A literature database on ecological sustainability in hierarchical production planning

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Abstract

This article describes a systematic literature search of research articles on the topics of ecological sustainability and production planning. Over 900 research articles deal intensively with these topics. These articles were catalogued and included in a database. They can be evaluated with an analysis tool, developed by the research group. The tool is available free of charge via a website of the research group.

1. Introduction

Sustainable concerns are increasing in almost every part of human society. Mainly because of the consumption of resources such as water or energy, production companies should produce or manufacture respectively more sustainably. This might be improved by planning.

In this article we limit ourselves to ecological sustainability and hierarchical production planning.

Already a first research in renowned scientific journals like the "Journal of Cleaner Production" or the "International Journal of Production Economics" show that so many articles on ecological sustainability in hierarchical production planning have been published that they cannot be covered in a single scientific publication. Since we are working on several different research questions for planning in our research group, we have performed a literature search for relevant articles. We have catalogued these articles and stored them in our own database. In addition, we have developed an analysis tool with which articles can be selected for specific research questions.

The remainder of this article is structured as follows. Section 2 contains the scope of the literature database and section 3 the methodology for the literature search. Information regarding the database and the analysis tool are given in section 4 and the article is summarized in section 5.

2. Scope of the literature database

Drivers for sustainable manufacturing are, for example, stakeholders such as employees, environmental activists and government bodies. Other factors such as limited availability of resources and rising energy costs lead to a greater significance of sustainability for companies. The goal to improve sustainability was already published in 1987 by the World Commission on Environment and Development, known as Brundtland Report (see Brundtland et al. 1987). Further, the U.S. Environmental Protection Agency define sustainable manufacturing as "[…] the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community and product safety." (U.S. Environmental Protection Agency 2020). Thus, it can be concluded that sustainable production should include at least two elements of the "triple bottom line", i.e. the economic pillar together with the environmental or social pillar (Akbar and Irohara 2018).

In present, the influence of industrial production on the environment is huge. In 2018, the industry sector accounted for 37% of global final energy usage and for 24% of global emission (IEA 2020). Furthermore, in Germany in 2018, 15% of the total waste has incurred in industry (Destatis 2020). In 2013, the industrial sector was responsible for more than 14% of the total water use in Germany (Eurostat 2017). In this respect, the research on sustainable manufacturing address the improvement of products, machines and processes.

According to Akbar and Irohara 2018 production planning and control (PPC) offers considerable potential for sustainable improvements, because a more effective and efficient use of resources is achieved. This is usually achieved without new investments and can be implemented immediately. A majority of the sustainable research for PPC focus on the ecological dimension – examples are: Absi et al. 2013, Akbar and Irohara 2018, Battini et al. 2014, Bouchery et al. 2012. With an adapted PPC, production programs and resource allocations can be used to directly improve related aspects such as energy consumption, waste production or emission. In the following, the planning hierarchy and ecological sustainability are described more in detail, since their contents are relevant for literature research and cataloguing within the database.

The operational PPC, as implemented in commercially available Enterprise Resource Planning (ERP) systems, is established in industrial practice – due to the following publications: Kurbel 2016, Stadtler 2012, Stadtler and Fleischmann 2012, Vollmann 2010 for example. As described in Hax and Meal (1975) as well as in Drexl et al. (1994), the PPC consists of a hierarchy of the planning levels; see also Claus et al. 2015: aggregate production planning, master production scheduling, lot sizing and scheduling (see Figure 1). Rough production plans at the highest level over a long planning period are increasingly refined over the individual planning levels, with increasingly shorter planning periods being considered. Finally, for a short-term period in the immediate future, it is determined for each individual resource (mainly machines) which product or workpiece is processed with this resource from when to when. Thus, each level is linked to the previous one in the hierarchy. If the planning levels are specified and solved by linear optimization problems, the fulfillment of the result of one planning level is guaranteed by restrictions on the next planning level.

