ESTABLISHED PRODUCTION PLANNING AND CONTROL AND ITS ENHANCEMENT WITH SUSTAINABILITY

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ABSTRACT

Against the background of the energy crisis, shortage of skilled workers, demographic change and other drivers, sustainable development is also becoming increasingly important for industrial companies. In this respect, production planning and control has an enormous influence on relevant objectives. In classical approaches of production planning and control as presented in this paper, economic-oriented objectives are taken into account to a large extent in decision making. This paper demonstrates that besides these classical models, a variety of approaches exist to influence ecological and social targets through production planning. These different models are assigned to sustainability areas and outlined by exemplary literature sources. Further research is needed, for instance, in the joint consideration of sustainability criteria along different planning levels and sustainable dimensions.

INTRODUCTION

In today's globalized economy, companies are faced more than ever with the task of securing their own locations in the long term and maintaining their competitiveness. On the one hand, increasingly shorter product life cycles, growing product and process diversity and high market dynamics require greater responsiveness, innovation and adaptability. On the other hand, companies are required to counteract cross-industry problems such as demographic change, the shortage of skilled workers, and competitive and cost pressures by taking appropriate measures. Thus, in addition to economic and organizational-oriented measures, the importance of sustainable development has become an important issue. In this context, sustainability can be defined as "a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (World Commission on Environment Development, 1987). With regard to production companies, Production Planning and Control (PPC) offers great potential for improving sustainability aspects (Terbrack et al., 2021; Trost et al., 2022).

In the following, a general description of a well-established PPC concept is given. Based on these fundamentals, the link between PPC and sustainability is highlighted and exemplified by several approaches. The article ends with a short outlook.

ELEMENTS OF HIERARCHICAL PRODUCTION PLANNING AND CONTROL

PPC is based on production resources with correspondingly available capacities (Herrmann and Manitz, 2021). The task of the PPC is to use these production resources to produce one or more end products on time and economically beneficial in order to satisfy a corresponding market demand. The solution of this planning task as an overall problem (by means of a simultaneous planning approach for all relevant decisions) is usually very complex and therefore, cannot be solved in the given time, even when using the best solution algorithms (Herrmann, 2011). Alternatively, the overall planning task can be decomposed into simpler sub-planning tasks whose individual solutions are reassembled into a corresponding overall plan. With the successive sub-planning problems, the organizational and temporal consideration depth increases (starting from a planning over several years on plant level up to a second-by-second consideration of individual machines). However, not all interactions between these sub-planning problems can be considered and only an approximate solution of the overall planning task can be achieved with such an approach (Herrmann and Manitz, 2021). An established form of this decomposition is the hierarchical production planning as proposed by Hax and Meal (1975). A further development is the capacity-oriented PPC according to Drexl et al. (1994), Günther and Tempelmeier (2020) and Tempelmeier (2023), which is visualized in Figure 1 and explained in the following.

For capacity-oriented PPC, a major influencing variable is the demand to be satisfied, which is initially mostly unknown (Herrmann and Manitz, 2021). Therefore, on the one hand, medium to long-term demand forecasts are prepared as a starting point for aggregate production planning. In addition, individual products that underlie a comparable cost as well as demand structure and require similar production processes are mostly grouped to product types. On the other hand, short-term demand forecasts are prepared for individual (main) products and used for master production scheduling and with regard to forecast-oriented material requirement planning. However, due to sometimes considerable stochastic influences, a demand cannot be predicted exactly. To take into account this stochastic influence, safety stocks are planned, resulting in corresponding capital commitment costs. Inventories should therefore be kept as low as possible and optimally distributed within a supply chain.

