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A Review of Production Planning Models: emerging features and limitations compared to practical implementation

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Abstract

In the last few decades, thanks to the interest of industry and academia, production planning (PP) models have shown significant growth. Several structured literature reviews highlighted the evolution of PP and guided the work of scholars providing in-depth reviews of optimization models. Building on these works, the contribution of this paper is an update and detailed analysis of PP optimization models. The present review allows to analyze the development of PP models by considering: i) problem type, ii) modeling approach, iii) development tools, iv) industry-specific solutions. Specifically, to this last point, a proposed industrial solution is compared to emerging features and limitations, which shows a practical evolution of such a system.

Keywords: production planning, literature review, Industry 4.0

1. Introduction

In the last few decades, production planning (PP) has grown significantly, thanks to the interest of both industry and academia - it is considered one of the most crucial decisions faced by companies [1-3]. A typical PP problem involves the management of different constraints and limited resources. Generally, a PP problem starts with a specification of customer demand that has to be matched by the production plan. Therefore, decisions have to be taken to understand which resources can be used and how to model their capacity and costs. Also, there may be uncertainty associated with demand, production function, and constraints.

The work in ref. [4] provided an in-depth review of models for PP research using different classification criteria. Building on this work, the first contribution of this paper is an update and detailed analysis of PP models to understand how PP models have been evolved in the last few years. Particularly, a comparison between our results and the ones provided by [4] is performed. Then, a specific PP software prototype is presented and analyzed according to the results of this review to map potential benefits and limitations.

The paper is organized as follows: Section 2 describes the research methodology adopted for this paper, Section 3 classifies PP models and provides an in-depth analysis. This will be followed by Section 4, in which we discuss the key findings concerning a proposed specific software proposition for emerging features and limitations, show a practical evolution of such a kind of system, and suggest an agenda for future developments. We conclude in Section 5 by providing overarching insights from our literature review.

2. Research methodology

For this research, we used the Scopus database, as it is one of the most consistent repositories of engineering, production,

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and business papers. The authors were searched in Scopus for articles with the term "production planning" and "master planning" in the title, abstract, or keywords. An initial selection was performed using the following criteria:

- Journal or review articles published in English.
- Journal or review articles published between 2014 and 2020 – as this work starts from the review provided by [4].

Such an initial interrogation resulted in a set of 53 papers, which was further reduced to 41 by excluding papers not relevant for this research purpose (e.g., no optimization models).

Following best practices for bibliometric analysis, the authors independently reviewed the dataset to verify the accuracy of records and fix potential errors. Figure 1 summarizes the review protocol.

The systematic literature review was performed using classic bibliometric techniques, following previous work performed by other scholars in this field.

For the analysis of publications, we adopted a simplified version of the framework proposed by [5], which consists of 3 dimensions of analysis, each related to a specific investigative rationale as presented in Table 1.

Table 1 – Framework used to analyze publication data

Grouping	Dimensions	Rationale
Analysis of publication data	Number of publications	Size of research field
	Time distribution of publications	Trends in the research field
	Most popular journals for publications	Journals where research is published

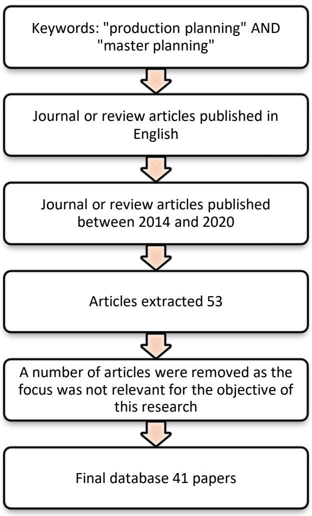

Fig.1. Review protocol

To classify model for PP, all of the papers were analysed and categorized according to [4]: problem type, aim, number of products, time period, nature of demand, capacities constraints, extensions, modelling approach, solution approach, development tool, application, limitations, and benefits.

The next section presents an overview of the main results of this literature review.

