Hindawi
Journal of Engineering
Volume 2017, Article ID 9305989, 15 pages
https://doi.org/10.1155/2017/9305989

Research Article

Telefacturing Based Distributed Manufacturing Environment for Optimal Manufacturing Service by Enhancing the Interoperability in the Hubs

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Received 16 June 2016; Revised 20 November 2016; Accepted 28 December 2016; Published 7 March 2017

Academic Editor: Luis Carlos Rabelo

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Recent happenings are surrounding the manufacturing sector leading to intense progress towards the development of effective distributed collaborative manufacturing environments. This evolving collaborative manufacturing not only focuses on digitalisation of this environment but also necessitates service-dependent manufacturing system that offers an uninterrupted approach to a number of diverse, complicated, dynamic manufacturing operations management systems at a common work place (hub). This research presents a novel telefacturing based distributed manufacturing environment for recommending the manufacturing services based on the user preferences. The first step in this direction is to deploy the most advanced tools and techniques, that is, Ontology-based Protégé 5.0 software for transforming the huge stored knowledge/information into XML schema of Ontology Language (OWL) documents and Integration of Process Planning and Scheduling (IPPS) for multijobs in a collaborative manufacturing system. Thereafter, we also investigate the possibilities of allocation of skilled workers to the best feasible operations sequence. In this context, a mathematical model is formulated for the considered objectives, that is, minimization of makespan and total training cost of the workers. With an evolutionary algorithm and developed heuristic algorithm, the performance of the proposed manufacturing system has been improved. Finally, to manifest the capability of the proposed approach, an illustrative example from the real-time manufacturing industry is validated for optimal service recommendation.

1. Introduction

In this era of information technology, manufacturing industries are accosting challenges due to globalization, high technology advancement, increased outsourcing, and high consolidation and at the same time an imminent movement (from rural to urban areas) of skilled technical labors has led to a risk (shortage of skilled laborers) to a greater extent. However, in today's scenario, a substantial number of manufacturing units are getting distributed due to shorter product life cycles, customizations, and rapid advancements in information and communication technology where the strongest interconnections between geographically distributed resources (machines, manufacturing lines, plants, and enterprises) can be possible. This highly efficient collaborative working environment has led to a stiffer competition among the globally distributed manufacturing units. Therefore, in order to ensure high competitiveness among them, industries have changed their trend from traditional manufacturing approaches to swiftly design and manufacture products of any quantity yet highly customized [1].

In view of attracting the customers, manufacturing unit worked in a distributed environment by being divided into small subcompanies having a distinctive fundamental business but centralized towards the production of a specific group of products that gives an upper hand to the small and medium scale enterprise (SMEs) to compete in the global economy. On the other hand, manufacturing units even go to the extent of sharing their skills, techniques, and knowledge base to achieve self-accomplishment in the ever changing global market [2]. Therefore, management of manufacturing functions inside the shop floor, that is, process planning and scheduling as well as enhancement of workers skill levels, is of great interest; this has been clearly discussed in the later sections.

Process planning and scheduling are two important functions in any manufacturing system, where process planning specifies which tasks (operations, controls, transports, and stores) to perform and scheduling refers to the allocation of resources in the shop over a planning horizon to manufacture the various tasks of the parts [3]. Obtaining the optimality by managing these two functions often witnesses conflict under traditional approach; that is, the manufacturing functions were carried out in a sequential manner, in which scheduling has been performed after generation of the process plans. This process leads to possible loss of real-time schedules (Bratoukhine et al., 2003; Wada and Okada, 2002; Cheng et al., 2001). In [4] the difficulties in traditional manufacturing approach and the obstacles to improving the productivity and responsiveness of the manufacturing systems have been clearly stated.

