Review

Production rescheduling review: Opportunities for industrial integration and practical applications

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A R T I C L E   I N F O

Keywords:
Production rescheduling
Reactive scheduling
Schedule recovery
Schedule repair
Dynamic scheduling

A B S T R A C T

Production rescheduling has been categorized according to applied approaches or application context. With the advent of the fourth industrial revolution, new perspectives and challenges for production rescheduling arise, mainly regarding inter- and intra-organizational integration. In addition, problem solving of production rescheduling in dynamic environments publish in scientific papers are difficult to be implemented in real industries. By means of a systematic literature review, this research aims to identify what have been studied about production rescheduling process, mainly solutions involving integration among industries and real cases applications. The results and discussions were presented in two sections, (1) basic data analysis and (2) data analysis with specific purposes. The few papers with industrial applications and the lack of papers about end-to-end digital integration substantiate identified research opportunities. This research provides a general overview of the state-of-the-art in production rescheduling.

1. Introduction

Due to the advent of new concepts, methods and technologies related to the fourth industrial revolution (Industry 4.0), all kinds of businesses will be affected. The adjectives smart, intelligent, autonomous, adaptive are used to rename updated processes. This wave started at manufacturing environments but, as it commonly happens, it has already crossed many other areas, including logistic and supply chain.

Among some aspects of Industry 4.0, Kagermann et al. [1] list three necessary integration features: (1) horizontal integration, (2) vertical integration and (3) end-to-end digital integration and; Hermann et al. [2] state its concepts are underpinned by six principles: (1) interoperability, (2) virtualization, (3) decentralization, (4) real-time capability, (5) service orientation and (6) modularity.

Liao et al. [3] report the lack of efforts on End-to-End Digital Integration. Ivanov et al. [4] say that industry 4.0 characteristics would make the network more capable of adapting to sudden changes, these smart supply chain networks have dynamic structures, which evolve over time. Some challenges and future directions are described by Waschneck et al. [5], such as: (1) decentralization and autonomous decisions, including the decomposition of scheduling problems, (2) flexibility and adaptability, including rescheduling strategies and (3) integration and networking, including integration of supply chain data into scheduling and dispatching decisions.

In dynamic manufacturing environments, downtimes are caused by unexpected disturbances in production processes. To mitigate the impacts in factory efficiency and avoid noncompliance of customer commitment, the need for schedule changes should be analyzed. The process of updating production schedule is called production rescheduling. According to Cardin et al. [6], facing a growing set of unpredicted events, the new models and methods designed for industries should be adaptable and reactive and, besides providing the efficient overall production performance, it should include a clear estimations of states (current and possible future) of their production system. In addition, the product traceability throughout the whole supply chain should be provided.

Some reviews have already dealt with the production rescheduling process, as this study will show. However, systematic literature reviews dealing with production rescheduling inter-organizational integration were not found. This research aims to identify what have been studied about production rescheduling process, mainly solutions involving integration among industries and real cases applications.

In the next section, insights from previous literature are verified to address research questions. Section 3 presents the research methodology. The results of the systematic literature review are reported in section 4. Finally, section 5 provides the conclusions and describes some ideas for further research.

