V (eds) Advances in management information systems. Human-computer interaction in management information systems: foundations, vol 5. M.E. Sharpe, pp 348–372
- Gabriel S, Bentler D, Grote EM, Junker C, Meyer zu Wendischhoff D, Bansmann M, Latos B, Hobscheidt D, Kühn A, Dumitrescu R (2022) Requirements analysis for an intelligent workforce planning system: a socio-technical approach to design AI-based systems. Procedia CIRP 2022(109):342–431–436. https://doi.org/10. 1016/j.procir.2022.05.274
- Gabriel S, Bentler D, Bansmann M, Latos B, Kühn A, Dumitrescu R (2023) Soziotechnische Gestaltung einer intelligenten Personaleinsatzplanung. Z Wirtschaftlichen Fabrikbetr (zwf) 118(1–2): 64–68. https://doi.org/10.1515/zwf-2023-1009
- Gallup-Institut (2022) Statistik Umfrage: Was soll ein Arbeitgeber Ihrer Meinung nach heutzutage bieten, um sein Personal zu halten bzw. Arbeitnehmer für sich zu gewinnen?
- Garhammer M (1994) Balanceakt Zeit. Auswirkungen flexibler Arbeitszeiten auf Alltag, Freizeit und Familie. Edition Sigma, Berlin
- Gefen D, Karahanna E, Straub DW (2003) Trust and TAM in online shopping: an integrated model. MISQ 27(1):51–90
- Grinter S, Hanscome R, Marian K, Chandra R, Xing J, Bobo D (2023) Market guide for workforce management applications. Gartner (https://www.gartner.com/en/documents/4641199)
- Guastaroba G, Côté JF, Coelho LC (2021) The multi-period Workforce scheduling and routing problem. Omega 102:102302. https://doi. org/10.1016/j.omega.2020.102302
- Guest D, Knox A, Warhurst C (2022) Humanizing work in the digital age: Lessons from socio-technical systems and quality of working life initiatives. Hum Relat 75(8):1461–1482
- Günther M (2010) Hochflexibles Workforce Management: Herausforderungen und Lösungsverfahren. Technische Universität Ilmenau (Dissertation. www.db-thueringen.de/servlets/ MCRFileNodeServlet/dbt_derivate_00022523/ilm1-2010000468. pdf)
- Gursoy D, Chi OH, Lu L, Nunkoo R (2019) Consumers acceptance of artificially intelligent (AI) device use in service delivery. Int J Inf Manage 49:157–169
- Gürsoy YB, Yılmaz ÖF, Çevikcan E (2023) Lot streaming in workforce scheduling problem for seru production system under Shojinka philosophy. Comput Ind Eng 185:109680. https://doi.org/ 10.1016/j.cie.2023.109680
- Hacker W (2006) Allgemeine Arbeitspsychologie. Psychische Regulation von Arbeitstätigkeiten, 2nd edn. Huber, Bern
- Hacker W, Richter P (1980) Psychologische Bewertung von Arbeitsgestaltungsmaßnahmen – Ziele und Bewertungsmaßstäbe. In: Spezielle Arbeits- und Ingenieurpsychologie in Einzeldarstellungen, vol 1. Verlag der Wissenschaften, Berlin
- Hackman JR, Oldham GR (1976) Motivation through the design of work: Test of a theory. Organ Behav Hum Perform 16(2):250–279

- Hackman JR, Oldham GR (1980) Work redesign. Addison-Wesley, Reading
- Hagemann V, Rieth M, Suresh A, Kirchner F (2023) Human-AI teams-Challenges for a team-centered AI at work. Front Artif Intell 6:1252897
- Hassenzahl M (2003) The thing and I: understanding the relationship between user and product. In: Blythe MA, Overbeeke K, Monk AF, Wright PC (eds) Funology: from usability to enjoyment. Springer, Dordrecht, pp 31–42
- Hess M (1988) Individuelle Arbeitszeitsysteme für Führungskräfte (Dissertation)
- Hesseln S, Zander G (2005) Wesentliche Funktionen der Personaleinsatzplanung. In: Fank M, Scherf B (ed) Handbuch Personaleinsatzplanung, Datakontext, Frechen
