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Review

Social Sustainability in Production Planning: A Systematic Literature Review

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Abstract: Sustainable production includes economic, environmental, and social aspects. However, social sustainability has received less attention, especially compared to the economic aspects. Next to technical and organizational measures, social improvements within supply chains can also be achieved through suitable production planning. Within production planning, production programs are determined, and the assignment of available resources (e.g., employees) is specified. Thus, the utilization and workload of employees are defined. This systematic literature review investigates to what extent such employee-related social aspects are reflected in production planning and discusses whether economic aspects dominate them. For this, a Scopus database search was carried out and 76 identified approaches were analyzed and categorized regarding the occurring employee-related social aspects and their implementation. Thus far, the approaches mainly consider single aspects on single planning levels. A consideration of a broad set of aspects along the entire production planning has rarely been studied. In particular, health and safety aspects are considered on the levels of assembly line balancing and job rotation. However, their impact is primarily determined by the specific settings of the decision-maker. To support decision-makers, only a few studies have investigated the effects based on real application scenarios. Further potential might be an extended modeling of social and economic interdependencies and a consideration of employee-related social aspects in medium- to long-term production planning.

Keywords: employee; human; production planning; social sustainability; literature review

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1. Introduction

To satisfy the demands of customers and employees, sustainable production gains importance. According to the World Commission on Environment and Development, economic, environmental, and social aspects should be equally considered in order to "[...] meet the needs of the present without compromising the ability of future generations to meet their own needs" [1]. While the economic and environmental aspects have already been discussed widely (see, e.g., [2]), the social dimension is often neglected [3]. Especially, economic aspects are often prioritized over social aspects, although social improvements could provide financial benefits [4].

Within supply chains, health and safety aspects are the most important enablers for social sustainability [5]. With insufficient consideration of such aspects, employee productivity [6] and satisfaction [7] decrease. Manufacturing companies can influence such employee-related social aspects through Production Planning and Control (PPC) [8], as PPC assigns employees to specific jobs. Thus, the concrete utilization and workload of employees is determined. Furthermore, the PPC is also affected by these aspects and the dependent employee productivity (e.g., processing times) and availability (e.g., due to illness). As described in [9–11], PPC consists of a hierarchy of planning levels: Aggregate Production Planning (APP), Master Production Scheduling (MPS), lot sizing, and scheduling.

In this paper, the focus is on the given influence of employee-related social aspects along the hierarchy of production planning. Since the statement that the pillars of sustainability should have equal priority is more of an ethical view, this does not mean that the same preferential weights must be assigned to each pillar in decision-making, regardless of the contextual situation. Based on that, we analyze to what extent the impact of social aspects is already included and whether economic aspects dominate them. These and existing research gaps are derived from answering the following Research Questions (RQs):

RQ1: How are employee-related social aspects implemented and how does this affect their impact?
RQ2: How comprehensively are social aspects integrated and to what degree are short-term and long-term planning decisions supported?
RQ3: How widely is the impact of social consideration investigated using realistic application scenarios?

In the past, different review papers on social aspects in production planning have been published. So far, the focus has been on physical aspects. For this, ergonomic risks (see [8,12–14]), respectively musculoskeletal disorders (see [12,15]), are addressed in general and the energy expenditure (see [12,14]) is considered. However, primarily, the studies analyze only one single level of hierarchical production planning. The focus has been on lot sizing (see [8,14]) and scheduling (see [8,12,13,15,16]). The modeling of social aspects is addressed in [12,13] by differentiating between an integration in the constraints or the objective function. However, the impact of employee-related social aspects has not been investigated so far. To our knowledge, this literature review is the first to systematically address the social impact and regard the entire planning hierarchy, a broad understanding of employee-related social aspects, and the types of implementation used.

For this, the article is structured as follows. In Section 2, the theoretical background regarding employee-related social aspects and their implementation is discussed. The methodology used in this systematic literature review is presented in Section 3. The categorization and a survey of the identified articles are provided in Section 4. In Section 5, the answer to the RQs and the current impact of employee-related social aspects are discussed. A possible path for future research is presented in Section 6, and the article ends with a conclusion in Section 7.

2. Theoretical Background

2.1. Employee-Related Social Aspects

An insufficient consideration of employee-related social aspects can lead to increased physical and mental exhaustion and, therefore, to a decrease in performance [17]. Further consequences are increased error rates [18,19], decreased employee productivity [6], and lower employee satisfaction [7]. Regarding employee health, an increased heart rate, frustration, or more aggressive behavior occur in the short term [20]. In the long term, these lead to psychosomatic illnesses and resignation or demotivation [20], which also cause reduced efficiency, productivity, and employee availability [6,21]. Reasons for these complaints are complex work stress factors [22]. From the employees' perspective, these include, for example, high work intensity [23–25], the number of overtime hours [25], and deviations from regular working hours [23,25].

To improve (social) sustainability, various indicators and standards have been developed (see, e.g., [26]). Ref. [27] created a categorization of sustainable indicators. For this, 11 different standards were analyzed and relevant indicators were identified. Based on the National Institute of Standards and Technology (NIST), [27] categorized aspects of sustainability into the following dimensions: environmental stewardship, economic growth, social well-being, technological advancement, and performance management. The dimension of social well-being is further subdivided into these three areas: employee, customer, and community. The employee area includes the categories: health and safety, development, and satisfaction. Similarly, the Global Reporting Initiative (GRI) standard is based on the "triple bottom line" approach. It distinguishes between the economic, environmental, and social dimensions of sustainability [28]. These dimensions include different standards on indicators for assessing the sustainability of a company. As employee-related indicators, the GRI standards: 401 (employment), 403 (occupational health and safety), and 404 (training and education) can be affected by the PPC. Thus, based on [27] and the GRI standards, this systematic literature review includes the following four social categories: (occupational) health and safety, development (training and education), satisfaction, and employment. Note that, in the area of development, this paper is limited to approaches that consider concrete measures for professional development (e.g., training). Approaches that consider the improvement of productivity through the repetition of the same or similar activities are not in the scope of this paper. In the literature, these are referred to as learning or, more specifically, autonomous learning. Ref. [29] first considered autonomous learning for manufacturing systems. So far, numerous articles and review papers have emerged (e.g., [30–34]). Using this general categorization of employee-related social aspects, we assess how comprehensively these aspects are integrated in previous approaches and derive appropriate subcategories for each area based on the identified articles (see Figure 1).

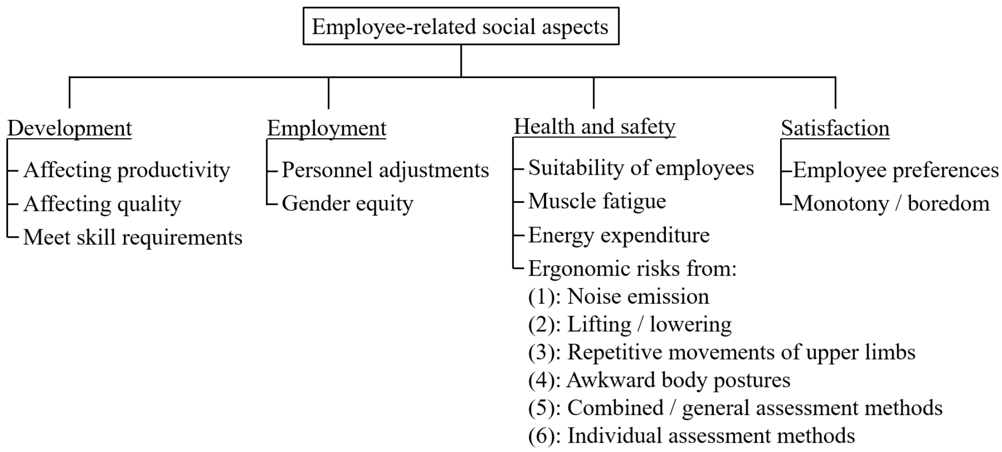

Figure 1. Categorization of employee-related social aspects.

In the area of development, it is considered that training of employees affects their performance. A distinction can be made between approaches that depict training-dependent productivity or training-dependent production quality. In addition, this area addresses also the requirement for employees to obtain appropriate skills through training measures in order to perform certain activities.

The employment area includes aspects related to possible personnel adjustments. For this, measures for capacity adjustment (e.g., hiring, firing, overtime) are integrated. Furthermore, aspects of equality between genders are also considered in the area of employment.

