22nd International Conference on Modelling and Applied Simulation
20th International Multidisciplinary Modeling & Simulation Multiconference

2724-0037 © 2023 The Authors.
doi: 10.46354/i3m.2023.mas.013

Modeling, simulation and intelligent algorithms for solving the machine-loading problem: a literature review

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Abstract

The aim of this paper is to increase the practitioners' and researchers' familiarity on modeling, simulation and intelligent algorithms for solving machine loading (ML) problem. To achieve this goal, this paper presents the results of a systematic literature review carried out on 54 scientific articles which have dealt with topic. The relating data was collected from the Scopus database; then, Microsoft Excel™ was used for descriptive analysis. The results of this review give some key learning of the trends of the use of modeling, simulation and intelligent algorithm for solving the ML problem and also provide a background for future research related to the field.

Keywords: Machine-loading; literature review; modeling; simulation; intelligent algorithms

1. Introduction

Loading problem is concerned with assigning the necessary operations of the selected jobs to various machines in an optimal manner, so as to minimize the system unbalance (SU) under technological constraints of limited tool slots and operation time (Santuka, Mahapatra, Dhal, & Mishra, 2015). The Machine Loading (ML) problem in Flexible Manufacturing System (FMS) environment can be described as follows: "given a set of part types to be produced with a set of tools that are needed for processing the part types on a set of machine together with using a set of resources such as material handling appliances, pallets and fixtures, how should the parts be assigned and tool allocated so that the productivity Is optimized?" (Kumar, Prakash, Shankar, & Baveja, 2006), (Yusof, Budiarto, Venkat, & Deris, 2011). Such a problem is combinatorial in nature and was proven to be NP-hard (Santuka, Mahapatra, Dhal, & Mishra, 2015).

Generally, ML problems can be handled using two main approaches: (i) optimization-based and (ii) heuristic-based. Optimization-based methods are robust in their applicability, though they to become impractical when the problem size increases, which usually occurs in manufacturing scenarios. On the contrary, heuristic approaches are usually dependent on rules and constraints of individual problems. Because of this nature, heuristic-based approaches always face difficulties in estimating results in a changed problem or environment, which poses issues in handling the ever-changing manufacturing requirements (Yusof, Budiarto, & Deris, 2014). In

recent years among metaheuristic, particularly interesting results were obtained by using Genetic Algorithms (GAs), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Tabu Search (TS), Simulated Annealing (SA), Firefly Algorithm (FA), Harmony Search (HS) and immune algorithm. Overall, it emerges that the ML problem in FMS is an issue deeply analysed.

In line with the consideration above, in this paper a comprehensive literature review of studies that have applied modelling, simulation, and intelligent algorithm to tackle the ML problem is presented. The objective of this review is to provide an overview of the state-of-the-art techniques, methodologies, and advancements in this domain. Through a systematic literature review, we derived a list of 54 papers retrieved from the Scopus database and published in major academic reference journals. Using these studies, this paper tracks and analyses the evolution of the research field based on the publication year and journals, identifies the most prominent countries and authors. Moreover, we determine key trends, methodologies, and challenges associated with the application of modelling, simulation, and intelligent algorithms to solve the ML problem.

The paper is structured as follows. The next section presents the process of data collection and the methodology used, followed by the main results from the review (Section 3). Finally, section 4 concludes the paper by summarising the key findings of the study, highlighting the main limitations and emphasizing future research directions.

2. Materials and Methods

To provide a clear, reproducible and scientific literature review of modelling, simulation and intelligent algorithms for solving ML problem, the process followed by Casino (2019) has been adopted. In particular, the overall methodological approach includes the following steps:

1. Identify the need for the review and develop the review protocol.
2. Identify the research, select the studies, assess the quality, extract data and synthesize the data.
3. Report the results of the review.