In industrial practice, it is often assumed that the forecasted quantity of end and intermediate products can

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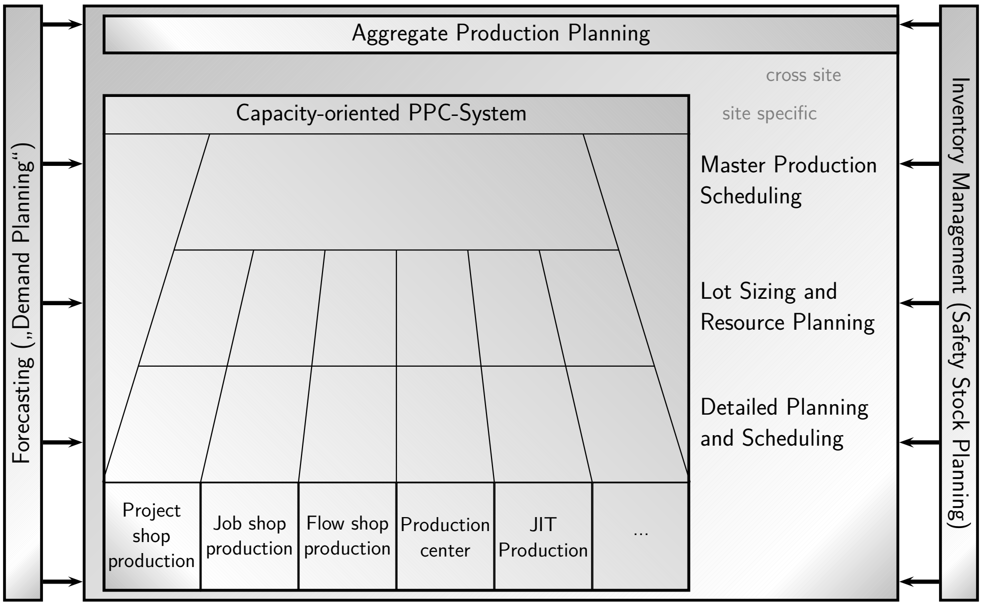

Fig. 1: Basic structure of a capacity-oriented hierarchical production planning (Herrmann and Manitz, 2021).

be produced or procured synchronously with demand (Herrmann and Manitz, 2021). Following this synchronization principle, inventories can be largely avoided. However, the available production capacities must be continuously adjusted to any, for example seasonal, peaks in demand or corresponding additional capacities must be utilized. The latter is done, for example, by means of extra shifts, overtime, temporary workers or outsourcing to external companies, which typically results in higher costs. Alternatively, an emancipation strategy can be used to respond to forecasted demand peaks. This involves shifting demand from periods of high demand to previous periods of low demand. However, this means that higher inventories and consequently higher capital commitment costs have to be accepted. The economically optimal solution is usually to be found between these two strategies. This decision problem is considered in aggregate production planning. Planning is usually carried out over a planning horizon of several years, whereby one period corresponds to one month. The production capacities to be taken into account are given as plant-specific or production segment-specific capacities. In addition to several models established in the literature, the outlined planning problem of aggregate production planning can be described and solved by the following linear optimization model APP (Günther and Tempelmeier, 2020; Herrmann and Manitz, 2021).

Sets

$\mathcal{K}$	product types ($k \in \mathcal{K}$)
T	planning horizon with $0 \leq t \leq T$

Parameters

b_t^{P}	available normal personnel capacity in period t
b_t^{T}	available technical capacity in period t
d_{kt}	demand for product type k in period t
f_k^{P}	personnel production coefficient of product type k
f_k^{T}	technical production coefficient of product type k
h_k	inventory holding cost rate for product type k per quantity unit and period
$U_t^{\max}$	max. additional personnel capacity in period t
u_t	cost of one unit of additional capacity in period t

Decision Variables

I_{kt}	inventory level of product type k at the end of period t
U_t	additional personnel capacity used in period t
x_{kt}	production quantity for product type k at the end of period t

Objective Function

The objective function of the APP model minimizes the inventory holding costs and the costs for additional capacity used.

$$\text{Minimize } Z = \sum_{k \in \mathcal{K}} \sum_{t=1}^{T} h_k \cdot I_{kt} + \sum_{t=1}^{T} u_t \cdot U_t \tag{1}$$

