SUSTAINABLE PRODUCTION PLANNING AND CONTROL: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

This article reviews the state of the art in research regarding sustainable extensions of hierarchical production planning. Sustainability is currently of considerable importance due to various interest groups. Hierarchical operational production planning and control is the state of the art in research as well as in industrial practice for planning of stations and their aggregations to production systems. Thus, it might be highly relevant to improve sustainability. In the literature mainly the scheduling level as well as the ecological dimension are considered. So the current research is limited to selected partial planning problems and incomplete with regard to sustainable aspects that emerge.

INTRODUCTION

Sustainability is highly discussed in science and industry. The drivers for sustainable development of production companies are, for example, various groups of stakeholders such as employees, environmental activists and government bodies. In addition, other factors such as the limited availability of resources, rising energy costs or the shortage of skilled workers are leading to a greater significance of sustainability aspects. This article therefore provides an overview of sustainability firstly. On the other hand, it presents a review of existing articles that consider quantitative approaches to the sustainable extension of existing models for production planning and control. Accordingly, the aim of this work is to review the state of the art regarding the extensions of different planning levels by ecological and social factors and to identify corresponding gaps in research.

The rest of the article is structured as follows. Chapter 2 introduces the sustainability and the used levels of production planning and control. In chapter 3 the review methodology and the descriptive results are presented. Chapter 4 gives an overview of the relevant literature and some selected papers are analysed in detail. Finally, the results are discussed (chapter 5) and the paper concludes with a brief summary (chapter 6).

PROBLEM DEFINITION

This article is based on the concept of capacity-oriented hierarchical production planning (in short PPC) discussed, for example, in Claus et al. (2015). The PPC is illustrated in Figure 1 which shows the vertical structure of production planning and the horizontal interfaces to the supply chain. Our focus is on the hierarchy of the level Master Production Scheduling (in short MPS), Lot Sizing and Scheduling.

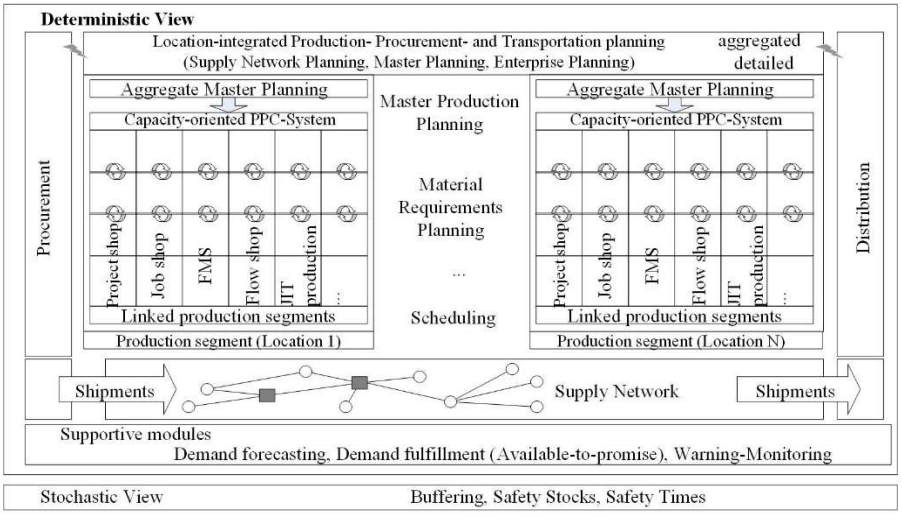

Figure 1: Concept of hierarchical production planning (see Claus et al. 2015)

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In addition, when considering sustainability, it should be noted that numerous definitions and interpretations exist for this term. The majority of sustainability definitions are similar to the extent that "*[...] sustainable development [...] must meet ecological, economic [and] social [criteria]*" (Rogall 2009), which also corresponds to the three-pillar concept established with the Brundtland Report (Hauff 1987). This paper therefore considers approaches that integrate ecological and social factors.

REVIEW METHODOLOGY AND DESCRIPTIVE RESULTS

The databases ScienceDirect, Wiley and WISO are known for a complete overview of high ranked publications. These databases were searched using three sets of keywords, which are listed in Table 1 and explained and justified later. From this received list of publications, relevant publications were identified on the basis of the abstracts. Relevant papers are those that make a positive contribution of sustainable factors within the framework of hierarchical production planning.