To address our primary research question, a systematic literature search was first carried out in March 2023 without timeframe restrictions and the results were subsequently updates in May 2023. The advanced retrieval function of the Scopus database was used to retrieve the papers related to ML problem and published to date. To ensure the quality of the literature, the document types were restricted to research articles and reviews written in English, while other publication types (such as the conference proceedings, book chapter, letters or editorials) were excluded. The preliminary search returned 56 records. The following keywords were used during the research phase: "machine loading" in article title and "algorithm" or "model" or "simulation" in article title, abstract and keywords. In particular, the following Scopus query used was:

(TITLE ("machine loading") AND TITLE-ABS-KEY ("algorithm" OR "model" OR "simulation")) AND (EXCLUDE (DOCTYPE, "cp") OR EXCLUDE (DOCTYPE, "ch")) AND (LIMIT-TO (LANGUAGE, "English")).

Then, two articles were excluded looking at the titles and abstracts, so the remaining 54 articles formed the sample to be included in the analysis. Microsoft Excel™ was used to record all available information about the papers, including authors, countries, sources title, approaches and outputs. Finally, a keywords' analysis was carried out, to inspect their frequency.

All authors conducted data extraction and the evaluation of literature quality independently, for ensuring rigor of the process.

3. Results and Discussion

In this section, the main results of the review are presented and discussed. In particular, some descriptive analyses were first made on the whole sample of papers reviewed, in terms of geographical distribution of the studies, journal, approaches and outputs. Finally, we examine and discuss the keywords analysis.

3.1. Descriptive statistics

The nations that contributed with at least one publication are shown in figure 1. To determine the country of the study, if conflict existed, the nationality of the first author was taken as reference, which is a common approach in review studies (Bottani & Vignali, 2019).