Constraints

$$I_{k,t-1} + x_{kt} - d_{kt} = I_{kt} \qquad \forall k \in \mathcal{K}, \forall 1 \leq t \leq T \tag{2}$$

$$\sum_{k \in \mathcal{K}} f_k^{\mathrm{T}} \cdot x_{kt} \leq b_t^{\mathrm{T}} \qquad \forall 1 \leq t \leq T \tag{3}$$

$$\sum_{k \in \mathcal{K}} f_k^{\mathrm{P}} \cdot x_{kt} - U_t \leq b_t^{\mathrm{P}} \qquad \forall 1 \leq t \leq T \tag{4}$$

$$U_t \leq U_t^{\max} \qquad \forall 1 \leq t \leq T \tag{5}$$

$$I_{kt} \geq 0, U_t \geq 0, x_{kt} \geq 0 \qquad \forall k \in \mathcal{K}, \forall 1 \leq t \leq T \tag{6}$$

$$I_{k0} \text{ given} \qquad \forall k \in \mathcal{K} \tag{7}$$

The aggregate production planning is followed by master production scheduling. The previous planning results can be integrated in terms of corresponding restrictions (fixed production quantities; available capacities) (see, e.g., Drexl et al., 1994; Tempelmeier, 2020). In master production scheduling, now, the end products are considered. In addition, it is taken into account that end products usually consist of intermediate products and therefore, need to undergo several production steps along time and in multiple production segments. This is expressed by capacity load factors, which summarize the time-related capacity load from the production of a quantity unit of an end product to a capacity load profile (Herrmann and Manitz, 2021). This comprises the capacity required for the end product as well as the capacity required in the various production segments to produce the intermediate products. In addition, this required capacity is distributed along corresponding lead-time periods which result from the production of a final product (including intermediate products). Based on that, the task of master production scheduling is to determine a production program over several periods and to coordinate it across the various production segments. This attempt is usually motivated by minimizing the relevant production, resource and inventory costs (Günther and Tempelmeier, 2020). One exemplary model for Master Production Scheduling (MPS) is the following (Günther and Tempelmeier, 2020).

Sets

$\mathcal{J}$	production segments ($j \in \mathcal{J}$)
$\mathcal{K}$	products ($k \in \mathcal{K}$)
T	planning horizon with $0 \le t \le T$

Parameters

b_{jt}	available normal capacity of production segment j in period t
d_{kt}	demand for product k in period t
f_{jkz}	capacity load factor: capacity load caused in production segment j by one quantity unit of product k in lead time period z
h_k	inventory holding cost rate for product k per quantity unit and period
$U_{jt}^{\max}$	maximum additional capacity of production segment j in period t
u_t	cost of one unit of additional capacity in period t
Z_k	maximum lead time to be considered for product k

Decision Variables

I_{kt}	inventory level of product k at the end of period t
U_{jt}	additional capacity used in production segment j in period t
x_{kt}	production quantity for product k at the end of period t

Objective Function

The objective function of the MPS model minimizes inventory holding costs and the costs of additional capacity used.

$$\text{Minimize } Z = \sum_{k\in\mathcal{K}}\sum_{t=1}^{T} h_k \cdot I_{kt} + \sum_{j\in\mathcal{J}}\sum_{t=1}^{T} u_t \cdot U_{jt} \tag{8}$$

Constraints

$$I_{k,t-1} + x_{kt} - d_{kt} = I_{kt} \qquad \forall k \in \mathcal{K}, \forall 1 \le t \le T \tag{9}$$

$$\sum_{k\in\mathcal{K}}\sum_{z=0}^{Z_k} f_{jkz} \cdot x_{k,t+z} - U_{jt} \le b_{jt} \qquad \forall j \in \mathcal{J}, \forall 1 \le t \le T \tag{10}$$

$$U_{jt} \le U_{jt}^{\max} \qquad \forall j \in \mathcal{J}, \forall 1 \le t \le T \tag{11}$$

