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RESEARCH PAPER

Reconfigurable Manufacturing Systems: From Automation Through Industry 4.0

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ABSTRACT
Nowadays, product evolution and commercialization are done in very short cycles, therefore the productivity and flexibility of current manufacturing systems are no longer competitive. As a result, a new generation of reconfigurable manufacturing systems (RMS) emerges. These systems should be responsive enough to cope with sudden market changes while maintaining excellent product quality at a low cost. The expert in Production Systems introduced RMSs in the 1990s, during industry 3.0, which was characterized by mass automation, but they also witnessed the 4th industrial revolution, dubbed "industry 4". Thanks to this 4th industrial revolution, RMSs have been able to leverage the technologies at the heart of Industry 4.0, such as artificial intelligence and machine learning, the Internet of Things (IoT) and digital twins to create an intelligent, dynamic, and above all, reconfigurable factory, Called the Reconfigurable Factory 4.0. In this context, this paper proposes an organized and up-to-date systematic review of the RMS literature. Addressing its various research axes, namely the design approach, the RMS and Industry 4.0, the RMS features and performance, the simulation part, and the significant approaches and technologies that have contributed to the development of a reconfigurable factory 4.0.

KEYWORDS: *Reconfigurable manufacturing systems; Industry 4.0; Literature review.*

1. Introduction

As a result of globalization and rapid socio-economic changes over the past decades, customers are becoming increasingly demanding and require customized solutions and products. However, these changes have led to an increase in the complexity of manufacturing environments and have raised many new challenges. A critical review of Dedicated Manufacturing Lines (DMLs) and Flexible Manufacturing Systems (FMSs) shows that these systems cannot meet the requirements imposed by the market, which are mainly : the cost, the quality of products and the responsiveness of the manufacturing system to market changes. Therefore, to remain competitive, companies must design production systems that ensure low-cost, high-quality products with adequate responsiveness to market changes. Reconfigurable Manufacturing Systems or RMSs, whose components are reconfigurable machines and reconfigurable controllers, as well as methodologies for their systematic design and management, constitute a new paradigm of manufacturing systems proposed as a solution to current needs. Table 1 presents a comparison between DML, FMS and RMS production systems [1-4]. As shown in table 1, RMSs seem to be a promising choice for industrial companies as they effectively increase productivity and system responsiveness and at the same time reduce production costs. Also, an RMS combines the high throughput of a DML, the flexibility of an FMS and the ability to respond efficiently to market changes at low cost. It is crucial to note that the RMS has several advantages, but in order to achieve the most efficient and suitable operation, different optimization approaches must be implemented throughout its construction and use.

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Tab. 1. Comparison between DML, FMS and RMS

	DML	FMS	RMS
System Structure	Fixed	Changeable	Changeable
Machine structure	Fixed	Fixed	Changeable
System Setting	Part	Machine	Family of components
Flexibility	No	General	Personalized
Scalability	No	Yes	Yes
Simultaneous use of tools	Yes	No	Yes
Productivity	High	Low	High
Cost	Low	Expensive	Medium

The previous reviews [5] and [6] demonstrate that there is a rich and diverse literature on RMSs. However, given the importance of the subject and the multiple research projects carried out on it every year, it is important to update the literary reviews in a regular way. In this context, the present document was created with the aim of creating an updated and organized literature review on the topic of the design and optimization of reconfigurable manufacturing systems. To that end, a diverse range of publications on the design, management, and industrial application of RMSs has been addressed. Table 2 presents a few literature reviews on RMSs. In addition, in order to keep the size of the literature as small as possible, we have selected only the most frequently cited articles over the past few years.

Tab. 2. Recent reviews on RMSs and target.

Ref	Year	Target
[7]	2004	Knowledge of reconfigurability and reconfigurable manufacturing systems.
[8]	2008	RMS requirements and strategies.
[9]	2014	Use of artificial intelligence in the design of RMSs.
[10]	2017	Reconfigurable machine tools.
[5]	2017	Analysis and synthesis of current design methods and evaluation of support tools.
[11]	2018	Principles of RMS design and operation.
[6]	2018	The fields of application, the main methodologies and tools of RMSs.
[12]	2021	Control and intelligence of distributed and decentralized machines.
[13]	2021	RMS optimization.
[14]	2021	Strategies for reconfiguring the workforce.

It is interesting to note from table 2 that the topic of reconfigurability spans a number of research axes, and each work therein focuses on a particular axis. To address this issue, the following article will cover the entire topic of RMSs. By addressing several research axes, namely design, optimization, RMS performance, etc. To that end, the remainder of this paper is organized as follows:

Section 2 provides a general introduction to RMSs as well as an overview of its characteristics and design principles. Section 3 describes the research methodology used to establish this study. Section 4 gives a literature review on RMSs, focusing on the various research areas, namely: the design approach, RMS & Industry 4.0, the features of the RMS, the performance of RMS, the simulation part, and the applied research & applications. The conclusions and future work are presented in the final section.

2. Reconfigurable Manufacturing System

2.1. Definition of RMSs

The RMS is a reconfigurable manufacturing system whose physical and logical structures at all levels of system components may be modified rapidly and affordably in order to adapt production capacity and functionality around a product family in reaction to unexpected market changes. The RMS is built on standard physical and logical modules (cells, machines, machine elements, handling equipment, storage equipment, controllers, tools, fixtures, etc.) that can be easily and reliably added, updated reorganized, exchanged or replaced to meet changing market demands [1, 2, 15, 16]. An RMS will have an open architecture that can be upgraded, updated, and reconfigured rather than being completely replaced, and it will give tailored flexibility for a certain product family [17, 1].

Using fundamental physical and logical modules that can be swiftly and reliably changed or replaced, a production system known as an RMS may be built. Reconfiguration allows for the addition, deletion, or modification of the capabilities of a specific module, control system, or machine design to modify production capacity in response to shifting technical or market needs [15, 16, 18].

2.2. The features of an RMS

An RMS contains a few essential components that provide a high level of market reactivity for the system. These six qualities should be included into the reconfigurable system from the design phase to provide a high degree of reconfigurability [17, 19, 20, 21]. These characteristics are:

- Customization (flexibility limited to one product family): A system's or machine's flexibility is restricted to a single product family; as a result, it is tailored specifically for that product family.
- Convertibility (design for changes in functionality): The capacity to readily modify current structure and machine functions to find new production goals.
- Scalability (design for capacity changes): easy modification of production capacity by the addition or removal of production resources (such as machines) and/or the replacement of system components
- Modularity (components are modular): The division of operational processes into units that may be adjusted and traded between production systems for the optimal layout.
- Integrability: (simple interfaces for rapid integration): employing a collection of mechanical, informational, and control interfaces that make integration and communication possible, one is able to swiftly and precisely combine modules.
- Diagnosability (design for easy diagnostics): The capacity to read the present status of the system automatically in order to discover and diagnose the sources of inaccurate output and promptly rectify it.

These features greatly influence the productivity and responsiveness of the system while reducing manufacturing costs. Table 3 shows the influence of the characteristics on the reconfiguration time, productivity, and life cycle costs of the system [22].

Tab. 3. Report on the main characteristics of an RMS

	Reconfiguration Time	Productivity	System Life-Cycle Costs
Modularity	↓		
Integrability	↓		↓
Customization		↑	↓
Scalability		↑	↓
Convertibility	↓	↑	↓
Diagnosability	↓	↑	↓

2.3. Design of RMS

For the design of an RMS, in order to secure the economic viability of multiple product generations and market conditions, [22] indicate that it is vital to adopt a long-term perspective to the production system. In other words, the system will be developed to be adaptable in terms of effectiveness and capacity. The concepts of reconfiguration should guide RMS design. A manufacturing system's ability to be reconfigured increases as these ideas are applied to it again. The ultimate objective is to create a dynamic factory that can quickly modify its production capacity while maintaining high levels of product quality. This is achieved by incorporating these ideas into the design of RMSs [19]. These principles are:

- In order to react to erratic market fluctuations and innate system occurrences, an RMS must have scalable production resources.
- A RMS need to be built around a family of goods, with just enough bespoke flexibility to manufacture any member of the family.
- Both the system as a whole and its individual parts should incorporate the key RMS features (physical and logical).
- A rapid adjustment (increment or reduction) of the capacity of an RMS should be possible in modest steps.
- An RMS must have the flexibility to swiftly adjust its capabilities to new items.
- An RMS's integrated adjustment features must make it easier to react quickly to unanticipated hardware faults.

3. The Research Method

The search engine GOOGLE SCHOLAR (scholar.google.com), as well as the E-ressource platform (eressources.imist.ma) were used to search and filter the articles presented in this document. Also, for the bibliographic management. The MENDELEY software was used not only for the management of references but also for the proposal of works similar to those found in the bibliography. The articles are then entered sorted and reorganized in an Excel file to be able to process the data easily. Following this methodology and after filtering the different documents obtained according to the degree of importance, we could select more than 160 articles published between 1999 and 2022 in different journals or conferences. The distribution of these publications throughout time is presented in Figure 1. This work focuses on recently published research, although it is necessary to present some previous works that contributed to the development of the fundamental concepts of RMSs. Also, this research encompasses many forms of documents (journal articles, book chapters, indexed conference papers). Figure 2 depicts the distribution of these publications based on the journals or conferences where they were published.