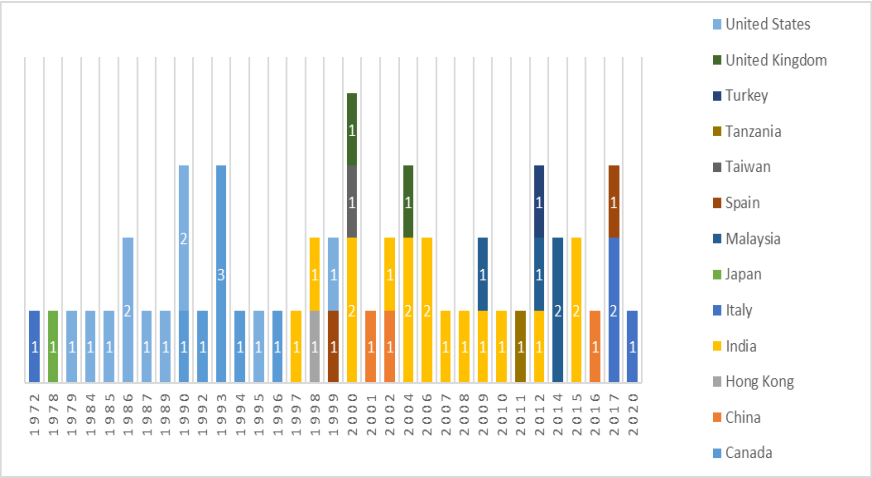


Figure 1. Trend of publications by journals

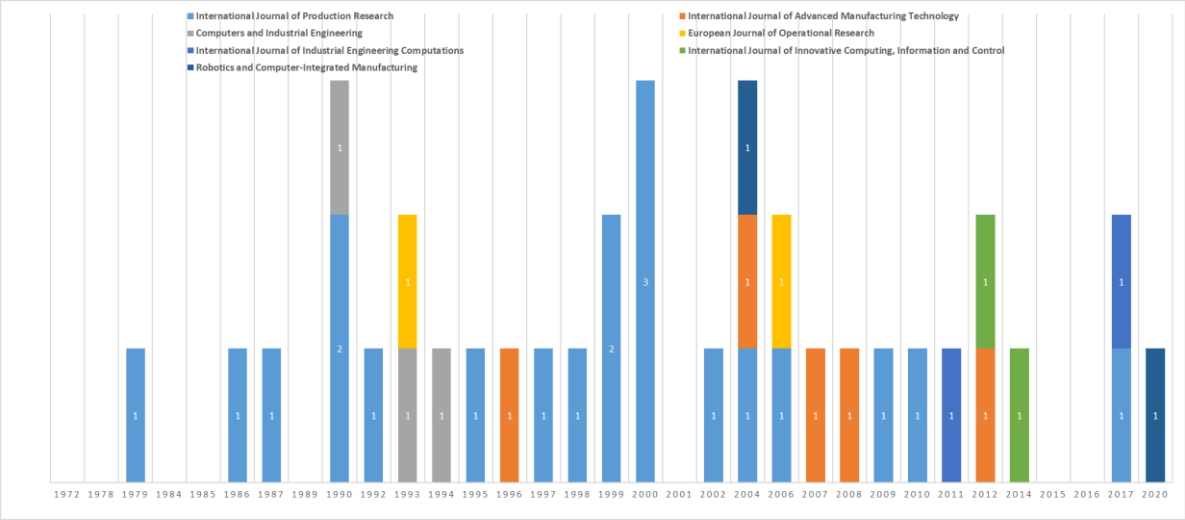
The podium is occupied by India, United States and Canada, with 16, 11 and 7 studies, respectively. As can be seen from figure 1, the United States appear with good continuity at the beginning of the time span, while Italy, on the contrary, has started focusing on these topics in recent times only. In the middle years, we mainly see India establishing itself.

Figure 2 outlines the top contributing authors along with the number of their papers. In total, 105 different authors contributed to the modelling, simulation and intelligent algorithms for solving the ML problem.

Figure 2. Top authors and the number of papers

Tiwari (India) dominates the ranking with 11 published articles, followed by Liang (Canada) and Dutta (Canada)with 6 and 4 papers each, respectively. It is interesting to note that all three of these authors are of nationalities present in the podium in figure 1.

Figure 3 presents the journals where the retrieved articles were published. To be more effective, the representation is limited to journals that published at least two papers.



The 54 papers retrieved have been published on a total of 25 different journals. The International Journal of Production Research stands at the top by publishing the highest number of papers (20 papers out of 53, 37.74% of the sample). International Journal of Advanced Manufacturing Technology is the second ranked journal in terms of publications (5 papers), followed by Computer and Industrial Engineering, with 3 publications. These three journals, taken together, have published more than half the sample of the papers of this study; it could be therefore argued that they are well established in the field of ML modelling/simulation.

Another interesting aspect considered is the approach used in the study. The definitions of the various methods used to classify the revised articles are proposed. Models are simplified representations of a system. Models capturing the structure and dynamics of scientific endeavor are expected to provide insights into inner workings of science. Model design typically involves the formulation of a scientific hypothesis or the identification of a specific structure or dynamics (Börner, Boyack, Milojević, & Morris, 2012). Simulation is a particular approach to studying models, which is fundamentally experiential or experimental. In principle, simulation is much like running field tests, except that a physical or computational model replaces the system of interest (White & Ingalls, 2016). An algorithm is any well-defined computational procedure that takes some values, or a set of values, as input and produces some value, or set of values, as output (Yanofsky, 2011). Informally, an algorithm is a list set of instructions, used to solve problems or perform tasks, based on the understanding of available alternatives (International Institute in Geneva, 2023).

Table 1 shows the results of the papers reviewed according to the approach used.

Table 1. The studies' approaches.

Approach	Articles
Modeling	13
Simulation	1
Algorithm	6
Modeling+Simulation	8
Modeling+Algorithm	2
Simulation+Algorithm	18
Simulation+Algorithm+Modeling	6

The most common approach is the combined usage of simulation and algorithm, with 18 studies, followed by modelling with 13 articles. It is interesting to note that simulation alone is used in one study only (Hungy & Chen, 2000). This study has used simulation to delineate a way for improving the efficiency of semiconductor wafer fabrications by better allocating operator resources.

The most popular intelligent algorithms for solving the ML problem were then identified. Figure 4 shows the algorithms used shared across the years.