$$I_{kt} \ge 0, U_{jt} \ge 0, x_{kt} \ge 0 \qquad \forall j \in \mathcal{J}, \forall k \in \mathcal{K}, \forall 1 \le t \le T \tag{12}$$

$$I_{k0} \text{ given} \qquad \forall k \in \mathcal{K} \tag{13}$$

Based on the resulting production program, now, the required consumption factors (e.g., raw materials) are determined in lot-sizing and resource planning (Herrmann and Manitz, 2021). Again, the results of the preceeding planning can be taken into account via corresponding restrictions. For each production segment, the necessary production and procurement order sizes are determined, which are needed for the respective assemblies and individual parts for the final products. By now, the capacities of individual resources are considered in the context of an operation-exact view. Moreover, the organizational principle of the respective production segment determines which concrete planning methods are used for the solution. In the following, flow and job shop production will be discussed as examples of frequently encountered principles. In flow shop production systems, one motivation is to ensure that the material flow along the successive stations is as uniform as possible (Herrmann and Manitz, 2021). A stationary demand is assumed, i.e., a demand progression at a constantly high level. That assumption makes it possible to determine the range of coverage of the resulting inventory based on the planned lot sizes. This range of coverage determines at which time a product has to be manufactured again. In addition to lot-size planning, the processing sequence should also be planned in flow shop production in order to ensure the necessary resource availability (Herrmann, 2011). In a job shop production, several operations compete for each resource with limited capacity. Therefore, a multi-product lot size problem has to be solved. Also, it has to be considered by which quantities each product is consumed by the higher-level product. This planning problem is known as the Multi-Level Capacitated Lot-Sizing Problem (MLCLSP) (Herrmann, 2009; Tempelmeier, 2023). One model formulation of the MLCLSP is the following (Günther and Tempelmeier, 2020; Herrmann and Manitz, 2021; Tempelmeier, 2023).

Sets

$\mathcal{J}$	resources ($j \in \mathcal{J}$)
$\mathcal{K}$	products ($k \in \mathcal{K}$)
T	planning horizon with $0 \le t \le T$

Parameters

a_{ki}	direct demand of product k for a quantity unit of product i

b_{jt}	available capacity of resource j in period t
d_{kt}	demand for product k in period t
h_k	inventory holding cost rate for product k per quantity unit and period
$\mathcal{K}_j$	quantity of products (operations) produced (completed) on resource j
M_k	a large number at least as large as the maximum possible lot size of product k
$\mathcal{N}_k$	quantity of directly superior products or directly subsequent operations of product k
p_{kt}	variable production costs for product k per quantity unit in period t
s_k	setup cost rate for product k
t_k^{B}	production time for product or operation k
t_k^{R}	setup time for product or operation k
z_k	minimum lead time for product or operation k

Decision Variables

I_{kt}	inventory level of product k at the end of period t
q_{kt}	production quantity (lot size) for product k at the end of period t
γ_{kt}	binary setup variable for product or operation k in period t

Objective Function

With the following objective function, the MLCLSP model aims to minimize inventory, setup and production costs.

$$\text{Minimize } Z = \sum_{k\in\mathcal{K}}\sum_{t=1}^{T}(h_k \cdot I_{kt} + s_k \cdot \gamma_{kt} + p_{kt} \cdot q_{kt}) \tag{14}$$

Constraints

$$I_{k,t-1} + q_{k,t-z_k} - \sum_{i\in\mathcal{N}_k} a_{ki}\cdot q_{it} - d_{kt} = I_{kt} \qquad \forall k\in\mathcal{K}, \forall 1\le t\le T \tag{15}$$

$$\sum_{k\in\mathcal{K}_j}(t_k^{\mathrm{B}}\cdot q_{kt} + t_k^{\mathrm{R}}\cdot\gamma_{kt}) \le b_{jt} \qquad \forall j\in\mathcal{J}, \forall 1\le t\le T \tag{16}$$

$$q_{kt} - M_k\cdot\gamma_{kt} \le 0 \qquad \forall k\in\mathcal{K}, \forall 1\le t\le T \tag{17}$$