- Hornbæk K, Hertzum M (2017) Technology acceptance and user experience: A review of the experiential component in HCI. ACM Trans Comput Interact 24(5):33
- Hossain N, Yokota F, Sultana N, Ahmed A (2018) Factors influencing rural endusers' acceptance of e-health in developing countries: a study on portable health clinic in Bangladesh. Telemed J Ehealth. https://doi.org/10.1089/Tmj.2018.0039
- Huang YK, Hsieh CH, Li W, Chang C, Fan WS (2019) Preliminary study of factors affecting the spread and resistance of consumers' use of AI customer service. ACM International Conference Proceeding Series
- Humphrey SE, Nahrgang JD, Morgeson FP (2007) Integrating motivational, social, and contextual work design features: a meta-analytic summary and theoretical extension of the work design literature. J Appl Psychol 92(5):1332–1356
- Igbaria M, Zinatelli N, Cragg P, Cavaye A (1997) Personal computing acceptance factors in small firms: a structural equation model. MISQ 1997:279–302
- ISO 9241-210 (2019) Ergonomics of human-system interaction—Part 210: Human-centred design for interactive systems
- Johannhörster V, Kohn M, Kunz T, Schleper J, Waldmann U (2024) Live-Ortung von Beschäftigten in der agilen Personaleinsatzplanung. Datenschutz Datensicher 7:450–455
- Katiraee N, Calzavara M, Finco S, Battini D (2021) Consideration of workforce differences in assembly line balancing and worker assignment problem. IFAC-PapersOnLine 54(1):13–18. https://doi. org/10.1016/j.ifacol.2021.08.002
- Kelly S, Kaye SA, Oviedo-Trespalacios O (2023) What factors contribute to the acceptance of artificial intelligence? A systematic review. Telematics Inform 77:101925
- Kim D, Kim S (2021) A model for user acceptance of robot journalism: influence of positive disconfirmation and uncertainty avoidance. Technol Forecast Soc Chang 163:120448. https://doi.org/10.1016/ j.techfore.2020.120448
- Kiran DR (2019) Chapter 23—master production schedules. In: Kiran DR (ed) Production planning and control. Butterworth-Heinemann, pp 331–344 https://doi.org/10.1016/B978-0-12-818364-9. 00023-8
- Kirchner E, Schmid U (2023) Hybride KI Wissen und Daten kombiniert nutzen. Plattform Lernende Systeme. https://www. plattform-lernende-systeme.de/files/Downloads/Publikationen/ KI_Kompakt/PLS_KI_Kompakt_Hybride_KI.pdf. Accessed 1 Sept 2024
- Kizgin H, Jamal A, Dey BL, Rana NP (2018) The impact of social media on consumers' acculturation and purchase intentions. Inf Syst Front 20(3):503–514
- Kluge A, Ontrup G, Langholf V, Wilkens U (2021) Mensch-KI-Teaming: Mensch und Künstliche Intelligenz in der Arbeitswelt von morgen. Z Wirtsch Fabrikbetr 116(10):728–734
- Kuberkar S, Singhal TK (2020) Factors influencing adoption intention of ai powered chatbot for public transport services within a smart city. Int J Emerg Technol 11(3):948–958

- Latos B, Steinmann B, Bentler D, Gabriel S, Guhr N, Iseke A (2024) Welche Einflussfaktoren machen den Unterschied? Ein Ansatz zur Erklärung der KI-Akzeptanz am Beispiel einer intelligenten Personaleinsatzplanung, "Arbeitswissenschaft in-the-loop: Mensch-Technologie-Integration und ihre Auswirkung auf Mensch, Arbeit und Arbeitsgestaltung", GfA, Sankt Augustin (Hrsg.): Frühjahrskongress 2024, Stuttgart
- Lee MC (2009) Factors influencing the adoption of internet banking: an integration of TAM and TPB with perceived risk and perceived benefit. Electron Commer Res Appl 8(3):130–141