To overcome the above-mentioned problems in traditional manufacturing approach in this customer-driven market, integration methods have been proposed to resolve the dilemmas in manufacturing functions. In [5, 6], the fundamental concept of process planning and production scheduling has been introduced. Till date, numerous strategies and methodologies have been developed for enhancing the adaptability of the integration approach on manufacturing systems for acquiring better execution of the framework [7]. As of late, much consideration towards agent/multiagent-based approach has been shown by a number of researches for integrating the manufacturing functions, especially in distributed environment. Li and Chaoyang [8] made a detailed literature review on Integration of Process Planning and Scheduling (IPPS), particularly on agent-based approach and its advantages over distributed manufacturing systems. An N-person noncooperative game-theoretic approach to generate the optimal process plans for multiple jobs in a networked-based manufacturing system has been presented [9]. To develop more effective and efficient solutions of the game, a hybrid adaptive genetic algorithm has been generated. The extension of the above work has been carried over in [10, 11]. In their work, a hybrid-DNA based evolutionary algorithm was developed for acquiring feasible process plans of multiple jobs. At last, their results demonstrated significant improvement over other algorithms and better performance of the system.

Additionally, to compensate the shortage of skilled labors the implementation of different approaches inside the production system to enhance its control is highly desired. One such approach is teleprocessing based manufacturing support system, called telefacturing. We define telemanufacturing as the activity where a firm utilizes services afforded via communication networks and across information superhighways to perform, in real time, operations and processes necessary to the design and production of items (Carl Wolf et al., 1996). Henceforth, to alleviate the above-mentioned issue of nonavailability of skilled workers, the current paper presents a new paradigm in the distributed manufacturing environment, that is, telefacturing which isolates the workforce and the factory, where the enterprise is established in such a way that it can function in areas which are more suited for manufacturing processes with lower tax rates and land values, whilst the workers can perform and reside in areas they wish such as metropolitan and urban areas. In this kind of pattern, workers in distant locations can be able to perform their job remotely by simply controlling robots and remote sensing and other telecommunication devices [1].

However, in such a geographically distributed environment, the most challenging part is the collaboration and coordination among enterprises for mutually exchanging the information [12]. It has been stated that an Ontology may be considered as a mode for interoperating all application software that can share the information during coordination by Panetto et al., 2012. Interoperability is defined as the capability of heterogeneous systems or components to communicate information and to utilize the data that has been exchanged. Though the system or components are heterogeneous, they are interlinked with each other through a network, as our primary intention is to ascertain that all the entities like machines, humans, software agents, and suppliers can reciprocate information and knowledge without any significant loss of data [13]. Owing to this, the necessity of interoperability has led to the following prerequisites; all the data shared by various agents must be systematized in a common form, and it is to be garnered in an Ontology. Approach to this Ontology has to be ensured by using common language, with adaptability to each entity (Daniel et al., 2004).

Motivated by these factors, we have explored the possible issues which may arise in real-time (virtually) implementation of telefacturing approach. In this study, we have concentrated on two aspects: initially, Integration of Process Planning and Scheduling in a proposed approach and, later, predicting the workers skill level and then enhancing their skills to perform multiple tasks from a common place (hub) thereby minimizing the processing time of each worker by assigning optimal appropriate tasks in a hub. In telefacturing, as all the enterprises have to communicate with hubs (a common place for workforce) to synchronize the varied tasks in a system of enterprises, machines, shop floors, suppliers, and interoperability issue may arise. All the jobs among the enterprises and the hubs and vice versa in a telefacturing environment may have diverse control systems, and exchange of information related to business processes, product data, and documents to the hubs has become tedious. Hence, to enhance the interoperability and to solve the communication among the enterprises and hubs it is necessary to develop a common language which is light in weight and easily transferrable. Therefore, we introduced Ontology-based XML (Extensible Mark-up Language) files which can be used as a common language to transfer the diversified information without any interruption and mutual exchange of massive data. In order to support the customer to access such large data, queries were made possible with the Ontology. In the quest to achieve the above-mentioned requirements, a framework has been developed with telefacturing approach and with a case the effectiveness of the model is tested. Moreover, a heuristic has been developed to determine the qualified worker among trained skilled workers for performing the multiple tasks at the hub according to the availability of the job. Consequently, the objectives include minimizing the processing time of each worker by assigning optimal appropriate tasks in a hub and henceforth reducing the workload of each hub.

