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Advanced Planning and Scheduling (APS) Systems: A Systematic Literature Review

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Abstract. Planning and scheduling are important functions for industrial systems to operate effectively. Their principal aim is to detail how production resources will be used so that its demand is timely met. In literature, there are several works that propose mathematical models for production planning and scheduling for different production scenarios, accounting for different resources configurations and other limitations. However, it was only recently that advanced planning and scheduling systems (APS), making use of these models, started being more widely used and discussed. This work presents the results of a systematic literature review, developed by applying the ProKnow-C method, on APS systems. An overview of the main publications is provided, classifying them in new methods, models or approaches; heuristic approaches; Lagrangian relaxation techniques; and genetic algorithms. The future of APS systems is also discussed, particularly regarding difficulties such as human dependence, use of spreadsheets, and their role in Industry 4.0 with the use of technologies such as the RFID and Cloud computing.

Keywords. Advanced Planning and Scheduling Systems (APS), Industry 4.0, Systematic Literature Review

Introduction

Advanced Planning Systems (APS), also known as Advanced Planning and Scheduling, are described in APICS Dictionary [1] as “any computer program that uses advanced mathematical algorithms or logic to perform optimization or simulation on finite capacity scheduling. These techniques simultaneously consider a range of constraints and business rules to provide real-time planning and scheduling, decision support, available-to-promise, and capable-to-promise capabilities” [2]. APS are transdisciplinary in nature, once they encompass and integrate knowledge in areas such as mathematical modelling, information technology, and production systems, among others.

Material Requirements Planning (MRP) was the first generation of planning systems, built around a bill of materials (BOM). Later, MRP systems were improved to deal with capacity requirements planning, as they provided feedback of information that led to the ability to adjust plans and regeneration, and became known Manufacturing Resource Planning (MRP II). In 1990, the term Enterprise Resource Planning started to be used, as software tools were gradually integrated on another areas of application, such as

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forecasting, long-term planning and critical resource planning [3]. The ERP can provide initial plans, but it often does not provide tools that assist the planner in analyzing and updating the proposed planning. Trying to fill the void of limited functionality in ERP solutions, advanced production planning (APS) software systems emerged [4].

Unlike traditional ERP systems, APS seeks to find viable plans close to optimum, while potential manufacturing bottlenecks are considered explicitly [5]. Many ERP and APS systems make it possible to include suppliers and customers in the planning procedure and thereby optimize an entire supply chain in real time [6, 7]. The APS has far surpassed the planning and scheduling functionality of the ERP system and has become an impressive and important tool in planning. A strong feature of APS is the ability to “simulate” different planning scenarios before the plan’s launch. APS does not replace, but complements existing ERP systems. The ERP system handles basic activities and transactions, such as customer orders, accounting, etc. while the APS system deals with the daily activities of analysis and decision support [3].

The purpose of this work is to analyze publications on APS systems. An overview of the main publications is provided (Sections 2 and 3), after presentation of the research design (Section 1), classifying them as dealing with new methods, models or approaches; heuristic approaches; Lagrangian relaxation techniques; and genetic algorithms (Section 3). The future of APS systems is also discussed (Section 4), particularly regarding difficulties such as human dependence, the use of spreadsheets, and their role in Industry 4.0 with the use of technologies such as RFID and Cloud computing. In the conclusion (Section 5), further perspectives for the advancement of APS are drawn.

1. Research Design

For this study, the bibliographic review method used to achieve the proposed objectives was the Knowledge-Constructivist Development Process (ProKnow-C). The process consists of four steps: (a) definition of the research question and research objectives; (b) selecting a portfolio of articles on the research topic; (c) bibliometric analysis of the portfolio; and (d) systemic analysis [8].

Research objective was established as gaining an understanding of the literature regarding advanced production planning systems. The Web of Science and Scopus reference databases were searched using the terms “Advanced Planning System” and “Advanced Planning and Scheduling” in the title, keywords and abstract fields limited to a period of 20 years (from 2001 to 2021). A total of 649 articles were retrieved, and after excluding duplicates, a total of 455 articles were selected for analysis of their alignment to the research objetives. By reading the titles, 140 articles were considered aligned. Scopus and Web of Science were searched again, this time to get the citation count of each one of the 140 articles. A threshold of 6 citations was established, which encompassed 46 papers that had 90% of the total citations of the set, forming repository K. The remaining 94 articles formed repository P.

Articles from repository K had their abstracts read and 29 were selected as fitting the objetives of he research, forming repository A. Authors of these articles were identified and formed a bank of authors (BA). Repository P was further analyzed for recent authors (published between 2018 and 2021), in a total of 12, and for articles that were authored from someone belonging to the bank of authors, in a total of 17. These 29 articles from repository P formed repository B. Abstracts of articles in repository B were read, eliminating 3 articles, that were merged with the 29 articles from repository A, forming repository C with 55 articles. Of these, 19 articles were not possible to be retrieved in full because of access restrictions, and the total number of articles to have their content analyzed was 36. Content of these articles is presented in the next two sections (2 and 3), with an analysis of this content performed in section 4.