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More research is needed to compare the performance of manufacturing systems under predictive-reactive rescheduling policies and other production planning functions. In addition, more research is needed to understand how interactions between rescheduling policies and real-time events related to jobs, dynamic scheduling has been defined under three categories: completely reactive scheduling, predictive-reactive (robust) scheduling, and robust pre-active scheduling. Two main alternatives to deal with the problem of updating schedules were discussed: schedule repair, and complete rescheduling.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Title</th>
<th>Objectives</th>
<th>Conclusions</th>
<th>Papers classification used</th>
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<tr>
<td>[12]</td>
<td>Reactive recovery of job shop schedules – A review</td>
<td>Explore the scope and status of both the existing and the proposed schedule recovery approaches. In addition, the different approaches will be compared and a robust plan for future work will be formulated.</td>
<td>Reactive scheduling of a job shop using various approaches for schedule recovery and repair were reported. In this paper, the various methods were summarized and compared on common measures. In addition, the factors that were lacking in the work were identified. A unified methodology was proposed, AutoSHARP, which is aimed at resolving the deficiencies in the existing approaches.</td>
<td>Summary of the reactive repair approaches: (1) Right-shift rescheduling; (2) Heuristic-based; (3) Multi-agents in distributed artificial intelligence; (4) Active scheduling; (5) Fuzzy logic; (6) Case-based reasoning; (7) Constraint-based scheduling; (8) Artificial intelligence techniques (neural networks and genetic algorithms).</td>
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<td>[13]</td>
<td>Rescheduling manufacturing systems: A framework of strategies, policies, and methods</td>
<td>Presents definitions appropriate for most applications of rescheduling manufacturing systems and describes a framework for understanding rescheduling strategies, policies, and methods. Discusses studies that show how rescheduling affects the performance of manufacturing systems, and it concludes with a discussion of how understanding rescheduling can bring closer some aspects of scheduling theory and practice.</td>
<td>Presented a framework for understanding rescheduling research and defined a number of terms used in rescheduling research and practice. No discussions about the details of the many algorithms used to generate and update production schedules.</td>
<td>Descriptions of selected papers using the rescheduling framework: environment, strategy, policies and methods.</td>
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<td>[14]</td>
<td>Process scheduling under uncertainty: Review and challenges</td>
<td>Provides an analysis of the sources of uncertainties in process scheduling, present different methods of describing the uncertain parameters and give a detailed literature review on existing approaches that address the problem of uncertainty in scheduling.</td>
<td>Summary - Scheduling methods were divided into two groups: reactive scheduling and preventive scheduling.</td>
<td>Scheduling methods: (1) Reactive scheduling, (2) preventive scheduling.</td>
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<td>[15]</td>
<td>A survey of dynamic scheduling in manufacturing systems</td>
<td>Defines the problem of dynamic scheduling and provides a review of the state-of-the-art of currently developing research on dynamic scheduling.</td>
<td>Two categories of real-time information commonly considered in the literature were identified: real-time events related to resources, and real-time events related to jobs. Dynamic scheduling has been defined under three categories: completely reactive scheduling, predictive-reactive (robust) scheduling, and robust pre-active scheduling. Two main alternatives to deal with the problem of updating schedules were discussed: schedule repair, and complete rescheduling.</td>
<td>The principles of several dynamic scheduling techniques, namely, heuristics, meta-heuristics, multi-agent systems, and other artificial intelligence techniques are described in detail.</td>
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<td>[6]</td>
<td>Coupling predictive scheduling and reactive control in manufacturing hybrid control architectures: state of the art and future challenges</td>
<td>Depict the main research challenges that are to be addressed before expecting a large industrial dissemination.</td>
<td>A review about Hybrid Control Architecture was introduced. Also research topics about the optimization of coupling of reactive-distributed and predictive/reactive centralized mechanisms is optimized was introduced.</td>
<td>Three main challenges were highlighted: the estimation of the future performances of the system in reactive mode, the design of efficient switching strategies between predictive and reactive modes and the design of efficient synchronization mechanisms to switch back to predictive mode.</td>
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Future work in the field of scheduling under uncertainty requires extended work in the direction of more effective and general method for dealing with the uncertainties in process industry.
2. Insights from previous literature reviews and research questions

Based on Brandenburg et al. [7], it is appropriate to affirm that summarizing the former reviews of scientific literature justifies the need for content analysis and positions current results to extant scientific research. Furthermore, the previous literature reviews background helps derive relevant information and structures the new study, in addition to helping identify open issues in the subject studied. Then, in order to define the research questions, a summary and analysis of papers that reviewed production rescheduling researches is presented in Table 1:

A few published literature were excluded due to one or more of the following reasons: lack of the full text to be assessed, not completely related (for example, applied to a specific area) or not relevant (published in journal without 2016 Thomson Reuters Impact Factor).

The selected reviews papers can be categorized into methodological approaches reviews [8,9,11,12] and theoretical approaches reviews [6,10]. They do not include integration aspects between factory and customers, the impact of factory rescheduling production in delivery commitments or inventory consumption information from customer to facilitate the factory decision about production rescheduling. In addition, although Cardin et al. [6] have reported about the challenges to be addressed before industrial dissemination, these authors as the others did not approach real industrial applications researches. While these reviews build the base for production rescheduling framework and methodologies approaches, they are not able to clarify on current developments of real industrial applications and future trends about production rescheduling with integrated decision.