In Section 2, we have briefly discussed telefacturing approach and developed a framework model based on it. In Section 3, we have used software Protégé 5.0 to develop an Ontology representing knowledge about jobs, machine, process plans, operating time, and so forth, and later XML files are generated. In Section 4, we presented a case study. Section 5 includes experiments with real-time data and explains the algorithm for the proposed method. In Section 5, discussions about results were specified. In Section 6, we have concluded with providing insights about the future work.

2. Collaborative Telefacturing Environment

Telefacturing is a new kind of distributed manufacturing environment where it enables the integrated information/knowledge right from product design to manufacturing with the capability of sharing resources between geographically distributed enterprises. In general, the enterprises are located in rural areas where the cheaper land costs are favorable. In the proposed telefacturing approach, factories could set up hubs in the closer proximity range to the residential areas. This virtual hub will act as an alliance of enterprises that are willing to share their skills, core competencies, and resources so as to respond swiftly to the market demands. In the near future, possessing or operating hubs of these kinds can also emerge as a potential business idea, as these hubs can also turn to be a common workplace for a number of factories. This collaborative service support system is capable of carrying out customer requests through manufacturing information network (application service layer) through virtual agents. It provides enterprises with resources such as capabilities and processes that are highly expensive and too complicated. It makes use of the expertise of various groups situated at various geographical areas and integrates distributed processes into the common manufacturing process.

Additionally, for the workers who do not like to work alone in the home, the hub is a place where the workers can socialize with other fellow employees [1]. According to the proposed concept of telefacturing, we present a framework model, which is illustrated in Figure 1. It is developed by incorporating three-degree networked structure (user/application/simulation).

In this aforementioned approach, the process initiates with customer requests whose work task can be taken care of by network based manufacturing service by means of either Customer User (CU) or Enterprise User (EU). Customer User is basically an organization which gets requests for manufacturing from the customers and to evaluate the tasks (identifying the related enterprises and interaction with servers and customer) with the help of their decision system. However, each customer has their own database and their own supporting system from which the enterprises can be chosen according to the task to be performed so as to provide a profitable solution in a productive manner. Analyzing manufacturing requests from multiple organizations is also possible here, whereas the Enterprise User because of its self-service providing capability (it has the facilities to perform some of the tasks of customer requests) part of the work can be taken care of by EU itself. The remaining operations can be chosen (so as to select potential enterprise for carrying out customer requests) from their available database in the application service layer. In this manner, CU and EU are able to achieve diverse and more challenging production tasks that are unaccomplished by a single enterprise (Zhang et al., 2010). After acquiring required product data and the enterprise's information, a suitable approach to defining the task requirements and its implementation in distributed environment is carried out.

Here, the jobs data can be exchanged and their operations can be performed through limited/higher bandwidth Internet connections, allowing the workers the flexibility to operate the machines at the shop floor either being at home or being at dedicated hubs. Additionally, workers in distant locations can be able to perform their job remotely by simply controlling robots and remote sensing and other telecommunication devices. This proposed approach offers copious advantages such as the dependency on manual workforce, and the consequent errors and injuries can be uprooted by minimizing human exposure to various potential health hazards. Manual laboring errors not only injure people but can also account for momentous economic loss by damaging machinery and tools. As mentioned earlier, it can also repress the operating costs by using the modest land for operation. In addition to that, a teleoperated factory does not have to comply with vital human requirements for lighting, food, and other services. Conjointly this approach allows for lower operating costs. Another noteworthy aid is that telefacturing factories can accommodate a minimal number of engineers and technicians sufficient enough to rectify certain issues like replacement of worn-out parts. In fact, to perform tasks with the above-mentioned virtual environment, it is necessary to have detailed information of the system configurations and its setup, and this will be investigated in our future work. In this work, our main idea is to improve the hubs and enterprises operations and thereby proper integration of both and also to improve the performance of the system. Telefacturing is also environment-friendly in the fact that it preserves the required time and energy for commuting workers from long distance during rush hours, as it gives them the flexibility to work from less populated areas with customized time schedule [1].

