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Integrated process planning and scheduling in networked manufacturing systems for I4.0: a review and framework proposal

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Abstract

Integrated process planning and scheduling in networked manufacturing systems plays a crucial role nowadays and in the forthcoming context of Industry 4.0 to enable effective and efficient decisions, and to improve the business market, based on collaboration, along with computer-based distributed manufacturing and management functions. In this paper some insights regarding a literature review carried out about this main subjects analysed are presented and discussed. Moreover, a framework for integrated process planning and scheduling in networked manufacturing systems is proposed and briefly described, along with some main underlying issues, which are further discussed. Thus, the main purpose of this research consists on presenting a proposed methodology, based on the study conducted, to enable to further assist either academia or industry to develop new tools, techniques and approaches for integrated process planning in networked manufacturing environments. The findings and contributions of this research can help in the implementation and improvement in distributed manufacturing environments, to be linked with small and medium enterprises, to further expand their potentialities through well suited integrated process planning and scheduling decision making processes.

Keywords Integrated process planning and scheduling · Networked manufacturing · I4.0

1 Introduction

In order to respond to today's intensely competitive environment and to obtain high product variety and customization, along with short product life cycles, networked manufacturing environments, along with integrated production planning and scheduling systems play a crucial role to shift manufacturing and management paradigms from deterministic to a more rigorous, autonomous and dynamically adaptive control based on a flexible, agile and collaborative manufacturing. A befitting answer to this need is based on integrated production planning and scheduling through networked manufacturing (NM). Liu et al. [1] define networked manufacturing as a set of manufacturing activities ranging from market control,

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manufacturing technologies and manufacturing systems that can help enterprises to improve the business management and enhance their competitiveness in the market. Therefore, the study and analysis of networked manufacturing has become a necessity due to its advantages in current competitive atmosphere, as it meets a number of, often conflicting, objectives and goals, such as reducing the manufacturing cycle time, shorter lead times, better interoperability, and maintaining the production flexibility leading to many feasible process plans, and all these requirements can be fulfilled through IPPS based on appropriate supporting technologies for enabling integration, interoperability and digitalization, for reaching imperative main and common enterprise goals.

Although the monolithic approach of traditional manufacturing has its own advantage, it is not sufficient in the current highly dynamic changing manufacturing environment occurring in the scope of I4.0. However, several problems related to the traditional manufacturing approach have been clearly stated [2]. To overcome these problems, researchers have realized that there is a need to integrate both the functions and the means to achieve better performance of the system. Subsequently, the need to integrate both of these issued activities have found the basis in the context of networked and collaborative manufacturing environments.

However, no conventional shop floor control system based on centralized or hierarchical control architecture can handle the required adaptive and autonomous control of manufacturing system. Therefore, the control architecture is gradually being shifted to the distributed, decentralized and autonomous control (DDAC) architecture. Since DDAC shop floor control system may have complete local autonomy, governing the reconfigurability, scalability as well as fault tolerance, which it is suitable for a dynamically changing environment in the scope of I4.0.

To achieve the successful information and knowledge exchange between different facilities, there is a need for internet and communication technology IoT (internet of things) through which it can be possible to link all of them. Some of the key literature reviews for planning and scheduling and their integration, regarding learning and other AI-based approaches, for instance based on multi-agent systems (MAS), or on other kind of approaches, such as simulation based, among others, are further detailed in this paper.

The main objective of this paper is to analyse, synthesise and present a comprehensive systematic literature review (SLR) of the role of integrated process planning and scheduling in networked manufacturing environments.

In an initial analysis of the selected literature of 51 research papers a framework was designed, which was used to elaborate on findings of this review, which will be referred to and discussed further in this paper. The structure of the paper is as follows. Section 2 briefly describes networked manufacturing systems. Section 3 discusses integrated production planning and scheduling, in general, and through underlying requisites regarding knowledge acquisition, and learning paradigms, along with knowledge management, data visualization and interpretation issues. Section 4 refers to enterprise modelling and integration, in a broad sense, and presents a proposed framework for an IIPS in the context of I4.0. Finally, Sect. 5 provides some main conclusions and planned future work.

2 Networked manufacturing systems

In networked manufacturing, job requests come from different customers with competitive relationships, i.e. the job scheduling concentrates on satisfying the individual objectives of each job. However, in a networked manufacturing environment, the machines with different capabilities are distributed geographically to perform various operations of the products.