Based on these findings, this research will address the following questions:

1. Which are the production rescheduling studies dealing with supply chain integration?
2. How is the production rescheduling applied in real industrial cases?
3. Which are the main production rescheduling research directions?

3. Research methodology

Fink [13] defines ‘A research literature review is a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researches, scholars, and practitioners’. According to Krippendorff [14], the content analysis provides new ideas, improves the research’s knowledge about a specific subject or informs practical actions. Moher et al. [15] states that systematic review is a review of questions that uses methods to identify, select and appraise research, and collect and analyze data from papers that are included in the review.

The systematic literature review methodology applied in this research, is a mixed methods approach gathering from models proposed by Fink [13], Krippendorff [14] and Moher et al. [15], following the steps: paper collection, data collection and synthesize results.

3.1. Papers collection

To assure the integrity of the papers selection, an explicit inclusion and exclusion criteria adapted from Liao et al. [3] was followed, as shown in the Table 2.

Paper selection is structured by following the method outlined in the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) Statement described by Moher et al. [15], as illustrated in Fig. 1.

To find the papers, the search string was constructed through the combination of the Boolean operator “or” among the following five terms: “production rescheduling”, “manufacturing rescheduling”, “reactive scheduling”, “schedule recovery” and “schedule repair”. The papers were collected from reputed databases, cited in other reviews articles [3,16–20], which cover the main journals in engineering, supply chain and other science areas: Scopus (www.scopus.com), Science Direct (www.sciencedirect.com) and Web of Science (www.webofknowledge.com).

In the screening phase, the duplicates were removed and the papers classified as SER, WF and NR1 were excluded. In sequence, a fast review of papers’ titles and abstracts (in case of more information needed, the other elements of the full text were consulted) was performed to elect the papers to be included in qualitative synthesis, papers classified as NR2, LR1 - LR6 and SA were excluded. Finally, following the Pareto principle (also known as the 80/20 rule), the articles were listed in descending citation quantity, following Google Scholar (www.scholar.google.com.br) information and papers that represent 80% of the total citation amount were included in quantitative synthesis.

3.2. Data collection

From the papers included in quantitative synthesis (except information collected to answer research question 3), two groups of data were collected, as presented in Table 3.

3.3. Synthesize results

The collected data were organized in a spreadsheet, the extracted information reports the current knowledge about production rescheduling, explains the findings and answers the research questions. The synthesized results are reported in the Results and discussion section.

4. Results

Based on the methodology adopted, 37 papers were included in quantitative synthesis. In this section, the results and discussions of systematic literature review are presented. The information was subdivided into the following sections: basic data analysis and an overview of included papers and data analysis with specific purposes.

Basic data analysis: an overview of included papers

Fig. 2 shows the 37 papers [21–57] included in quantitative synthesis. The bars show the quantity of citations of each paper and, the lines show that these papers represent 81% of total citation quantity of the 136 papers included in qualitative synthesis.

Fig. 3 shows that the production rescheduling issue has been studied over the years, but it is still the focus of recent researches. Only 8,1% (3 papers) of the studies were published in conference proceedings, which are: Brown [47], ElMaraghy et al. [50], Fattahi and Fallahi [25].

Fig. 4 shows the quantity of published papers per journal, 10 journals have published more than 1 article of the 34 journals’ articles. All 18 journals are classified in 2016 Thomson Reuters Impact Factor.

4.1. Data analysis with specific purposes: three research questions

Based on the 37 papers included in quantitative synthesis, the research questions are answered in this section. Fig. 5 illustrates the papers’ classification in relation to content-based category and industry 4.0 integration features, supporting the answers to the first two research questions.

4.1.1. Which are the production rescheduling researches that are studying supply chain integration?

As showed in Fig. 5, there are no research efforts in studying production rescheduling in end-to-end digital integration. In addition, only 13.5% (5 papers) have vertical integration features [32,37,48,51,55], the others (32 papers, 86.5%) are horizontal integration solutions.
Table 2
Inclusion and exclusion criteria and their explanations.