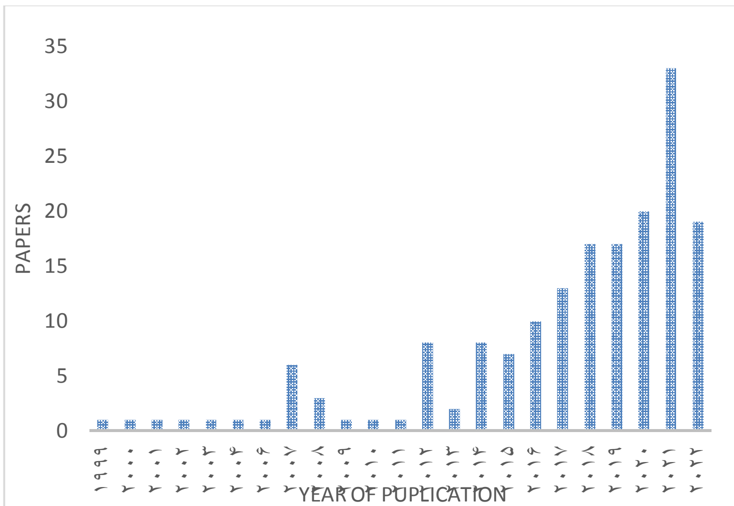

Fig. 1. Distribution per year of publication

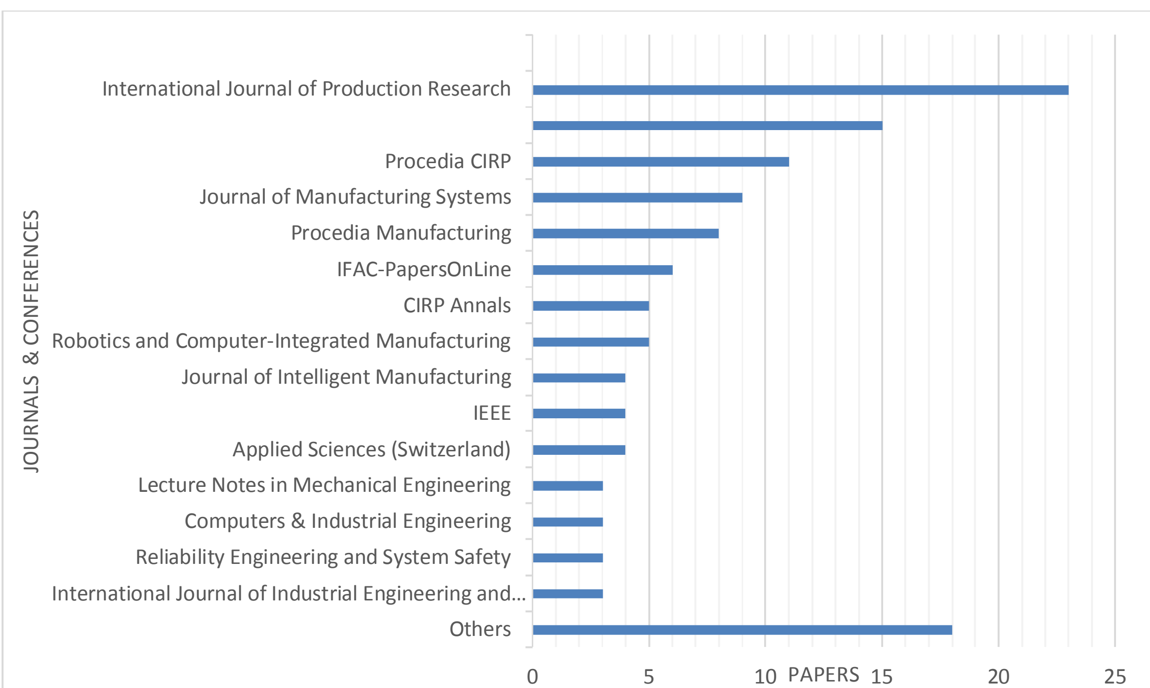

Fig. 2. Distribution per journals & conferences

4. RMS Research Trend

Since the introduction of the RMS concept in the late 1990s [1, 17], research in this area has increased and expanded considerably. This research on RMS covers multiple issues and different levels of structuring of a manufacturing system [23], from the highest level of structurin²g (network and factory) to the lowest level (workstation). Figure 3 depicts the many themes addressed in relation to reconfigurable manufacturing systems. These principal areas of study are:

- Design approach.
- RMS & Industry 4.0 :
- Features of the RMS (listed in section 2.2).
- Performance of RMS.
- The simulation part.
- The applied research & applications.

The remainder of this part presents the analysis of each topic as well as the work completed in each stream. Figure 3 illustrates the principal areas of RMS research.

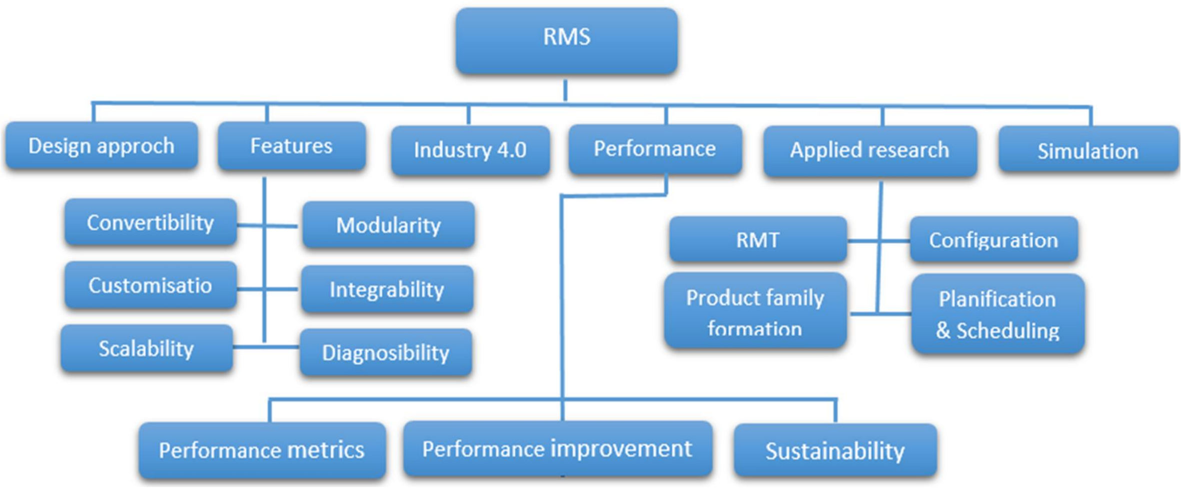

Fig. 3. Research areas on RMS

4.1. The design approach

In the literature, the solutions presented to solve the RMSs design problem are numerous, and they address the problem from different perspectives with different levels of detail. Many authors indicate that there is a lack of a systematic design method for RMSs [2, 3, 4, 24, 25, 26]. For example, [26] present a review of existing methods for designing the system architecture, its configuration, and its control system design. They conclude that a systematic design method is missing. However, given the account, numerous researchers have recently resorted to system engineering to answer the issue of designing an RMS as a complex system [27] or work that addresses the design of RMS through approximatively multicriteria approaches. In [27], the author divides the problem of designing RMSs into several parts: production process design, system level design, machine level design, control system design and management system design. Table 4 presents the different works carried out in the multiple perspectives of the design of RMS.

Tab. 4. Literature review, general designing of RMS

Ref	Year	Target
[28]	2007	Design of RMS strongly coupled
[29]	2007	Reconfigurable machine design concepts
[30]	2009	design using Petri nets
[19]	2010	Concepts for reconfigurable machine designs
[31]	2011	A method for developing the design of RMS
[32]	2013	The RMS's quick response time
[33]	2014	Designing a manufacturing system architecture
[34]	2015	Support system for reconfigurable manufacturing system design and optimization
[35]	2015	Cloud-based design and production.
[36]	2017	Machine selection in reconfigurable manufacturing system (RMS) design using a flexibility-based multi-objective approach
[37]	2017	Journey and future of reconfigurable manufacturing systems
[38]	2018	a multi-objective approach for the design of RMS

[39]	2019	A plan for designing a mobile RMS
[40]	2019	reconfigurable manufacturing systems: dynamic design and management
[41]	2019	Module-based machinery design of RMS.
[42]	2020	creation of a framework for RMS to choose the optimum collaboration path between machines
[43]	2021	Framework for designing and assessing a RMS based on the integration of moveable robots
[44]	2021	Designing and operating reconfigurable production systems using ergonomic principles
[45]	2021	A multi-objective particle swarm optimization, design and scheduling of RMS.
[46]	2021	Designing a balance-first sequence-last algorithm RMS: a mathematical model for balancing reconfigurable manufacturing systems with performance guarantees
[47]	2021	A Comparative Analysis Tool for Reconfigurable Manufacturing System Concept Designs
[48]	2022	Using a Genetic Algorithm to Design a Reconfigurable Manufacturing System

4.2. The features of the RMS

As discussed in Section 2.2, an RMS should be designed from the outset with six key features in mind: Customizability, Convertibility, Scalability, Modularity, Integrability, and Diagnostibility. Because they greatly affect the system's productivity and responsiveness while also lowering manufacturing costs. Several publications in the literature address the integration of these characteristics into the design process, as well as how they might increase the performance of the RMS. In terms of RMS scalability, a plan should be implemented that allows for an incremental increase in system capacity [49, 50, 51]. In this regard, [52] describes an RMS scalability design technique that uses an optimization method based on evolutionary algorithms to discover the most cost-effective way to reorganize an existing system. The authors also developed a modular, flexible, scalable, and reconfigurable technique to produce microsystems based on additive manufacturing and electronic printing [53]. In [54], the key characteristics of an RMS are quantified based on a study of the reconfiguration of reconfigurable machine parts and manufacturing cells. The quantitative models are then used as the foundation for building an RMS evaluation index system based on the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE). Table 5 lists the most pertinent studies on RMS features.