$$I_{kt}\ge 0,\ q_{kt}\ge 0,\ \gamma_{kt}\in\{0,1\} \qquad \forall k\in\mathcal{K}, \forall 1\le t\le T \tag{18}$$

$$I_{k0} = 0, I_{kT} = 0 \qquad \forall k\in\mathcal{K} \tag{19}$$

In industrial practice, however, material requirements planning is regarded as a higher-level planning problem (Herrmann and Manitz, 2021). In this context, the multi-level multi-product lot-sizing problem is decomposed into isolated single-product lot-sizing problems. By this, mutual dependencies are neglected. In particular, considering the capacity demands of resources by the (single) products in isolation usually leads to non-feasible production schedules because multiple products require the available capacity of the resources. These neglected dependencies result in delays and customer due dates cannot be met. In the subsequent step of resource planning, the production orders created in lot-sizing are assigned to specific work systems and released for production. The limited capacities of the resources are taken into account and the higher-level target dates must be met. All time-consuming operations (including setup and transport times) are considered. While often only A-products are included in lot-sizing or material requirements planning, now, all products (including B- and C-products) are considered. In the literature, the outlined problem is described as the Resource-Constrained Project Scheduling Problem (RCPSP) and is listed below (Günther and Tempelmeier, 2020; Herrmann and Manitz, 2021).

Sets

$\mathcal{J}$	resources ($j\in\mathcal{J}$)
$\mathcal{K}$	operations ($k\in\mathcal{K}$)
T	planning horizon with $1\le t\le T$

Parameters

R_j	number of available resource units of resource j
r_{kj}	number of resource units of resource j required for operation k
FEZ_k	earliest possible end date of operation k
SEZ_k	latest permissible end date of operation k
N	number of the last operation in the order network; $N = \lvert\mathcal{K}\rvert$
$\mathcal{P}_k$	quantity of preceding operations in the order network from the point of view of operation k
p_k	duration of the operation k

Decision Variables

x_{kt}	binary variable indicating whether operation k is completed in period t

Objective Function

Via the following objective function, the RCPSP model aims at minimizing the cycle time.

$$\text{Minimize } Z = \sum_{t=\mathrm{FEZ}_N}^{\mathrm{SEZ}_N} t\cdot x_{Nt} \tag{20}$$

Constraints

$$\sum_{t=\mathrm{FEZ}_k}^{\mathrm{SEZ}_k} x_{kt} = 1 \qquad \forall k\in\mathcal{K} \tag{21}$$

$$\sum_{t=\mathrm{FEZ}_h}^{\mathrm{SEZ}_h} t\cdot x_{ht} \le \sum_{t=\mathrm{FEZ}_k}^{\mathrm{SEZ}_k}(t-p_k)\cdot x_{kt} \qquad \forall k\in\mathcal{K}, \forall h\in\mathcal{P}_k \tag{22}$$

$$\sum_{k\in\mathcal{K}} r_{kj}\sum_{i=t}^{t+p_k-1} x_{ki} \le R_j \qquad \forall j\in\mathcal{J}, \forall 1\le t\le T \tag{23}$$

$$x_{kt}\in\{0,1\} \qquad \forall k\in\mathcal{K}, \forall 1\le t\le T \tag{24}$$

The RCPSP model thus calculates the shortest possible schedule (i.e., shortest makespan) of all operations under consideration, taking into account the time dependencies between the operations (an operation can only start when the preceding operation has finished) and all capacity limits of the resources used (Briskorn and Hartmann, 2021). The subsequent scheduling (resource allocation planning) represents the link between planning and execution. For each individual resource and period (e.g., a day), the sequence of the jobs to be processed is determined. Then, the jobs are assigned to the corresponding resource and period via resource planning. Taking into account all setup and operating states as well as available tools and transport vehicles, this results in a resource allocation that is accurate to a minute or second. In industrial practice, this is often done by the usage of priority rules (Herrmann, 2011; Günther and Tempelmeier, 2020).