<table>
<thead>
<tr>
<th>Inclusion/Exclusion</th>
<th>Criteria</th>
<th>Criteria explanation</th>
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<tbody>
<tr>
<td>Inclusion</td>
<td>Closely related (CR)</td>
<td>• The research efforts of a paper are explicitly and specifically dedicated to production rescheduling&lt;br&gt;• Time Span: Before the end of February/2018;&lt;br&gt;• Subject Area: Engineering;&lt;br&gt;• Document Type: Conference paper or article;&lt;br&gt;• Source Type: Conference Proceedings or Journals;&lt;br&gt;• Language: English.</td>
</tr>
<tr>
<td>Exclusion</td>
<td>Search engine reason (SER)</td>
<td>A paper has only its title, abstract, and keywords in English but not its full-text</td>
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<tr>
<td></td>
<td>Without full-text (WF)</td>
<td>A paper without the full text to be assessed</td>
</tr>
<tr>
<td></td>
<td>Review papers (RP)</td>
<td>Review papers already discussed in “Insights from previous literature reviews” section</td>
</tr>
<tr>
<td></td>
<td>Non-related (NR)</td>
<td>NR1: A paper is not an academic article. For example, editorial materials, conference reviews, contents, or forewords&lt;br&gt;NR2: A paper is not aligned with “production rescheduling”, the title indicates other subject that is not related to “production rescheduling”</td>
</tr>
<tr>
<td></td>
<td>Loosely related (LR)</td>
<td>LR1: Production rescheduling is only used as an example fact&lt;br&gt;LR2: Production rescheduling is only used as a part of its future research direction, future perspective or future requirement&lt;br&gt;LR3: Production rescheduling is only used as a cited expression&lt;br&gt;LR4: Production rescheduling is only used in keywords and/or references&lt;br&gt;LR5: Researches about production reschedule in static environment&lt;br&gt;LR6: Researches that the main subject is the initial production schedule: predictive schedule, proactive schedule, robust schedule.</td>
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<td></td>
<td>Specific area (SA)</td>
<td>Production rescheduling is only used for a specific application area: oil operations, gas industry, thermal power, airline schedule, flight schedule, aircraft operations, nurse schedule, power systems, electricity market, energy systems, wind turbines, marine machinery, water distribution, gas refinery, oil refinery, fuel systems, remanufacturing operations, holistic manufacturing systems, air traffic, air transportation, construction processes, concrete structures, chemical processes, bus transportation, vehicle routing, train schedule, shipping operations, project scheduling, maintenance schedule, life cycle studies, steel industry, iron industry, fiber industry</td>
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Fig. 1. PRISMA flow reporting the different phases of the systematic.

4.1.2. What are the production rescheduling studies applied in real industries?

Fig. 5 also illustrates that most of the studies are theoretical solutions, 26 papers (70.3%). Four other papers (10.8%) present discussions about the production rescheduling process. Seven papers (18.9%) are classified as practical applications, presented information extracted from these articles follows:

• **Job shop scheduling optimization in real-time production control** presented an optimization algorithm using simulation as an evaluation procedure of the criterion to obtain an optimal schedule of jobs within a workshop. It is hoped that the system (which is being tested in an actual application) will stimulate the user to continuously improve his or her skill and knowledge [37];

• **On-Line Simulation and Control in Manufacturing Systems** presented a novel on-line simulation framework for multi-resource constrained Flexible Manufacturing Systems (FMSs). The proposed framework was applied for the control of an industrial printed circuit board assembly system [50];

• **Knowledge-based predictive and reactive scheduling in industrial environments** presented a knowledge-based framework, based on object oriented technology, for building scheduling systems aimed at solving real-world problems. The suitability of the proposed approach has been tested in the implementation of industrial scheduling systems currently in use. In all cases the systems were very well accepted and easily incorporated by the human schedulers [32];

• **An MILP framework for batch reactive scheduling with limited discrete resources** reported the development of a new MILP reactive scheduling algorithm to revise the short-term schedule of resource constrained multistage batch facilities due to unexpected events like equipment breakdowns and worker absenteeism. The proposed MILP algorithm was successfully applied to a real-world case study involving unexpected equipment breakdowns and manpower changes [27];