As a new and advanced manufacturing paradigm, networked manufacturing pattern suits the global trends towards a knowledge-based economy and global manufacturing environment. In networked manufacturing environments, the mode of production has shifted from make-to-stock to make-to-order, in which the active participation of customers, submitting job requests, which tend to be highly customized, to the manufacturing system are accomplished [3].

A networked manufacturing system (NMS) can be defined as a manufacturing-oriented network that employs the Internet and other related technologies to cater the needs of distributed manufacturing environments. It has the capability to encapsulate the manufacturing enterprises' information and to provide the manufacturing services through which interoperability between enterprises can be achieved.

The networked manufacturing environment is distinct from the traditional manufacturing environment in many ways, and summarized information about NMS is presented in Table 1. As can be realised through the information presented in Table 1, there is a set of fundamental functionalities required to enable to reach appropriate NMS.

As mentioned by Li and Chaoyong [4], in the case of the traditional manufacturing systems, process planning and scheduling functions aim to acquire optimal results for all the jobs, which are different from individual optimal results for each job. In networked based manufacturing, owing to the role played by the competition factors among different jobs, the objectives for process planning and scheduling is slightly different from that in traditional manufacturing.

In traditional manufacturing, the machines associated with jobs are located and constrained in a single workshop or enterprise. However, for networked based manufacturing jobs and machines are distributed in different workshops or enterprises located globally at larger distances. Thus it can be inferred that for networked based manufacturing situation, it is similar to one found in flexible manufacturing system where many possible machines, operations are feasible but not on the same shop floor.

Alternatively, it can be said that in networked manufacturing scenario, generation of optimal process plans for each job, in the presence of several dynamic constraints, such as the present status of machines, tools, and fixtures at a given manufacturing place, is posing a genuine challenge in the design and development of appropriate integrated production planning and scheduling systems.

3 Integrated production planning and scheduling

In this section, an extensive literature is briefly presented and described, in order to further realise about the present status of research and methodology adopted in the IPPS on networked manufacturing environments. In recent years, the area of IPPS is playing a major role, particularly to the current emerging manufacturing paradigms in many ways in I4.0.

Process planning and scheduling problems are considered as a non-polynomial (NP) hard problem [5–7], thus there is no algorithm that provides the exact solution in polynomial time. In general, the solution of IPPS in manufacturing systems is carried out with mainly three kinds of approaches such as nonlinear process planning (NLPP), closed loop process planning (CLPP), and distributed process planning (DPP). The detailed description of these approaches and their features, advantages, and disadvantages [8–10] are summarized in Table 2.

The basic idea behind an integrated approach for process planning and scheduling functions was first introduced by Chryssolouris [11, 12]. Sundaram et al. [13] proposed a group scheduling algorithm in job shop environment to minimize the makespan and to balance the load for machines. Later, with the integration approach, the performance of the manufacturing system has been improved. Subsequently, several issues involved in the integration of manufacturing functions are addressed [14]. In their work, a dynamic feedback mechanism was introduced for effective coordination among various resources. They reported a significant impact on the system performance with a reduction in the number of late parts, total tardiness and flow times. Wang and Shen [15] proposed an integrated model and developed the concept of a dynamic feedback system for finding the alternative process plans for networked manufacturing system. Through their approach, the flexibility of the manufacturing system has been improved. Cai et al. [16] stated that with NLPP approach an integration of the process planning and scheduling couldnot obtain the optimal results due to its one-way information flow. If the parts are huge in number, their alternative process plans are exponentially increasing in number which can create huge problem for data storage. Also, some of the process plans, out of all, are not feasible according to the real-time status of the manufacturing environment [17].

Shafaei and Brunn [18] introduced Flex Plan model for IPPS approach for the selection of suitable process plans by considering available manufacturing resources. Here, the authors successfully implemented the reactive re-planning approach to catering the disturbances occurring on the shop floor. A simulation based genetic algorithm approach for IPPS has been proposed by Lee and Kim [19]. Instead of creating the alternative process plans, in their work authors used agenetic algorithm for near-optimal process plan selection. To execute the performance measures, i.e. makespan and lateness, dispatching rules, such as shortest processing time (SPT), and earliest due date (EDD) rules were implemented. From the results, they have concluded that more than 20% of the reduction in makespan has been achieved through their approach, while comparing with random process planning selection operation.