Tab. 5. Lists of publications in features of RMS

Ref	Year	Convertibility	Customization	Scalability	Modularity	Integrability	Diagnosibility
[49]	2006			✓			
[50]	2007			✓			
[51]	2008			✓			
[55]	2012			✓			
[56]	2012			✓			
[56]	2016					✓	
[53]	2016			✓	✓		
[57]	2017	✓	✓			✓	
[52]	2017			✓			
[58]	2017				✓		
[54]	2017	✓	✓	✓	✓	✓	✓
[59]	2017						✓
[60]	2018	✓		✓			
[61]	2018	✓		✓			
[62]	2018				✓		
[63]	2019				✓		
[47]	2021	✓					
[64]	2021			✓			
[65]	2021			✓			
[66]	2021	✓	✓	✓	✓	✓	✓
[67]	2022		✓		✓		

4.3. The RMS & industry 4.0

The creation of a "smart, dynamic factory" that can swiftly adjust its production capacity and diversity while maintaining a high level of quality at an affordable price has been a major focus in recent years [27]. To meet these expectations, Industry 4.0 is characterized by its adaptability, flexibility, and efficiency, which allow it to meet the needs of customers in today's market. It represents a significant advance in the organization and supervision of the entire value chain. This concept applies to the entire life cycle from manufacturing to product delivery [68]. Therefore, manufacturers are seeking for "smart" and "reconfigurable" machines more than ever before in order to rapidly and dynamically satisfy the needs of today, tomorrow, and the lifespan of their goods [69]. In [69], which evaluates the state of the art in distributed and decentralized machine control and intelligence in a unique approach, basic research on reconfigurable manufacturing systems (RMS) is examined. This presentation offers a fresh perspective on the intelligence and reconfigurability of the next generation of Industry 4.0 production machines. According to [70,71], for Industry 4.0 to become a reality, it is essential to implement horizontal integration of the B2B value network, end-to-end the integration of the engineering value chain, and vertical integration of the factory. In this context, [71] suggests employing a vertical integration technique to construct a flexible and changeable smart factory. They came up with the idea that smart items and machines could converse and bargain with one another in order to reconfigure themselves for the flexible manufacturing of various products. Massive amounts of data may be collected from smart items and sent to the cloud via the IWN (Wireless Industrial Network). In order to increase system performance, this provides system-wide coordination and feedback based on data analysis. Self-organized reconfiguration, feedback, and data synchronization define the framework and operating system of the smart factory [71].

In the pharmaceutical industry, a data-driven reconfigurable production mode of the Smart Factory for pharmaceutical manufacture is presented in [72] to address the rising need for agility, flexibility, and low cost in the healthcare sector. The observation layer, the deployment layer, and the execution layer are the three key levels that make up the smart factory architecture. The perception layer, which oversees pharmaceutical production planning, introduces a knowledge base based on the semantic manufacturing ontology. The demand for pharmaceutical manufacturing and the condition of the low-level machine resource data are used to develop reconfigurable plans. IEC 61499 is also introduced for feature modeling and machine control [72]. Regarding to [73] an innovative vision of teaching and training is essential in Industry 4.0 to prepare students for the challenges of the real shop floor environment. This highlights the value of grounded theoretical notions in real-world applications. To maintain the future generation's desire, educate them about cutting-edge technologies, and accomplish the aims of sustainable manufacturing, rational and logical approaches, such as virtual reality, are essential [73]. To this purpose, the authors provide a way for applying the primary virtual reality-based visualization methodology in the production of goods. It seeks to familiarize students with the idea of Industry 4.0 and the reconfigurable manufacturing system (RMS) in order for them to anticipate the RMS's design, interact with it, comprehend how it works, and assess its performance.

4.4. The performance of RMSs

Since its introduction into the industrial sector, a number of studies have focused on the industrial performance of reconfigurable manufacturing systems (RMSs). There are works that are interested in the measures of performance indicators and others that participate in the improvement of their performance. Of these works, the majority of the research is oriented towards the sustainability side because it represents a very important lever to ensure the economic, social, and environmental feasibility of several product and system generations.

4.4.1. The performance metrics

In order to maintain competitiveness, companies need to monitor the current state of the production system and take appropriate performance measures [74]. In [74], which focuses on performance measurements and how to select the optimal configuration for a reconfigurable manufacturing system. According to the authors, the performance of the reconfigurable manufacturing system is affected by different performance indicators such as ramp-up time, cost, reliability, availability, turnaround time, reconfiguration time, etc. In the same concept, in [75], a combinatorial technique is presented to assess the compound performance indicators (CPIs) of a repairable RMS.

This approach incorporates the stationary state probabilities of repairable reconfigurable machine tools (RMTs) and the inventory state probabilities of buffers using an enhanced universal generating function. The simulation findings validate the RMS performance evaluation's correctness. Thus, it is beneficial for boosting machine dependability, resource consumption efficiency, and decision making regarding RMS setup with buffers. Also in [76] a composite performance measure (CPM) was suggested, which uses a combined score to evaluate the performance of the RMS based on all 10 performance measures. The Analytic Hierarchical Process (AHP) approach is used in the CPM development technique, and the weighting of each performance metric is also taken into account. [76] Provides an overview of the important performance parameters that are taken into account while selecting and comparing alternative setup.

4.4.2. The performance improvement

Following the discussion of the many techniques of measuring performance, it is critical to understand how these metrics and indicators may be improved. Several publications listed in the literature in this area focus on increasing RMS performance. According to [77] choosing an appropriate configuration is crucial since it influences a number of performance metrics that affect the system's responsiveness, economy, and reliability. In this context, [77] proposes a comprehensive decision-making approach that takes into account cost, machine utilization, operational capacity, machine reconfigurability, configuration convertibility, and reliability as performance measures in order to choose the best configuration for the one-piece reconfigurable flow line. The issue has been presented as a multiple-criteria decision-making problem, and the fuzzy best worst case approach is used to combine the decision-linguistic maker's preferences in order to get the appropriate weights for each criterion. Despite their degree of automation, these systems need human operators to carry out particular activities, such moving auxiliary modules from the warehouse to the RMTs and assembling/disassembling those [78]. Due of the interaction between humans and machines, this issue creates pertinent ergonomic and safety concerns. The technical aim function reduces the amount of time needed for reconfiguration, or for the RMTs to be outfitted with the necessary auxiliary modules and for the components and auxiliary modules to be moved between RMTs. According to ISO 11228-3, the ergonomic goal function reduces the repetitive motions made human operators during job operations. The findings demonstrate that there is a good balance between the two target functions, demonstrating the feasibility of enhancing the ergonomic circumstances for human operators without noticeably lengthening the overall time needed to reconfigure the RMTs and transfer the components and auxiliary modules [78].

In [79], the authors affirms that human interaction is one of the important factors influencing system performance in the majority of industrial settings. Worker tasks are anticipated to change frequently as reconfigurable manufacturing systems (RMS) are implemented. The system designer may receive advice on necessary skill levels, training programs, job design, task assignment, work organization, and possibilities for system modification to achieve higher quality results from the ability to predict the likelihood of errors brought on by human involvement. Multi-attribute utility analysis was used in [79] to create a model for calculating the probability of human error in RMS based on task characteristics, work environment, and worker capabilities. For the dynamic management of RMSs, the authors in [80] propose a linear programming optimization model that best balances the reconfiguration of RMTs while taking into account the availability of auxiliary modules, that is, the work required to install and remove auxiliary modules from the machines, and the flow of parts between RMTs. An operational case study application broadens the discussion of the model, and a multi-scenario analysis that examines how total system performance changes as a function of accessible auxiliary modules brings the research to a close.

The combined presence of several components on the same RMT in each time shown by the data points to the critical role of auxiliary modules in developing functional and adaptable structures appropriate for processing multiple parts. Furthermore, according to [81], whether or not a production process to be conducted is capable of meeting the stated performance requirements is dependent on the reliability of the machines and technical equipment that compose the system being created. The reliability of a manufacturing system as a whole is heavily dependent on how the various components are structured since they all have varying degrees of reliability.

In [81], the authors talks about how to choose a manufacturing system's structure that can adjust to changing machine reliability while maintaining the stability of the production process. The reliability of reconfigurable systems can be increased by replacing or reordering components without affecting their reliability [82]. A cost-effective technique to increase the dependability of reconfigurable systems is presented in [82] by combining the benefits of the replacement method with the rearrangement method. Then, based on the integrated technique, a 0-1 integer programming model of multi-objective optimization is developed to achieve the reconfiguration with the highest system reliability and the lowest reconfiguration cost. The multi-objective model is solved using the coarse-grained parallel genetic algorithm (CPGA), and the novel efficiency function allows the multi-objective issue to be reduced to a single-objective problem.