The aim of health and safety is to reduce the physical and mental hazards to which employees are exposed. For this purpose, it is considered that certain activities require corresponding physical and mental characteristics in order to avoid or reduce health hazards (suitability of employees). Furthermore, a reduction of MusculoSkeletal Disorders (MSDs) is intended. In the considered approaches, the physical fatigue an employee has to face is regarded. Muscle fatigue represents a static fatigue analysis based on the assumption that the fatigue of a muscle is related to the external load of the muscle, to the time of the load, and to the Maximum Voluntary Contraction (MVC) [35]. This enables the determination of a Maximum Endurance Time (MET), which is the maximum time a muscle can sustain a load. The energy expenditure method, introduced by [36], represents a dynamic fatigue analysis. The metabolic rate for corresponding activities is estimated by incorporating individual employee parameters (e.g., gender, body weight), as well as working parameters (e.g., posture, working speed, weight of the load, duration of the load). Moreover, this enables the determination of a rest allowance (see, e.g., [37,38]), which can be used to improve the fatigue level. However, the assessment of MSD cannot be separated from the analysis of ergonomic conditions [39]. In this respect, the factors considered in the approaches are ergonomic risks from: noise emission (1), lifting/lowering (2), repetitive movements of upper limbs (3), awkward body postures (4), combined/general assessment methods (5), and individual assessment methods (6). For the assessment of these factors, different direct, observational, subjective, and other psychophysiological methods exist. In the following, the most commonly used methods of risk assessment are briefly outlined. For further details on the measurement methods, we refer the interested readers to [40]:

- Daily Noise Dosage (DND) represents the time-weighted average of the combined sound level in the workplace [41,42].
- The National Institute for Occupational Safety and Health Lifting Equation (NIOSH-Eq) [43] provides the relationship between the load to be handled and a recommended load via the Lifting Index (LI). The recommended load reflects, for example, the weight of the load, the frequency and duration of lifting, the angle of symmetry, as well as the horizontal and vertical position.
- The OCcupational Repetitive Action tool (OCRA) assesses the risk of upper limbs [44]. For each hand, the risk from high-frequency repetitive activities is determined. The ratio between the actual and recommended frequency of activities (number of repetitions per minute) is calculated.
- The Ovako Working Analysis System (OWAS) is an observational method for evaluating posture in order to adjust working methods and workplaces [45].
- Rapid Upper Limb Assessment (RULA) addresses the posture of the upper limbs, neck, and trunk [46]. Rapid worksheets are provided, which allow the determination of the risk value in seven steps. Considered are, for example, applied forces, postures, as well as the repetition frequency.
- Rapid Entire Body Assessment (REBA) also addresses posture [47]. However, as an extension to RULA, REBA refers to the ergonomic risks for the whole body.
- The Ergonomic Assessment Work Sheet (EAWS) is an assessment method for general ergonomic risks [48]. For the assessment, factors such as postures, action forces, repetitive upper limb stresses, and other whole-body risk factors are combined. The result is two risk values, one for the whole body and one for the upper limbs.

With regard to employee satisfaction, it is considered firstly that employees have different preferences. These include preferences for assignment to specific jobs, as well as preferences for as many, respectively as few, assignment changes as possible. Secondly, in the area of satisfaction, the boredom of employees due to monotonous work is addressed as a psychological and cognitive aspect. The goal is to reduce employee boredom and increase employee motivation in order to improve employee performance.

2.2. Types of Implementation

Through the type of implementation of employee-related social aspects, we discuss which impacts of these aspects are enabled by the corresponding modeling. The general categorization of implementation types for employee-related social aspects is based on the differentiation of [12,13], who distinguish between implementation as a constraint, within a single-objective function and within a multi-objective function. Additionally, we derive subcategories based on the identified articles to further characterize how different types of implementation affect the social impact (see Figure 2).

For modeling employee-related social aspects as a constraint, a distinction is made between effect modeling and value limitation. Effect modeling involves how a social aspect affects a certain criterion. Thus, the correlations between social and other (primarily economic) aspects are reflected (e.g., how training measures affect the processing time). Moreover, concrete characteristics of social aspects can be limited in the constraints (value limitation). For this, upper, respectively lower, bounds are defined, which affect the social impact.

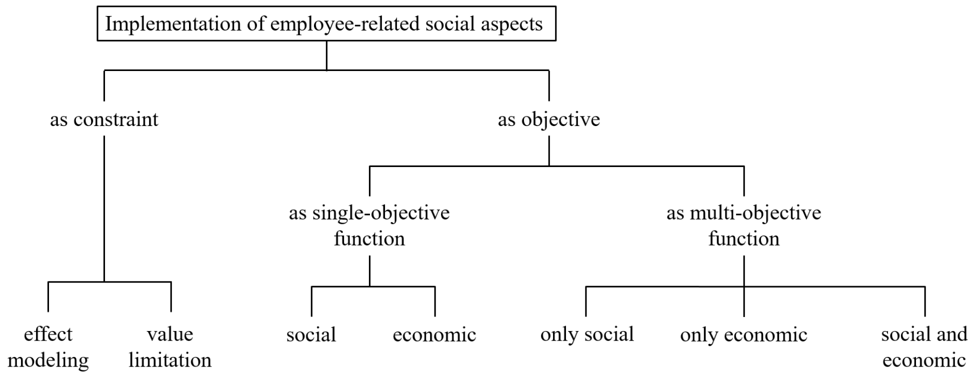

Figure 2. Categorization of existing implementation types of employee-related social aspects.

Next to a consideration of employee-related social aspects within the constraints, these can also be included in the objective function. For this, first, a distinction can be made whether a single-objective function or a multi-objective function is formulated. However, a more detailed differentiation is required to assess the social impact. Within a single-objective function, social aspects can be integrated directly—"social" (e.g., minimization of ergonomic risk values)—or transformed into an economic variable—"economic" (e.g., minimization of required recovery times). According to a transformation of the social aspects into an economic objective, social aspects are only improved if this results in an economic advantage. Within a multi-objective function, only social, only economic, or social and economic variables can be considered. If only social variables are included, several social aspects are optimized comparable to the consideration of social variables within a single-objective function. Thereby, for single-objective, as well as for multi-objective functions, the economic requirements are modeled in the constraints. If only economic variables are considered, the social aspects are transformed into economic variables comparable to the consideration of economic variables within a single-objective function and are included with further economic objectives. If social and economic variables are considered simultaneously, both are included directly in the objective function. In order to give a comprehensive overview, we also indicate the applied solution technique, if the social aspects are considered in the objective function. Section 4 presents the concrete categorization of the identified approaches, and in Appendix A (Table A1), a summary is given.

3. Methodology

This systematic literature review was conducted based on an established methodology as presented in Figure 3 (according to [49,50]), which is regularly used for systematic literature reviews on aspects of production planning (see, e.g., [2,13,51–54]).

The first step was to define the scope of the research (step A). As described in Section 1, this paper focuses on approaches to hierarchical production planning that include employee-related social aspects. To answer the defined RQs, the identified articles are categorized and the state-of-the-art analyzed.

For the initial search (step B), previous literature reviews were first searched (see [55]), identifying the review papers mentioned in Section 1. From these and the identified articles, the keywords shown in Table 1 were derived iteratively.

The keywords were used to perform the literature search (step C) in the Scopus database, searching the title, abstract, and keywords. For this, one keyword from group 1 and one keyword from group 2 were combined. We mentions that, due to the low number of hits, the keywords "aggregate production planning" and "master production scheduling" were used separately. Furthermore, the literature reviews mentioned in Section 1 showed an increasing number of articles in recent years. Therefore, to give an overview of the current state-of-the-art, articles from the last 10 years were considered. The research was last carried out on 9 May 2022. The result was 1303 articles (without duplicates). A PRISMA flow diagram summarizing the literature search process can be found in Appendix B (Figure A1).

Table 1. List of keywords for literature search.

Group 1 (Social)		Group 2 (Hierarchical Production Planning	
- boredom - ergonomic - fatigue - noise	- satisfaction - social - training	- “lot sizing” - “inventory control” - “job rotation” - “line balancing”	- “single machine” AND scheduling - “parallel machine” AND scheduling - “flow shop” AND scheduling - “job shop” AND scheduling
		- “aggregate production planning” - “master production scheduling”	

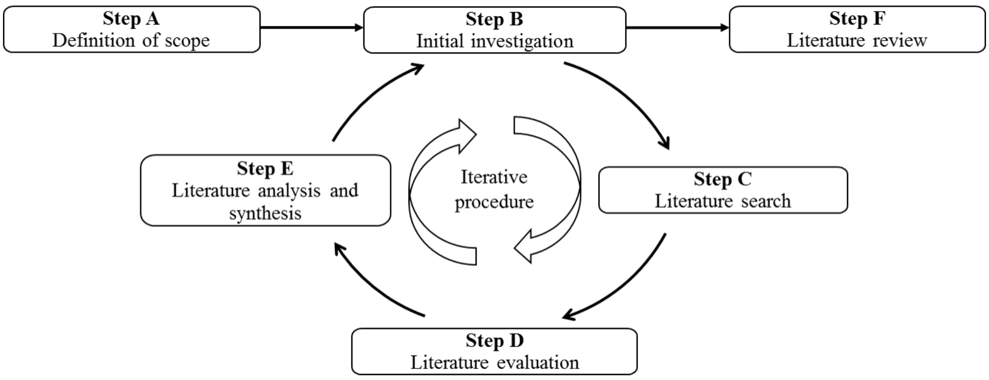

Figure 3. Six step-methodology for developing a literature review [49,52].

In step D, these articles were evaluated in two stages. First, the articles were pre-selected by reviewing the title and abstract. This resulted in the identification of 136 articles, for which the full texts were read in the second step. Finally, 76 relevant papers were identified. The pre-selection and the identification of relevant articles were based on the following criteria:

- Only peer-reviewed journal articles in English were considered.
- Only articles that address planning problems of hierarchical production planning and employee-related social aspects were considered.
- Only approaches that specify the planning problem as an optimization problem and solve it by exact or heuristic methods were considered.
- Approaches that consider only autonomous learning as a social aspect were not considered.

The relevant literature was analyzed and synthesized in step E. For each planning level, the analysis followed the categorization schemes described in Section 2 (see Figures 1 and 2). Furthermore, in order to evaluate the high number of approaches at the scheduling level, a more detailed differentiation was made. Based on [13], a distinction was made between single-machine, parallel-machine, job shop, and flow shop scheduling as typical machine and resource configurations. Furthermore, the Assembly Line Balancing Problem (ALBP) as a special form of the flow shop problem and the worker assignment/job rotation as a special class of scheduling problems were considered.