Kumar and Rajotia [20] suggested an on-line scheduling approach in computer aided process planning for a job shop scheduling problem to determine the flow time and a number of tardy jobs. Subsequently, in the similar problem,

Table 1 Functionalities of networked manufacturing systems (NMS)

Functionalities	Description
System monitoring	It is the monitoring done by the intelligent systems to make it more dynamic and efficient
Information consultation	It is the input data gathered from the management teams, experts and cloud
Manufacturing service	It is the available service in the cloud to be provided if the current service is finished or delay is caused
Production planning and scheduling	It is the arranging, controlling and optimizing work and workloads in a production process or manufacturing process

Table 2 Different kind of approaches and their characteristics in IPPS

S. no.	IPPS approaches	Features	Advantages	Disadvantages
1	NLPP	1. Alternative process plans exist which offers a high degree of routing flexibility to schedule 2. It can improve the off-line scheduling performance so as to quickly react to the disturbances on the shop floor 3. Information flow is one-way i.e., from process planning to production planning. Thus, may be impossible to achieve optimal results while integrating the manufacturing functions 4. Out of many alternative process plans, some of them are not feasible according to real-time shop status 5. It is highly complex to allocate the resources to all the generated alternative process plans	Providing all the alternative process plans enhances the flexibility of the process plans therefore to achieve optimal or near optimal results	Due to providing all the alternative process plans of the parts, the problem is a case of combinatorial explosive
2	CLPP	1. Here, each generated process plan is feasible based on the current shop floor conditions 2. It is necessary to get the real time information of the manufacturing system for processing 3. The process planning and scheduling departments have to be changed and reorganized to get the full advantage 4. Due to the capability of capturing real time information, it requires upgraded hardware and software 5. The solution space is limited for conducting subsequent operations of the system	Based on the current shop floor status, all generated process plans are valuable	CLPP requires real –time information and the current process plans data. It is very difficult to regenerate, update the process plans for each schedule
3	DPP	1. This method can integrate process planning and scheduling functions without generating superfluous process plans 2. Parallel processing of process planning and scheduling is possible 3. Due to the capability of capturing real time information, it requires upgraded hardware and software 4. With this approach, finding out a feasible solution from large space in a reasonable time is difficult 5. The process planning and scheduling departments of an organization must be reorganizing according to the requirements	Collaboration, integration, and coordination is possible with DPP approach	The Integration approach is hierarchical in nature thus it is not possible to optimize both process plans and scheduling plans simultaneously

the authors have considered machine capacity and cost while assigning the operations to the machines. The IPPS approach along with their developed decision support system, the parts processing has also been handled [21].

Zhou and Dieng-Kuntz [22] proposed a GA-based IPPS approach to improve the scheduling objectives, such as minimize the makespan, minimizing the number of rejects, and to minimize the processing cost, in a job shop scheduling environment. The mentioned work has been extended by considering balancing the load on each machine. To solve this problem, a particle swarm optimization (PSO) algorithm has been proposed for effective results [23]. Li et al. [24] developed a two-layer representation of GA based chromosomes for alternative process plan and scheduling plan string. With this effective genetic representation and operation scheme, IPPS approach has been adopted for job shop scheduling problem to minimize the makespan. They did also prove that integration approach performs far better than the traditional approach. Later, they modified the GA and proposed a hybrid GA by incorporating Tabu search to solve the job shop scheduling problem with IPPS. Instead of the previously mentioned two layer concept, they proposed a three-layer representation for process plan, scheduling, and machine string to minimize the makespan [25].

Moon et al. [26] presented a topological short test technique and conducted different experiments by varying order size, number of operations, and resources selection rules to improve the performance of a supply chain by optimizing the makespan. It is important to find the maintenance cost of the obtained feasible process plan from many alternative process plans. Thus, Wang et al. [5] proposed an IPPS approach for batch size production with simulated annealing algorithm to find optimal process plan in prismatic parts. In their approach, the authors correlated the tardiness and the cost of maintaining the process plan. From their results, it is clear that tardiness of a job has been improved by reducing the cost of process plan at a lower level.