4.4.3. RMS & sustainability

Responsibility, commitment, corporate social responsibility, corporate accountability, total societal impact, corporate governance. All of these phrases are related to a larger notion known as sustainability. The phrase "sustainable development" refers to any actions that enable growth to occur in a way that satisfies the requirements of the present generation without risking the ability of future generations to do the same [83]. Today, the idea of sustainability is separated into three categories: social, ecological, and economic. The next generation of manufacturing systems must be able to adapt swiftly and affordably to the industrial market. The objective is to adapt to shifting market demands while reducing harmful environmental effects. Reconfigurable manufacturing systems (RMS) can improve system sustainability and response to market demands due to its flexibility and features [84]. In terms of features, [84, 85] shows how the RMSs' convertibility, customizability, and modularity affect their durability. Convertibility is measured from the perspective of the RMS by taking configuration convertibility, machine convertibility, and handling device convertibility into account. [84] Demonstrates how the sustainable manufacturing performance of RMSs varies as a function of system convertibility using known sustainable manufacturing indicators. [85] examines the impact and possibilities of Modular Architecture Principles (MAPs) on the sustainable design of open architecture goods. According to [86, 87, 88, 89, 90, 91], increasing sustainability is primarily about minimizing total production time, total production cost and the amount of environmentally hazardous waste. Environmental hazardous waste includes hazardous liquid waste and emissions (GHG). For this purpose, [88] presents a linear programming technique (I-MOILP) and its comparison with the two methods (AMOSA) and (NSGA-II). Also, in order to reduce emissions and hazardous materials during product development, [92] presents Multidisciplinary Green Bill of Materials (MDG-BOM) with a green bill of materials model, also to enable multiple departments to integrate various CAD design data sources and control/track changes at each step of the process, an intelligent spreadsheet for MDG-BOM management was created.

4.5. The applied research on RMS

This section discusses the primary RMS application areas that have been proposed in the literature. This research focuses on the design of Reconfigurable Machine Tools (RMT), the challenge of product family development, scheduling and production planning in reconfigurable systems, and the selection of the RMS configuration.

4.5.1. Reconfigurable machine tools RMT

The novelty of RMS is that the system's structure, as well as its machines and controls, may be rapidly updated in reaction to market (demand and product) changes. RMS heavily relies on the reconfigurable machine tool (RMT). RMTs, as opposed to typical CNCs, are intended for a specific, specialized range of operating needs and can be cost-effectively changed when requirements change [93].When developing RMTs, the selection of relevant modules is a critical decision element in meeting production requirements successfully and efficiently. However, selecting relevant modules is a difficult undertaking since it is a multi-domain mapping process that strongly relies on expert domain knowledge, which is typically unstructured and implicit. [94] Proposes an ontology-based RMT module selection approach to efficiently assist RMT designers. First, an ontology is created to explicitly express the taxonomy, attributes, and causal relationships of/between three core domain concepts: the machining feature, the machining process, and the RMT module involved in the RMT design. Second, a four-step sequential approach is devised to aid in the selection of optimal RMT modules by using coded knowledge from a knowledge base. The technique takes a given family of parts as input, infers the needed machining operations as well as the RMT modules automatically using rule-based reasoning, and then produces a set of RMT configurations capable of machining the output family of parts. Finally, an example of manufacturing a family of plates is used to show the usefulness of the ontology-based RMT module selection process. The results suggest that the technique is helpful in supporting designers by picking modules and producing configurations in the RMT design in a timely and suitable manner. In [95], a novel method for RMT design is put forth that is closely related to the process planning of a specific family of box-like parts. The most similar process plans for a given part family can be determined and used for RMT structural design using the similarity calculation model. As a result, the designed RMTs can achieve rapid conversion of processing functions with minimal module replacement or adjustment to achieve part family production. Following reconstruction, the correctness of the new machine tool must first be ensured, putting greater emphasis on the flexibility of error definition and modeling [96]. As a result, [96] presents a method for numerical and structure-adaptive geometric error definition and modeling in order to respond fast to changes in the RMT structure. First, a coding method is proposed for expressing the machine tool component with structure and motion information so that geometric error definition and modeling can be automated. Then, as kinematic and structural properties, a common expression of geometric mistakes is offered. According to the configuration tree, the geometric error identification coefficient matrix is defined and calculated using an assignment algorithm. Finally, the geometric error modeling modules are defined, and the sequential multiplication computation is shown to create the geometric error model automatically. According to [96], a reconfigurable machine tool is a group of machines that may be configured in a variety of ways to fulfill production requirements. [96] Considers the production scheduling problem on a shop floor with reconfigurable machine tools to be an extension of the flexible job shop scheduling problem (FJSSP).

4.5.2. The configuration of RMS

The system's state that reacts to a specific context is known as a configuration. To define the system configuration, a set of system parameters that determine the configuration must be defined. A change in a parameter signifies a change in the system setup. Reconfiguration is the procedure that allows the system to transition from one configuration to another, and it frequently necessitates the execution of means and persons. The configuration of an RMS is changed during its operational phase due to the occurrence of reconfiguration trigger events, or DRs. A reconfiguration trigger event is an event that necessitates system reconfiguration. It can be intrinsic and extrinsic [27]. Configuration selection for reconfigurable manufacturing systems (RMS) is one of the critical issues that must be addressed to move RMS deployment from its infancy to maturity [97]. The quality of RMSs, as well as the resources necessary to bring them into dependable production, are primarily controlled by the speed with which the reconfiguration process is carried out [98]. [98] Offers a mechanism for comparing various reconfiguration implementation methods. To differentiate the impact of the offered solutions, three classes of reconfiguration are specified. The procedure employs a recently established indexing mechanism for the building of RMS process modules based on the axiomatic design methodology. The resources and time required to implement the reconfiguration process are calculated using weighting criteria. [97] Proposes and demonstrates a system for production line configuration selection (MFL) utilizing a non-dominated sorting genetic algorithm-II (NSGA-II). The framework includes the production of a product on a multi-stage reconfigurable serial production line (RSPFL) to increase RMS performance while taking numerous objectives into account as selection criteria. With the same goal of achieving good performance [99] defines a new reconfiguration effort index that considers all reconfiguration efforts at the process level rather than just machine configuration effort. The newly constructed reconfiguration index is employed as an objective function to solve the RMS design problem, allowing the optimum process plan with the least amount of reconfiguration effort to be obtained. Taking advantage of RMS modularity, [100] provides a novel 0-1 nonlinear integer programming model to optimize the configuration of modular goods and RMSs at the same time, based on unique client requirements. To solve this model, a genetic algorithm-based solution is provided, and its parameters are tweaked using a full two-level factorial design. To address the classic RMS's convertibility issues, the Delayed RMS (D-RMS) was proposed. D-fundamental RMS's principle is to keep partial production capacity by postponing reconfiguration to the last stages of the manufacturing system. To implement D-RMS with deferred reconfiguration, configuration design is necessary. As a result, [101] provides a D-RMS configuration design approach. The industrial robot is also considered in the configuration design to suit the requirement for smart production. [102] Presents a networked autonomous reconfigurable manufacturing system with decentralized management of individual autonomous lines that may be modified via manufacturing modules for diverse production tasks. In a similar vein, [103] proposes a new class of open architecture machine tools (OAMTs) that consists of a fixed standard platform and various custom modules that can be quickly added and interchanged. By incorporating custom modules into its OAMTs, the production system can be modified to meet the requirements of process planning.

4.5.3. Product family formation

An RMS is designed around a family of products with enough flexibility to manufacture them all. These products are grouped into families based on certain shared characteristics such as modularity, sequence of manufacturing operations, etc. Each product family requires a system configuration to produce them, and switching from one product to another or more generally from one product family to another requires reconfiguring the system. According to [19], designing around a family of products instead of a single specific product allows designers to plan a system that supports different variations of the same product family with minimal changes to the production system. The design of an RMS is strongly related to the product portfolio, as the system should be able to produce several product variants within a product family, but also different generations of the same product family [104, 105, 106]. Thus, the effectiveness of an RMS depends on the formation of the best set of product families.

For more than a decade, both research and practice have focused on the formation of product families [107]. There are several approaches to defining what constitutes a product family [108]. However, because the RMS is built around product families to reduce flexibility and increase efficiency, product families must be designed alongside the production system [109]. Three concerns have been identified in the literature in this regard: grouping products into product families, designing the corresponding optimal configuration, and adapting system configurations to changing product families [110, 111]. Several approaches to addressing these concerns are available in the literature.

Table 6 summarizes the various papers on product family design found in the literature.

Tab. 6. Review on product family formation.

Ref	year	Keywords
[112]	2000	commonality index of components
[113]	2000	the component communality and process communality
[114]	2002	customer needs
[108,115]	2004; 2007	Operational Similarity, AHP analytical hierarchical processing
[116]	2007	modularity, commonality, compatibility, reusability, and demand
[117]	2008	Tool and direction
[118]	2007; 2009	the component level
[119]	2011	Bill of materials BOM
[120]	2014	cell configuration
[121]	2014	the assembly sequences, product demand and commonality
[122]	2016	Bill of materials BOM, components and assembly structure
[123]	2016	bypassing moves and idle machines
[124]	2016	Component, interface synergy
[125]	2018	Datum Flow Chain DFC
[126]	2018	Pareto, commonality and modularity
[127]	2020	LPCS, ALC, D-RMS system.
[128]	2020	dynamic expression
[139]	2021	MBPF
[130]	2022	Differential Evolution (DE)
[131]	2022	D-RMS, machine learning, K-medoids, LPCS.
[132]	2022	ELECTRE III

4.5.4. Planification & Scheduling of RMS

The reconfigurable manufacturing system (RMS) is anticipated to offer low-cost, high-response customization. Optimizing reconfiguration to generate mass-customized durable items in RMS, on the other hand, is a complicated task that necessitates multi-criteria decision making. It is linked to three issues: process planning, scheduling, and layout optimization, all of which must be combined to enhance the RMS's performance [133, 134] Seeks to merge the three challenges mentioned above and devise an effective method for solving them all at once. It develops a multi-objective mathematical model that simultaneously optimizes process planning, task scheduling, and the open-field layout problem in order to increase the RMS's sustainability.