APPROACHES FOR SUSTAINABLE PRODUCTION PLANNING

Ecologically-oriented links

With regard to the integration of ecological aspects in PPC, the classification from Trost et al. (2019b) is taken up, according to which a distinction is made between the four dimensions waste, resource use, emissions and energy. In the multitude of scientific papers, these ecological concerns are addressed in different ways. Thereby, a monetary representation is evident to a large share. However, as soon as constant prices (for example, a constant electricity price) are assumed, ecological objectives are addressed in such approaches as well (Terbrack et al., 2020).

So far, the most frequently included ecological dimension in the field of sustainable PPC is energy utilization (Terbrack et al., 2020), whereby energy is predominantly to be interpreted as electrical energy. By considering the energy consumption (energetic work) and the load profile (energetic power) but also the energy costs, the approaches described in the following can be used to take this ecological dimension into account. In addition, decentralized renewable self-generation of energy is considered, which leads to a lower dependence of the public-available energy supply. For a detailed discussion of energy-oriented PPC, we refer to Terbrack et al. (2021).

A large part of the scientific work on energy-oriented PPC addresses the energetic work and thereby aims on minimizing the total energy consumption or the total energy costs (Terbrack et al., 2021). For example, Li et al. (2020) present a multi-criteria optimization model that minimizes total energy consumption as well as cycle time for a job shop environment. Similarly, approaches can be found that minimize energy consumption only during certain periods, such as time windows of high-energy prices or a high supply of conventional and high-emission energy sources, in order to reduce energy costs as well as emissions. An example is given in the scheduling approach of Sun and Li (2014), in which the objective function includes minimizing electricity consumption during short-term announced periods to respond to high market energy demand during these periods. Planning models that integrate energetic power take into account all or selected production resources for this purpose and aim to reduce energy demand. In most cases, the peak load or the highest average load is integrated into the decision-making process in order to avoid stabilization costs associated with such load peaks as well as the provision of energy by high-emission backup power plants. For example, Dababneh et al. (2016) present a planning approach that serves for minimizing the peak load related to production and HVAC (Heating, Ventilation, Air Conditioning). In addition to these typical approaches for optimizing production-specific energy utilization, planning models for energy-flexible production are being published with increasing frequency. In the context of such an orientation of PPC to the energy supply, one attempt lies in minimizing energy procurement from external sources or non-renewable energy sources by considering different generation and procurement options. Often, this is achieved by targeting volatile energy generation from renewable energy sources (see, e.g., Abikarram and McConky, 2017). This is accompanied by the goal of increasing self-sufficiency and maximizing revenue from the sale of onsite-generated energy. An example of the latter is represented by the flow shop scheduling model of Fazli Khalaf and Wang (2018), which maximizes the expected profit from the feed-in of renewable energy in addition to minimizing the energy costs. Likewise, to enable a time-elastic utilization of volatile energy sources to a certain extent, the integration of energy storage solutions is increasingly outlined (see, e.g., Wang et al., 2020).

Besides an energy-oriented PPC, production planning approaches as described below, which take into account waste generation or resource utilization, can contribute to the sufficient availability of raw materials. The availability of raw materials can be improved by reducing/avoiding production waste and by an efficient use and reuse of production resources. At the same time, the corresponding raw material costs can also be influenced.