2. Advanced Planning and Scheduling (APS) Systems

In the research field, APS studies mainly focus on theoretical perspectives including model complexity, problem scope and design of algorithms [9]. Other studies show that there are several problems involved in using planning software such as high complexity, lack of training and knowledge among managers and personnel, low-data accuracy, and lack of support from the software vendor [10, 11]. The advanced planning and scheduling (APS) problem has received increasing attention from the research community in recent years, as seen next.

Palmer [12] and Sundaram and Fu [13] discuss the integrated process of planning and scheduling; Gupta *et al.* [14] consider the two-machine flowshop scheduling problem, which seeks to find a minimum total flow time schedule subject to the condition that the makespan of the schedule is minimum; Hankins el al. [15] discuss the advantages of using alternative machines tool routings to improve the productivity of a machine shop. Holloway and Nelson [16] suggest an alternative formulation of the job shop scheduling problem, based on the concept that capacity constraints and operation precedence relations are allowed to be violated if keeping due dates is more important; Biskup and Jahnke [17] analyze the problem of assigning a common due date to a set of jobs and scheduling them on a single machine assuming that the processing times of those jobs are controllable and considering a situation in which it is only possible to reduce all the processing times by the same proportional amount; Lin [18] discuss the problem of minimizing either the maximum tardiness or the number of tardy jobs in a two-machine flowshop with due date consideration; Sung and Min [19] consider a scheduling problem for a two-machine flowshop incorporating batch processing machines (BPMs), which considers the earliness/tardiness (E/T) measure and a common due date; Hastings et al. [20] use a form of forward loading to schedule jobs on the available capacity; Sum and Hill [21] propose a new framework for manufacturing planning and scheduling systems; Cheng and Gupta [22], Baker and Scudder [23] and Gordon et al. [24] consider the general planning and scheduling problem, in which the most common objective is the minimization of the makespan, due to the growing interests in JIT production strategy in industry; Kim and Kim [25] explore a problem of short term production for products having multi-level structures, with the objective of minimizing the weighted sum of tardiness and earliness of the items based on Group Technology (GT). Shen et al. [26] reviews the APS from theoretical aspects in terms of planning, scheduling and their integration, particularly on agent based approaches. David et al. [27] implement APS in an aluminium conversion industry; Neumann,et al. [28] propose an APS to support supply chain planning under the observed limited resources.

3. Methods, Algorithms and Mathematical Models

Advanced planning systems use complex mathematical algorithms to forecast demand, to plan and schedule production within specified constraints, and to derive optimal sourcing and product-mix solutions [3]. In this research we grouped the different works into four main categories regarding how they approached the solution to the APS problem, after analyzing the content and grouping the works in the bibliographic portfolio: new methods, models or approaches; heuristic approaches; Lagrangian Relaxation Techniques; and genetic algorithms. Other approaches exist, but were not categorized within any of these groups and are not presented here. These categories and a summary of works follow.

Studies focused on **new methods, models or approaches**: Palmer [12] develops a method based on simulated annealing (SA); Taal and Wortmann [29] describe an intuitive planning method that integrates MRP with finite capacity planning, based on scheduling techniques; Lasserre [30] proposes a decomposition approach to solve the APS problem; Moon et al. [31] suggest an advanced planning and scheduling model which integrates capacity constraints and precedence constraints to minimize the makespan only; Hsu et al. [32] develop a cloud-based advanced planning and scheduling (CAPS) system because the cost to implement the APS systems in Small and medium-sized manufacturing enterprises (SMEs) are to high for satisfying the specific production characteristics and planning constraints; Zhong et al. [33] propose an RFID-enabled real-time advanced production planning and scheduling shell; Bose and Pekny [34] present a method using the model predictive control concept for solving planning and scheduling problems; Guo et al. (2009) [35] use particle swarm optimisation to integrate planning and scheduling in an application to achieve meaningful APS; Smith et al. [36] discuss a particular constraint-based solution framework as well as a specific architecture for configuring the APS system, in order to establish APS in complex application domains; McKay and Wiers [37] use standard software for designing an APS, which integrates the HPP concept in a factory; Torabi et al. [38] present a holistic three-level fuzzy HPP and scheduling methodology was introduced for multi-product and identical parallel machines in a batch process environment; finally, Brandimarte and Calderini [39] develop a two-phase hierarchical Tabu search for efficient planning and scheduling.