The presented steps (steps B to E) were performed iteratively to specify the established criteria and limitations. For the preparation of this systematic literature review (step F), the described result of these iterations was used.

4. Categorization and Survey of Existing Approaches

4.1. Aggregate Production Planning

For APP, employee-related social aspects from the areas of development and employment have been considered so far (see Table 2). Note that no articles at the MPS level could be identified that included employee-related social aspects.

In the area of development, employee training is implemented, which generates respective costs. Refs. [56–58] indicate that the productivity of employees is affected by training measures. The effects of training on productivity are formulated always in the constraints as effect modeling. For this, Refs. [57,58] define a training-level-dependent productivity factor that affects general capacity load factors. Ref. [56] directly defines training-level-dependent capacity load factors. Within the objective function, the total costs (total losses) are minimized. Thus, the training-dependent employee productivity is economically included, for example, by minimizing labor costs, hiring/firing costs, and training costs. Furthermore, Ref. [57] minimize the sum of the maximum shortages and personnel adjustments within a multi-objective function. Refs. [56,58] formulates a single-objective function.

Refs. [59,60] demonstrates that training improves production quality. They assume that trained employees cause fewer errors. The quality is maximized within a multi-objective function, next to minimizing the costs and maximizing the customer service (satisfaction) level. For this, the quality is expressed by the share of trained employees. In [60], production quality also depends on the supplier's quality. Furthermore, Ref. [59] define a minimum level of training that has to be maintained. For minimizing the customer satisfaction level, they minimize the absolute difference between delivery date and due date. Thus, earliness and tardiness are minimized.

Table 2. Literature categorization for aggregate production planning.

Reference	**Social Aspect**					**Implementation**				
	Development			Employment		As Constraints		As Single-Objective Function	As Multi-Objective Function	
	AP	*AQ*	*MSR*	*PA*	*GE*	*EM*	*VL*	*Economic*	*Only Economic*	*Social and Economic*
[56]	X					X		GA, PSO		
				X			X	GA, PSO		
[57]	X					X				MONLP
				X			X			MONLP
[58]	X					X			LP-metric	
				X			X		LP-metric	
[59]		X		X			X			GP
[60]		X								GP
[61]			X			X		RL		
[62]				X						GA
[63]				X			X			GoNDEF
					X					GoNDEF

AP—Affecting Productivity, AQ—Affecting Quality, EM—Effect Modeling, GA—Genetic Algorithm, GE—Gender Equity, GoNDEF—Generator of Non-dominated and Efficient Frontier, GP—Goal Programming, MONLP—Multi-Objective Nonlinear Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), MSR—Meet Skill Requirements, PA—Personnel Adjustments, PSO—Particle Swarm Optimization, RL—Reinforcement Learning, VL—Value Limiting.

Ref. [61] considers that different production levels require different training levels (skill requirements). Employees of the highest training level carry out the training from less trained employees during production. Accordingly, the number of trained employees affects the production output. Within a single-objective function, the profit is maximized. Thereby, meeting the skill requirements is monetarily considered by means of training-level-dependent personnel costs.

In the area of employment, the focus is on limiting personnel adjustments. For this, in the constraints, the share of hiring and layoffs relative to the number of employees in the previous period [56–59] and on acceptable layoffs [63] is restricted. Furthermore, the personnel adjustments are always accounted for monetarily within the objective function by costs for hiring/firing. Only [57,62,63] additionally include personnel adjustments as a social variable within a multi-objective function, simultaneous to economic variables. For this, the sum of fired employees [63], the sum of fired and hired employees [62], and the difference between hired and fired employees [57] are minimized. Thus, different aims could be observed: reducing total layoffs [63], reducing total adjustments [62], or reducing absolute changes of the number of employees [57].

Gender equity is only addressed in [63]. Next to profit, emissions, use of renewable energy sources, overtime, number of layoffs, backorders, number of CSR projects carried out, and the number of innovative projects carried out, also the difference between female and male employees is optimized within a multi-objective function. Furthermore, the deviations between the number of female and male employees are limited within the constraints.

4.2. Lot Sizing

Within lot sizing, aspects of health and safety have been integrated so far. Considering primarily extended EOQ approaches, the approaches regard the energy expenditure and ergonomic risks from lifting/lowering, as well as from individual assessment methods (see Table 3).

Table 3. Literature categorization for lot sizing.

Reference	**Social Aspect**		**Implementation**			
	Health and Safety		As Constraints		As Single-Objective Function	As Multi-Objective Function
	EE	*ER*	*EM*	*VL*	*Economic*	*Social and Economic*
[64]	X		X		analytical	
[65]	X	(2)	X		analytical	
[66]		(2)		X		MOP
[67]		(6)		X		MONLP
[68]		(6)			NLP	

EE—Energy Expenditure, EM—Effect Modeling, ER—Ergonomic Risks, MO(NL)P—Multi-Objective (Nonlinear) Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), NLP—Nonlinear Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), VL—Value Limiting, (2)—lifting/lowering, (6)—individual assessment methods.

The energy expenditure is integrated in [64,65]. For this, the energy expenditure is assessed according to [36]. Furthermore, exceeding a corresponding energy expenditure requires a rest allowance (according to [38]). To improve the energy expenditure, the rest allowance is valued monetarily. Considering that employees do not work during rest time, the potential cost impact from this production loss (non-productive time) is assessed with a cost factor within a single-objective function. The objective is to minimize the total costs, consisting of picking, traveling, storing, and resting costs.

Ergonomic risks from lifting and lowering activities are included in [65,66] and assessed according to the NIOSH-Eq. For this, [66] minimize the risk value directly within a multi-objective function, besides minimizing the costs. Additionally, the maximum accepted ergonomic risk is limited. Ref. [65] models the constraint that exceeding a defined risk value requires the use of additional equipment. Within the single-objective function, respective costs are considered for the potential use of the equipment.

Refs. [67,68] use an individual method to assess the ergonomic risks. Ref. [68] regards the emission of hazardous gases (sulfur dioxide). Thereby, emissions are evaluated with a cost factor and minimized within a single-objective function. In [67], the working hours are minimized as a metric for the social performance of a company. Additionally, the maximum acceptable working hours are limited. Besides, economic (costs) and environmental (carbon footprint) aspects are minimized within a multi-objective function.

4.3. Single-Machine, Parallel-Machine, Job Shop, and Flow Shop Scheduling

Due to the small number of articles, single-machine, parallel-machine, job shop, and flow shop scheduling were considered together. Included are social aspects from the area's development, health, and safety, as well as satisfaction so far (see Table 4).

Table 4. Literature categorization for single-machine, parallel-machine, job shop, and flow shop scheduling.

Reference	Production Planning Level	Social Aspect				Implementation			
		Development	Health and Safety		Satisfaction	As Constraints		As Single-Objective Function	As Multi-Objective Function
		AP	*EE*	*ER*	*EP*	*EM*	*VL*	*Economic*	*Social and Economic*
[69]	s-m	X				X		heuristic	
[70]	f-s	X				X			GA
[71]	j-s		X			X		heuristic	
[72]	j-s			(1)					GA
[73]	j-s			(1)					GA
[74]	f-s			(1)					DMORA
[75]	f-s			(1)					MOCGWO
[76]	j-s			(5)					GA
[77]	p-m				X				ϵ-con.
[78]	p-m				X		X		heuristic
[79]	p-m				X				heuristic

AP—Affecting Productivity, con.—constraint, DMORA—Discrete Multi-Objective Rider optimization Algorithm, EE—Energy Expenditure, EM—Effect Modeling, EP—Employee Preferences, ER—Ergonomic Risks, f-s—flow shop scheduling, GA—Genetic Algorithm, j-s—job shop scheduling, MOCGWO—Multi-Objective Cellular Grey Wolf Optimizer, p-m—parallel-machine scheduling, s-m—single-machine scheduling, VL—Value Limiting, (1)—noise emission, (5)—combined/general assessment methods.

The area of employee development is addressed in [69,70]. For a single-machine configuration, Ref. [69] consider (besides autonomous learning) an induced learning for which a fixed time interval (e.g., for training activities) is scheduled. For this, a correlation between training and makespan is modeled in the constraints by learning dependent processing times. Within a single-objective function, the makespan is minimized. Regarding a flow shop configuration, in [70], the use of new technologies affects the processing times, while lost days occur for the qualification of employees. Using a multi-objective function, the makespan and energy consumption are minimized and the weighted difference between job opportunities and lost days is maximized.

Health and safety aspects are included in job shop and flow shop configurations. The energy expenditure is addressed in [71] for a job shop configuration. For this, age-dependent processing times are defined and corresponding energy expenditure values are derived within the constraints (according to [36]). According to [38], a rest allowance is modeled, which affects the makespan, and within a single-objective function, the dependent makespan is minimized.

Furthermore, the ergonomic risks from noise emission and from a combined/general risk assessment are considered. A machine-dependent noise emission (according to [80]) is addressed in [72,73] for a job shop configuration and in [74] for flow shop scheduling according to an individual machine noise matrix. A machine-dependent and operation-mode-dependent noise emission (based on [73]) is introduced by [75] for a flow shop configuration. Next to the noise emission, further objectives are directly minimized within a multi-objective function, for example makespan [72–75], energy consumption [73,75], and total dust pollution [74]. Ref. [72] additionally minimizes the CO_2 emissions, the waste and water consumption, the average manipulated weight, the exposure time to vibrations, and the temperature exposure.