With regard to waste prevention, two main aspects are addressed in the existing PPC literature. First, disassembly activities of recycled or defective products are integrated into the planning process. In this sense, for example, Kang and Hong (2012) present a planning approach that minimizes the costs of disassembly, remanufacturing, manufacturing, and storage of products and ensures demand satisfaction. Second, waste minimization can be achieved through planning solutions in the area of cut optimization by aiming at the maximum utilization of a material to be split (see, e.g., Mobasher and Ekici, 2013). Closely linked to waste minimization is the consideration of resource consumption (such as material or water). Thus, there is a clear correlation between the proportion of resources used (such as production material) and that of unused resources (e.g., scrap or waste), which is why the two ecological dimensions usually complement each other. To reduce material usage and the associated costs, it can be distinguished between three different approaches. On the one hand, PPC can be extended to take into account repair processes of products, which have become defective during production (see, e.g., Schrady, 1967). On the other hand, a reduction of production-related material consumption can be achieved by reprocessing returned products. In this context, the planning and control of the production of new products must be supplemented by the scheduling of remanufacturing activities (see, e.g., Polotski et al., 2017). Furthermore, the disassembly of recycled products as described above can, in addition to reducing waste, also minimize resource consumption by reusing the recovered materials in the manufacturing of new products (see, e.g., Entezaminia et al., 2016). With regard to the use of water as a resource, a further distinction can be made between three objectives in production planning. For example, Jiang et al. (2010) present a planning solution for the dyeing industry to reduce production time as well as fresh water consumption and wastewater generation by considering the sequence-dependent processing time and associated water consumption. Another approach is the reuse of water that has already been used. With this in mind, Pulluru and Akkerman (2018), for example, develop an approach that takes into account the quantity and quality of water supplied and schedules process and cleaning operations based on this. In this approach, water used in cleaning processes can be reused in downstream operations. Furthermore, approaches can be found that integrate discharge or reuse of used, respectively contaminated water (see, e.g., Chang and Li, 2006).

In addition to the approaches described above, there exist PPC models that also address production-related emission output. Besides a consideration of emission costs (see e.g., He et al., 2015), approaches to minimize emission quantities can be found (see e.g., Wu et al., 2018). In both cases, a distinction can be made with regard to the source of the emissions: e.g., Hong et al. (2016) take up the minimization of process-related emissions, respectively the associated costs. Besides process-related emissions, there are approaches that integrate energy-related emissions in the sense of indirect emissions into production planning. In this context, the use of non-renewable energy sources or energy procurement from the power grid is linked to emissions, which can then also be reduced by reducing energy consumption (see e.g., Wu et al., 2018).

Socially-oriented links

In the context of socially-oriented PPC, approaches can be categorized into the following areas according to Trost et al. (2022) (see Figure 2). For a comprehensive discussion, we refer to Trost et al. (2022).

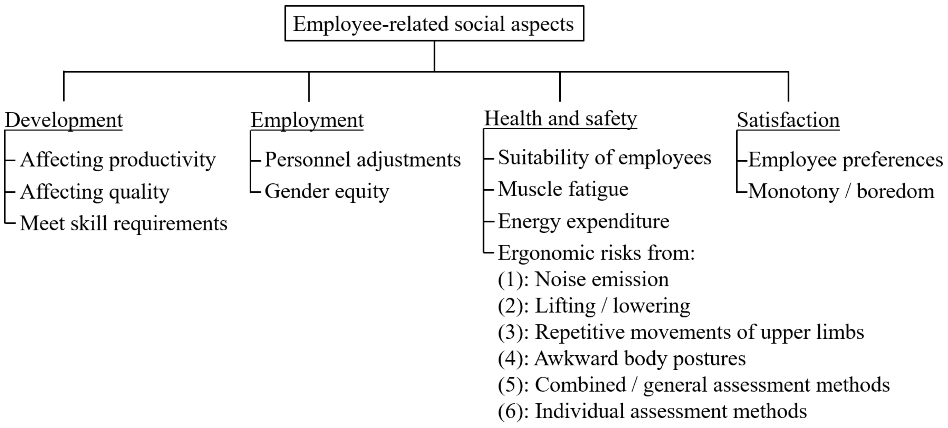

Fig. 2: Categorization of employee-related social aspects (Trost et al., 2022).