Table 1: Overview of keyword combinations

Sustainability related keywords	**Production planning related keywords**	**Review related keywords**
Sustain*	„Production Planning“	Review
Social	„Scheduling“	State of*
Ecologic*	„Lot Sizing“	Overview
Fatigue	„Master Production Scheduling“	Survey
Learn*		
Exhaust*		
Human*		
Ergonomic*		
Waste		
Energy		
Emission		
CO_2		
Environment*		

The first set of keywords represents the consideration of sustainability. In this respect, this contribution is based on the GRI (Global Reporting Initiative) standard which includes guidelines for the preparation of sustainability reports (GRI 2019). The modular GRI standard currently comprises 36 standard modules, which are divided into more than 120 indicators. These describe the company, its performance and the preparation of the report itself. Thus, 11 economic, 35 ecological and 40 social performance indicators can be identified. In order to determine the corresponding keywords, the content of the individual standard modules was analysed with regard to their influence by the PPC. In addition to the general keywords such as "sustain*", "ecologic*" and "social", the following keywords were derived from the GRI standard for the environmental dimension: "emission", "waste" and "energy*". For the social dimension, the keywords: "learn* ", "human*" and "ergonomic*" were inferred. Further keywords were deduced to cover another sustainability aspects. The second set of keywords is based on the already mentioned concept of hierarchical production planning and the last set of keywords is used to search specifically for reviews. This results in a total of 208 keyword combinations for which title, abstract and keywords from 2014 to 2019 were looked for.

A total of 2,879 papers were found from the methodology described above. After reviewing the abstracts and removing all duplicate contributions, a total of 18 contributions were identified as relevant. After a complete review of these contributions, further contributions were classified as not relevant, as they do not contain a comprehensive literature review or the levels of production planning are not the focus of the work. In the end, 10 relevant papers were identified.

ANALYSIS OF SELECTED LITERATURE

The contributions will focus exclusively on quantitative approaches. Empirical findings are only used to quantify different contexts. For example in Peng and Xu (2014), there are presented empirical models of energy consumption and energy flow. Furthermore, with the exception of Bazan et al. (2016), all contributions, parallel to single-objective approaches, point to the existence of multi-objective approaches, whereby the former dominate.

Tables 4 to Table 6 present the classification of the overview papers selected as relevant. The classes considered, were derived from the analysis of the individual articles and differentiate between the solution methodology used and ecological as well as social factors (see Table 2).

Table 2: Indices for the description of solution methodology and sustainability factors

Indices	Description
I.	Linear optimisation
II.	Non-linear optimisation
III.	Heuristic
IV.	Simulation
a.	Energy
b.	Waste
c.	Use of resources
d.	(CO_2) Emission
i.	Learning
ii.	Fatigue
iii.	Energy expenditure
iv.	Health risks

In addition, Le Hesran et al. (2019), Akbar and Irohara (2018) and Grosse et al. (2017) refer to individual approaches that use algorithms (e.g. S-graph algorithm).

Further, the contributions will be analysed with regard to the existing research focus. The main areas of research identified are represented by the indices in Table 3. Strongly considered means that this is the focus of the approach contained in the overview paper and barely considered means that only a few articles consider these

aspects. After the following presentation of the classification of relevant identified overview papers (see Table 4 to Table 6), these are briefly summarized, beginning with the oldest contribution.

Table 3: Indices for the description of research priorities

Indices	Description
++	Strongly considered
+	Considered
(+)	Barely considered

Table 4: Classification of Review-Paper for Master Production Scheduling

Master Production Scheduling	Method				Ecology				Social			
	I.	II.	III.	IV.	a.	b.	c.	d.	i.	ii.	iii.	iv.
Biel and Glock (2016)	+				+							

Table 5: Classification of Review-Paper for Lot Sizing

Lot Sizing	Method				Ecology				Social			
	I.	II.	III.	IV.	a.	b.	c.	d.	i.	ii.	iii.	iv.
Bazan et al. (2016)	(+)				(+)			(+)				
Biel and Glock (2016)	(+)				(+)			(+)				
Grosse et al. (2017)	+								+		(+)	
Le Hesran et al. (2019)	++	+	+			++						