3. Analysis of PP optimization models

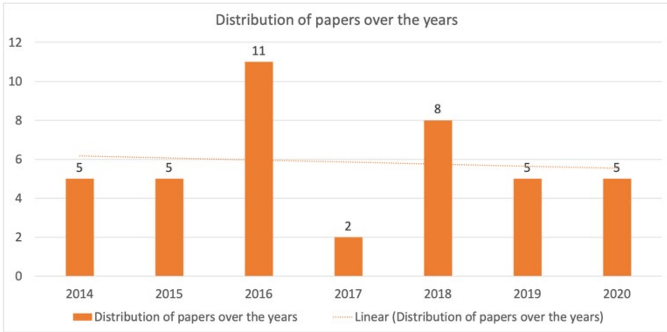

Fig.2. Distribution of publications over the year

Figure 2 presents the distribution of publications over time, which shows stable evolution within the PP research field – with peaks in 2016 and 2018. Figure 3 presents the top journals where PP research was published. The ranking is led by the International Journal of Production Research and Computers and Industrial Engineering with 10 and 5 publications, respectively.

The review of the studies published over the past 7 years allowed us to identify the most frequently used modeling approaches in the PP.

The top 3 problems faced by papers are Production planning and Aggregate production planning (APP) (39%), Integrated procurement–production planning (7%), and Capacitated lot-sizing problem (5%). This result is partially aligned with the results of [4], who found that the top 3 topics were Master Production Scheduling (MPS), Supply chain planning (SCP), and APP with a focus around multi-period, multi-level, multi-items capacitated aggregate problems.

It is important to highlight that the survey provided by [4] had a broader analysis point of view – it looked at the tactical planning optimization model while this analysis focuses on the production planning optimization model.

[6] faces the aggregate production planning problem – particularly a mathematical model of multi-product multi-period has been formulated. It offers the possibility to change the search parameters of the genetic algorithm to tuning the desired results. The main limitation of this model is that the different parameters have been considered constant over the planning period useful mainly for short-term tactical planning.

[7] proposes a risk-oriented integrated procurement–production approach for tactical planning. "The decision-maker selects first risk-based and performance-based decision criteria that match his strategy and his industrial context". The model creates the set of possible plans including their performance and risk measures, to better support the selection of a procurement–production plan.

[8] presents a capacitated lot-sizing problem to determine a cost-optimal plan for both production and maintenance. A regression-based approach is developed to set the production time, which is used in capacity constraints.

Figure 4 shows the ranking of the most used modeling approaches in PP. Fuzzy programming and Multi-objective programming are the most used approaches with 11 and 8 publications, respectively. These approaches were ranked fourth and fifth in the [4]. The most used modeling approaches in 2013 were Linear/Integer/Mixed integer linear programming and Stochastic programming. Table 2 shows the comparison between the result of this paper and the ones provided by [4].

Table 2 – Comparison of most used modelling approaches

Modelling approaches	Most used Modelling approaches 2014-2020	Most used Modelling approaches 2006-2013 [4]
Fuzzy programming	[#1] ⇑	[#5]
Multi-objective programming	[#2] ⇑	[#4]
Linear/Integer/Mixed integer programming	[#3] ⇓	[#1]
Heuristics algorithms and metaheuristics	[#3]	*
Hybrid models	[#4] ⇑	[#13]
Non-linear programming	[#5] ⇓	[#3]
Stochastic Programming (Regression based approach included)	[#7] ⇓	[#2]
Robust optimization	[#8] ⇓	[#6]

* not identified as relevant in Díaz-Madroñero et al (2013)

Arrows represent if a modelling approach increases or decreases its position with respect to Díaz-Madroñero et al (2013)

Fuzzy modeling is an approach based on the fuzzy set theory. In [9] a distinction is made between randomness and fuzziness. "Essentially, randomness has to do with uncertainty concerning membership or non-membership of an object in a nonfuzzy set. Fuzziness, on the other hand, has to do with classes in which there may be grades of membership intermediate between full membership and non-membership"

[10] proposes a fuzzy model to solve hub location–allocation problems where the hub nodes are considered as industrial townships in which manufacturing plants and a central distribution warehouse are established. The goals of the fuzzy model are i) minimize total cost and ii) the average waiting time for products. Fuzzy chance-constrained programming and Torabi & Hasini method have been used to solve the location–allocation problem.

[11] develop a multi-objective possibilistic linear model for analysing an aggregate production planning problem. The proposed framework for the APP problem also offers to design the parameters such as costs, capacities, machining times, forecasted demand in the possibilistic environment and it, therefore, provides the most effective and efficient compromise result.