The penalty for product delay, total manufacturing cost, hazardous waste, and greenhouse gas emissions are all reduced. When looking for Pareto-optimal solutions, economic and environmental indicators are established to adjust the Pareto efficiency. Raw search yields the exact Pareto-optimal answers, which are then compared to the model without environmental indicators.

To produce approximation Pareto-optimal solutions with great efficacy and efficiency, NSGA-III is used. The similar vision of [135] concentrates on a comprehensive method of production planning in a reconfigurable manufacturing system. The energy consumption and material fluxes incurred on the reconfigurable manufacturing system are defined through the process plan detailing how to build a part. Alternative system reconfigurations are evaluated dynamically in terms of several holistic criteria such as energy usage, environmental consequences, and throughput. A multi-objective production planning model is created to minimize energy usage while maximizing throughput. IPPS (Integrated Process Planning and Scheduling) is a manufacturing technique that views process planning and scheduling as a single operation rather than two separate processes performed sequentially [136]. [136] Proposes a new heuristic for the IPPS problem for reconfigurable manufacturing systems (RMS). It takes into consideration RMT machines multi-configuration to combine process planning and scheduling. In particular, with the emergence of the Internet of Things (IoT) as a global concern in recent years, many companies or manufacturers have attempted to integrate it into their intelligent systems. The advancement of IoT technology has enabled the collection of hidden information within systems. [137, 138] concentrated on the IoT-based reconfiguration decision-making system with data collecting system. Using the data acquired by the IoT sensors, the decision-making system identified a reconfiguration situation and created a reconfiguration strategy. [137] addresses the significance of incorporating IoT into RMS and establishing a mathematical model to handle planning difficulties in order to save time, money, and effort in reconfiguration .

4.6. Simulation part of RMS

Despite this expected trend in the field of RMS manufacturing, there is little literature on the simulation part for RMS design. According to [139] simulation of a production line's manufacturing process is critical for reducing the cost and time of production line design. Traditional simulation approaches are either limited in quality or rely on real-world equipment and external tools. The digital twin is a key component of Industry 4.0 and is thought to be the next generation of simulation. However, the digital twin's application to industrial process simulation has received insufficient attention. [139] Offers an integrated manufacturing simulation and digital twin platform (DTMSIP) incorporated in a cyber-physical system to model and analyze the manufacturing process of production lines in advance (CPS). DTMSIP, which is powered by the CPS Plug-and-Play, may serve as both monitoring and simulation, with accuracy maintained by accurate digital mapping. In the same perspective, [140] offers a fresh approach by integrating the Industry 4.0 idea into a manufacturing procedure, where reconfigurable machines are employed to make up for the loss of production of a specialized production line as a result of a machine failure. Using FlexSim, a simulation-based technique is built to test two broad configurations against three major performance indicators (KPIs) [141].

5. Conclusion

Reconfigurable manufacturing systems (RMS) have been described as a viable manufacturing solution that supports the transition from mass production to custom production while maintaining high quality at low cost. Since 1999, a number of studies have focused on the design and optimization of RMS to create automated and reconfigurable factories. However, with the fourth industrial revolution, known as Industry 4.0, new technologies such as artificial intelligence and machine learning, digital twins, additive manufacturing, etc. have appeared. As a result, it is critical to use these technologies to improve RMS design with the ultimate goal of having reconfigurable and intelligent manufacturing. This review presents a current assessment of the RMS literature, covering the main research themes such as design approaches, RMS characteristics, reconfigurability in Industry 4.0, product family development, simulation, and so on. According to the literature review, various research streams have gained significant attention from the research community, such as the analysis of design techniques, the investigation of RMS features (particularly scalability), and durability, which is a critical topic for today's and tomorrow's industries. Others, such as simulation of RMSs and reconfigurability towards Industry 4.0, require additional investigation. These latter two axes (in the industrial field) imply the necessity to further strengthen research in these areas in order to help the current market in its transition to reconfigurability 4.0. But the question is:

How can we leverage Industry 4.0 to achieve Reconfigurability 4.0?

This question is a first step in expanding our knowledge of RMS and key Industry 4.0 technologies to support the industry of the future in its transition to tomorrow's reconfigurable production and to what are called 4.0 factories.

References

[1] Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritschow, G., Ulsoy, G., & van Brussel, H. Reconfigurable manufacturing systems. CIRP Annals - Manufacturing Technology, Vol. 48, No. 2, (1999), pp. 527-540.

[2] ElMaraghy, H.A. Reconfigurable Process Plans For Responsive Manufacturing Systems. In: Cunha, P.F., Maropoulos, P.G. (eds) Digital Enterprise Technology. Springer, Boston, MA, (2007).

[3] Seyed, M. G., Rahmani, D., & Moslemipour, G. Routing flexibility for unequal-area stochastic dynamic facility layout problem in flexible manufacturing systems. International Journal of Industrial Engineering and Production Research, Vol. 31, No. 2, (2020), pp. 269-285.

[4] Malhotra, V, T Raj, and A Arora. ―Excellent Techniques of Manufacturing Systems: RMS and FMS.‖ International Journal of Engineering Science and Technology Vol. 2, No. 3, (2010), pp. 137-42.

[5] Andersen, A. L., Brunoe, T. D., Nielsen, K., & Rösiö, C. Towards a generic design method for reconfigurable manufacturing systems: Analysis and synthesis of current design methods and evaluation of supportive tools. Journal of Manufacturing Systems, Vol. 42, (2017).

[6] Bortolini, M., Galizia, F. G., & Mora, C. Reconfigurable manufacturing systems: Literature review and research trend. In *Journal of Manufacturing Systems* Vol. 49, (2018), pp. 93-106.

[7] Setchi, R. M., & Lagos, N. Reconfigurability and reconfigurable manufacturing systems - State-of-the-art review. *2nd IEEE International Conference on Industrial Informatics, INDIN'04*. (2004).

[8] Bi, Z. M., Lang, S. Y. T., Shen, W., & Wang, L. Reconfigurable manufacturing systems: The state of the art. *International Journal of Production Research*, Vol. 46, No. 4, (2008), pp. 967-992.

[9] Renzi, C., Leali, F., Cavazzuti, M., & Andrisano, A. O. A review on artificial intelligence applications to the optimal design of dedicated and reconfigurable Le manufacturing systems. *International Journal of Advanced Manufacturing Technology*, Vol. 72, (2014), pp. 1-4.

[10] Gadalla, M., & Xue, D. Recent advances in research on reconfigurable machine tools: a literature review. In *International Journal of Production Research* Vol. 55, No. 5. (2017).

[11] Koren, Y., Gu, X., & Guo, W. Reconfigurable manufacturing systems: Principles, design, and future trends. In *Frontiers of Mechanical Engineering* Vol. 13, No. 2, (2018).

[12] Morgan, J., Halton, M., Qiao, Y., & Breslin, J. G. Industry 4.0 smart reconfigurable manufacturing machines. *Journal of Manufacturing Systems*, Vol. 59, (2021), pp. 481-506.

[13] Yelles-Chaouche, A. R., Gurevsky, E., Brahimi, N., & Dolgui, A. Reconfigurable manufacturing systems from an optimisation perspective: a focused review of literature. *International Journal of Production Research*, Vol. 59, No. 21, (2021). pp. 6400-6418.

[14] S. Ehsan Hashemi-Petroodi, Alexandre Dolgui, Sergey Kovalev, Mikhail Y. Kovalyov & Simon Thevenin Workforce reconfiguration strategies in

manufacturing systems: a state of the art, International Journal of Production Research, Vol. 59, No. 22, (2021), pp. 6721-6744.

[15] Mehrabi, M. G., Ulsoy, A. G., Koren, Y., & Heytler, P. Trends and perspectives in flexible and reconfigurable manufacturing systems. Journal of Intelligent Manufacturing, Vol. 13, No. 2, (2002).

[16] Mehrabi, M. G., Ulsoy, A. G., & Koren, Y. Reconfigurable manufacturing systems: key to future manufacturing. Journal of Intelligent Manufacturing, Vol. 11, No. 4, (2000).

[17] Koren, Y. Reconfigurable manufacturing and beyond. In CIRP 3rd international conference on reconfigurable manufacturing, (2005).

[18] Mehrabi, M. G., Ulsoy, A. G., & Koren, Y. Reconfigurable manufacturing systems and their enabling technologies. *Article in International Journal of Manufacturing Technology and Management*, Vol. 1, No. 1, (2000), pp. 114-131.

[19] Koren, Yoram, and Moshe Shpitalni. Design of Reconfigurable Manufacturing Systems.‖ Journal of Manufacturing Systems Vol. 29, No. 4, (2010), pp. 130-41.

[20] Koren, Y., and Galip Ulsoy. Vision, Principles and Impact of Reconfigurable Manufacturing Systems.‖ Powertrain International Vol. 5, No. 3, (2002), pp. 14-21.

[21] Rösiö, Carin. Supporting the Design of Reconfigurable Production Systems.‖ School of engineering, University of Malardalen, (2012).