A general ergonomic risk includes [76] for job shop scheduling (assessed according to EAWS). Besides this social aspect, the makespan and energy consumption are minimized within a multi-objective function.

The employee satisfaction is reflected by task- and worker-specific preferences within a parallel machine configuration. For this purpose, a corresponding preference/satisfaction parameter is defined to determine the satisfaction of assigning tasks to workers. Refs. [77,78] formulate a multi-objective function to maximize employee satisfaction as well as on-time delivery. Ref. [78] additionally defines a minimum acceptable employee satisfaction. For maximizing the employee satisfaction, a variety score, and minimizing the maximum completion time, [79] introduce a multi-objective function. The variety score reflects the preferences of employees regarding varying job assignments.

4.4. Assembly Line Balancing Problem

Approaches of ALBP primarily focus on health and safety aspects. Especially the energy expenditure and ergonomic risks are addressed (see Table 5). Furthermore, the suitability of employees and the muscle fatigue as health and safety aspects are integrated. The areas of development and employment are only considered in [81]. For this, a required skill level of hired and inexperienced employees can be achieved through training measures. The personnel adjustments are considered by hiring and firing of employees. The objectives of the multi-objective function are minimizing the number of stations for a given cycle time and minimizing the costs for hiring, firing, training, and salary.

Table 5. Literature categorization for assembly line balancing problem.

Reference	**Social Aspect**						**Implementation**						
	Development	Employment	Health and Safety				As Constraints		As Single-Objective Function		As Multi-Objective Function		
	MSR	*PA*	*SE*	*MF*	*EE*	*ER*	*EM*	*VL*	*Social*	*Economic*	*Only Social*	*Only Economic*	*Social and Economic*
[81]	X						X					GA,PSO	
		X										GA,PSO	
[82]			X					X					
					X		X	X		MIP			
[83]				X									ϵ-con.
[84]				X					IDS				
[85]					X								MOP
[86]					X		X			MIP			
[87]					X		X	X		MIP			
[88]					X			X					GA
[89]					X			X					GA
[90]					X		X	X		heuristic			
[91]					X								BDA
[92]					X		X			MIP			
[93]					X								GA
[94]						(3)							MRBCRS
[95]						(3)		X					
[96]						(3)		X					heuristic
[97]						(3)							RIPGA
[98]						(4)							GA
[99]						(4)							GA
[100]						(4)							MOP
[101]						(4)							heuristic
[102]						(5)							MOP
[103]						(5)			GRASP				
[104]						(5)			MIP				

Table 5. *Cont.*

Reference	Social Aspect						Implementation						
	Development	Employment	Health and Safety				As Constraints		As Single-Objective Function		As Multi-Objective Function		
	MSR	*PA*	*SE*	*MF*	*EE*	*ER*	*EM*	*VL*	*Social*	*Economic*	*Only Social*	*Only Economic*	*Social and Economic*
[105]						(5)					GRASP		
[106]						(5)							MOP
[107]						(5)							MOP
[108]						(6)		X					
[109]						(6)		X					

BDA—Benders' Decomposition Algorithm, con.—constraint, EE—Energy Expenditure, EM—Effect Modeling, ER—Ergonomic Risks, GA—Genetic Algorithm, GRASP—Greedy Randomized Adaptive Search Procedures, IDS—Iterative Dichotomic Search, MF—Muscle Fatigue, MIP—Mixed-Integer Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), MOP—Multi-Objective Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), MRBCRS—Multiple-Rule-Based Constructive Randomized Search, MSR—Meet Skill Requirements, PA—Personnel Adjustments, PSO—Particle Swarm Optimization, RIPGA—Restarted Iterated Pareto Greedy Algorithm, SE—Suitability of Employees, VL—Value Limiting, (3)—repetitive movements of upper limbs, (4)—awkward body postures, (5)—combined/general assessment methods, (6)—individual assessment methods.

Regarding the area of health and safety, Ref. [82] consider the suitability of employees by the psychological demand of workstations using a weighted rigidity measure. The rigidity measure reflects the flexibility in work methods and the opportunity for individual decision-making. While minimizing the costs within a single-objective function, the maximum acceptable psychological demand is limited within the constraints.

Refs. [83,84] include the general muscle fatigue (according to [35]). Thereby, the current capacity of the muscle depends on the MVC and the external load the muscle is exposed to. In [83], the fatigue score and the number of stations are minimized for a given cycle time within a multi-objective function. Ref. [84] additionally considers the muscle recovery (according to [110]). They present an exact algorithm for low- and medium-sized instances. Within the algorithm, first the number of workstations is minimized for a given cycle time. Subsequently, the muscular capacity is improved iteratively.

The energy expenditure is included in different ways. In [82], exceeding a given energy expenditure parameter requires the use of additional equipment. This causes costs that are minimized within a single-objective function. Furthermore, the energy expenditure is limited. In [86,87,90,92], exceeding a respective threshold requires a rest allowance. The correlation between energy expenditure and rest allowance is modeled in the constraints, affecting the cycle time. For this, a maximum cycle time is given, and additionally, in [87,92], the maximum ergonomic load is limited. Within a single-objective function, the objective is to minimize the number of operators/stations [86,87]. Ref. [90] minimizes the smoothness index in order to have similar workstation processing times and the costs per cycle considering the costs of stations and resources per minute. Ref. [92] minimizes the cycle time. Directly within a multi-objective function, the energy expenditure is included in [85,88,89,91,93]. Thereby, for a given number of stations, the energy expenditure and the cycle time per station, as well as the respective deviations between the stations are minimized in [85]. Furthermore, for a given number of stations, Ref. [91] minimizes the cycle time, the total energy expenditure for the assembly line, and the total energy expenditure of each station (by minimizing the total energy expenditure of the station with the maximum energy expenditure). Furthermore, Ref. [91] consider a human–robot collaboration and maximize the number of operations allocated to the preferred resource. The preferred resources (human or robot) for each operation are considered by a proposed classification. For a given cycle time, Refs. [88,89] minimize the deviations in the energy expenditures between stations and the number of stations. Additionally, Ref. [88] minimize a required skill score of stations. In [89], the ALBP is extended by job rotation, and they consider costs of equipment installed, including collaborative robots. Furthermore, for a given cycle time, Ref. [93] minimize the number of stations and a smoothness index, which is the standard deviation of the energy expenditure.

Furthermore, from the area of health and safety, the ergonomic risks from repetitive movements of the upper limbs, from awkward body postures, and from combined/general assessment methods, as well as individual assessment methods are addressed. Refs. [94–97] include the ergonomic risk from repetitive movements of the upper limbs (assessed according to OCRA). For a given cycle time, Ref. [95] limit the acceptable deviations of the risk value between stations and minimizing the number of stations within a single-objective function. Furthermore, for a given cycle time, Ref. [96] minimize the deviations of the risk value between stations, the average risk value over all stations, the number of stations, and the number of stations with a very high risk (red stations) within a multi-objective function. Additionally, a maximum acceptable risk value is defined within the constraints. For a given number of stations, Ref. [94] minimize the average risk value over all stations, the deviations of the risk values between stations, the number of red stations, and the cycle time, and Ref. [97] minimize the maximum ergonomic risk and cycle time within a multi-objective function.

The ergonomic risk from awkward body posture is assessed according to OWAS in [99] and by RULA in [98,100,101]. A multi-objective function is modeled to minimize the variation of the risk value between stations. Additionally, for a given number of stations, Ref. [99] minimize the maximum risk value and the deviations between a given cycle time and workstation time. Ref. [101] presents a two-step approach. In the first step, the cycle time is minimized. This is followed by a reassignment, if the composite index of variation is improved. This is calculated as the weighted and normalized sum of the deviations of the cycle time and the ergonomic risk related to the previous solution (step 1). For a given cycle time, Refs. [98,100] minimize the risk deviations between stations and the number of stations. Furthermore, Ref. [98] minimize the maximum ergonomic risk and [100] the deviations of workstation time between stations.

A combined/general assessment method is applied in [102–107]. Within a single-objective function, Refs. [103,104] combine and minimize the ergonomic risks from the movements of the upper limbs (assessed according to OCRA), awkward body postures (assessed according to RULA), and lifting/lowering activities (assessed according to the NIOSH-Eq). Given the number of stations and cycle time, different specifications of the objective function are introduced to minimize the maximum risk, the absolute risk deviations between stations, and the difference between the maximum and minimum risk. Within a multi-objective function, the ergonomic risk is minimized in [102,105] regarding the movements of the upper limbs (assessed according to OCRA), awkward body postures (assessed according to RULA), and lifting/lowering activities (assessed according to the NIOSH-Eq). Next to maximum risk value, Ref. [102] minimize the spatial workstation area, as well as the cycle time for a given number of stations. Additionally, Ref. [105] minimize the risk variances between stations for a given number of stations and cycle time. Furthermore, within a multi-objective function, Ref. [106] minimize the number of stations for a given cycle time and distribute the ergonomic risk equally among stations. For this, they regard a combined ergonomic risk from lifting/lowering (assessed according to the NIOSH-Eq), movements of the upper limbs (assessed according to OCRA), and awkward body postures (assessed according to OWAS), as well as a general ergonomic risks (assessed according to the EAWS) and further assessment methods. Ref. [107] minimize the cycle time and the deviations of the ergonomic risk between stations for a given number of stations within a multi-objective function. They combine ergonomic risks from lifting, twisting of the wrist, twisting of the hip, and squatting.