Haddadzade et al. [27] proposed an IPPS approach to handle the operations of complex prismatic components in a job shop environment and to minimize the due dates and the cost. Baykasoglu and Ozbakir [28] implemented an IPPS approach with generic process plan method to generate feasible process plans, and dispatching rule based heuristic to generate feasible schedules. To optimize the performance measures, such as flow time and cost of process plan, a multi-objective-based tabu search algorithm was employed. Results confirmed that an increase of process plan flexibility decreases the cost of process plan. Rajkumar et al. [29] developed a multi-objective greedy randomized adaptive search procedure (GRASP) to minimize the makespan and to maximize the total workload, total flow time, and tardiness in the context of flexible job shop environment. The proposed approach was used to test four benchmark data sets, and it had demonstrated capability to solve IPPS problems. An IPPS approach in the context of Holonic manufacturing system to balance the load for all the machines is highlighted. Thereafter, to be part of solving the problem, a hybrid PSO algorithm and differential evolutionary algorithm has been proposed to find out the better results [30]. Nakandala [31] presented an integrated approach for manufacturing and distribution network within a supply chain context of a global car Company. The authors found that through the integrated approach, interfacing of individual networks has been eliminated. Furthermore, they also stated that for further improvements on the supply chain network the integrated approach is capable of providing flexibility, visibility, and maintainability.

Capturing dynamic behavior of the manufacturing system to perform the manufacturing functions is one of the complex tasks in a recent manufacturing environment. To deal with this problem, several researchers [11, 32–34] have proposed different models and methodologies. Chan et al. [35] proposed a dynamic feature based IPPS approach for improving the smallest slack time criterion in a batch size production system. Moreover, an artificial intelligence based feature extractor model was implemented to extract the features of the product. Subsequently, a rough process plan was constructed by considering one machine setup on the shop floor to enhance the scheduling of batch size production. An N-person non-cooperative game-theoretic approach to generate the optimal process plans for multiple jobs in a networked-based manufacturing system was presented [30]. The networked manufacturing system is a new field in the area of distributed manufacturing environment which has many dimensions.

3.1 Knowledge acquisition and learning

With the rise in current cloud-based business programming frameworks and administrations, some new modules of the cloud based data management (CBDM) framework are required including data and inventory network administration. The cloud-based data administration module enables a group of collaborators to trade and offer drone advancement related data throughout the preparation process. Semantic online plan and manufacturing information portrayal can fundamentally computerize the outline and manufacturing procedures and increment profitability while utilizing a machine-comprehensible learning portrayal method. The semantic web index enables plan and manufacturing specialists to enhance and seek for precision by utilizing semantics as opposed to utilizing ranking algorithms. The data administration module additionally enables specialists to catch the right data from the perfect individual in light of Social Network Analysis (SNA). This component can essentially enhance correspondence and coordinated effort in the outline of manufacturing process [36].

From a manufacturing mechanization viewpoint, the digital framework of CBDM alongside the semantic web-based manufacturing knowledge representation can possibly robotize manufacturing methods. In particular, the machine-readable knowledge representation scheme, called Web Service Description Language (WSDL), and Universal Description Discovery and Integration (UDDI) permits fabricating specialists to distribute their assembling administrations in a machine-readable language. Moreover, the formal portrayal of the manufacturing assets empowers the programmed recovery of the required assembling administrations in light of the semantic matchmaking of required and distributed manufacturing administration specifications. For example, in this case situation, CBDM enables the group to consequently recover a rundown of 3D printers that are fit for building the propellers in view of the distributed manufacturing specifications [37].

In the coming space just a portion of the R&D difficulties are illustrated from the significantly greater arrangement of research fields which are identified with CPPS: x Context-versatile and self-sufficient frameworks [38]. Strategies for thorough, nonstop setting mindfulness, for acknowledgment, examination and translation of arrangements and expectations of items, frameworks and interested clients, for model creation for application field, area and for mindfulness regarding knowledge about own circumstances, status and alternatives for activities are to be produced [39].

The main after effects of applying the SoA innovation to the compartmentalization of an adaptable assembly cell, as it has been determined in [40, 41], created and executed in the EU FP6 STREP Project 'Coordinated surrounding insight and information based on administrations for complex assembling and mechanical production systems—InLife'. The assembly cell is changed in a SoA stage, where every mechanical segment has a characterized part as 'service consumer' as well as 'specialist organization' [40, 41].

3.2 Knowledge management

According to [42] a new networked manufacturing model has been provided through Cloud manufacturing to the emerging manufacturing industries. The main characteristics of the knowledge of group enterprise in cloud manufacturing are—heterogeneous, dynamic, polyphyletic and distributed. Based on the concept of knowledge as a service, implementing the tactic knowledge and the explicit knowledge sharing, a prototype of cloud manufacturing has been presented in [42].