[22] Rösiö, C., & Jackson, M. Enable changeability in manufacturing systems by adopting a life cycle perspective. In 3rd International Conference on Changeable, Agile, Reconfigurable andVirtual Production, (2009), pp. 612-621.

[23] Wiendahl, H.-P., Hoda. ElMaraghy, P. Nyhuis, M.F. Zäh, H.-H. Wiendahl, N. Duffie, and M. Brieke. Changeable Manufacturing - Classification, Design and Operation.‖ CIRP Annals - Manufacturing Technology Vol. 56, No. 2, (2007), pp. 783-809.

[24] Bi, Z.M., S.Y.T Lang, W. Shen, and L. Wang. Reconfigurable Manufacturing Systems: The State of the Art.‖ International Journal of Production Research Vol. 46, No. 4, (2008), pp. 967-92.

[25] Malhotra, Vasdev, Tilak Raj, and Ashok Arora. Evaluation of Barriers Affecting Reconfigurable Manufacturing Systems with Graph Theory and Matrix Approach.‖ Materials and Manufacturing Processes Vol. 27, No. 1, (2012), pp. 88-94.

[26] Rösiö, Carin, and Kristina Säfsten. Reconfigurable Production System Design – Theoretical and Practical Challenges.‖ Journal of Manufacturing Technology Management Vol. 24, No. 7, (2013), pp. 998-1018.

[27] Lameche, K. (n.d.). *Proposition d'une méthodologie pour la conception des systèmes de production reconfigurables et d'un outil associé d'aide à la décision par simulation de flux*.

[28] Bi, Z., Lang, S. Y. T., & Wang, L. Design of reconfigurable manufacturing systems with strongly coupled nature. *Chinese Journal of Mechanical Engineering (English Edition)*, Vol. 20, No. 1, (2007).

[29] Katz, R. Design principles of reconfigurable machines. *International Journal of Advanced Manufacturing Technology*, Vol. 34, (2007), pp. 5-6.

[30] Li, J., Dai, X., Meng, Z., Dou, J., & Guan, X. Rapid design and reconfiguration of Petri net models for reconfigurable manufacturing cells with improved net rewriting systems and activity diagrams. *Computers and Industrial Engineering*, Vol. 57, No. 4, (2009).

[31] Oke, A. O., Abou-El-Hossein, K., & Theron, N. J. The design and development of a reconfigurable manufacturing system. *South African Journal of Industrial Engineering*, Vol. 22, No. 2, (2011).

[32] Koren, Y. The rapid responsiveness of RMS. *International Journal of Production Research*, Vol. 51, (2013), pp. 23-24.

[33] Benkamoun, N., ElMaraghy, W., Huyet, A. L., & Kouiss, K. Architecture framework for manufacturing system design. *Procedia CIRP*, Vol. 17, (2014).

[34] Micieta, B., Binasova, V., & Haluska, M. System for support the design and optimization of reconfigurable manufacturing systems. *MM Science Journal*, (2015).

[35] Wu, D., Rosen, D. W., Wang, L., & Schaefer, D. Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. *CAD Computer Aided Design*, Vol. 59, (2015).

[36] Haddou Benderbal, H., Dahane, M., & Benyoucef, L. Flexibility-based multi-objective approach for machines selection in reconfigurable manufacturing system (RMS) design under unavailability constraints. *International Journal of Production Research*, Vol. 55, No. 20, (2017).

[37] Singh, A., Gupta, S., Asjad, M., & Gupta, P. Reconfigurable manufacturing systems: journey and the road ahead. In *International Journal of System Assurance Engineering and Management* Vol. 8, (2017).

[38] Haddou Benderbal, H., Dahane, M., & Benyoucef, L. Modularity assessment in reconfigurable manufacturing system (RMS) design: an Archived Multi-Objective Simulated Annealing-based approach. *International Journal of Advanced Manufacturing Technology*, Vol. 94, (2018), pp. 1-4.

[39] Alix, T., Benama, Y., & Perry, N. A framework for the design of a reconfigurable and mobile manufacturing system. *Procedia Manufacturing*, Vol. 35, (2019).

[40] Bortolini, M., Galizia, F. G., & Mora, C. Dynamic design and management of reconfigurable manufacturing systems. *Procedia Manufacturing*, Vol. 33, (2019).

[41] Gauss, L., Lacerda, D. P., & Sellitto, M. A. Module-based machinery design: a method to support the design of modular machine families for reconfigurable manufacturing systems. *International Journal of Advanced Manufacturing Technology*, Vol. 102, (2019), pp. 9-12.

[42] Kurniadi, K. A., & Ryu, K. Development of a framework for selecting the best collaboration path between machines for reconfigurable manufacturing systems. *Procedia Manufacturing*, Vol. 51, (2020), pp. 1267-1274.

[43] Beauville Dit Eynaud, A., Klement, N., Roucoules, L., Gibaru, O., Durville, L., & Beauville dit Eynaud, A. Framework for the design and evaluation of a reconfigurable production system based on movable robot integration. *The International Journal of Advanced Manufacturing Technology*, (2021).

[44] Bortolini, M., Botti, L., Galizia, F. G., & Regattieri, A. Bi-objective design and management of reconfigurable manufacturing systems to optimize technical and ergonomic performances. *Applied Sciences (Switzerland)*, Vol. 11, No. 1, (2021).

[45] Dou, J., Li, J., Xia, D., & Zhao, X. A multi-objective particle swarm optimisation for integrated configuration design and scheduling in reconfigurable manufacturing system. *International Journal of Production Research*, Vol. 59, No. 13, (2021).

[46] Lahrichi, Y., Deroussi, L., Grangeon, N., & Norre, S. A balance-first sequence-last algorithm to design RMS: a matheuristic

with performance guaranty to balance reconfigurable manufacturing systems. *Journal of Heuristics*, Vol. 27, Nos. 1-2, (2021).

[47] Napoleone, A., Brunoe, T. D., Andersen, A. L., & Nielsen, K. A Tool for the Comparison of Concept Designs of Reconfigurable Manufacturing Systems. *Procedia CIRP*, Vol. 104, (2021), pp. 1125-1130.

[48] Bortolini, M., Cafarella, C., Ferrari, E., Galizia, F. G., & Gamberi, M. Reconfigurable Manufacturing System Design Using a Genetic Algorithm. *Smart Innovation, Systems and Technologies*, *262 SIST*, (2022).

[49] Deif, A. M., & Elmaraghy, W. Effect of reconfiguration costs on planning for capacity scalability in reconfigurable manufacturing systems. International Journal of Flexible Manufacturing Systems, Vol. 18, No. 3, (2006).

[50] Deif, A. M., & Elmaraghy, W. Investigating optimal capacity scalability scheduling in a reconfigurable manufacturing system. In *International Journal of Advanced Manufacturing Technology* Vol. 32, Nos. 5-6, (2007).

[51] Deif, A. M., & ElMaraghy, H. A. Assessing capacity scalability policies in RMS using system dynamics. *International Journal of Flexible Manufacturing Systems*, Vol. 19, No. 3, (2008).

[52] Koren, Y., Wang, W., & Gu, X. Value creation through design for scalability of reconfigurable manufacturing systems. *International Journal of Production Research*, Vol. 55, No. 5, (2017).

[53] Scholz, S., Mueller, T., Plasch, M., Limbeck, H., Adamietz, R., Iseringhausen, T., Kimmig, D., Dickerhof, M., & Woegerer, C. A modular flexible scalable and reconfigurable system for manufacturing of Microsystems based on additive manufacturing and e-printing. *Robotics and Computer-Integrated Manufacturing*, Vol. 40, (2016), pp. 14-23.

[54] Wang, G. X., Huang, S. H., Yan, Y., & Du, J. J. Reconfiguration schemes evaluation based on preference ranking of key characteristics of reconfigurable manufacturing systems. *International Journal of Advanced Manufacturing Technology*, Vol. 89, (2017), pp. 5-8.

[55] Niroomand, I., Kuzgunkaya, O., & Asil Bulgak, A. Impact of reconfiguration characteristics for capacity investment strategies in manufacturing systems. *International Journal of Production Economics*, Vol. 139, No. 1, (2012).

[56] Andersen, A.-L., Rösiö, C., Bruch, J., & Jackson, M. Reconfigurable Manufacturing-An Enabler for a Production System Portfolio Approach. *Procedia CIRP*, Vol. 52, (2016), pp. 139-144.

[57] Farid, A. M. Measures of reconfigurability and its key characteristics in intelligent manufacturing systems. *Journal of Intelligent Manufacturing*, Vol. 28, No. 2, (2017).

[58] Lameche, K., Najid, N. M., Castagna, P., & Kouiss, K. Modularity in the design of reconfigurable manufacturing systems. *IFAC-PapersOnLine*, Vol. 50, No. 1, (2017).

[59] Xia, T., Xi, L., Pan, E., & Ni, J. Reconfiguration-oriented opportunistic maintenance policy for reconfigurable manufacturing systems. *Reliability Engineering and System Safety*, Vol. 166, (2017).

[60] Andersen, A. L., Larsen, J. K., Brunoe, T. D., Nielsen, K., & Ketelsen, C. Critical enablers of changeable and reconfigurable manufacturing and their industrial implementation. *Journal of Manufacturing Technology Management*, Vol. 29, No. 6, (2018), pp. 983-1002.