3. Ontology Knowledge for Telefacturing Environment

In a telefacturing environment, the manufacturing tasks are related to planning, allocation, ordering, machining of parts, assembling, and so forth. Therefore, it is necessary to e-standardize the resources that can be helpful for sending and exchanging the information. It can be accomplished by

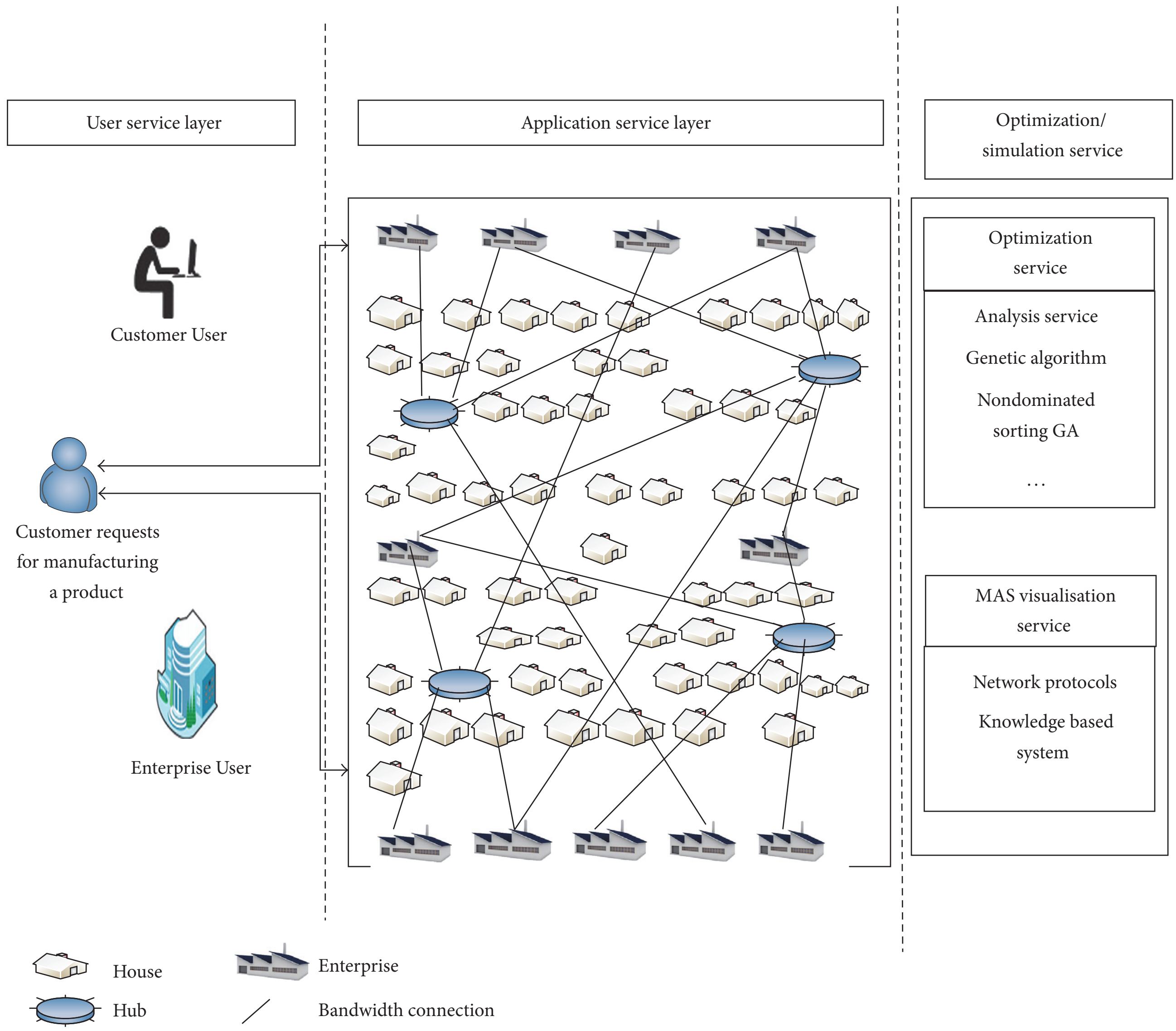


Figure 1: The framework of the proposed telefacturing approach.

using Ontology, and it is defined as the means of knowledge representation. Ontology is able to provide all the definitions of components or systems and their communications in a distributive environment so as to make a common understanding for reciprocation of information [14]. RDF and OWL files generated from an Ontology are World Wide Web consortium (W3C) standard semantic language for publishing and sharing of information online (Jinag et al., 2010).

In order to achieve the above standardization, in this diversified distributed manufacturing system, addressing interoperability is the key. Many authors have decomposed interoperability into several layers. However, European Interoperability Framework (EIF) have categorized interoperability into three layers: technical, semantic, and organizational layers. Technical interoperability deals with issues related to connecting computer system and services. Such issues are data mixing, data exchange, security related, and interlinking services. Meanwhile, semantic interoperability deals with validating that the exact definition of exchanged data is understandable by applications other than originally intended applications. Organizational interoperability deals with business administration and goals and processes to amalgamate organizations that are willing to exchange information. Open standards like XML and Ethernet will help to overcome the issues of technical interoperability [15].

One of the primary needs of this environment is collaborative information management system [16], where it can be able to offer its support to geographically distributed enterprises in completing the task collaboratively in many ways. Figure 2 illustrates database framework for the proposed telefacturing approach where it consists of two modules: enterprise and hub database. An enterprise database is used to save the product resource information, BOM, process plans, engineering drawings, supplier related information, and so forth for maintaining the consistency of enterprise's data and