Approaches on development can contribute to the qualification of the workforce and reduce dependence on qualified employees who are available externally. Following the planning hierarchy, employee training is mostly considered at the level of aggregate production planning. In that manner, corresponding production plans contain, for example, time slots for employee qualification. A distinction is made between approaches that influence productivity (see, e.g., Aziz et al., 2018) or production quality (see, e.g., Madadi and Wong, 2014) because of training measures. The productivity impact is thereby mapped via corresponding dependent capacity load factors. It is assumed that qualified employees need less time to perform production tasks. By minimizing the costs, thereby a correspondingly sufficient training level is indirectly achieved. The influence on production quality is based on the assumption that qualified employees make correspondingly fewer errors. Furthermore, previous approaches take into account that the fulfillment of production tasks requires a corresponding qualification and experience of the employees (see, e.g., Karimi-Majd et al., 2017). With regards to that, increased productivity through appropriate training levels can lead to lower unit labor costs. Furthermore, the required flexibility of working hours can also be influenced by the PPC. For example, Trost et al. (2019a) integrate the deviations of standard working hours into the MPS. It is shown that the fluctuations can be reduced by more than 60% in some cases.

In addition to these longer-term oriented planning approaches, which consider the demand for corresponding employees, the focus of existing approaches to socially-oriented PPC is predominantly on maintaining the workforce in the company. This is mainly taken into account in the context of assembly line balancing and job-rotation. Thereby, employee satisfaction and health & safety aspects are integrated into PPC. On the one hand, this serves to ensure that the workforce can be deployed for as long as possible with high productivity and quality, especially regarding the demographic change and the associated aging workforce. On the other hand, the attractiveness of the company as an employer can be increased.

The most frequently considered social category in the context of socially oriented PPC is health & safety. With this regard, various evaluation criteria can be addressed. For example, Botti et al. (2020) outline that employees should have appropriate qualification, experience, body size, and age requirements to ensure safe & healthy performance of production tasks. Abdous et al. (2018), on the other hand, aim to reduce muscular fatigue. This is because the fatigue of a muscle depends on the external load on the muscle, the time of loading, and the maximum muscle contraction (Ma et al., 2009). This allows the determination of a maximum ensurance time, i.e., the maximum time a muscle can sustain a load. Employee energy expenditure is integrated with individual employee parameters (e.g., gender, body weight) as well as work parameters (e.g., posture, work rate, weight of load, and duration of load). This allows an estimation of the expected metabolic rate as well as a determination of required recovery times (see, e.g., Finco et al., 2020). In contrast, the majority of approaches to health & safety aspects through appropriate PPC are concerned with the assessment of ergonomic risks. In this context, the ergonomic conditions of the workplaces (taking into account the production orders assigned/to be assigned) are evaluated with respect to various criteria (cf. Figure 2). For example, in Mossa et al. (2016), a maximum risk value due to repeated movements of the upper limbs must not be exceeded. The risk value is determined via OCRA (OCcupational Repetitive Action tool) (Occhipinti, 1998).

With regard to employee satisfaction, existing approaches on PPC on the one hand integrate concrete employee preferences when assigning production orders (see, e.g., Liu et al., 2019). On the other hand, the aim is to reduce work monotony through appropriate job rotation (see, e.g., Ayough et al., 2020). In this context, work monotony results primarily from the repeated assignment of employees to stations/production tasks. By changing the assignment of employees, the aim is to reduce this work monotony, which contributes to increasing employee motivation and productivity.

OUTLOOK

In this article, we outlined a well-established concept of hierarchical production planning. Based on exemplary approaches we pointed out that PPC is capable of improving sustainable objectives.

Besides classical economic motivations, models on sustainable PPC can address the utilization of energy and raw materials and contribute to an adequate and stable supply. It can also influence emissions and the associated costs. Furthermore, it has been shown how the availability of human capital can be addressed in the context of socially-oriented production planning and how, in particular, aspects of employee satisfaction as well as health & safety can be taken into account in the decision-making process. In addition, unit labor costs and the required flexibility of working hours can be influenced.

Despite the different described fields of action with regard to sustainable PPC, to the best of our knowledge, a joint consideration of sustainable objectives is still missing and therefore, an open research issue. On the one hand, the coordination of sustainable objectives along the different planning levels within hierarchical production planning could enhance the potential for sustainable improvement and thus, should be part of future research. On the other hand, the same holds true for a simultaneous integration of multiple sustainable objectives.

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