[61] Asghar, E., Zaman, U. K. uz, Baqai, A. A., & Homri, L. Optimum machine

capabilities for reconfigurable manufacturing systems. *International Journal of Advanced Manufacturing Technology*, Vol. 95, Nos. 9-12, (2018), pp. 4397-4417.

[62] Otto, J., Vogel-Heuser, B., & Niggemann, O. Automatic Parameter Estimation for Reusable Software Components of Modular and Reconfigurable Cyber-Physical Production Systems in the Domain of Discrete Manufacturing. *IEEE Transactions on Industrial Informatics*, Vol. 14, No. 1, (2018).

[63] Saliba, M. A., Azzopardi, S., Pace, C., & Zammit, D. A heuristic approach to module synthesis in the design of reconfigurable manufacturing systems. *International Journal of Advanced Manufacturing Technology,* (2019).

[64] Gola, A., Pastuszak, Z., Relich, M., Sobaszek, Ł., & Szwarc, E. Scalability analysis of selected structures of a reconfigurable manufacturing system taking into account a reduction in machine tools reliability. *Eksploatacja i Niezawodnosc*, Vol. 23, No. 2, (2021).

[65] Jiping, Z. Critical Analysis of Scalability of Reconfigurable Manufacturing Systems. *Journal of Machine and Computing,* (2021).

[66] Shang, X., Milisavljevic-Syed, J., Huang, S., Wang, G., Allen, J. K., & Mistree, F. A key feature-based method for the configuration design of a reconfigurable inspection system. *International Journal of Production Research*, Vol. 59, No. 9, (2021), pp. 2611-2623.

[67] Campos Sabioni, R., Daaboul, J., & le Duigou, J. Concurrent optimisation of modular product and Reconfigurable Manufacturing System configuration: a customer-oriented offer for mass customisation. *International Journal of Production Research*, Vol. 60, No. 7, (2022), pp. 2275-2291.

[68] *Industrie 4.0 : tout savoir sur la quatrième révolution industrielle*. (n.d.). Retrieved (2022).

[69] Morgan, J., Halton, M., Qiao, Y., & Breslin, J. G. Industry 4.0 smart reconfigurable manufacturing machines. *Journal of Manufacturing Systems*, Vol. 59, (2021), pp. 481-506.

[70] Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination. *Computer Networks*, Vol. 101, (2016).

[71] Wang, S., Wan, J., Li, D., & Zhang, C. Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks*, (2016).

[72] Wan, J., Tang, S., Li, D., Imran, M., Zhang, C., Liu, C., & Pang, Z. Reconfigurable smart factory for drug packing in healthcare industry 4.0. *IEEE Transactions on Industrial Informatics*, Vol. 15, No. 1, (2019).

[73] Salah, B., Abidi, M. H., Mian, S. H., Krid, M., Alkhalefah, H., & Abdo, A. Virtual reality-based engineering education to enhance manufacturing sustainability in industry 4.0. *Sustainability (Switzerland)*, Vol. 11, No. 5, (2019).

[74] Kumar, G., Goyal, K. K., & Batra, N. K. Role of Performance Measures in the Configuration Selection of Reconfigurable Manufacturing System. *Lecture Notes in Mechanical Engineering,* (2021).

[75] Zhang, Y., Zhao, M., Zhang, Y., Pan, R., & Cai, J. Dynamic and steady-state performance analysis for multi-state repairable reconfigurable manufacturing systems with buffers. *European Journal of Operational Research*, Vol. 283, No. 2, (2020). pp. 491-510.

[76] Singh, P. P., Singh, H., & Madan, J. A Review of Performance Measures for system Configuration in Reconfigurable Manufacturing system. *Industrial*

Engineering Journal, Vol. 11, No. 5, (2018).

[77] Kumar, G., Goyal, K. K., Batra, N. K., & Rani, D. Single part reconfigurable flow line design using fuzzy best worst method. *OPSEARCH*, Vol. 59, No. 2, (2022).

[78] Bortolini, M., Botti, L., Galizia, F. G., & Regattieri, A. Bi-objective design and management of reconfigurable manufacturing systems to optimize technical and ergonomic performances. *Applied Sciences (Switzerland)*, Vol. 11, No. 1, (2021).

[79] Elmaraghy, W. H., Nada, O. A., & Elmaraghy, H. A. Quality prediction for reconfigurable manufacturing systems via human error modelling. *International Journal of Computer Integrated Manufacturing*, Vol. 21, No. 5, (2008).

[80] Bortolini, M., Ferrari, E., Galizia, F. G., & Regattieri, A. An optimisation model for the dynamic management of cellular reconfigurable manufacturing systems under auxiliary module availability constraints. *Journal of Manufacturing Systems*, Vol. 58, (2021), pp. 442-451.

[81] Gola, A. Reliability analysis of reconfigurable manufacturing system structures using computer simulation methods. *Eksploatacja i Niezawodnosc*, Vol. 21, No. 1, (2019).

[82] Zhao, J., Si, S., & Cai, Z. A multi-objective reliability optimization for reconfigurable systems considering components degradation. *Reliability Engineering and System Safety*, Vol. 183, (2019), pp. 104-115.

[83] *Babagolzadeh, R., Rezaeian, J., & Khatir, M. V. Multi-objective fuzzy programming model to design a sustainable supply chain network considering disruption. International Journal of Industrial Engineering and Production Research,* Vol. 31, No. 2, (2020), pp. 217-229.

[84] Huang, A., Badurdeen, F., & Jawahir, I. S. Towards Developing Sustainable Reconfigurable Manufacturing Systems. *Procedia Manufacturing*, Vol. 17, (2018), pp. 1136-1143.

[85] Mesa, J. A., Esparragoza, I., & Maury, H. Modular architecture principles–MAPs: a key factor in the development of sustainable open architecture products. *International Journal of Sustainable Engineering*, Vol. 13, No. 2, (2020).

[86] Touzout, F. A., & Benyoucef, L. Sustainable multi-unit process plan generation in a reconfigurable manufacturing environment: A comparative study of three hybrid-meta-heuristics. *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA*, *2018-September*, (2018), pp. 661-668.

[87] Khezri, A., Benderbal, H. H., & Benyoucef, L. A Sustainable Reconfigurable Manufacturing System Designing with Focus on Environmental Hazardous Wastes. In *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA* (2019), pp. 317-324).

[88] Touzout, F. A., & Benyoucef, L. Multi-objective sustainable process plan generation in a reconfigurable manufacturing environment: exact and adapted evolutionary approaches. *International Journal of Production Research*, Vol. 57, No. 8, (2019).

[89] Ghanei, S., & Algeddawy, T. An Integrated Multi-Period Layout Planning and Scheduling Model for Sustainable Reconfigurable Manufacturing Systems. *Journal of Advanced Manufacturing Systems*, Vol. 19, No. 1, (2020), pp. 31-64.

[90] Khettabi, I., Boutiche, M. A., & Benyoucef, L. NSGA-II vs NSGA-III for the Sustainable Multi-Objective Process Plan Generation in a Reconfigurable Manufacturing Environment. *IFAC-PapersOnLine*, Vol. 54, No. 1, (2021), pp. 683-688.

[91] Khezri, A., Benderbal, H. H., & Benyoucef, L. Towards a sustainable reconfigurable manufacturing system (SRMS): multi-objective based approaches for process plan generation problem. *International Journal of Production Research*, Vol. 59, No. 15, (2021), pp. 4533-4558.

[92] Kurniadi, K. A., & Ryu, K. Development of multi-disciplinary green-bom to maintain sustainability in reconfigurable manufacturing systems. *Sustainability (Switzerland)*, Vol. 13, No. 17, (2021).

[93] Landers, R. G., Min, B.-K., & Koren, Y. (n.d.). *Reconfigurable Machine Tools*.

[94] Ming, Z., Zeng, C., Wang, G., Hao, J., & Yan, Y. Ontology-based module selection in the design of reconfigurable machine tools. *Journal of Intelligent Manufacturing*, Vol. 31, No. 2, (2020), pp. 301-317.

[95] Wang, Y., Zhang, G., Wang, J., Liu, P., & Wang, N. Reconfigurable machine tool design for box-type part families. *Machines*, Vol. 9, No. 8, (2021).

[96] Mahmoodjanloo, M., Tavakkoli-Moghaddam, R., Baboli, A., & Bozorgi-Amiri, A. Flexible job shop scheduling problem with reconfigurable machine tools: An improved differential evolution algorithm. *Applied Soft Computing Journal*, Vol. 94, (2020).

[97] Ashraf, M., & Hasan, F. Configuration selection for a reconfigurable manufacturing flow line involving part production with operation constraints. *International Journal of Advanced Manufacturing Technology*, Vol. 98, Nos. 5-8, (2018).

[98] Puik, E., Telgen, D., van Moergestel, L., & Ceglarek, D. Assessment of reconfiguration schemes for Reconfigurable Manufacturing Systems based on resources and lead time. *Robotics and Computer-Integrated Manufacturing*, Vol. 43, (2017).

[99] Ameer, M., & Dahane, M. Reconfiguration effort based optimization for design problem of Reconfigurable Manufacturing System. *Procedia Computer Science*, Vol. 200, (2022).

[100] Sabioni, R. C., Daaboul, J., & Le Duigou, J. An integrated approach to optimize the configuration of mass-customized products and reconfigurable manufacturing systems. *International Journal of Advanced Manufacturing Technology*, Vol. 115, Nos. 1-2, (2021), pp. 141-163.