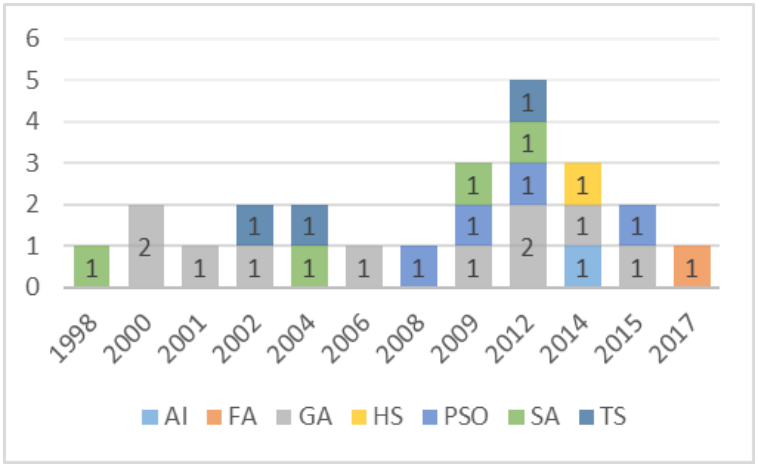


Figure 4. Major intelligent algorithms used for solving ML problem

Considering the ML problem, it is apparent that GA, PSO, SA and TS are the most popular algorithms used, with 10, 4, 4 and 3 applications, respectively. The GA, as can be seen from figure 4, is used some continuity over time, while FA is only used in 2017.

It is interesting to offer some thoughts on the origin and period of these algorithms. HS algorithm was proposed by Geem et al. in 2001, PSO in 1995 (Kennedy & Eberhart, 1995), TS in 1986 (Glover, 1986) and SA in 1983 (Kirkpatrick et al., 1983). Holland developed GAs based on Darwin's evolutionary theory in 1988 (Goldberg, et al., 1988), subsequently, in 1992, Holland expanded the GA (Holland, 1992). The FA is instead more recent; it was first developed by Yang at Cambridge University in late 2007 (Yang, 2010); probably, this is one of the reasons why it has been applied to the ML problem to a lower extent.

Yusof, Budiarto and Deris (2012) have proposed a constraint-chromosome GA to map the right chromosome representation to the domain problem as well as to help avoid getting trapped in local minima. The objective functions are to minimize the SU and increase throughput (TH), while satisfying the technological constraints.

Santuka, Mahapatra, Dhal, & Mishra (2015) have instead suggested the usage of PSO to solve the ML problem. Mutation, a commonly used operator in GA, has been introduced in the prosed PSO approach so that trapping of solutions at minima or premature convergence can be avoided. Results obtained by the proposed heurist are encouraging at significantly less computational effort.

Yogeswaran, Ponnambalam and Tiwari (2009) have proposed an efficient evolutionary algorithm by hybridising the GA and SA algorithm to solve a ML problem in FMS. The two aims are: minimising SU and maximising system TH in the occurrence of technological constraints such as available machining time and tool slots.

The output returned by the studies reviewed are shown in figure 5.

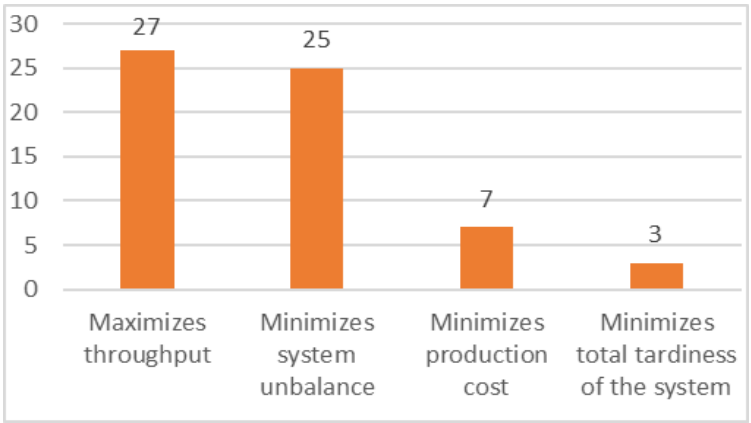


Figure 5. Output type

With respect to the topic of the articles, 27 papers were related to maximizing the TH while 25 have addressed the SU minimization. In addition, seven articles refer to production cost minimization and three explore the minimization of the total tardiness of the system.