Fig.3. Distribution of publications over journals

[12] studies a generalized mixed-integer linear production planning problem with multi-period and multi-item specification in a make-to-order manufacturing system. In this system, a holding company assigns the customers' orders to its subsidiary companies in a way to minimize the total cost as well as minimizing the maximal production utilization which consequently leads to the fair allocations of production loads.

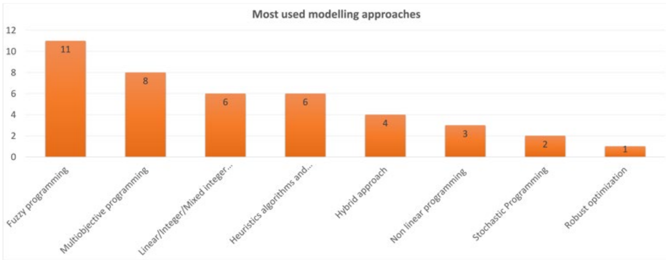

Fig.4. Distribution of publications over the most used modelling approaches

The fourth most used modelling approach is heuristic algorithm and meta-heuristics. A heuristic approach provides a solution for large size problem within a reasonable time with close to the optimal solution.

[13] considers the integration problem of production, maintenance, and quality for a capacitated lot-sizing production system subject to deterioration. A genetic algorithm (GA) is proposed to solve the integrated model efficiently. Finally, a comparison of the performance between Simulated Annealing (SA) and GA is presented. Although the gap of the expected total cost between GA and SA is small in all tests, in general, GA outperforms SA.

Figure 5 presents the most used tools in PP optimization models. It is important to highlight that 21 references do not provide any implementation or development details. However, 20 references report the names of the tools used to develop and solve the PP models. The main tools are LINGO (software), GAMS (optimization modeling language), CPLEX (software), Matlab (optimization modeling language), Anylogic (Simulation software), Gurobi (software), and Python (programming language). Concerning the paper that used Python as optimization software, it is important to highlight that no details have been provided on the libraries used within the software. These results are basically in line with what was highlighted by [4].

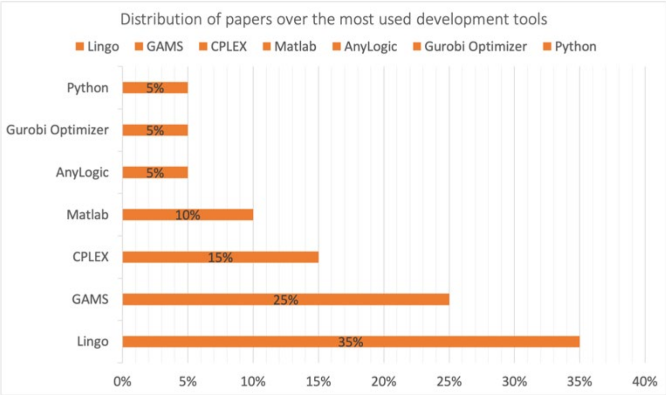

Fig.5. Distribution of publications over the most used development tools

Figure 6 shows the main industries in which the PP models were applied. Of the 41 papers analyzed, 19 were validated by practical applications in real-world environments or inspired in real practices from several industrial sectors. Semiconductor and automotive industries are the most used industrial sectors for practical applications.

[14] investigates the integration of production planning and scheduling for flexible fabrication systems in consideration of stochastic characteristics such as the moving time and the processing time in the semiconductor industry. Indeed, semiconductor fabrication consists of hundreds of process steps, and each process step has its own characteristics.

[15] addresses an integrated production and distribution planning problem comprising of multiple manufacturers serving multiple selling locations. A novel fuzzy multi-objective mixed-integer programming model is formulated considering multi-product, multi-period, and multi-site manufacturing environment. Minimization of the total cost, delivery time, and backorder level are the three fuzzy objectives represented by the piecewise linear membership function. A real-world case in the automobile industry is considered for demonstrating the analytical results of the proposed approach.

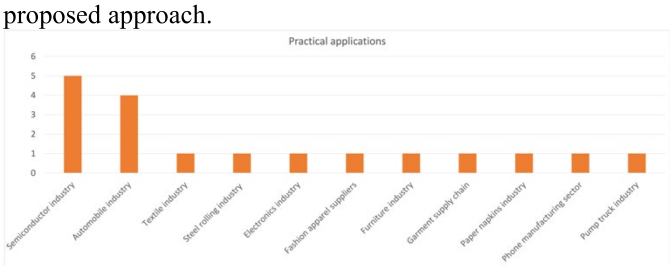

Fig.6. Practical applications

4. Critical discussion of research findings

The Cooperative Supply Chain (Coop SC) framework is a prototype capable of supporting a decision-making process through adequate, modern, and flexible tools, capable of hosting algorithms from third parties.