Table 6: Classification of Review-Paper for Scheduling

Scheduling	Method				Ecology				Social			
	I.	II.	III.	IV.	a.	b.	c.	d.	i.	ii.	iii.	iv.
Peng and Xu (2014)	+				+							
Giret et al. (2015)	++	(+)	+	(+)	++	(+)	(+)	+				
Biel and Glock (2016)	++				++			(+)				
Gahm et al. (2016)	++	+	+	(+)	++							
Grosse et al. (2017)	++		(+)	+					++	(+)	++	++
Otto and Battaia (2017)	++		++	(+)						(+)	++	+
Akbar and Irohara (2018)	+		++		++	(+)	(+)	+				(+)
Azzouz et al. (2018)	++		+						++			
Le Hesran et al. (2019)	+		(+)			+						

Peng and Xu (2014) consider energy efficient production systems. The focus here is on the integration of the ecological dimension in the sense of energy efficiency, with particular emphasis on reducing and monitoring energy consumption. For the considered production systems, 3 levels are distinguished. With regard to the levels of hierarchical production planning considered here, only the shop floor level is considered more closely. This includes a production scheduling where energy wastage is avoided by considering different operating modes. The work of Mouzon et al. (2007), who implement this for a single machine problem, should be mentioned here as an example. As an essential result the necessity of a consideration of several levels for an energy-efficient production is emphasized.

Giret et al. (2015) also deal with the topic of energy efficiency in their review, whereby only the scheduling level is considered. The term sustainability refers to the consideration of the input and output of the production system. The social dimension is not considered. The classification is based on input- and output-oriented models and mixed approaches. The majority of the models are input-oriented and consider topics such as: energy peak avoidance (e.g. Bruzzone et al. 2012) or energy cost minimisation (e.g. Luo et al. 2013). The output-oriented approaches focus in particular on CO_2 emissions (e.g. Zhang et al. 2015). Mixed-oriented approaches primarily combine energy and CO_2 emissions (e.g. Fang et al. 2011). Giret et al. (2015) see future perspectives in the deepening of hybrid models that can react to unforeseeable events. However, it is pointed out that the addition of further influencing factors increases the complexity of decision-making models, so that more bottom-up approaches should be pursued.

Bazan et al. (2016) investigate mathematical models for reverse logistic. In the process, the existing literature with regard to environmental aspects is reviewed. Bazan et al. (2016) identify the work of Schrady (1967) as the origin of the models for reverse logistic. For the literature search, therefore, only works citing Schrady (1967) were considered. The papers must also include an EOQ (economic-order-quantity) model or JELS (joint economic lot size) model. However, the majority of the work does not consider the environmental aspects in the mathematical model. In the few models, environmental aspects are taken into account, it is done either as a component of unit production costs or as a combined quality and environmental factor. Overall, Bazan et al. (2016) identify a need for research in the consideration of environmental aspects in reverse logistics. In addition, they point

out that disposal costs have so far been considered primarily. Aspects that can be derived from this, such as land requirements for disposal or ecological degradability, have not yet been considered.

In their review, Biel and Glock (2016) consider energy-efficient decision-making models for production planning. They are also oriented towards hierarchical production planning. At the lot sizing level, for example, Zanoni et al. (2014) have integrated various operating modes of machines and their energy consumption for a two-stage production system. The consideration of energy on the basis of different machine operating modes is also widespread at the scheduling level. Thus, Shrouf et al. (2014) consider a single-machine scheduling problem under time-variable energy prices and mode-dependent power consumption. Wang et al. (2015) also consider the power consumption in a multi-station scheduling problem. In addition, emissions such as CO_2 gases are also taken into account. In summary, it can be stated that isolated solutions and no holistic approaches are discussed. However, it also becomes clear that a long-term consideration, for example, of CO_2 emissions is still open. At the levels of lot sizing and scheduling, there is also a need for further research into the consideration of varying electricity prices and time-dependent CO_2 emission correlations.

Gahm et al. (2016) consider energy-efficient scheduling. The contributions are classified according to 3 main points of view. First, models are considered that improve energy efficiency by reducing actual energy consumption. In the model by Mouzon et al. (2007), for example, energy consumption is minimized by switching off machines instead of leaving them in stand-by mode. Another area covers aspects of energy supply. These include the internal infrared structure for power generation or storage, such as a combined heat and cold storage system by Agha et al. (2010). In addition, these include coordination methods such as price-controlled (e.g. Nolde and Morari 2010) or event-driven (e.g. Sun and Li 2014) energy consumption adjustment. In the third area, energy demand is controlled via various operating modes. Overall, the importance of production planning for improving energy efficiency is underlined and its work provides a comprehensive framework for classifying current and future literature.