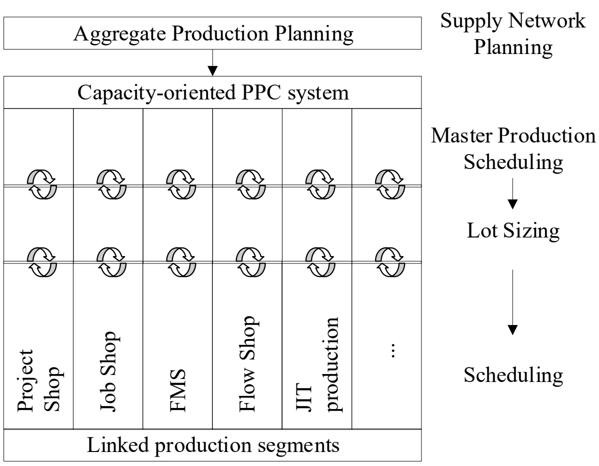

Figure 1: Concept of hierarchical production planning

In detail, see Claus et al. 2015, aggregate production planning performs capacity planning over a medium-term period for a production site and product types in such a way that the costs for additional capacity, inventories and eventually more (like transport costs) are minimal. Master production scheduling synchronize the available and required capacities for end products and their important components across all production segments of the production site in such a way that the same costs as with aggregate production planning are minimal, and so that the production program determined by the aggregate production planning is fulfilled. The next planning level(s) depend on the production types like the ones shown in Figure 1. Primarily for job shops the next two levels consists of lot sizing and scheduling. Lot sizing, multi-level lot sizing to be precise, determines production orders for end products and their components as well as individual parts (according to the bill of materials) for production segments in such a way that setup and inventory costs are minimal and so that the production program determined by the master production scheduling is fulfilled. Scheduling dispatches the operations from the work plans of the production orders to individual resources such as machines or employees so that the start and end dates of the production orders, determined by lot sizing, are met. In the case of flow shops a simultaneous lot sizing and scheduling is performed – on only one planning level.

In classical approaches for the PPC, economic objectives such as meeting due dates, i.e. avoiding delays, are regarded. In this case, the ecological dimension is usually not taken into account, resulting in too much waste and emissions (e.g. more frequent set-ups can lead to higher energy consumption). Therefore the hierarchical production planning has to be extended by suitable indicators.

Within the ecological oriented research, indicators for the condition and the influence on the environment have been developed. However, since the ecological footprint of manufacturing has many different characteristics, it cannot be represented in one key figure alone. Many standardizing guidelines have taken on the task of defining various indicators. As suggested in Zarte et al. (2019), this article is oriented on the GRI (Global Reporting Initiative) Standard. The GRI is an international and independent organization, which provide definitions, requirements and indicators for the three pillars of sustainability. The corresponding GRI standards represent global best practice for public reporting on sustainable impacts. Sustainability reporting based on these standards provides information on an organization's contributions to sustainable development, the associated impacts and how these are managed. In the industry, reporting according to the GRI standard is well established, e.g. by German automotive concerns, and is therefore of particular relevance. Regarding the ecological dimension, there are the following eight standards: materials, energy, water and effluents, biodiversity, emissions, waste, environmental compliance and supplier environmental assessment (see GRI 2020). However, the standards environmental compliance and supplier environmental assessment cannot be influenced by the PPC. The remaining standards include indicators such as the organization's energy consumption, greenhouse gas emissions and waste volumes.

3. Methodology of literature review

We follow the review methodology published in Vom Brocke et al. (2009). Their approach consist of five steps: (I) Definition of review scope, (II) conceptualization of topic, (III) literature search, (IV) literature analysis and synthesis, (V) research agenda.

This article is limited to the steps (I) to (III) and steps (IV) and (V) can be proceed with the analysis tool described in section 4.

For the first step, i.e. review scope, we use the results of section 2.

For the second step, we follow the advice in Vom Brocke et al. (2009) to directly start the process with database search by keywords. As database we use ScienceDirect; we discuss their relevance later.

In order to obtain a wide range of potentially relevant hits in the first search process, our keywords are very generic. Based on the considerations in section 2, we derive the keywords for sustainability from the GRI standard. They are:

- biodiversity,
- CO2,
- ecological,
- emission,
- energy,
- environment,
- material,
- sustainable,
- waste and
- water.

In case of planning we use the main planning problems – and consider in addition their synonyms:

- aggregate production planning,
- supply network planning,
- master production scheduling,
- master production planning,
- lot sizing and
- scheduling.

In order to perform a literature search of ecological sustainability in hierarchical production planning, we perform a concrete keyword search as follows. At least one sustainable related keyword is linked with at least one planning level related keyword via the Boolean operator “AND”.