The Coop SC framework considers the entire supply chain. It does not include processes that are part of one of the "worlds" (source, make, deliver) but considers all of the actors coming from the supply, production, and distribution accordingly to a multi-level and multi-site approach. The Coop SC framework is based on the following multi-level structure

- Supplier relationship management
  - supplier performance management
  - supplier collaboration module
- Production management
  - finite capacity planning
  - production scheduling
  - production real-time data collection and monitoring
- Distribution resource planning
  - network design and optimization
  - multi-level inventory management
- Demand management
  - mathematical forecast
  - consensus forecast.

In the Coop SC framework, not only situations that require intervention by the user are highlighted, but a series of possible actions aimed at solving the problem is promptly proposed. This is possible thanks to the availability of a library of implemented algorithms, which can be invoked by the user. Each action performed within the framework triggers a process workflow capable of involving multiple actors within the logistics chain that, in turn, will choose the type of behavior to be implemented, triggering other reactions supporting the complex management of such networks.

Table 3 – Coop SC vs Literature Review evidence

Criteria	Coop SC	Coop SC vs Literature Review
Problem type	MPS, Material Requirement Planning (MRP), SCP, APP, Hierarchical Production Planning (HPP)	Full coverage
Number of products and number of levels	Multi-item, Multi-level	Aligned to 177 out of 250
Time period	Big bucket model, multi-level	Aligned to 169 out of 177
Nature and demand	Deterministic	Aligned to 207 out of 250
Capacities or resource constraints	Supply, Capacity, Inventory	Aligned to 229 out of 250
Extensions on: Demand	Backlogs, Partial Substitution, Time Window	Aligned to 101 out of 141
Extensions on: Set-ups	Carry-overs; Sequence-dependent; Family	Full coverage
Extensions on: Production times	Overtime and Subcontracting	Aligned to 56 out of 60
Extensions on:	Parallel machines including the machine index	Aligned to 19 out of 34

Multiple and parallel machines		
Extensions on: Multisite	Network, Convergent, Cojoined	Aligned to 41 out of 57
Extensions on: Remanufacturing activities and/or quality issues	No	Out of coverage
Modelling approach	Hybrid (Simulation + Heuristic + Linear/Integer/Mixed integer linear programming)	Aligned to 168 of 250
Solution approach	Decomposition and aggregation heuristics, metaheuristics, problem-specific and greedy heuristics	Aligned to 10 out of 250
Development tools	C+CPLEX/Java+CPLEX	Aligned to 29 out of 180
Application	Real industrial application mainly discrete + batch processes	Aligned to 10 out of 70
Limitations	Solution methods; No disposal activities; No pricing on demand; No transport capacity or issues	Aligned to 100 out of 250
Benefits	Solution procedure; Inventory, Production, Customer, Set-up costs; Application in real environment	Aligned to 167 out of 200

After reviewing the selected papers on tactical production planning, this section provides a comparison between the Coop SC project and the relevant features (Table 3) that emerged from more than 250 contributions, categorized according to [4] and described at the end of section 2. For 'Problem Type' the proposed approach can support all the types: MPS, MRP, SCP, APP, HPP showing full coverage of LR evidence. Concerning the 'Number of products and number of levels', in line with most of the reviewed papers that deal with parts and raw materials planning correspond to multi-level lot-sizing modeling approaches, Coop SC can operate multi-item, multi-level calculations presenting an alignment to 177 out of 250 reviewed items.

The proposed approach considers a big bucket model on a multi-level configuration since multiple items can be produced in the same bucket about the 'Time period' category showing an alignment to 169 out of 177 contributed papers on the topic.

As the majority of the contributions analyzed (207 out of 250), the Coop SC is a deterministic system. The 'Capacities or resource constraints' is fully supported by a combined approach considering supply, machines, and operators' capacity, inventory but without transportation, presenting a full alignment to the total of LR contributions.