Grosse et al. (2017) deal with the consideration of social factors in production and logistics. The classification of the articles is between 4 human elements (Perceptual, cognitive/mental, moto/physical, psychosocial) and 3 levels of decision support problems (Inventory Management and Lot Sizing (IM&LS), production and assembly management (P&AM), Intra-logistics and warehouse management). From the point of view of the hierarchical production planning considered here, the first two levels of decision-making problems are considered in particular. For the IM&LS area, reference is made to a large number of studies that take learning into account. Further work on this level deals with cognitive (e.g. Khan et al. 2014) and physical (e.g. Andriolo et al. 2016) aspects. These include human errors or the consideration of health risks. In the P&AM area, too, there are primarily papers that consider cognitive (e.g. Bautista et al. 2016) or physical (e.g. Dode et al. 2016) social aspects. Overall, it is summarized that social aspects are predominantly considered at the scheduling level, although the number of papers that consider the social dimension is generally small. One possible reason given for this is the lack of quantifiability of social effects. In addition, it became clear that the existing approaches are focused to cognitive and physical social aspects.

In their review, Otto and Battaia (2017) consider physical social aspects at the scheduling level. After a description of various existing methods of load measurement, the paper contains a summary of the existing literature. For job rotation, it becomes clear that the aim is usually to achieve an even distribution of the workload per employee. An example of this is the work of Otto and Scholl (2013), who have developed a heuristic solution method. For the line balancing problem, Otto and Battaia (2017) describe the development of various studies beginning with the work of Gunther et al. (1983), which reduce physical stress. Another work is that of Choi (2009), which defines 13 different parameters for describing physical risks per task. All in all, it refers to a lack of data to determine ergonomic risks, which makes it difficult to take social aspects into account. Future research is therefore expected to involve greater cooperation between the fields of ergonomics, production science and operation research.

In their review, Akbar and Irohara (2018) cover both the environmental and social dimensions at the scheduling level. Classification is based on the production system under consideration of the model type, the objective function and the solution method used. It is found that 49 of the 50 contributions have a different planning structure. In summary, a stronger consideration of ecological aspects is referred compared to the social dimension. The topics of energy and CO_2 emissions are addressed with priority. Therefore, sustainability aspects should be considered more strongly in future research. In this regard, for the ecological dimension: emissions, pollution and resource consumption and for the social dimension: customer- and employee-oriented aspects are highlighted.

In their review, Azzouz et al. (2018) explicitly consider learning effects at the scheduling level. They continue the research of Biskup et al. (2008). First, existing mathematical descriptions of learning are summarised. The work is classified according to the following categories. The category position-based learning comprises learning effects on the basis of produced quantities. The category processing time-based learning, on the other hand, takes into account the piecework processing times. For example, Kua and Yang (2006) integrate that the current processing time depends on the previous cumulative processing time. In addition, Cheng et al. (2013) for position-based learning and Cheng et al. (2009) for processing time-based learning consider that learning effects do not occur indefinitely, but only up to a certain learning level. Wang and Xia (2005) also consider an exponential

learning process. Finally, there are also some combined approaches. Cheng et al. (2008) distinguish between mechanical (position-based) and human (processing time based) learning. In summary, it is stated that learning is predominantly considered using the log-linear model by Wright (1936). In addition, reference is made to the work of Janniak et al. (2011), who challenge the relevance of considering social aspects in planning models with a short planning horizon. Since various studies have already highlighted this relevance and future flexible production systems also require a short-term social orientation, Azzouz et al. (2018) can counteract this. Nevertheless, a long-term view of social aspects is also necessary but missing.

At the scheduling level, Le Hesran et al. (2019) consider the reduction of waste, which includes wastewaters. After listing the literature according to thematic blocks of operative production planning, the articles were evaluated with regard to economic and ecological objectives, the applied solution method and the scheduling approach. In addition to linear optimization models, heuristics and genetic algorithms are also considered for the solution methods. The scheduling approach distinguishes between deterministic, proactive and reactive approaches. For the economic and ecological perspective, aspects such as productivity, profit, set-up times as well as waste, waste water and material or fresh water consumption are considered. In summary, a future need for research is emphasized regarding the consideration of environmental influences in a long planning horizon, since short-term oriented optimization models may not be cost-optimal due to the neglect of long-term environmental effects.