The new service-oriented networked manufacturing model presented by Li enriches and expands the resource sharing range and service model in cloud computing, it promotes green, service, agile and intelligence-oriented manufacturing development. The knowledge of manufacturing in this model maximizes the use of resources available inside the enterprise as well as improves the design manufacturing capabilities [42].

According to [42] cloud manufacturing accentuates the significance of learning that empowers knowledge reuse and creative manufacturing, since innovation has turned out to be a standout amongst the most basic figures in enterprise competition. Cloud is not just a system which empowers distributed resources and abilities interconnected but a vault where multidisciplinary knowledge is pooled. Consequently, a manufacturing cloud is a learning cloud brimming with astuteness also. Moreover, AI methods like genetic algorithms, neural networks, and evolutionary algorithms are important to empower decision making as well as intelligent processing.

As shown previously in Fig. 1, knowledge and AI technologies are unavoidable in most of the aspects in cloud manufacturing, basically offering support for two life cycles, product life cycle and cloud service life cycle. Concerning the previous, knowledge and AI advancements assume an imperative part in advancing development and enhancing proficiency in all phases of an item life cycle, for example, outline, creation, testing, recreation and administration. With respect to the last mentioned, knowledge and AI advances offer support for entire life cycle of cloud services varying from publishing, storing, matching, integrating, trading, execution, charging, scheduling, evaluation and other phases.

3.3 Data visualization

Based on the literature review, following suggestions were provided by the authors in [43, 44] for further research from the perspective of system design, development and diffusion in this particular field:

1. Building up measures to speak to different assembling assets and abilities is crucial to the advancement of cloud assembling. Right now, extraordinary assembling ventures utilize distinctive systems and methods to incorporate their dispersed assets and abilities. Thus, different assembling assets and abilities wind up being portrayed and spoken to utilizing distinctive information or semantic model and structures without bounding together elements, information sorts and details [43, 44].
2. To permit conceivable mix of assembling assets and capacities crosswise over undertakings and supply chains, utilizing institutionalized information or semantic models and structures to speak to virtualised assets is fundamental. STEP, XML, WSDL and metaphysics method can be utilized to encourage the institutionalization procedure and characterize