After the keyword search, the resulting articles are further evaluated if they are relevant in terms of the scope determined in section 2. For this purpose all abstracts and, if this is not sufficient, the full texts of the articles are analysed.

In addition, we add all articles (in our database), which are referenced by the already identified articles and which are relevant (for our search); we call this backward search.

ScienceDirect includes more than 16 million research articles of more than 2 500 journals. There are several guides which assess the quality of journals – mainly in terms of how often their articles are cited; e.g. British Academic Journal Quality Guide or the German VHB-Jourqual3 ranking.

We take a closer look at the VHB-Jourqual3 ranking, limiting ourselves to the ranks from A+ to B and looking at all 923 items in our database. We did not find any relevant articles in journals such as Journal of Scheduling. This is probably because very specific procedures and problems are published in this journal. Moreover, this might be the reason why we found only 6 journals from the (restricted) VHB-Jourqual3 ranking, each of which published at least 10 articles out of our 923 found articles and which are not searched by ScienceDirect. To give the reader some insights, these 6 journals are listed in the following – their VHB-Jourqual3 rank is given in parentheses and they are ordered by the number of the articles found: International Journal of Production Research (B), Computers and Industrial Engineering (B), Computers and Operations Research (B), Operations Research (A+) and Journal of the Operational Research Society (B). To the journals OR Spectrum (A), which contains 8 out of our 923 articles, and Production and Operations Management (A), which contains 3 out of our 923 articles, the consideration just mentioned probably is true, but these journals might become relevant in the future. Examples of journals searched by ScienceDirect are, again the VHB-Jourqual3 rank is given in parentheses: European Journal of Operational Research (A), International Journal of Production Economics (B) and Journal of Cleaner Production (B). Concrete 4 journals with VHB-Jourqual3 rank of A and 16 journals with VHB-Jourqual3 rank of B are searched by ScienceDirect.

4. Literature database and analysis tool

The initial keyword search resulted in 4 039 hits. After the two-step evaluating process, we received 253 relevant articles. The subsequent backward search resulted in further 670 relevant articles. Thus, we stored 923 articles in our database.

All articles were analysed in terms of the problems addressed, modelling techniques, algorithms and empirical studies. This lead to the following categories at the highest cataloguing level: planning level, objective function and restrictions, modelling and solution approach, shop floor characteristics as well as numerical examples and results.

We use this database to obtain the relevant literature for specific research questions and also for a literature review in a publication. To support these two tasks, we have implemented an analysis tool. Our analysis tool can be used to narrow down the subject areas to focus on special topics regarding ecological sustainability in PPC. Free of charge access is possible via the following website of our research group: www.oth-regensburg.de/sustainable-production-planning.

In principle, the analysis tool is a search engine through our database. The search is controlled by:

- enhanced cataloguing as a refinement of the mentioned highest cataloguing level and
- natural language queries, which are interpreted by the tool in a logical way.

Technically, a SQL query is generated on the website via the programming language PHP. The SQL queries contain the search topics of the user. Then, a connection with the database is established, the query is processed and the results are shown on the website. Note that the usage of the analysis tool is described on the website.

The user of the analysis tool could ask for articles on energy consumption. Of course the database contains many articles on this criterion, but only a small selection is listed. With increasingly specific questions, the selection is narrowed down further and further. Thus, if the user is interested in

- single machine,
- energy consumption costs,
- tardiness and earliness is minimized simultaneously,
- Mixed Integer Non Linear Problem,
- heuristic solution procedure and
- JIT penalty

just a few article are in our database, especially Lee et al. (2017).

5. Summary and outlook

This article indicates that research on hierarchical production planning is increasingly trying to improve sustainability. Through a very broad search, we identified 923 articles which address problems, questions, models, solutions etc. on ecology and simultaneously on hierarchical production planning. With a digital search only, not all journals can (inevitably) have been considered. By analyzing the articles referenced by those that are found via ScienceDirect (i.e. our backward search) it might be that we have reduced the limitations of ScienceDirect significantly. Thus, the 923 articles might include at least one article from each researcher who has published in this area. But, the coverage of the articles is probably not complete. All references to these 923 articles are available free of charge via our analysis tool on a website of the research group. Our tests show that our analysis tool selects a small number of very relevant articles on specific ecological research issues in production planning. We will use this capability of our tool to compare our research with the state of the art.

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