RESULTS

While in the previous section the articles were classified according to the solution methods used and according to ecological and social extensions, it is now analysed to what extent sustainable aspects have already been implemented in the operational PPC. For this, a distinction is made between these sustainability dimension and the individual levels of hierarchical production planning. The result is, that existing review papers predominantly consider ecological aspects at the scheduling level.

In detail, from the existing work it becomes clear, that most of the publications deal with energy and CO_2 emissions. Other aspects such as other greenhouse gases, waste reduction, resource conservation, waste water avoidance or the ecological degradability of resources are only considered to a limited extent. In addition, ecological aspects are currently considered primarily at the scheduling level and to some extent at the lot sizing level. This makes it possible to map short-term effects in particular. Therefore, there is a gap for the long term consideration, to take account of long-term environmental impacts in the planning models as well. However, short-term planning models also should be researched in order to take account of further ecological aspects and the increasing flexibility of production systems.

In contrast to the ecological dimension, there is limited work in the social field. The existing papers focus primarily on the integration of learning effects. These aspects are mainly considered on the level of lot sizing and scheduling. Further aspects to be considered are job rotation at the scheduling level in order to distribute the workload evenly among the employees and to avoid peak workloads. However, comparable to the ecological dimension, mainly models with a short planning horizon are considered. However, as the example of job rotation shows, short-term approaches can only distribute the existing workload. It is not possible to reduce the overall burden. Accordingly, there is a need for research that looks at social aspects over a long-term planning horizon and aims to improve working conditions.

The authors have set themselves the goal of closing this gap in the long-term consideration of social aspects. In Trost et al. (2017) and Trost (2018), for example, a corresponding approach is presented which makes it possible at the Master Production Scheduling to control the relationship between personnel capacity requirements and available capacity. This can be interpreted as a concrete handling of the work intensity and enables a long-term limitation of the workload. In addition, this approach is combined with aspects of personnel requirements planning so that the development and reduction of personnel resources is made possible and therefore, the workload of the employees can be reduced without restricting the performance of the entire production system. Further, an examination of different concrete employee workload intervals enables the consideration of further aspects such as employee workload-dependent processing times or error rates, cases of illness as well as employee fluctuations. The latter is, among other things, an aspect which should be considered in sustainability reporting according to the GRI standard. A current study by Trost, Claus and Herrmann on the potential of an adapted approach to Master Production Scheduling with regard to the improvement of existing deficits in working conditions, such as excessive work intensity, is also included in this conference proceedings. However, a major barrier to current research, is the lack of measurability of social aspects. In addition, beside the existing isolated approaches and parallel to the ecological dimension future work should also consider holistic approaches to PPC that link the various planning levels in addition. Further, the overview papers classified as relevant, have been their focus in most cases on analysing the state of the art at individual planning levels and sustainability dimensions. As a second step of the literature research presented here, therefore it is planned to apply the methodology presented here to an analysis of the primary literature in order to provide a more comprehensive overview of all planning levels and sustainability aspects.

CONCLUSSION

This article offers a systematic literature review of existing review papers that can be assigned to a sustainable

PPC. A comprehensive scheme of keywords was developed and applied. The most promising 10 papers are analysed in detail. However, mainly the scheduling level and the ecological dimension are considered. Further, these papers show a strong focus on the environmental dimension, with the focus on energy and CO_2 emissions. In the social field, on the other hand, learning effects are mainly taken into account. All in all, there is a need for research in both dimensions to consider further aspects, such as waste reduction, resource conservation, the work intensity of employees and the associated employee exhaustion. In addition, previous approaches have mainly focused on short-term aspects and have partially neglected long-term effects. As a result, currently long-term effects of sustainable factors are almost disregarded. These are, for example, increased sickness rates or error rates due to a high work intensity. Therefore it is the task of future research to consider sustainable aspects in approaches with a long planning horizon. In addition, further ecological aspects such as the avoidance of waste and resource-saving production must be integrated into the planning models and for the social dimension, aspects such as work intensity, deviations in regular working hours and sufficient staffing must be taken into account. In addition, the existing and future approaches of individual planning levels must be brought together to form holistic approaches across the entire PPC. This concerns the ecological as well as the social dimensions and a holistic approach to sustainability.

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