Some of the researchers took a **heuristic approach** to solve the APS problem: Nasr and Elsayed [40] present two heuristics to determine an efficient schedule for the n jobs/m machines problem, with alternative machine tool routings allowed for each operation; Kolisch and Hess [41] introduce three efficient heuristic solution methods: a biased random sampling method, and two tabu-search-based large-step optimization methods for the problem of scheduling multiple, large-scale, make-to-order assemblies under resource, assembly area, and part availability constraints; Chung et al. [42] consider a kind of job shop scheduling problem in which each job has its due date; Bahl and Ritzman [43] provide an integrated model and a heuristic solution procedure which decomposes the overall problem into smaller sub-problems and solves them in an iterative form; Faaland and Schmitt [44] devise a two-phase heuristic technique to generate feasible schedules by solving a sequence of maximum flow problems; Agrawal et al. [45] exploit a precedence network to represent the precedence relationships among items and then developed a heuristic approach to generate near-optimal schedules, employing critical path concept.

Other researchers based their research on solving the APS problem focused on the **Lagrangian Relaxation Technique**: Czerwinski and Luh [46] chose an improved Lagrangean relaxation technique to address the APS problem with the objective function containing quadratic earliness and tardiness penalties, but the solution oscillation has not been completely eliminated, which slows convergence of the algorithm; Shin et al. [47] focused on scheduling area by developing two improved Lagrangean relaxation methods that are able to satisfy the special requirements; Hoitomt et al. [48] and Luh et al. [49] discusses that both the Langrangean Method and its applications prove that is is flexible enough to deal with a variety of scheduling problems; Yoneda [50] presents two of the Lagrangean relation method features to improve its potential for practical application: its scalability and its simple logic; Kuroda et al. [51] and Kuroda [52] apply the algorithm to a variety of situations, in order te explore the possible applications of the Lagrangean reIaxation method to dynamic scheduling problems; Shin et al. [53] develop a feasibility study that applied the Lagrangean relaxation method to Available To Promise (ATP) logic in a simple order based APS environment.

Likewise, some researchers based their research on solving the APS problem on the development of a **genetic algorithm (GA)**: Pongcharoen et al. [54] develop a genetic algorithm-based tool which includes a repair process to rectify infeasible schedules for the planning and scheduling of complex products with multiple resource constraints and deep product structure; Chen et al. [11] develop a genetic algorithm (GA) to minimize cost of both production idle time and tardiness or earliness penalty of an order; Dellaert et al. [55] discuss the multi-level lot-sizing (MLLS) problem in MRP systems and develop a binary encoding genetic algorithm and five specific genetic operators to ensure that exploration takes place within the set of feasible solutions; Caraffa et al. [56] consider the problem of minimizing the makespan of n jobs in an m machine flowshop operating without buffers; Lee et al. [57] propose an operation-level APS model, integrated planning, and scheduling with outsourcing, as might apply to a practical manufacturing supply chains; Shao et al. [58] propose a modified genetic algorithm-based methodology for the integration of planning and scheduling.

4. Difficulties and Role in Industry 4.0

Throughout the analysis of the contents of the papers in the bibliographic portfolio, authors identified a set of difficulties for the future development of APS and their role in Industry 4.0. These are related to human dependence, use of spreadsheets, and the use of Industry 4.0 technologies, mainly RFID and Cloud computing. These topics are discussed next. These difficulties, together with the role APS play in Industry 4.0, constitute a transdisciplinary issue in the advancement of APS technology, that must be considered in future works.

4.1. Human Dependence

APS aim at automating and computerizing the planning processes by use of simulation and optimization. Still, the decision-making is done by planners with insight in the particular supply chain and know-how on the system constraints and feasibility of created plans. Thus, APS aim to bridge the gap between the supply chain complexity and the day-to-day operational decisions. This requires, however, that planners are able to model and setup decision rules for the planning and optimization [3]. In addition, the role of the human planner has been a widely addressed topic. Humans possess both cognitive strengths and weaknesses that influence the quality of planning [4]. And reasons for not following the planned orders have a wide variety: The planner does not trust the techniques generating the schedule, the planner does not update the parameters of the ERP system that are needed, or the planner has more information than the system. It can also be that the planner has the feeling that an increased mental effort will increase the outcome of the resulting plan or schedule, which is not necessarily true [59, 60, 4].

APS systems were established to predict future production schedules by exact mathematical optimization techniques and heuristics. However, APS systems lack of a part of flexibility, such as the control strategies for sequencing that are permanently defined. The current APS systems cannot provide the optimal configuration of the control strategy based on the current situation [61]. In addition, a solution of the possible combinations of control strategies regarding the dependencies of individual jobs and machines is too complex for humans [32].

4.2. Use of Spreadsheets

Spreadsheet applications as the primary medium for planning is one of the major contributors to planning developments in practice, in which planners need to analyse the plans, analyse issues and looks for resolving of problems [62]. Many have recognized the need for improving existing planning solutions by introducing (improved) spreadsheet solutions throughout the years [63, 64, 65].