- Li N, Li Y, Sun M, Kong H, Gong G (2017) An optimization method for task assignment for industrial manufacturing organizations. Appl Intell 47(4):1144–1156. https://doi.org/10.1007/s10489-017-0940-1
- Liang Y, Lee SA (2017) Fear of autonomous robots and artificial intelligence: Evidence from national representative data with probability sampling. Int J of Soc Robotics 9(3):379–384
- Mansini R, Zanella M, Zanotti R (2023) Optimizing a complex multiobjective personnel scheduling problem jointly complying with requests from customers and staff. Omega 114:102722. https:// doi.org/10.1016/j.omega.2022.102722
- Martins R, Oliveira T, Thomas MA (2016) An empirical analysis to assess the determinants of SaaS diffusion in firms. Comput Human Behav 62:19–33
- Metall IG (2017) Arbeitszeit sicher, gerecht und selbstbestimmt. Ergebnisse Zahlen und Fakten zur Arbeitszeit. https://www. igmetall.de/download/20170529_2017_05_29_befragung_ansicht _komp_489719b89f16daca573614475c6ecfb706a78c9f.pdf (Created 05.2017). Accessed 10 July 2023
- Mlekus L, Maier GW (2021) More hype than substance? A meta-analysis on job and task rotation. Front Psycholoy 12:633530. https:// doi.org/10.3389/fpsyg.2021.633530
- Mlekus L, Bentler D, Paruzel A, Kato-Beiderwieden AL, Maier GW (2020) How to raise technology acceptance: user experience characteristics as technology-inherent determinants. Gr Interakt Org 51:273–283
- Mo Y, Zhao D, Du J, Syal M, Aziz A, Li H (2020) Automated staff assignment for building maintenance using natural language processing. Autom Constr 113:103150. https://doi.org/10.1016/j. autcon.2020.103150
- Mockenhaupt A (2021) Digitalisierung und Künstliche Intelligenz in der Produktion – Grundlagen und Anwendung. Springer Vieweg, Wiesbaden
- Morgeson FP, Campion MA (2003) Work design. In: Borman WC, Ilgen DR, Klimoski RJ (eds) Handbook of psychology: Industrial and organizational psychology, vol 12. John Wiley, Hoboken, pp 423–452
- Morgeson FP, Humphrey SE (2006) The Work Design Questionnaire (WDQ): developing and validating a comprehensive measure for assessing job design and the nature of work. J Appl Psychol 91(6):1321–1339
- Morgeson FP, Humphrey SE (2008) Job and team design: Toward a more integrative conceptualization of work design. In: Martocchio J (ed) Research in personnel and human resource management, vol 27. Emerald Group Publishing Limited, United Kingdom, pp 39–91
- Mütze-Niewöhner S, Mayer C, Harlacher M, Steireif N, Nitsch V (2022) Work 4.0: human-centered work design in the digital age. In: Frenz W (ed) Handbook industry 4. 0 : law, technology, society. Springer, Berlin, Heidelberg, pp 985–1019
- Nolte F, Guhr N, Richter A (2020) The journey towards digital work empowerment—conceptualizing IS-induced change on the shop floor. In: Proceedings of the 41st International Conference on Information Systems (ICIS)

- Oertig M, Zölch M (2020) HR-Strategien zur Flexibilisierung der Personalressourcen. In: Zölch M, Oertig M, Calabrò V (eds) Flexible Workforce
- Othman M, Bhuiyan N, Gouw GJ (2012) Integrating workers' differences into workforce planning. Comput Ind Eng 63(4):1096–1106. https://doi.org/10.1016/j.cie.2012.06.015
- Özder EH, Özcan E, Eren T (2020) A systematic literature review for personnel scheduling problems. Int J Info Tech Dec Mak 19(06):1695–1735. https://doi.org/10.1142/S0219622020300050
- Park YJ, Jones-Jang SM (2023) Surveillance, security, and AI as technological acceptance. Ai Soc 38(6):2667–2678. https://doi.org/ 10.1007/s00146-021-01331-9