Refs. [108,109] consider the ergonomic risk using an individual assessment method. For a given cycle time, the number of stations is minimized within a single-objective function. Additionally, a maximum acceptable ergonomic risk is defined, which [109] derive from empirical studies as a gender- and age-specific threshold.

4.5. Worker Assignment/Job Rotation

Approaches for worker assignment/job rotation primarily include aspects of health and safety (see Table 6). Furthermore, employee satisfaction regarding monotonous work is addressed. The area of employment, specifically meeting skill requirements, is only considered in [111]. For this, each station requires a respective skill level. The skill levels can be achieved through training measures (and autonomous learning), which cause respective costs. The costs are minimized using a single-objective function.

Regarding the health and safety area, Refs. [112–114] consider the suitability of employees. Within a multi-objective function, Ref. [112] optimize 39 ergonomic and competency criteria and Ref. [113] assess the employee suitability based on 42 criteria. Ref. [114] reflects the employee suitability by age, size, skill level (according to suitability test), and experience (according to company affiliation) and model a dependent productivity. A single-objective function is used to minimize the dependent cycle time.

Table 6. Literature categorization for worker assignment/job rotation.

Reference	**Social Aspect**						**Implementation**						
	Development	Health and Safety				Satisfaction	As Constraints		As Single-Objective Function		As Multi-Objective Function		
	MSR	*SE*	*MF*	*EE*	*ER*	*MB*	*EM*	*VL*	*Social*	*Economic*	*Only Social*	*Only Economic*	*Social and Economic*
[111]	X						X			heuristic			
						X		X					
[112]		X									GA		
[113]		X									MOP		
					(3)			X			MOP		
[114]		X					X			MIP			
[115]			X				X			heuristic			
[116]			X		(2)				GA				
[117]			X										ICRO
[89]				X				X					GA
[118]					(1)			X					
[119]					(1)			X					
						X	X			GA, RGA			
[120]					(1)			X					
[121]					(3)	X					GA		
[122]					(3)			X	MINLP				
[123]					(4)			X	MINLP				
[124]					(4)			X	MINLP				
[125]					(5)				heuristic				
[126]					(5)				TS				
[127]					(5)						GA		
[128]					(6)			X	MIP				
[129]					(6)			X					MOP
[130]					(6)			X	MIP				
[131]					(6)			X					
[132]						X	X					VNS	
[133]						X	X			GA			

EE—Energy Expenditure, EM—Effect Modeling, ER—Ergonomic Risks, GA—Genetic Algorithm, ICRO—Improved Chemical Reaction Optimization, MB—Monotony/Boredom, MF—Muscle Fatigue, MI(NL)P—Mixed-Integer (Nonlinear) Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), MOP—Multi-Objective Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), MSR—Meet Skill Requirements, RGA—Randomized Greedy Algorithm, SE—Suitability of Employees, TS—Tabu Search, VL—Value Limiting, VNS—Variable Neighborhood Search, (1)—noise emission, (2)—lifting/lowering, (3)—repetitive movements of upper limbs, (4)—awkward body postures, (5)—combined/general assessment methods, (6)—individual assessment methods.

Muscle fatigue in [115] is assessed from the execution of previous and current jobs (according to [35]). For this, muscle fatigue affects the Human Error Probability (HEP), which is minimized within a single-objective function. In [116], muscle fatigue is modeled (according to [134]), considering work intensity, as well as work duration related to six different body regions. The weighted and summed up risk values are minimized within a single-objective function, in addition to the ergonomic risks from lifting/lowering. Next to minimizing the cycle time, Ref. [117] minimize the muscle fatigue (according to [21]) directly within a multi-objective function for a human–robot collaborative assembly cell. Fatigue in this case depends on the task execution and a break time (recovery).

The energy expenditure is only considered in [89], who enhance an ALBP by job rotation (see Section 4.4).

For reducing the ergonomic risks from noise emission, Refs. [118–120] limit the acceptable noise level. For this, they use the DND. According to [41], in [118], the daily permissible noise exposure limit is 90 dBA. In [119,120], the daily permissible noise exposure limit is 85 dBA (according to [42]). As the objective function, Ref. [118] present different alternatives to maximize a competence score and to minimize the number of required workers. The competence score reflects the appropriate assignment of required and available competencies per station and employee. Within a single-objective function, Ref. [119] minimize the total delay caused by deficiency of skill and job satisfaction and Ref. [120] minimize the labor costs, consisting of daily wages and overtime wages.

The ergonomic risks from lifting/lowering within the job rotation is only addressed in [116]. In addition to the muscle fatigue, the ergonomic risk (assessed according to the NIOSH-Eq) is minimized. Furthermore, they also consider the working height. For this, they formulate a single-objective function, where the weighted sum of the different risk scores is minimized.

Assessed according to OCRA, Refs. [113,121,122] consider the ergonomic risk from repetitive movements of the upper limbs. For this, Refs. [113,122] define a maximum acceptable risk value within the constraints. In [121], the ergonomic risk value is directly minimized within a multi-objective function. Furthermore, within a multi-objective function, Ref. [113] maximize a movement score between successive periods simultaneous to the employee suitability. The movement score assesses the physical load of employees. Thus, differences in the movement scores in successive periods contribute to the change between load and recovery. Ref. [122] introduce two alternative single-objective functions. The first alternative maximizes the production output subject to the maximum ergonomic risk and the maximum acceptable coefficient of variation of the risk over all stations. The second alternative is to minimize the standard deviation of the ergonomic risk over all stations, ensuring required production levels.

The ergonomic risks from awkward body postures are addressed in [123,124] within a single-objective function. In [123], as the first alternative, the coefficient of variation of awkward body postures (assessed according to RULA) is minimized and a given production output to be achieved. In the second alternative, the production output is maximized and the maximum acceptable coefficient of variation of ergonomic risk is limited. Each case also limits the maximum acceptable ergonomic risk. In [124], the ergonomic risks are assessed according to REBA. Additionally, the successive assignment of employees to stations with high ergonomic loads for the same body part is limited.

Refs. [125–127] include a combined/general risk assessment. Within a single-objective function, the value of the general risk (assessed according to EAWS) is minimized [125,126]. In [127], ergonomic risks regarding different body parts and from different movements are combined into an overall risk. Within a multi-objective function, each score of the ergonomic risk from the movements of the upper limbs (assessed according to OCRA), awkward body postures (assessed according to RULA), and lifting/lowering activities (assessed according to the NIOSH-Eq) is minimized.

The ergonomic risk is also included in [131] as hazard exposure using an individual assessment method and limiting the maximum acceptable risk. Within a multi-objective function, the number of workers and the worker-task changeover are minimized and a worker-task fit-score is maximized. The worker–task fit-score results from a suitable assignment of the required and necessary competencies per station and employee. Furthermore, using an individual assessment method, [128] limit the maximum allowable Hand–Arm Vibrations (HAVs). Three different model specifications are considered. In Model 1, costs are minimized without considering HAV. In Model 2, HAVs are integrated and the monetary deviations from Model 1 are minimized. Only HAVs are minimized in Model 3. In [129,130], the physical workload is assessed according to an individual method. Ref. [130] describes this as a company internal standard consisting of 5 categories and 20 subcategories. A single-objective function is formulated to minimize the risk value while limiting successive assignments to stations with a high ergonomic workload for the same body part. In [129], a multi-objective function is modeled to minimize the cycle time and the risk value where successive assignments to stations with high physical workload are limited.

The area of satisfaction is addressed in [111,119,121,132,133] regarding monotonous work. Next to required employee skills (development area), Ref. [111] consider that employees are suitable for different stations, which is referred to as multi-functionality. By limiting the minimum and maximum acceptable multi-functionality within the constraints, employee preferences for frequent and infrequent rotations are considered. Furthermore, a minimum time interval between repeated assignments is defined. Refs. [119,132,133] model that processing times depend on employee boredom (besides autonomous learning and forgetting). The interdependencies between the assignments and the autonomous learning/forgetting (employee skills), as well as the boredom are formulated within the constraints. Within a multi-objective function, Ref. [132] minimize the dependent idle time, the deviation from a given cycle time, the number of deviations, and the number of employees. Furthermore, within a single-objective function, in [119,133], the weighted and normalized sum of the difference between the upper bound and the current skill, as well as motivation level is multiplied with a maximum delay of a machine and the assignment variable. Thus, time losses caused by insufficient employee skills and boredom are minimized. Additionally, in [133], a minimum time interval must be maintained between two repetitive employee assignments to a station. In [121], the satisfaction is interpreted as monotony due to repeated and similar job assignments. Within a multi-objective function, the number of repetitive assignments is directly minimized, next to the ergonomic risk value (assessed according to OCRA).

5. Discussion

5.1. RQ 1: How Are Employee-Related Social Aspects Implemented, and How Does This Affect Their Impact?

Employee-related social aspects are integrated in the objective function in most of the approaches (in 70 from 76 approaches) and in the constraints in about 55% of the approaches (in 42 from 76 approaches), while only in six approaches, the social aspect is exclusively addressed within the constraints [95,108,109,118,120,131]. Regarding a consideration within the objective function, primarily multi-objective functions are formulated (in 42 approaches), while social, as well as economic variables are optimized simultaneously (social and economic variables) (in 34 approaches). For single-objective functions, social aspects are primarily transformed into economic variables (in 17 approaches). However, the concrete impact of social aspects cannot necessarily be deduced from these. Therefore, in the following, we discuss what effects the different types of implementation can have on the social impact.