Likewise, Hsu, T. H., et al. [32] conducted a study of small and medium-sized manufacturing enterprises (SMEs) in Taiwan and found that most of the manufacturing industries (e.g., metal manufacturing, machinery and equipment manufacturing etc.) still heavily rely on the spreadsheet-based production planning and scheduling with ERP systems. Very few SMEs have implemented the advanced planning and scheduling (APS) systems due to the high implementation cost for satisfying the specific production characteristics and planning constraints.

This is in contradiction to the late push for digitalization, where more advanced and integrated IT systems are seen as the solution for planning and control [66] and big developments are seen in computing power, algorithm development, with a growing research focus on concepts such as digitalization and Industry 4.0, which focus heavily on automation of decision-making by using big-data and advanced algorithms on one hand, and production planning and scheduling not showing significant improvements in practice over the last twenty years on the other especially with the use of spreadsheets [2].

4.3. RFID applications

The use of RFID in APS has attracted a lot of attention from researchers in recent years. Brewer et al. [67] adopted RFID for dynamic scheduling on a manufacturing shop-floor to control the logistics operations. Johnson [68] used RFID to guide the repair work in a car production line. Huang et al. [69] proposed an RFID-based scheduling system for walking-worker assembly islands with fixed-position layouts [33].

There are several typical characteristics in RFID enabled production applications. First, paper-based operations are eliminated [70]. Second, manufacturing data become real-time, accurate, complete and consistent. Third, changes and disturbances could be captured on a real-time basis. Finally, the physical movements of materials and information flows are tracked and traced and synchronised [71, 33].

These characteristics have positive impacts on production decision making. RFID data enable realtime visibility and traceability, forming the fashion of ‘what you see is what you do and what you do is what you see’ [72]. Decisions could be made on a timely basis by means of feedback from manufacturing sites with much reduced transfer delay.

Real-time visibility and traceability enable better cooperation among different parties, improving the overall production efficiency [33].

However, decision makers are still facing challenges. First, the use of RFID technology speeds up the decision-making process, demanding more prompt actions from decision makers. In such a case, it is more difficult for them to make precise and on-time decisions because they often suffer from conflictive and dynamic objectives [73]. Second, they lack a collaborative mode in terms of decision-making procedures and corresponding information systems, which can effectively and efficiently guide their behaviours [74]. Finally, it was first mentioned that two challenges cause a gap between the highly synchronised information flow at manufacturing sites and unstandardised procedures for decision making. The gap presented earlier might be bridged by advanced planning and scheduling (APS) [33].

4.4. Cloud APS

In the past, enterprises often invested high capital in many physical devices and servers. The pressure not only comes from the high capital investment but also the time and manpower to install and maintain the operating systems and software services [75, 76]. The characteristics of cloud manufacturing is to connect production resources to the cloud and virtualize them, thus the cost of manpower and equipment can be shifted on to cloud suppliers to save the operating costs. Enterprise pays for the requirement of actual operation instead of high investment [77] and It does not require high-end devices to have high-speed computing ability, as long as they are in the network environment [33].

5. Conclusions and Futures Perspectives

Production planning systems are not keeping up with the latest advances in the field of technology, especially when we talk about the new concepts of digitalization, digital transformation and industry 4.0, with the application of big data, Cloud hosting, automation, IoT and advanced algorithms. We found some approaches focusing on RFID, but their applications are still somewhat timid. There is a lack for a transdisciplinary perspective in dealing with all of these topics.

We can see that the human factor is still decisive for the correct functioning of an APS system (as seen in Section 4.1), that the systems depend on data inputs, that they depend on generating of scenarios and that the manager needs to have a great knowledge about the factory and the process to be able to parameterize all the resources of the APS,in order to generate reliable programming scenarios. Often, these managers use spreadsheets to support APS, since the systems are still complex to be used and not very flexible. And these spreadsheets provide the flexibility to input and modify data, giving the manager more autonomy.

Another point observed is that there are many methods, approaches, algorithms and mathematical models, which have been taken into account by researchers over the past few years, but still in this bibliographic review, few studies were found that focus on the APS problem with the application of artificial intelligence algorithms.

Thus, there is still a very open field for research, which researchers can focus on in the future, especially when we bring the context of industry 4.0 to the APS. How can we have more flexible and more intuitive systems for the use of managers? How can we apply the concept of Big Data to APS? How can we design a Cloud systems architecture without affecting other systems and looking at the reality of each company? How can we apply artificial intelligence concepts to give more autonomy to APS systems and reduce the dependence on people for its correct use? Which IoT and RFID applications can be integrated into the APS context for the exchange of information and real-time operation of this system? These and other questions are transdisciplinary issues that must be addressed in an integrative perspective for the study and advancement of knowledge regarding Advanced Planning and Scheduling (APS) Systems.

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