It is important to specify that out of the 54 articles analyzed, 13 have deal with part selection. For example, in the study by Arikan & Erol (2012), ML and part selection are formulated as a mixed-integer programming model which is handled sequentially; the authors solved it using a diversification-strategy-added version of the hybrid TS/SA algorithm. Mgwatu (2011) has demonstrated the importance of incorporating and solving the machining optimization problem jointly with part selection and ML problems, to avoid unbalanced workload in the FMS.

3.2. Keywords analysis

Twenty-five papers lacked the author's keywords and were therefore excluded from this analysis. The analysis of the authors' keywords for the papers included in the review (54-25=29 articles) generated an original list of 132 different term. The general keywords "machine loading", "algorithm" and "model" were also excluded from the analysis, as they were used to run the query and are, therefore, expected to be the most frequent terms. Moreover, we have adjusted synonyms, acronyms (e.g., Flexible Manufacturing System sometimes indicated with FMS) and spelling. Considering only those having frequency equal or greater than 2, we find 14 keywords overall, as can be seen from figure 6.

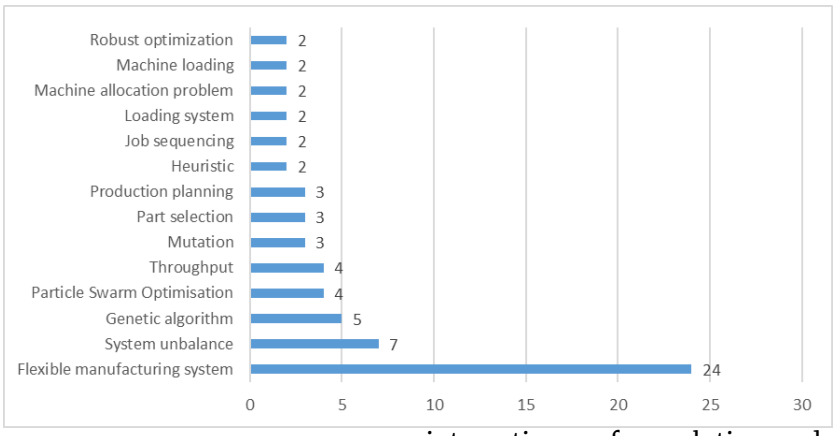


Figure 6. Most frequently used keywords

The figure above indicates that "Flexible manufacturing system" is the most frequent keyword (24 papers), highlighting the correlation between ML and FMS. "System unbalance" and "Genetic Algorithm" take second position with frequency = 7 and 5, respectively. The keywords "Particle Swarm Optimisation" and "Throughput" also appear recurrently in the researched literature.

4. Conclusions

Our review reveals that modelling and simulation techniques have emerged as powerful tools for understanding the complexities of the ML problem. They enable researchers to develop realistic virtual environments and simulate different scenarios, facilitating the evaluation of various loading strategies and their impact on system performance.

Furthermore, the integration of intelligent algorithms, such as GA, ACO, and machine learning approaches, has shown promising results in optimizing ML processes. These algorithms exhibit the ability to adapt, learn, and generate near-optimal or optimal loading solutions, thus improving production efficiency and reducing costs.

We discuss the key findings and insights obtained from the literature review, highlighting the strength and limitations of existing approaches. Additionally, we identify future research directions, including the need for more robust and scalable algorithms, the integration of real-time data and dynamic environments, and the exploration of hybrid approaches combining modelling, simulation, and intelligent algorithms. Overall, this literature review serves as a valuable resource for researchers and practitioners in the field of manufacturing and production planning, providing a comprehensive understanding of the application of modelling, simulation, and intelligent algorithms for addressing the ML problem.

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