With effect modeling within the constraints, social aspects are transformed into an economic objective. So far, this has been applied especially for considering that training measures affect productivity [56–58,69,70] and training measures are necessary to meet employee skill requirements [61,81,111]. Additionally, the energy expenditure is primarily addressed by effect modeling [64,65,71,82,86,87,90,92]. Furthermore, [68] (emission of hazardous gases), as well as [56–59,63] (personnel adjustments) transform the social aspect directly within the objective function by evaluating it with a respective cost rate, and Ref. [60] derive the production quality directly in the objective function from the share of trained employees. Thus, social improvements only occur if also an economic advantage occurs.

If the social aspects are limited in the constraints (value limitation), their impact depends on the defined thresholds. Typically, the limit is set to prevent employee overloads. However, how these should be determined to avoid an employee overload is not further discussed. Only in the area of health and safety can appropriate limits be derived if common methods for assessing the social aspects are applied, for example energy expenditure [82,87–89], the DND [118–120], the NIOSH-Eq [66], and OCRA [95,96,113,122].

Only social variables are primarily included in approaches for worker assignment/job rotation [112,113,116,121–128,130]. For this, mainly single-objective functions are formulated, and only [112,113,121,127] include further social aspects within a multi-objective function. For the ALBP, Refs. [84,103,104] include exclusively social variables within a single-objective function and [104] within a multi-objective function. If only social variables are considered in the objective function, the social dimension might dominate. However, the economic conditions are modeled in the constraints. Thus, economic restrictions (e.g., cycle time, number of stations or workers) have to be respected. Since no concrete specifications are made for determining suitable economic parameters, it is to be expected that these will initially be determined from an economic point of view. Therefore, social improvements might be possible only if the economic optimum is adhered to.

When social and economic variables are modeled simultaneously in a multi-objective function, the impact of the social aspects depends on the particular solution method and the settings of the Decision-Maker (DM). Refs. [96,100] optimize the number of stations first and the other objective criteria thereafter. Thus, the social dimension is only improved if an economic optimum is maintained. In [94], an economic objective criterion (cycle time) also dominates. Furthermore, within the articles, a priori, as well as a posteriori solution methods are applied. Using a priori methods, the DM specifies individual preferences before solving the model [57,59,60,77,79,83,88,89,91,98,99,101,102,107,117,129]. Thereby, the included objective criteria are usually transformed into a weighted (and normalized) single-objective function. The respective weights of each objective criterion are to be determined in advance by the DM. However, within the identified approaches, the DM is not further supported regarding a suitable specification of these parameters and weights. For approaches using an a posteriori method, first, (Pareto) efficient frontiers are identified [62,63,70,72–76,78,85,97]. Accordingly, a suitable solution can be selected from the set of identified (non-)dominated points to meet the DM's preferences. Additionally, this enables the assessment of trade-offs between different objective criteria. Thus, an equal impact of social and economic variables might be possible, respecting the DM's preferences.

Within the articles, different types of modeling are used, which provide social improvements. However, so far, the balance between social and economic dimensions is not considered and investigated in more detail. Especially, the economic settings (e.g., limits within the constraints, weights within the objective function) are essential for the social impact. However, the focus has not been on the analysis of such different model settings. It remains open what effects changed economic conditions have. Only in the approaches that use an a posteriori solution method, this can be derived from (Pareto) efficient frontiers.

5.2. RQ 2: How Comprehensively Are Social Aspects Integrated, and to What Degree Are Short-Term and Long-Term Planning Decisions Supported?

Within the approaches, social aspects from all considered areas could be identified. However, there is a significant prevalence for the health and safety area (60 from 76 approaches). Thereby, primarily ergonomic risks (in 41 approaches) and energy expenditure (in 13 approaches) are included. Regarding the further areas, an equally high consideration of social aspects can be observed: development—10 approaches, employment—7 approaches, and satisfaction—8 approaches.

Even if a broad set of social aspects is introduced within the articles, most approaches only address aspects of one area solely. Only [56–59,81] include aspects from development (affecting productivity [56–58], affecting quality [59], meeting skill requirements [81]), as well as employment (personnel adjustments). Furthermore, the employee satisfaction (monotony/boredom) is combined with the employment area (meeting skill requirements [111]) and with health and safety aspects (ergonomic risks from noise emission [119], from repetitive movements of upper limbs [121]). Furthermore, within a single social area, only a few approaches consider multiple aspects. For this, Ref. [63] regard personnel adjustments and gender equity (employment area). Within the health and safety area, the suitability of employees is combined with the energy expenditure [82] and with ergonomic risks from repetitive movements of upper limbs [113]. Additionally, Ref. [65] regard the energy expenditure, as well as ergonomic risks from lifting/lowering. Ref. [116] includes muscle fatigue and ergonomic risks from lifting/lowering. Thus, there is no approach with a comprehensive integration of multiple social aspects from different areas so far. However, for a broad set of aspects, the approaches demonstrate how single aspects could be integrated. Accordingly, a more comprehensive combination of several aspects remains open. Nevertheless, it should be mentioned that the social aspects are considered at different planning levels.

So far, social aspects are considered at the APP, lot sizing, and scheduling level, while most articles could be identified for the ALBP (29 approaches) and worker assignment/job rotation (24 approaches). Accordingly, more than two-thirds occur on these two planning problems, where [89] presents a combination of both. Thus, long-term planning decisions are rarely supported. Furthermore, the approaches address primarily one single planning level.

The area of development (affecting productivity [56–58], affecting quality [59,60], meet skill requirements [61]) and employment (personnel adjustments [56–59,62,63], gender equity [63]) are usually addressed at the APP level. A reason for this concentration of the APP might be that, due to training measures and personnel adjustments, the available capacities are affected, which have to be harmonized with the production program. This is usually realized within the long-term production planning. However, Refs. [69,70,81,111] demonstrate that aspects of development (affecting productivity [69,70], meet skill requirements [81,111]) and employment (personnel adjustments [81]) also might be relevant for the scheduling level (single-machine scheduling [69], flow shop scheduling [70], ALBP [81], worker assignment/job rotation [111]).

The health and safety aspects are addressed within approaches for lot sizing, as well as scheduling. Even if at the lot sizing level, health and safety aspects (energy expenditure [64,65], ergonomic risks from lifting/lowering [65,66], and ergonomic risks from individual assessment methods [67,68]) have always been integrated so far, there is a significant prevalence of the scheduling level (especially ALBP and worker assignment/job rotation). Thus, health and safety aspects are rarely addressed within long-term planning decisions. Regarding the suitability of employees and muscle fatigue, a comparable number of approaches for the ALBP and worker assignment/job rotation can be observed. Only the energy expenditure primarily is considered for the ALBP [82,85–93]. Nevertheless, also for job shop scheduling [71], the energy expenditure might be relevant so far. However, most frequently, ergonomic risks from different assessment methods are integrated, whereby no prevalence of a specific method can be observed. The existence of these proven assessment methods could be a reason for the significant focus of these aspects, because it enables an objective and generally valid evaluation of corresponding planning specifications. Furthermore, this also explains the focus on scheduling approaches, as the assessment methods usually consider concrete movements. Such details are usually provided for short-term planning decisions.

Regarding the satisfaction area, employee preferences are only considered for parallel-machine scheduling [77–79] and monotony/boredom only for worker assignment/job rotation [111,119,121,132,133]. Specifically, monotony/boredom results from repeated assignments of employees to stations/tasks. Accordingly, these aspects are primarily addressed within worker assignment/job rotation, which attempts to achieve an even distribution of work through assignment changes.

The different frequency of the corresponding social aspects within the individual planning levels is reasonable. However, this does not necessarily indicate that a consideration at several planning levels is not feasible or relevant, as demonstrated by certain approaches. However, especially in the area of health and safety, suitable methods are required that enable an aggregated assessment of social aspects, so that they can also be applied, for example, within long-term planning approaches. Such a consideration at several planning levels is relevant insofar as in the planning hierarchy, the single levels are linked to each other via corresponding restrictions. Since this has not been investigated in the approaches so far, on the one hand, it remains open how the integration of social aspects into medium- to long-term planning influences the subsequent planning levels. On the other hand, the extent to which social aspects integrated into short-term planning can already be influenced by the higher planning levels is also not investigated.

5.3. RQ 3: How Widely Is the Impact of Social Consideration Investigated Using Realistic Application Scenarios?

In addition to the presented literature categorization, we also regard the investigations carried out within the approaches. Thereby, about half of the approaches stated that their research is based on real industrial application cases. Primarily, data from the automotive industry are used. However, a specific company is presented, for example, in [56–59,70,73,102–105].

Regarding the analyses presented in the approaches, mainly the aim is to prove the suitability of the proposed solution method. Only a few approaches discuss real social and economic correlations. Refs. [65,132], for example, demonstrate that due to the implementation of social aspects, the economic results do not decrease and, in some cases, even improve. However, in both approaches, the social aspects are transformed into economic variables by effect modeling. Thus, an economic decrease could not be expected from the social implementation, only from a more realistic modeling. Furthermore, Refs. [63,107,109,122,128,129] demonstrate that, due to social improvements, the economic optimum will not be achieved. However, the relative improvements in the social dimension are higher than the relative deviations from the economic optimum. For example, Ref. [63] show that environmental, social, and cultural aspects can be improved simultaneously by 61%, 36%, and 95%, respectively, while reducing the profit by 1.73%. Additionally, Refs. [107,122] present for their application scenario that the existing industrial solution can also not achieve the economic optimum. In comparison to existing industrial solutions, the social, as well as the economic dimension could be improved.