[101] Nie, S., Huang, S., Wang, G., & Yan, Y. Configuration Design of Delayed Reconfigurable Manufacturing System(D-RMS). In *Lecture Notes in Mechanical Engineering* (2022), pp. 63-71.

[102] Li, X., Bayrak, A. E., Epureanu, B. I., & Koren, Y. Real-time teaming of multiple reconfigurable manufacturing systems. *CIRP Annals*, Vol. 67, No. 1, (2018).

[103] Leng, J., Liu, Q., Ye, S., Jing, J., Wang, Y., Zhang, C., Zhang, D., & Chen, X. Digital twin-driven rapid reconfiguration of the automated manufacturing system via an open architecture model. *Robotics and Computer-Integrated Manufacturing*, Vol. 63, (2020).

[104] Rösiö, C., & Jackson, M. Enable changeability in manufacturing systems by adopting a life cycle perspective. In 3rd International Conference on Changeable, Agile, Reconfigurable andVirtual Production, (2009), pp. 612-621.

[105] Andersen, A. L., Brunoe, T. D., Nielsen, K., & Rösiö, C. Towards a generic design method for reconfigurable manufacturing systems: Analysis and synthesis of current design methods and evaluation of supportive tools. *Journal of Manufacturing Systems*, Vol. 42, (2017).

[106] Goyal, K. K., Jain, P. K., & Jain, M. A comprehensive approach to operation sequence similarity based part family formation in the reconfigurable

manufacturing system. *International Journal of Production Research*, Vol. 51, No. 6, (2013).

[107] Jianxin Jiao, R., Pokharel, S., Kumar, A. and Zhang, L. "Development of an online quality information system for e-manufacturing", Journal of Manufacturing Technology Management, Vol. 18 No. 1, (2007), pp. 36-53.

[108] M. R. Abdi & A. W. Labib Grouping and selecting products: the design key of Reconfigurable Manufacturing Systems (RMSs), International Journal of Production Research, Vol. 42, No. 3, (2004), 521-546,

[109] ElMaraghy, H., G. Schuh, W. Elmaraghy, F. Piller, P. Schnsleben, M. Tseng, and A. Bernard. Product Variety Management.‖ CIRP Annals - Manufacturing Technology Vol. 62, No. 2, (2013), pp. 629-52.

[110] Bryan, A., J. Ko, S. J. Hu, and Y. Koren. Co-Evolution of Product Families and Assembly Systems.‖ CIRP Annals - Manufacturing Technology Vol. 56, No. 1, (2007), pp. 41-44.

[111] Tarek AlGeddawy & Hoda ElMaraghy A model for co-evolution in manufacturing based on biological analogy, International Journal of Production Research, Vol. 49, No. 15, (2011), pp. 4415-4435.

[112] Kota, S., Sethuraman, K., and Miller, R. "A Metric for Evaluating Design Commonality in Product Families." ASME. J. Mech. Des. December 2000; Vol. 122, No. 4,(1998), pp. 403-410.

[113] Jiao, J. and Tseng, M.M. "Fundamentals of product family architecture", Integrated Manufacturing Systems, Vol. 11, No. 7, (2000), pp. 469-483.

[114] McAdams, D.A. and Wood, K.L. 'A Quantitative Similarity Metric for Design-byAnalogy', Journal of Mechanical Design - Transactions of the ASME, Vol. 124, No. 2, (2002), p. 173.

[115] Abdi, M., Labib, A. Products Design and Analysis for Transformable Prod, (2007).

[116] Kashkoush, M., & ElMaraghy, H. Product family formation by matching Bill-of-Materials trees. *CIRP Journal of Manufacturing Science and Technology*, Vol. 12, (2016), pp. 1-13.

[117] Kashkoush, M., & Elmaraghy, H. Product family formation for reconfigurable assembly systems. *Procedia CIRP*, Vol. 17, (2014), pp. 302-307.

[118] Wang, G. xin, Huang, S. han, Shang, X. wen, Yan, Y., & Du, J. jun. Formation of part family for reconfigurable manufacturing systems considering bypassing moves and idle machines. *Journal of Manufacturing Systems*, Vol. 41, (2016), pp. 120-129.

[119] Lafou, M. et al. 'Manufacturing System Flexibility: Product Flexibility Assessment', Procedia CIRP, Vol. 41, (2016), pp. 99-104.

[120] Stief, P., Dantan, J.-Y., Etienne, A., & Siadat, A. *ScienceDirect ScienceDirect A new methodology to analyze the functional and physical architecture of existing products for an assembly oriented product family identification,* (2018).

[121] Baylis, K., Zhang, G., & McAdams, D. A. Product family platform selection using a Pareto front of maximum commonality and strategic modularity. *Research in Engineering Design*, Vol. 29, No. 4, (2018), pp. 547-563.

[122] Huang, S., & Yan, Y. Design of delayed reconfigurable manufacturing system based on part family grouping and machine selection. *International Journal of Production Research*, Vol. 58, No. 14, (2020), pp. 4471-4488.

[123] Zhang, H., Qin, S., Li, R., Zou, Y., & Ding, G. Progressive modelling of feature-centred product family development. *International Journal of Production Research*, Vol. 58, No. 12, (2020), pp. 3701-3723.

[124] Gauss, L., Lacerda, D. P., & Cauchick Miguel, P. A. Module-based product family design: systematic literature review and meta-synthesis. In *Journal of Intelligent Manufacturing* Vol. 32, No. 1, (2021), pp. 265-312.

[125] I. M. Ali, H. H. Turan, R. K. Chakrabortty, S. Elsawah and M. J. Ryan, "An Integrated Differential Evolution-based Heuristic Method for Product Family Design Problem," *2021 IEEE Congress on Evolutionary Computation (CEC)*, (2021), pp. 25-32.

[126] Nie, S., Huang, S., Wang, G., & Yan, Y. Configuration Design of Delayed Reconfigurable Manufacturing System(D-RMS). *Lecture Notes in Mechanical Engineering,* (2022).

[127] Zaabar, I., Polotski, V., Bérard, L. *et al.* A two-phase part family formation model to optimize resource planning: a case study in the electronics industry. *Oper Res Int J* (2022).

[128] Gao, S., Daaboul, J., & Le Duigou, J. Process planning, scheduling, and layout optimization for multi-unit mass-customized products in sustainable reconfigurable manufacturing system. *Sustainability (Switzerland)*, Vol. 13, No. 23, (2021).

[129] Choi, Y. C., & Xirouchakis, P. A holistic production planning approach in a reconfigurable manufacturing system with energy consumption and environmental effects. *International Journal of Computer Integrated Manufacturing*, Vol. 28, No. 4, (2015), pp. 379-394.

[130] Bensmaine, A., Dahane, M., & Benyoucef, L. A new heuristic for integrated process planning and scheduling in reconfigurable manufacturing systems. *International Journal of Production Research*, Vol. 52, No. 12, (2014), pp. 3583-3594.

[131] Kurniadi, K. A., & Ryu, K. Development of IOT-based Reconfigurable Manufacturing System to solve Reconfiguration Planning Problem. *Procedia Manufacturing*, Vol. 11, (2017).

[132] Han, S., Chang, T. W., Hong, Y. S., & Park, J. Reconfiguration decision-making of IoT based reconfigurable manufacturing systems. *Applied Sciences (Switzerland)*, Vol. 10, No. 14, (2020).

[133] Leng, B., Sun, H., Si, G., Xia, T., & Wang, H. Digital Twin and Manufacturing Simulation Integrated Platform embedded in cyber-physical system. *Journal of Physics: Conference Series*, Vol. 1983, No. 1, (2021).

[134] Hassani, Z. I. M., El Barkany, A., El Abbassi, I., Jabri, A., & Darcherif, A. M. New model of planning and scheduling for job-shop production system with energy consideration. Management and Production Engineering Review. Polish Academy of Sciences, (2019).

[135] Azarian, M., Yu, H., & Solvang, W. D. A Simulation-Based Approach for Improving the Performance of a Manufacturing System. In *IEEE/SICE International Symposium on System Integration, SII 2021* (2021), pp. 543-547.

[136] Production and Reconfigurable Manufacturing. In: Dashchenko, A. I. (eds) Reconfigurable Manufacturing Systems and Transformable Factories. Springer, Berlin, Heidelberg.

[137] Galan, R., Racero, J., Eguia, I., & Garcia, J. M. A systematic approach for product families formation in Reconfigurable Manufacturing Systems. *Robotics and Computer-Integrated Manufacturing*, Vol. 23, No. 5, (2007), pp. 489-502.

[138] Lai, X., Gershenson, J.K. Representation of similarity and

dependency for assembly modularity. Int J Adv Manuf Technol Vol. 37, (2008), pp. 803-827

[139] Alizon, F, Shooter, SB, & Simpson, TW. "Assessing and Improving Commonality and Diversity Within a Product Family." Proceedings of the ASME 2006 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 1: 32nd Design Automation Conference, Parts A and B. Philadelphia, Pennsylvania, USA, (2006), pp. 899-909.

[140] Shih, H.M. 'Product structure (BOM)-based product similarity measures using orthogonal procrustes approach', Computers & Industrial Engineering, Vol. 61, No. 3, (2011), pp. 608-628.

[141] Ossama, M., Youssef, A. M. A., & Shalaby, M. A. A Multi-period Cell Formation Mod IWN it is critical to understand how these metrics and indicators may be improved.el for Reconfigurable Manufacturing Systems. *Procedia CIRP*, Vol. 17, (2014), pp. 130-135.

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