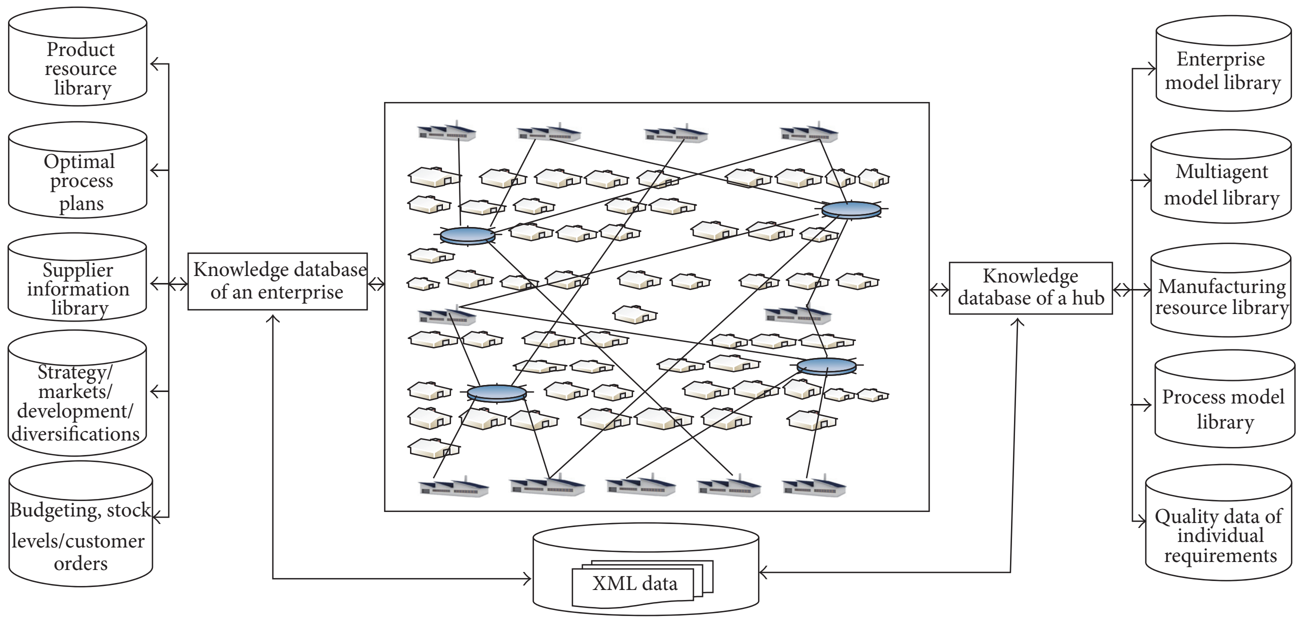


Figure 2: Framework illustrating databases of hub and enterprise.

to reduce data termination. Here, the primary knowledge for enterprise and task evaluation is kept in hub database that offers support to the selection of potential enterprises, valuation of manufacturing capabilities of the enterprises, quality control service, profits, production status, and so on. The above-mentioned approach of storing the information in databases will help to resolve the problem behind exchanging and integration of diversified information structure in the telefacturing environment. In the next sections, the proposed approach implementation over the real case with prototype example is carried.

4. Case Study of Telefacturing Based Manufacturing System

This case study has been taken from a medium scale industry which is located in southern part of India. The region of this industry has evolved into a potential manufacturing base that includes several other enterprises. All these enterprises supplement each other to manufacture a specific range of products. Due to the prevalence of problems such as interoperability, high labor costs, and shortage of skilled laborers, these industries are hardly competitive in the global manufacturing scenario. In order to overcome all the above issues, industries are analyzing the possibility of incorporating collaborative manufacturing techniques. In light of these developments, companies need to find enterprises with similar interests to enhance their manufacturing resources. We have considered a set of jobs submitted by different customers denoted as n. Each job has a number of alternative process plans representing various ways of sequential operations. In other words, a number of machines may perform different operations for alternative process plans. On the other hand, in this proposed manufacturing methodology, alternative machines are located in different geographical areas to perform the required operations on the job. This could be one of the difficult tasks in the present manufacturing approach containing heterogeneous support systems. Due to the flexibility of the proposed method, integration of process planning and scheduling helps us to make an optimal process plan, even though transportation times between machines are vital for process plan and scheduling. The objective of this paper is to provide an approach that can minimize the makespan of multiple jobs and to identify the qualified worker for performing tasks in the hub with a motive to minimize the processing time for each worker, thereby determining the total training cost for each worker. The notations are clearly described in the Notations. Subsequently the mathematical model for the above-mentioned two scenarios is formulated as follows.

4.1. Phase I: Minimizing the Makespan to Complete the Multiple Jobs of Distributed Enterprises

Mathematical model is as follows:

$$\text{Minimization of makespan } Z = \text{Max} \quad C_{jopm}. \tag{1}$$

Subject to Constraints. The first operation in the alternative process plan p of job j is indicated as

$$C_{j1pm} + A\left(1 - X_{jp}\right) \geq pt_{j1pm}, \quad j \in [1, N], \; p \in \left[1, G_j\right], \; m \in [1, K]. \tag{2}$$

The last operation in the alternative process plan p of job j is indicated as

$$C_{jQ_{jp}pm} - A\left(1 - X_{jp}\right) \leq C_{jopm}, \quad j \in [1, N], \; p \in \left[1, G_j\right], \; m \in [1, k]. \tag{3}$$