Nevertheless, an analysis of the social and economic interactions is only examined in a few approaches using real scenarios. Given this uncertainty about the real effects of social improvements, social aspects are more likely to be addressed defensively. The DM, for example, will probably determine the required model settings in a more classical (economic) way, since the effects of a higher social priority cannot be estimated thoroughly. Furthermore, the approaches predominantly consider specific planning problems. It would be valuable in the future if corresponding benchmark data sets were available, such as exist for the ALBP. Especially since the focus in the approaches is primarily on the development of suitable solution methods, these could be used in the future to validate the methods.

5.4. Current Impact of Employee-Related Social Aspects in Approaches of Hierarchical Production Planning

The identified approaches of hierarchical production planning address a broad set of social variables, which enable a comprehensive consideration. Furthermore, different implementation types are applied. Thus, the articles introduce different approaches to improve social aspects. However, compared to the economic dimension, the impact of the social aspects might be less significant. For this, especially the following reasons were identified:

- The modeling within the individual approaches usually provides a broad range of social impacts. However, the actual impact of the employee-related social aspects depends on the specific DM's model settings. However, regarding realistic application scenarios investigated so far, the focus is primarily on the verification of the solution methods applied. The effect of including social aspects is rarely analyzed. Thus, the DM is insufficiently supported to determine suitable model settings.
- In general, a large number of employee-related social aspects could be identified. However, the approaches primarily address only one of these aspects. Thus, on the one hand, the impact of the social dimension is only partially represented. On the other hand, possible interactions and synergies also remain unused. A possible reason for the missing modeling of such interdependencies is the lack of quantitative data on these relationships.
- Employee-related social aspects are included usually at single planning levels (especially at the scheduling level). In hierarchical production planning, each level is linked to the preceding level in the hierarchy, and if (as considered here) the planning levels are specified and solved as optimization problems, the realization of the result of one planning level has to be ensured by restrictions on the next planning level. Accordingly, on the scheduling level, for example, the previously planned production program has to be realized and the available capacities have to be respected. Thus, possible social improvements are limited and dominated by economic aspects. Additionally, the economic aspects also dominate in the APP so far, because social aspects have been primarily transformed into economic criteria; thus, they will only be improved in the case of an economic benefit.

Therefore, even the general modeling within the approaches enables equal attention to social and economic aspects, such social sustainability might not be expected. Due to the selective consideration of single aspects, as well as planning levels, the primarily economically oriented implementation of social aspects, and the rare analyses of social and economic interdependencies, an economic dominance is to be assumed.

6. Pathways for Future Research

The analysis indicates that the planning levels and employee-related social aspects are addressed with different intensities. The area of health and safety has received great attention so far, but it is primarily addressed within the ALBP and worker assignment/job rotation. Due to the high importance of this area, a consideration also at the APP and MPS level might be a relevant topic for future research. Due to a longer-term consideration, the respective (additional) resources can be planned and the production program can be adjusted, which in short-term production planning are restrictive. This might be relevant, especially if health and safety aspects affect the employee productivity or quality, as well as if further employees are necessary to improve the employee health. Similarly, training measures and personnel adjustments are already considered at the APP. However, a suitable aggregation of the social assessment from individual jobs to the product level is required.

Furthermore, economic criteria do not necessarily deteriorate if social and economic interdependencies are integrated (effect modeling), in some cases even improving them. So far, such modeling considers that higher employee skill levels cause higher quality, as well as productivity, and that from certain energy expenditure values, processing times increase due to additional rest allowances. Similar correlations might be expected for further employee-related social aspects. For example, regarding the frequently observed ergonomic risks, a higher degree of employee availability due to decreased illness might be assumed. To consider such effects, which could be observed in the long-term, but depend on short-term assignments, a coordination over several planning levels might be advantageous.

Besides extending the planning levels, the employee-related social aspects included might also be extended. So far, possible synergies from the consideration of several employee-related social aspects have not been investigated. For example, time intervals for physical recovery (health and safety) can be used for continuous training measures (development).

Regarding the analyses provided by the approaches, often, the focus is on verifying the chosen solution method. For better understanding how social improvements affect the economic dimension, further analyses of the resulting trade-offs are required. With this, the DM can be supported regarding parameter settings and weightings of the objective criteria.

In summary, the following two general research directions can be derived from the research gaps presented:

1. Enhanced extent and level of consideration from social aspects;
2. Increased analysis of real economic effects due to social improvements.

The first point refers to an expansion of the social aspects and planning levels considered. This refers in particular to the fact that, so far, mainly individual aspects have been considered at a single planning level. For a higher impact of the social dimension, it seems to be necessary that, on the one hand, several social aspects are considered simultaneously. This reflects the fact that social aspects do not occur in an isolated manner. Furthermore, this enables the consideration of corresponding interactions between the individual aspects, which can be both positively and negatively correlated. For example, the physical burden on employees can be reduced by correspondingly changing job assignments, which also reduces possible monotony. However, this also requires appropriate training measures. On the other hand, the improvement of concrete social aspects should be discussed at several planning levels. Especially the area of health and safety has so far been considered mainly at the scheduling level. The approaches have shown that social improvements are possible. Corresponding improvements can, of course, also be achieved by adjusting capacity availability and requirements (number of employees, production program). However, it remains open which concrete social and economic trade-offs are required for this. A short-term adjustment of the number of employees or the production program to achieve a social improvement is hardly feasible. A respective analysis would be possible via a medium- to long-term planning approach. A longer-term view would also enable the analysis of the effects of inadequate social conditions on indirect costs (e.g., due to illness, fluctuation), which have not yet been addressed. In view of the increasing shortage of skilled workers and demographic change, consideration of such long-term effects seems particularly relevant. However, in this context, it is also important to determine how such correlations arising from short-term resource allocation can be appropriately aggregated.

The second research direction relates to the analyses performed in the approaches. So far, the focus is on the validation of the presented solution methods. However, in addition to these suitable methods for the reliable and fast solution of real planning problems, additional insights are required regarding necessary model settings. On the one hand, this requires the consideration of real scenarios up to the derivation of suitable benchmark data sets. These could be used in the future to validate new solution methods and to achieve a higher comparability of the analyses. On the other hand, a stronger focus on the effects of social integration is necessary. The DM has to be supported more strongly in model configuration. So far, it has been shown that social improvements are possible. It remains open how the considered economic conditions have been determined. In addition, it remains unanswered which disadvantages have to be accepted in order to achieve further social improvements or whether the improvements achieved are sufficient. Although, the latter requires the determination of corresponding general applicable threshold values, as it is possible, for example, in the evaluation of noise emission.

7. Conclusions

This paper makes an important theoretical contribution to the literature by conducting a systematic literature review on the consideration of social aspects in production planning and control. To our knowledge, this is the first time that all levels of the planning hierarchy, a broad understanding of social aspects, and their modeling types have been considered. Furthermore, it is discussed for the first time how this affects the impact of social aspects.

For this, 76 relevant articles were identified that include employee-related social aspects along the hierarchy of production planning. The planning levels APP, MPS, lot sizing, and scheduling, as well as the social areas development, employment, satisfaction, as well as health and safety were considered. To answer the RQs (see Section 1), the articles were categorized and analyzed. For this, a categorization scheme was derived from social standards, as well as the identified articles regarding the social aspects (see Figure 1) and their implementation types (see Figure 2).

The analysis indicated that employee-related social aspects are primarily implemented as a direct variable in the objective function (RQ 1). Correlations between social and economic variables (effect modeling) are modeled in the areas of development and energy expenditure. The impact of social aspects depends primarily on the DM's model settings, which are rarely supported. Primarily, health and safety aspects are included for the ALBP and the worker assignment/job rotation (RQ 2). In general, the approaches focus on only one planning level and one social aspect. Within the analyses provided, verifying the solution method dominates (RQ 3). Based on the remaining studies, it was concluded that improving social aspects does not necessarily lead to economic disadvantages. Significant social improvements can be achieved in some cases, accepting small deviations from the economic optimum. However, in general, it is to be expected that economic aspects dominate social aspects, although the general modeling would permit greater social impact.

In order to give higher priority to social aspects, different potentials could be identified. Due to the high relevance of health and safety aspects, their integration into the MPS and APP might be advantageous. This medium- to long-term harmonization of available resources and the production program with the short-term requirements of resource allocation is still open. Further potentials arise from enhanced modeling of economic benefits (lower illness rates due to lower ergonomic risks, for example). Additionally, only a few approaches analyze the social improvements regarding their economic effects. A better understanding of these interdependencies would support the decision-making regarding parameter setting and weighting of objective criteria, which are essential for the impact of social aspects.

For industrial companies, the insights from this systematic literature review can be useful in making decisions about how to incorporate social aspects into production planning based on an understanding of the current state-of-the-art. By presenting the results of the systematic analysis, this work can provide useful insights for improving working conditions. In particular, it can serve as an important resource for companies in terms of which aspects can be considered, how they are modeled, and for which planning problems they have been considered so far. In addition, it reveals which specific methods are used to assess ergonomic risks (e.g., OCRA, NIOSH-Eq, EAWS).

Finally, some limitations should also be mentioned. First, only articles that are available in the database Scopus could be identified. Furthermore, the terminology of the social aspects is not standardized. Thus, multiple synonymous terms exist. Additionally, the results are limited by the formulated restrictions regarding the planning hierarchy and the consideration of planning problems specified as optimization problems and solved by exact or heuristic methods (see Section 3). Thus, decision-making problems extending the regarded planning hierarchy (e.g., warehousing, order picking) and alternative modeling and solutions (e.g., simulation approaches) were not covered.