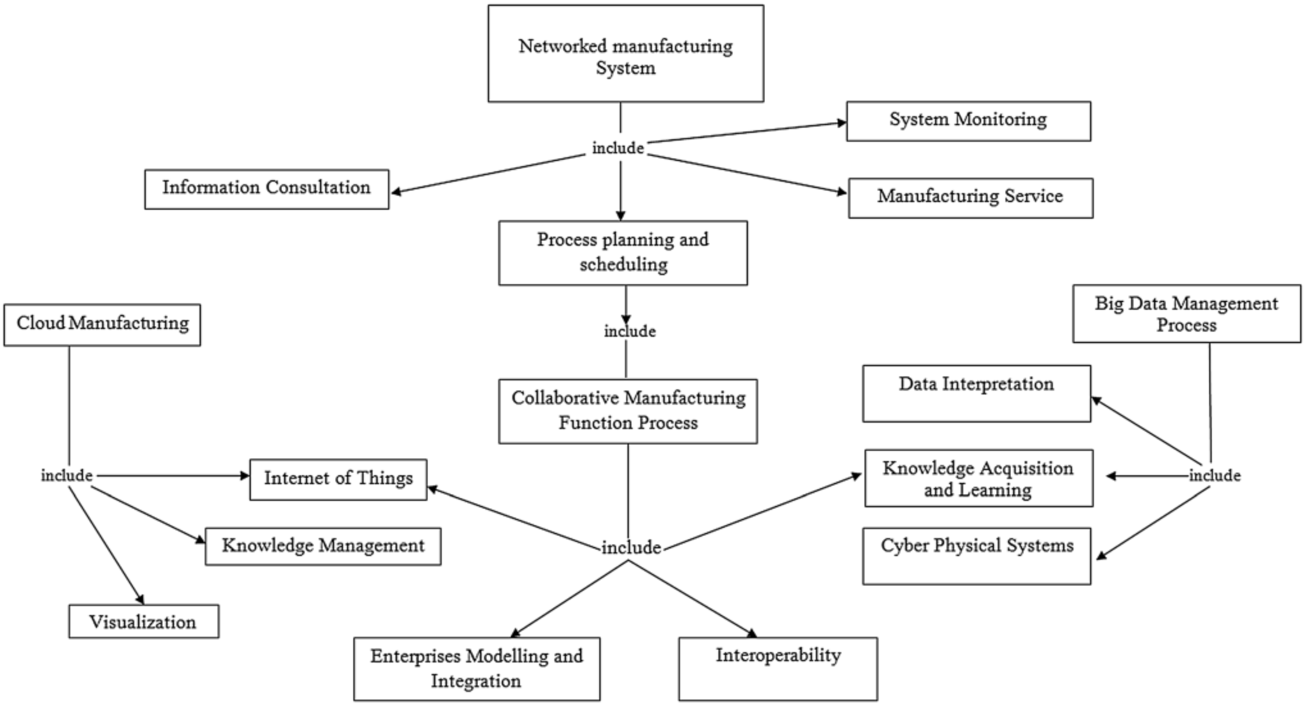

Fig. 1 Main topics related to integrated production planning and scheduling in networked manufacturing environments

information models and structures for asset and administration depictions [45].

3. Creating 'incorporation as an administration' and conventions for cloud-based combination is an exploration challenge. Fabricating cloud can be grouped into open cloud and private cloud. Fabricating undertakings may build producing cloud benefit stage inside big business and utilize some assembling assets accessible on the general public arranged open assembling cloud benefit stage [46].
4. It is basic to execute powerful security administration systems and strategies to simplicity security issues [47].
5. To decrease the obstruction for the reception of cloud assembling, it is fundamental to construct utility models that consider the income, time and dependability for asset specialist co-operation, asset benefit demander and asset benefit operator required in the asset benefit exchanges. To augment the utility for partners in the exchange procedure, the utility, harmonies between various sorts of clients should be researched in points of interest. Flow examine on utility models and utility coordination strategies in cloud assembling is still toward the starting stage. Intrigued analysts are prescribed to analyse the related reviews and practice in the field of lattice administration [48].

3.4 Data interpretation

Recently, technological promotions have led to engulf of data from exceptional domains (e.g., health care and scientific sensors, user-generated data, Internet and financial companies, and supply chain systems) over the past two decades. The phrase big data was stamped to capture the meaning of this emerging trend. In addition to its abrupt volume, big data also exhibits other unique characteristics as compared with traditional data. For instance, big data is commonly unstructured and require more real-time analysis. This maturation calls for new system architectures for data acquisition, transmission, storage, and large-scale data processing mechanisms.

A vast amount of organized information is created in the business and logical research fields. Administration of these organized information depends on the development of relational database management systems (RDBMS), data warehousing, online analytical processing (OLAP), and business process management (BPM). Information examination is to a great extent grounded in data mining and factual investigation. These two fields have been completely considered in the previous three decades. In this regard, an arrangement on machine-learning strategies in view of learning representation, is turning into a dynamic research field. Most present machine-learning calculations rely on upon human-planned portrayals and information highlights, which is a perplexing errand for different applications. Deep learning calculations join representation learning and take in numerous levels of portrayal of expanding intricacy/reflection. Using data characteristics, temporal and spatial mining can separate learning structures spoken to in models and examples for rapid information streams and sensor information. Driven by security worries in online business, e-government, and medicinal services applications, protection safeguarding information mining is turning into a dynamic research range. Over the previous decade, due to the developments on accessibility of occasion information and process revelation and conformance-checking methods, handle mining has raised as another exploration field that spotlights on utilizing occasion information to dissect forms.

Producers require common sense direction. Makers need to comprehend what sorts of information to test, which sensors to utilize and where along the creation line to introduce them. For instance, to enhance earthenware material quality, which is trying to achieve, a producer might need to screen the execution of apparatus and in addition the structure of the item. Research is expected to decide the best setups of sensors. Five holes in savvy producing development should be filled [49].

Savvy producing frameworks must develop as data is accumulated. As to start with, sensors would screen the conditions of existing hardware. As new requirements for quality and proficiency develop, more sensors can be added to take after the most valuable parameters. The semiconductor business, for instance, has enhanced the nature of its wafers by following and modifying its procedure settings [50].