In comparison to these features, LR evidence focuses mainly on developing efficient algorithms for typical lot-sizing extensions, such as the inclusion of backlogs, set-up times, sequence-dependent set-ups, et. Thus, the main contribution of the reviewed articles is to propose efficient solution methods, which outperform previous procedures in the literature in terms of CPU time or optimality or production, inventory, set-ups, or transport costs. Despite that, multi-item big-bucket models are the majority for single-item models, but mono-level BOM is more common. Moreover, most of the reviewed articles consider capacity constraints related to productive resources and inventory space. On the other hand, the consideration of uncertain parameters related to unpredicted and variable production environments is an additional improvement in the proposed models. In our opinion, and independently of the production area, the reviewed articles address but do not model the situations related to current complex industrial environments and their impact on tactical decisions, such as the markets characterized by low demand and high competition, environmental aspects, offshoring of suppliers and importance of transport. This is in line with the specific technical choices taken to design and implement Coop SC.

Instead, several extensions are identified in the analyzed papers in addition to those cited above, for example, the consideration of production times (overtime, undertime, and subcontracting), multiple and parallel machines, and remanufacturing activities and quality issues. Among them, extensions related to demand and set-up properties are those more included in the reviewed models.

The extensions of Coop SC satisfy this situation and trend:

I. Demand Backlogs with substitution and time window,
II. Set-ups with carry-overs, sequence-dependent, and family,
III. Production times with overtime and subcontracting,
IV. Multiple and parallel machines with parallel machines including the machine index,
V. Multisite with network, convergent, cojoined.

Unfortunately, remanufacturing and quality issues have not been considered and represent a current limitation of the framework.

Even if some articles have been validated using data from real-world manufacturing firms, most reviewed articles perform numerical experiments with randomly created instances. In this respect, Coop SC is a step further being designed and implemented to satisfy real-world implementation, representing one of the unique models that are reported to be implemented and incorporated into the planning systems of the companies considered.

We believe that this could significantly reduce the gap between academic research and industry, as reported in the LR analysis. Coop SC has been thought for industrial practitioners to solve production problems easily without having to learn new modeling or programming languages so reducing or eliminating problem-dependent solution methods based mainly on operations research principles and programming languages.

Mathematical programming-based solution procedures and specific solution methods such as heuristic algorithms are proposed in most of the analyzed papers, and to a lesser extent metaheuristic. According to this, Coop SC allows for a hybrid approach based on simulation, heuristic, Linear/Integer/Mixed integer linear programming, capable to decompose and aggregate heuristics, metaheuristics, problem-specific and greedy heuristics. When required, C+CPLEX/Java+CPLEX developing tool can be used.

The need to obtain optimal results (or near to optimal) makes the option of using CPLEX a powerful approach.

Anyway, this can prove a great difficulty for SMEs which cannot afford to buy these expensive, specific tools or to hire specialists in these fields. From our point of view, Coop SC represents a production-planning model that reflects the current problems in complex industrial production environments and that can be implemented with highly customizable and easy-to-use tools that integrate into the firm's current information systems (ERP, APS, et.) to bridge this gap.

Evidence from LR presents some limitations in terms of features or application domain (i.e., sustainability issue and/or real industrial applications). While the proposed system addresses the second aspect, the sustainability aspects are missing and should suggest specific developments in this direction.

5. Conclusions

In this study, a specific PP software prototype (Coop SC) based on a practical approach to the current problems in complex industrial production settings has been discussed using the evidence of comparison to outline potential advantages and weaknesses. A literature review has been performed to understand the evolution of PP models over the last decade. The framework adopted for this review is the one developed by [4], which consists of 13 criteria: problem type, aim, the number of products, time period, nature of demand, capacities constraints, extensions, modeling approach, solution approach, development tool, application, limitations, and benefits. The results of this literature review are substantially aligned with [4]. Finally, a comparison between the Coop SC project and the relevant features (Table 3) that emerged in [4] is performed.

Coop SC can be implemented with highly customizable and easy-to-use tools, which connect to the current information systems in the firm and are supported by innovative work-flow management architecture. This allows industrial practitioners to face and solve production problems efficiently without the need of learning new modeling or programming languages. Hence, reducing or eliminating problem-dependent solution methods based mainly on operations research principles and programming languages.

The specific technical choices operated in the Coop SC framework development may help to address the situations related to current complex industrial environments and their impact on tactical decisions, such as the markets characterized by low demand and high competition, offshoring of suppliers, and importance of transportation. Anyway, remanufacturing, and environmental aspects have not been properly considered concerning LR evidence.

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