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Appendix A

Table A1. Summary of literature categorization.

Reference	**Production Planning Level**	**Social Aspect**											**Implementation**						
		Development			Employment		Health and Safety				Satisfaction		As Constraints		As Single-Objective Function		As Multi-Objective Function		
		AP	*AQ*	*MSR*	*PA*	*GE*	*SE*	*MF*	*EE*	*ER*	*EP*	*MB*	*EM*	*VL*	*Social*	*Economic*	*Only Social*	*Only Economic*	*Social and Economic*
[56]	APP	X											X			GA, PSO			
	APP				X									X		GA, PSO			
[57]	APP	X											X						MONLP
	APP				X									X					MONLP
[58]	APP	X											X					LP-metric	
	APP				X									X				LP-metric	
[59]	APP		X		X									X					GP
[60]	APP		X																GP
[61]	APP			X									X			RL			
[62]	APP				X														GA
[63]	APP				X									X					GoNDEF
	APP					X													GoNDEF
[64]	Lot sizing								X				X			analytical			
[65]	Lot sizing								X	(2)			X			analytical			
[66]	Lot sizing									(2)				X					MOP
[67]	Lot sizing									(6)				X					MONLP
[68]	Lot sizing									(6)						NLP			
[69]	s-m	X											X			heuristic			
[70]	f-s	X											X						GA
[71]	j-s								X				X			heuristic			
[72]	j-s									(1)									GA
[73]	j-s									(1)									GA
[74]	f-s									(1)									DMORA
[75]	f-s									(1)									MOCGWO
[76]	j-s									(5)									GA
[77]	p-m										X								ϵ-con.
[78]	p-m										X			X					heuristic
[79]	p-m										X								heuristic
[81]	ALBP			X									X					GA, PSO	
	ALBP				X													GA, PSO	

Table A1. *Cont.*

Reference	Production Planning Level	Social Aspect											Implementation						
		Development			Employment		Health and Safety				Satisfaction		As Constraints		As Single-Objective Function		As Multi-Objective Function		
		AP	*AQ*	*MSR*	*PA*	*GE*	*SE*	*MF*	*EE*	*ER*	*EP*	*MB*	*EM*	*VL*	*Social*	*Economic*	*Only Social*	*Only Economic*	*Social and Economic*
[82]	ALBP						X							X					
	ALBP								X				X	X		MIP			
[83]	ALBP							X											ϵ-con.
[84]	ALBP							X							IDS				
[85]	ALBP								X										MOP
[86]	ALBP								X				X			MIP			
[87]	ALBP								X				X	X		MIP			
[88]	ALBP								X					X					GA
[89]	ALBP, JR								X					X					GA
[90]	ALBP								X				X	X		heuristic			
[91]	ALBP								X										BDA
[92]	ALBP								X				X			MIP			
[93]	ALBP								X										GA
[94]	ALBP									(3)									MRBCRS
[95]	ALBP									(3)				X					
[96]	ALBP									(3)				X					heuristic
[97]	ALBP									(3)									RIPGA
[98]	ALBP									(4)									GA
[99]	ALBP									(4)									GA
[100]	ALBP									(4)									MOP
[101]	ALBP									(4)									heuristic
[102]	ALBP									(5)									MOP
[103]	ALBP									(5)					GRASP				
[104]	ALBP									(5)					MIP				
[105]	ALBP									(5)							GRASP		
[106]	ALBP									(5)									MOP
[107]	ALBP									(5)									MOP
[108]	ALBP									(6)				X					
[109]	ALBP									(6)				X					
[111]	JR			X									X			heuristic			
	JR											X		X					
[112]	JR						X										GA		
[113]	JR						X										MOP		
	JR									(3)				X			MOP		

Table A1. *Cont.*

Reference	**Production Planning Level**	**Social Aspect** Development			Employment		Health and Safety				Satisfaction		**Implementation** As Constraints		As Single-Objective Function		As Multi-Objective Function		
		AP	*AQ*	*MSR*	*PA*	*GE*	*SE*	*MF*	*EE*	*ER*	*EP*	*MB*	*EM*	*VL*	*Social*	*Economic*	*Only Social*	*Only Economic*	*Social and Economic*
[114]	JR						X						X			MIP			
[115]	JR							X					X			heuristic			
[116]	JR							X		(2)					GA				
[117]	JR							X											ICRO
[118]	JR									(1)				X					
[119]	JR									(1)				X					
	JR											X	X			GA, RGA			
[120]	JR									(1)				X					
[121]	JR									(3)		X					GA		
[122]	JR									(3)				X	MINLP				
[123]	JR									(4)				X	MINLP				
[124]	JR									(4)				X	MINLP				
[125]	JR									(5)					heuristic				
[126]	JR									(5)					TS				
[127]	JR									(5)							GA		
[128]	JR									(6)				X	MIP				
[129]	JR									(6)				X					MOP
[130]	JR									(6)				X	MIP				
[131]	JR									(6)				X					
[132]	JR											X	X					VNS	
[133]	JR											X	X			GA			

AP—Affecting Productivity, APP—Aggregate Production Planning, AQ—Affecting Quality, BDA—Benders' Decomposition Algorithm, con.—constraint, DMORA—Discrete Multi-Objective Rider optimization Algorithm, EE—Energy Expenditure, EM—Effect Modeling, EP—Employee Preferences, ER—Ergonomic Risks, f-s—flow shop scheduling, GA—Genetic Algorithm, GE—Gender Equity, GoNDEF—Generator of Non-dominated and Efficient Frontier, GP—Goal Programming, GRASP—Greedy Randomized Adaptive Search Procedures, ICRO—Improved Chemical Reaction Optimization, IDS—Iterative Dichotomic Search, JR—Worker assignment/Job rotation, j-s—job shop scheduling, MB—Monotony/Boredom, MF—Muscle Fatigue, MI(NL)P—Mixed-Integer (Nonlinear) Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), MOCGWO—Multi-Objective Cellular Grey Wolf Optimizer, MO(NL)P—Multi-Objective (Nonlinear) Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), MRBCRS—Multiple-Rule-Based Constructive Randomized Search, MSR—Meet Skill Requirements, NLP—Nonlinear Programming (if no customized solution method was identified, e.g., use of an off-the-shelf solver), PA—Personnel Adjustments, p-m—parallel-machine scheduling, PSO—Particle Swarm Optimization, RGA—Randomized Greedy Algorithm, RIPGA—Restarted Iterated Pareto Greedy Algorithm, RL—Reinforcement Learning, SE—Suitability of Employees, s-m—single-machine scheduling, TS—Tabu Search, VL—Value Limiting, VNS—Variable Neighborhood Search, (1)—noise emission, (2)—lifting/lowering, (3)—repetitive movements of upper limbs, (4)—awkward body postures, (5)—combined/general assessment methods, (6)—individual assessment methods.

Appendix B

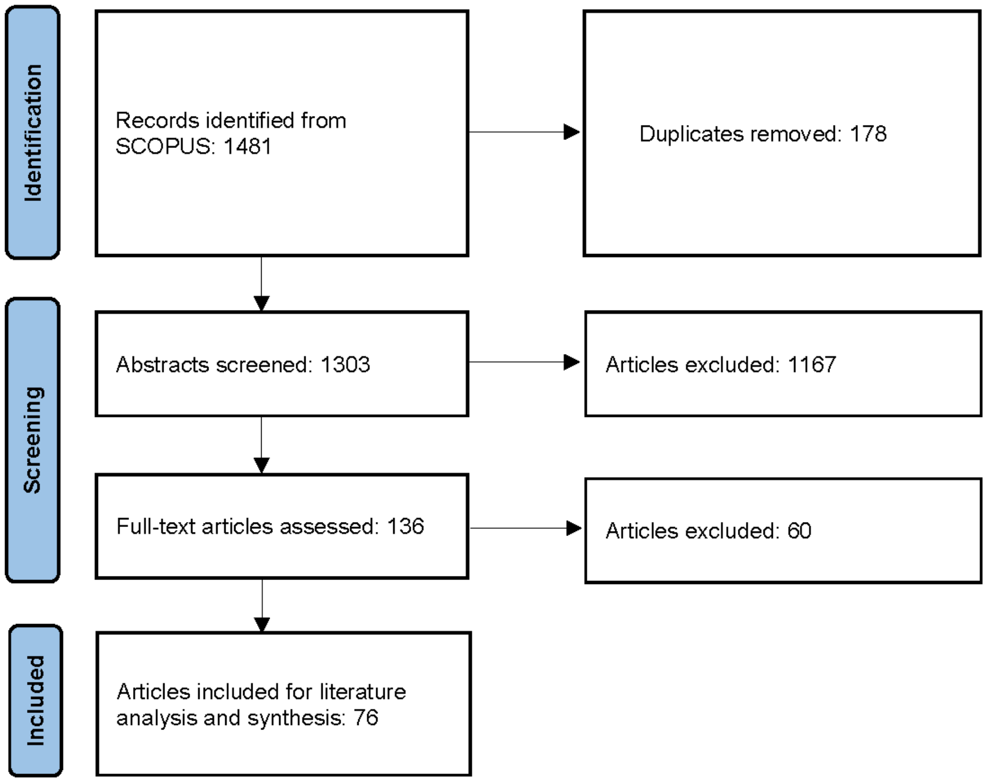

Figure A1. PRISMA flow diagram.

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