Enhance information gathering, utilize and sharing is of upmost importance nowadays and further in the context of I4.0. Here, most organizations need involvement. Some erroneously trust that their databases are too huge for examination. Others worry over authoritative and legitimate parts of information utilize. What is more, quality matters more than amount. Boisterous or unpredictably inspected estimations are of little utility. The recurrence at which information is gathered and to what extent they are put away should be resolved. High volumes of quick estimations cost more to store; however long haul information is fundamental for demonstrating. Fitting periods for averaging should be resolved. Machine vibrations must be taken after on timescales of seconds or less, while temperatures can be arrived at the midpoint of more than 10 min or longer periods. Moreover, conventions are expected to address information protection, assurance and security.

4 Enterprise modelling and integration

Enterprise modelling (EM) is the art of combining enterprise knowledge, which adds value to the enterprise, be it a single enterprise, a private or government organization, or a networked enterprise (e.g. extended enterprise, virtual enterprise or smart organization). Enterprise Integration (EI) deals with facilitating information flows, systems interoperability and knowledge sharing among any kind of organization. Enterprise Interoperability, as one of the many facets of EI, provides two or more business entities (of the same organization or from different organizations and irrespective of their location) with the facility to exchange or share information (wherever it is and at any time) and to use functionalities of one another in a distributed and heterogeneous environment [51–54]. Molina et al. [55] asserts that Enterprise Modelling has evolved over the last three decades from fact modelling to Knowledge Management while at the same time Enterprise Integration has evolved from computer systems integration and CIM to Enterprise Interoperability and e-commerce.

This paper has provided a short overview of the field in terms of where we stand, and what has to be done next. Moreover, it also proposes an extension of the CIMOSA framework to host extended principles for Enterprise Modelling and Integration, expressed through Fig. 2.

Figure 2 illustrates a proposed architecture of a NMS. The NMS starts with a request from the customer whose product task can be handled by the web-based manufacturing service through two different modes namely Customer User (CU) and Enterprise user (EU). CU is defined as a customer or organization that accepts the manufacturing requests from the customers to analyse and process the production tasks with the support of web-based decision system in order to provide a feasible solution in an effective manner. Through web-based manufacturing service (WBMS), it is possible to analyse manufacturing product requests of multiple organizations. On the other side, the functionality of the EU is the same as the CU mode at the initial stage, but due to its self-service providing capability, the requested product can be served entirely by EU itself. In most of the practical cases, a serving of all the product requirements by single EU is almost impossible. Thus, similar to CU, the EU searches for qualified enterprises with the support of web-based decision system to fill the requirements of the unfinished tasks such as the finding of potential enterprises, communication with remote servers, interactions with the customers, and remote optimization services.

In this example, the EU can serve as a directive Company in this virtual organization where it can take initiation to interact with the customer, and collaborating with other