- Parker SK, Boeing AA (2023) Workplace innovation in the digital era: a role for SMART work design. In: A research agenda for workplace innovation. Edward Elgar Publishing, pp 91–112
- Parker SK, Grote G (2022) Automation, algorithms, and beyond: Why work design matters more than ever in a digital world. Appl Psychol 71(4):1171–1204
- Parker SK, Knight C (2024) The SMART model of work design: a higher order structure to help see the wood from the trees. Hum Resour Manage 63(2):265–291
- Parker SK, Wall TD, Cordery JL (2001) Future work design research and practice: towards an elaborated model of work design. J Occupat & Organ Psyc 74:413–440
- Parker SK, Morgeson FP, Johns G (2017) One hundred years of work design research: looking back and looking forward. J Appl Psychol 102(3):403
- Patel N, Trivedi S, Faruqui N (2023) A novel sedentary Workforce scheduling optimization algorithm using 2 nd order polynomial kernel. In: 2023 International Conference on Smart Computing and Application (ICSCA) Hail, 05.02.2023–06.02.2023 IEEE, pp 1–7
- Rerkjirattikal P, Olapiriyakul S (2021) Noise-safe job rotation in multiworkday scheduling considering skill and demand requirements. J Ind Prod Eng 38(8):618–627. https://doi.org/10.1080/21681015. 2021.1951856
- Rinaldi M, Fera M, Bottani E, Grosse EH (2022) Workforce scheduling incorporating worker skills and ergonomic constraints. Comput Ind Eng 168:108107. https://doi.org/10.1016/j.cie.2022.108107
- Rischmeyer N (2021) Machine learning as key technology of AI: automated workforce planning. In: Glauner P, Plugmann P, Lerzynski G (eds) Digitalization in healthcare. Future of Business and Finance. Springer, Cham, pp 235–244
- Ruiz-Torres AJ, Mahmoodi F, Kuula M (2017) Quality assurance laboratory planning system to maximize worker preference subject to certification and preference balance constraints. Comput Oper Res 83:140–149. https://doi.org/10.1016/j.cor.2017.02.002
- Ryan RM, Vansteenkiste M (2023) Self-determination theory. In: The Oxford handbook of self-determination theory. University Press, Oxford, pp 3–30
- Sager M (2007) Entwicklung einer Methodik zur Gestaltung von flexiblen Arbeitszeitsystemen. Chemnitz (Dissertation. https://nbnresolving.org)
- Scherf B (2005) Ein Vorgehensmodell zur Personaleinsatzplanung. In: Fank M, Scherf B (eds) Handbuch Personaleinsatzplanung. Datakontext, Frechen, pp 15–52
- Schlick C, Bruder R, Luczak H (2018) Arbeitswissenschaft. Springer Vieweg, Berlin
- Schuhmann D, Wagner H (2022) Handbuch Arbeitszeit. Manteltarifverträge im Betrieb, 4th edn. Bund, Frankfurt Main
- Sharma R (2024) Human resource management practices: enhancing employee engagement and retention in a global context. J Adv Manag Stud 1(2):19–24
- Shin D, Zhon B, Biocca FA (2020) Beyond user experience: What constitutes algorithmic experiences? Int J Inf Manage 52:1–11. https://doi.org/10.1016/j.ijinfomgt.2019.102061

- Shrestha YR, Ben-Menahem SM, Krogh G (2019) Organisational decision-making structures in the age of artificial intelligence. Calif Manage Rev 61(4):66–83. https://doi.org/10.1177/000812561986 2257
- Simonsen J, Robertson T (2013) Routledge international handbook of participatory design vol 711. Routledge, New York
- Smit S, Tilman T, Lund S, Manyika J, Thiel L (2020) The future of work in Europe: Automation, workforce transitions, and the shifting geography of employment. www.mckinsey.com/featuredinsights/future-of-work/the-future-of-work-in-europe