Different processes for a job expressing different operations that are unable to be processed simultaneously are

$$C_{jopm} - C_{j(0-1)pm_1} + A\left(1 - X_{jp}\right) \geq Pt_{jopm}, \quad j \in [1, N], \; O \in \left[1, Q_{jp}\right], \; p \in \left[1, G_j\right], \; m, m_1 \in [1, K]. \tag{4}$$

Each machine can only process one operation at a time and this can be expressed as a constraint for the machine:

$$C_{jopm-Cqrsk} + A\left(1 - X_q\right) + AY_{jopQrsm} \geq Pt_{jopm}, \quad j, Q \in [1, N], \; r \in \left[1, Q_{jprs}\right], \; O, p, S \in \left[1, G_j, p\right], \; m \in [1, K]. \tag{5}$$

One alternative process plan can be selected for each job:

$$\Sigma_1 X_{jp} = 1, \quad p \in \left[1, G_j\right]. \tag{6}$$

Only one machine should be selected for each operation.

4.2. Phase II: Minimizing Human Processing Time for Hubs Effective Performance

Objective functions are as follows:

$$\text{Min} \quad Z_1 = \sum_{p=1}^{P} \sum_{q=1}^{Q} \sum_{l=1}^{L} C^l_{pq} \theta^l_{pq}. \tag{7}$$

Constraints are as follows:

$$\sum_{q=1}^{q} \phi_{pq} = 1, \quad \forall p, \tag{8}$$

$$\sum_{l=1}^{l} \theta^l_{pq} > 1, \quad \forall p \; \phi_{pq} = 1, \tag{9}$$

$$\sum_{p=1}^{P} \sum_{q=1}^{Q} \theta^l_{pq} = 1, \quad \forall l, \tag{10}$$

$$1 \leq \sum_{p=1}^{P} \phi_{pq} \leq W_q, \quad \forall q, \tag{11}$$

$$1 \leq \sum_{p=1}^{W} G_{pq}, \quad \forall q, \tag{12}$$

$$\sum_{q=1}^{Q} \sum_{l=1}^{U} H_{uql} = 1, \quad \forall q, \tag{13}$$

$$\sum_{u=1}^{U} \sum_{l=1}^{U} H_{uql} = 0, \quad \left(\forall q \sum_{p=1}^{W} G_{pq} = 0\right), \tag{14}$$

$$\sum_{Q=1}^{q} \sum_{L=1}^{U} H_{uql} \leq \sum_{q=1}^{Q} \sum_{L'=1}^{U} H_{(u=1)q'L'}, \quad u = (2, 3, \ldots, U). \tag{15}$$

The aforementioned objectives, that is, minimizing the total cost incurred for training all workers (Z_1), minimization of the sum of squares of deviations from mean of processing times for all workers in each hub (Z_2), and minimization of human processing time for hubs effective performance (Z_3), are given by (7), respectively. Equation (8) ascertains that a worker is allocated for performing of a job at one hub. Hence, the movement of workers among hubs is not preferred. Equation (9) represents that each worker in a hub can perform more than one operation of a product. Literally, it shows that workers in hubs have multiple skills, which is different from that in the original conveyor assembly line. Equation (10) ensures that an operation in a particular hub is only performed by one worker. Work sharing among workers is not taken into consideration. Equation (11) is the reducing worker(s) constraint that the total number of workers in the cell system needs to be smaller than that of the assembly line. Equation (12) is the rule of cell formulation, which ensures that each formatted cell should contain at least one worker. Equation (13) is the assignment rule by which a product batch is only assigned to a cell. Equation (14) is the rule of assigning constraint that means a product must be assigned to a cell in which one worker at least is assigned. Equation (15) is the assignment rule by which product batches must be assigned sequentially.

5. Experimentation and Discussion

In order to prove the effectiveness of concepts, methodology, architecture, and techniques of the proposed telefacturing approach, we have experimented the telefacturing environment for distinct product requests from various customers and available machines in the distributed environment.