• **A multilevel, control-theoretic framework for integration of planning, scheduling, and rescheduling** proposed an integrated multilevel, control-theoretic framework for effectively handling integration of planning, scheduling, and rescheduling. As an illustrative case study, cyclic scheduling of a simple refinery flow sheet involving continuous lube production in a resource constrained hybrid flow-shop was presented to demonstrate the proposed methodology [48];

• **A fuzzy logic based production scheduling/rescheduling in the presence of uncertain disruptions** reported the development of a decision support system RES-FRB for fuzzy predictive-reactive scheduling of identical parallel machines. It was applied to a real-life scheduling problem identified in a pottery company [57];

• **Real-time scheduling for reentrant hybrid flow shops: A decision tree based mechanism and its application to a TFT-LCD line** suggested a real-time scheduling mechanism in which a decision tree is used to select an appropriate dispatching rule so that the computational
burden required for carrying out simulations can be eliminated. The decision tree based real-time scheduling mechanism was applied to a TFT-LCD manufacturing line [28].

4.1.3. What are the main production rescheduling research directions?

The recent papers included in qualitative synthesis addressed the research directions:

- 3 papers did not inform recommendations for future researches [58–60].
- 4 papers suggested the application of their proposed method to different environments:
  - Kundakci and Kulak [61] introduced efficient hybrid Genetic Algorithm (GA) methodologies for minimizing makespan in dynamic job shop scheduling problem. In future studies, proposed methods may be applied to different job scheduling environments such as parallel machines, flow shop, flexible job shop and open shop. Also, different performance measures can be used in future studies;
  - Rahmani and Ramezanian [62] proposed a novel reactive model based on a classical objective function (total weighted tardiness) and two new surrogate measures, stability and resistance to change. For future research, this problem can be considered for other shop floor scheduling problems and other classical objectives can be used to evaluate this method. Also, the effect of this approach on other random disruptions such as machine breakdown and order cancellations can be investigated and analyzed;
  - Setiawan et al. [63] developed a dynamic scheduling algorithm when a cutting tool is broken during unmanned and a rescheduling needed. The complete-reactive scheduling algorithm was proposed to find the solution. Meanwhile this research would be further developed for predictive-reactive scheduling and

Fig. 2. Quantity of citation per paper and its respective cumulative weight.

Fig. 3. Quantity of papers per year.
Bayar et al. [66] did several recommendations for the future. They relied on biological immunity to guide the design of a knowledge-based approach, and to use it to monitor disruptions and risks in manufacturing systems. The suggested approach involved functions specifically dedicated to deal with a variety of disruptions and risks, such as detection, identification of consequences and reaction to disruptions. Several research directions can be investigated. For example, the detection of disruptions and identification of consequences could be based on approaches such as control charts and fuzzy logic theory to handle uncertainties. The evaluation of impacts and risks can benefit from the immune network theory. Case based reasoning can be involved to reuse stored responses. A quantitative analysis is also needed to assess the performance of the system, in respect for example to its response time. Interoperability issues also need to be investigated. These research directions represent the focus of our future works.

5. Conclusions

In this paper about production rescheduling process, gaps and opportunities for integration among industries and the needed of practical applications were identified.

The basic data analysis shows: (1) Production rescheduling has been researched over the years, but this subject still is interesting in the current time; (2) The most cited papers were published in prominent journals; (3) Among the most cited researches, there are no evidences of production rescheduling process integrated with other organizations (neither supplier nor customer). Most studies proposed solutions for horizontal integration and; (4) Most papers have proposed solutions validated through computational experiments.

The data analysis with specific purposes answers our research questions and gives future directions: (1) There is a big gap about researches for production rescheduling applying end-to-end digital integration. For instance, new studies could be developed in order to integrate production rescheduling between Contract Manufacturer (CM) industries and their customers; (2) Practical applications in real industries should be performed, especially using the research-action and case study methodologies and; (3) Other recommendations for future can also be analyzed in the recent papers.

Some limitations in this research were noted, as follows: (1) only three databases were consulted, (2) the inclusion criteria were limited to the English language, conference papers or articles and engineering subject area and (3) some studies applied for specific areas were excluded. Despite of this, the systematic literature review follows a proper
methodology to answer the addressed research questions and therefore the study’s purpose was achieved. Obtained results serve as a general overview of the state-of-the-art in production rescheduling.

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References


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