- Sohn K, Kwon O (2020) Technology acceptance theories and factors influencing artificial Intelligence-based intelligent products. Telematics Inform 47:101324
- Statista (2023) Umfrage. Welche der folgenden Arbeitszeitmodelle würden Sie gerne in Anspruch nehmen? 1. August 2017. https:// de.statista.com/download/MTY3OTI0MTIwMCMjMTI3NDEw MyMjMTAxNjY3MyMjMSMjcGRmIyNTdGF0aXN0aWM=. Accessed 10 July 2023
- Strohm O, Ulich E (eds) (1997) Unternehmen arbeitspsychologisch bewerten. Ein Mehr-Ebenen-Ansatz unter besonderer Berücksichtigung von Mensch, Technik und Organisation. Mensch, Technik, Organisation, vol 10. vdf, Zürich
- Ulich E (2005) Arbeitspsychologie, 6th edn. Schäffer-Poeschel, Stuttgart
- Ulich E (2011) Arbeitspsychologie, 7th edn. Schäffer-Poeschel, Stuttgart
- Ulich E (2013) Arbeitssysteme als Soziotechnische Systeme eine Erinnerung. Psychol Des Alltagshandelns 6(1):4–12
- Vahedi-Nouri B, Tavakkoli-Moghaddam R, Hanzálek Z, Dolgui A (2022) Workforce planning and production scheduling in a reconfigurable manufacturing system facing the COVID-19 pandemic. J Manuf Syst 63:563–574. https://doi.org/10.1016/j.jmsy.2022. 04.018
- Vegetti M, Henning G (2022) Ontology network to support the integration of planning and scheduling activities in batch process industries. J Ind Inf Integr 25:100254. https://doi.org/10.1016/j.jii. 2021.100254
- van der Velden M, Mörtberg C (2015) Participatory design and design for values. In: van den Hoven J, Vermaas P, van de Poel I (eds) Handbook of ethics, values, and technological design. Springer, Dordrecht https://doi.org/10.1007/978-94-007-6970-0_33
- Venkatesh V, Bala H (2008) Technology acceptance model 3 and a research agenda on interventions. Decis Sci 39(2):273–315
- Venkatesh V, Morris M, Davis F, Davis M (2003) User acceptance of information technology: toward a unified view. MISQ 27(3):425–478
- Venkatesh V, Thong JY, Xu X (2016) Unified theory of acceptance and use of technology: a synthesis and the road ahead. J Assoc Inf Syst 17(5):328–376
- Verbeek PP (2011) Moralizing technology: Understanding and designing the morality of things. University of Chicago Press
- Volland J, Fügener A, Brunner JO (2017) A column generation approach for the integrated shift and task scheduling problem of logistics assistants in hospitals. Eur J Oper Res 260(1):316–334. https://doi.org/10.1016/j.ejor.2016.12.026
- Wang W, Xie K, Guo S, Li W, Xiao F, Liang Z (2023) A shift-based model to solve the integrated staff rostering and task assignment problem with real-world requirements. Eur J Oper Res 310(1):360–378. https://doi.org/10.1016/j.ejor.2023.02.040
- Wiendahl HP (2002) Wandlungsfähigkeit, Schlüsselbegriff der zukünftigen Fabrik. Werkstatttech Online 92(4):122–127
- Wu X, Schworm P, Yi L, Glatt M, Aurich JC (2023) An approach to Quantum Annealing-based workforce assignment in manufacturing systems. Procedia CIRP 120:1022–1027. https://doi.org/10. 1016/j.procir.2023.09.119

- Xiong Y, Li Z (2022) Staffing problems with local network externalities. Econ Lett 212:110338. https://doi.org/10.1016/j.econlet. 2022.110338
- Zölch M, Oertig M, Calabrò V, Kahriman A (2020) Flexibilisierung in der modernen Arbeitswelt. In: Zölch M, Oertig M, Calabrò V (eds) Flexible Workforce

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.