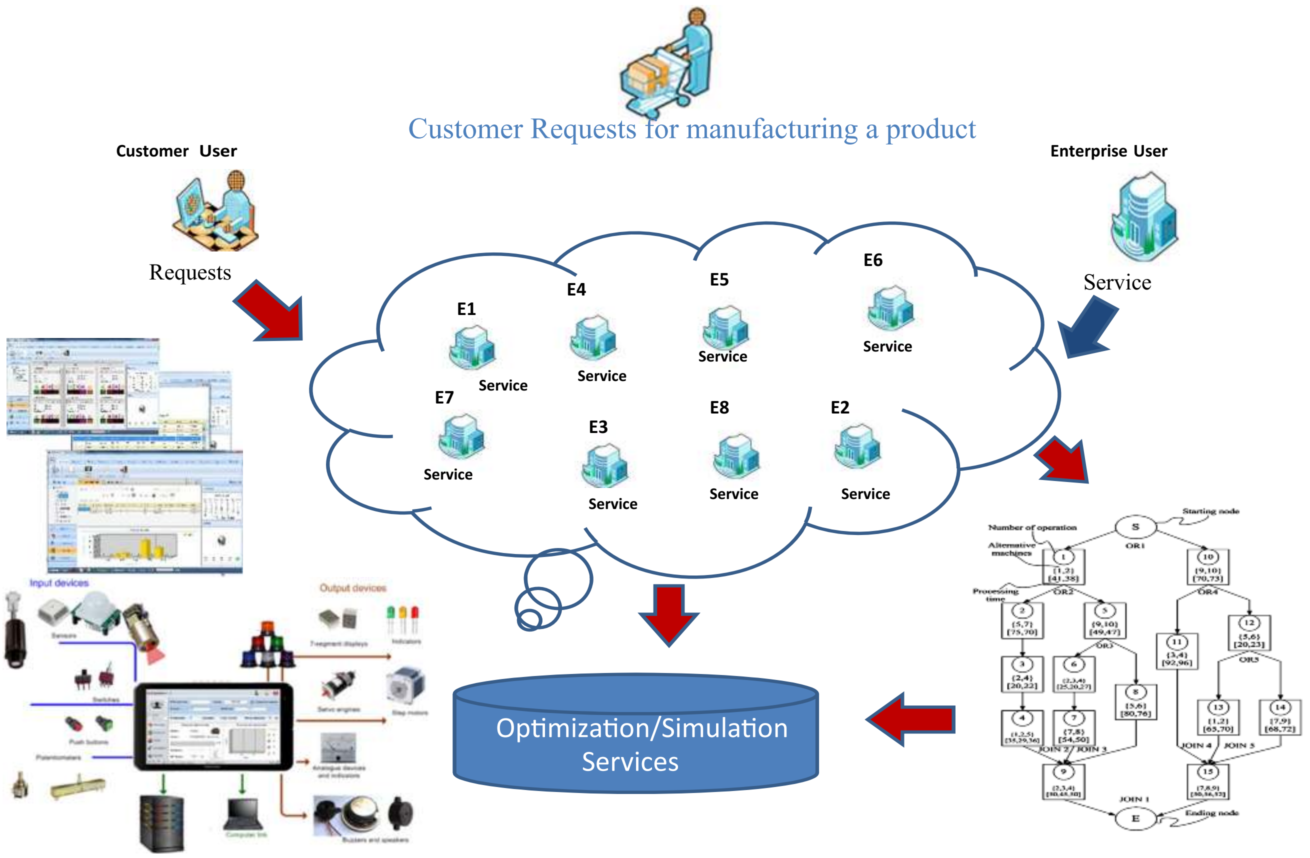

Fig. 2 Networked manufacturing system architecture [56]

related enterprises as a coordinator. This way, User, and EU are able to accomplish varied and more demanding production tasks that are unattainable by a single enterprise. However, after finding the necessary product data and the enterprises' information, an effective approach to describe the manufacturing functions requirements and their implementation on networked manufacturing environment is accomplished. Thereafter, with suitable metaheuristics and simulation techniques, the complex problems in distributed manufacturing environment such as IPPS can be solved to achieve the objectives of the User that can be a solution to the final customer. Some of the basic features of networked manufacturing system are summarized below:

- Networked manufacturing is derived from the concept of a network of enterprises with network based manufacturing as its pattern. It has all the information of enterprises that can provide the procedure of enterprises operation such as feature extraction, data pre-processing, process planning, remote scheduling, and business management in the global environment with the internet as its service.
- Networked manufacturing can provide support to the entire product life cycle.
- It has the ability to improve the competitiveness of the enterprises such that quick response can be achieved.
- The networked manufacturing systems have the capability to reconfigure and reorganize its manufacturing functions when the demands are fluctuating rapidly.
- Collaboration between geographically dispersed enterprises is possible through networked manufacturing environments where effective access to remote resources can lead to low-cost and high-speed product design and manufacturing, based on smart devices, along with the use of wireless communication devices, dashboards and other mobile means, sensors, along with other tools and peripherals.

5 Conclusion

In this paper a comprehensive systematic literature review (SLR) of recent and state-of-the-art papers was carried out, on the role of integrated process planning and scheduling (IPPS) in the context of networked manufacturing environments (NME), in the scope of Industry 4.0, which was vital to draw a framework and to shed light on the future research avenues. The systematic review enabled to draw, as main conclusion, that IPPS and NME continue to be unexplored thus there is still need for further and even more intense and serious developments regarding IPPS in the context of NME and I4.0. Moreover, the SLR methodology used was useful to identify the gaps in the literature which did lead to further establish future opportunities to conduct the research. It is clear from the conducted study and the developed methodology that further research can assist both academia and industry to develop new tools, techniques, and methodologies for IPPS in NME. Moreover, the subject analysed on the conducted research study may help further the implementation and improvement in distributed manufacturing environments, to be linked with small and medium enterprises, to further expand their potentialities through well suited IPPS under NME.

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