5.1. Implementation Based on Ontology. Ontology offers all the information about the resources used in the enterprises like equipment data, human resources, operation task related data, product type data, process time, and so forth. Ontology-based approach enables affiliation of all the information communicated between the systems/components in a collective framework. This unification of all the data helps to overcome the interoperability issue in a heterogeneous environment. With Figure 3 we have shown the used Protégé 5.0 to develop an Ontology representing a domain of 6 distinct product requests from various customers and 8 different machines located geographically.

5.1.1. Generation of XML/RDF Files. The platform for sharing information across the virtual network is crucial to enable various information services to the customers. Data related to the product that is available in enterprise's database often come in particular CAD format, and files are larger in size. Hence it is necessary to translate the data into a web-supported format (XML) to make it available across the entire network. Figure 4 shows that the conversion can be supported by using Protégé 5.0 software. It uses previously stored Ontology data to generate XML files. As mentioned earlier, XML format is the feasible way of transferring data across the network of the heterogeneous system. On the other

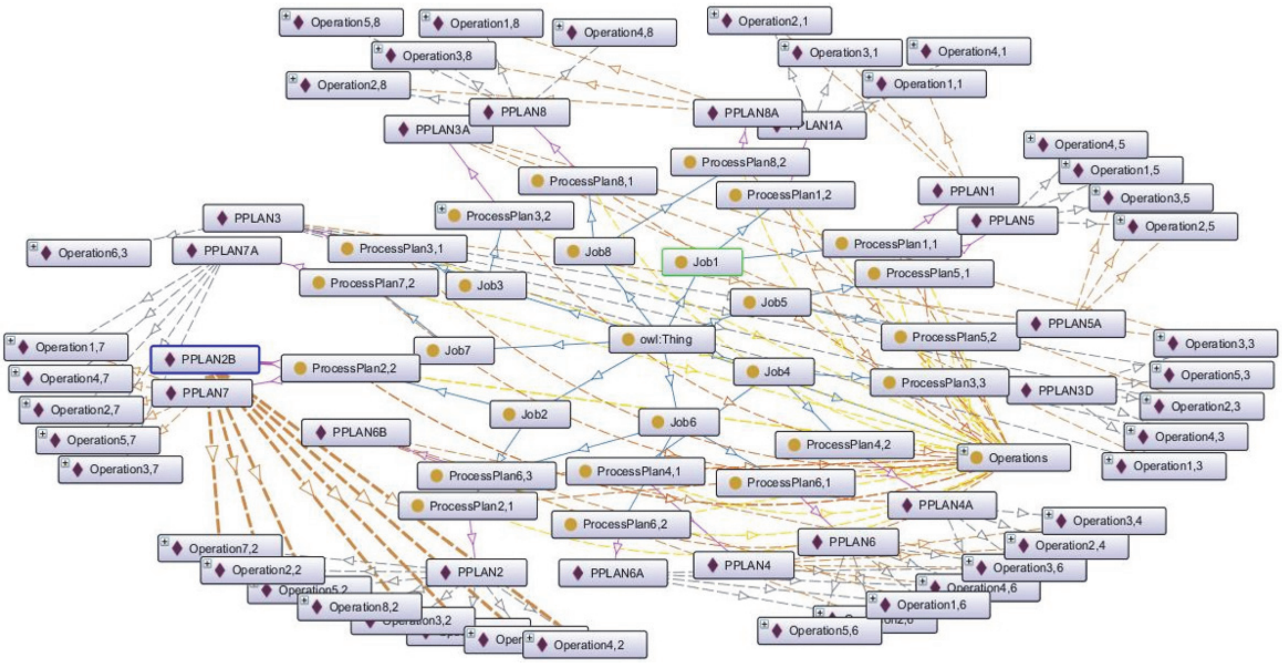


Figure 3: Development of Ontology.

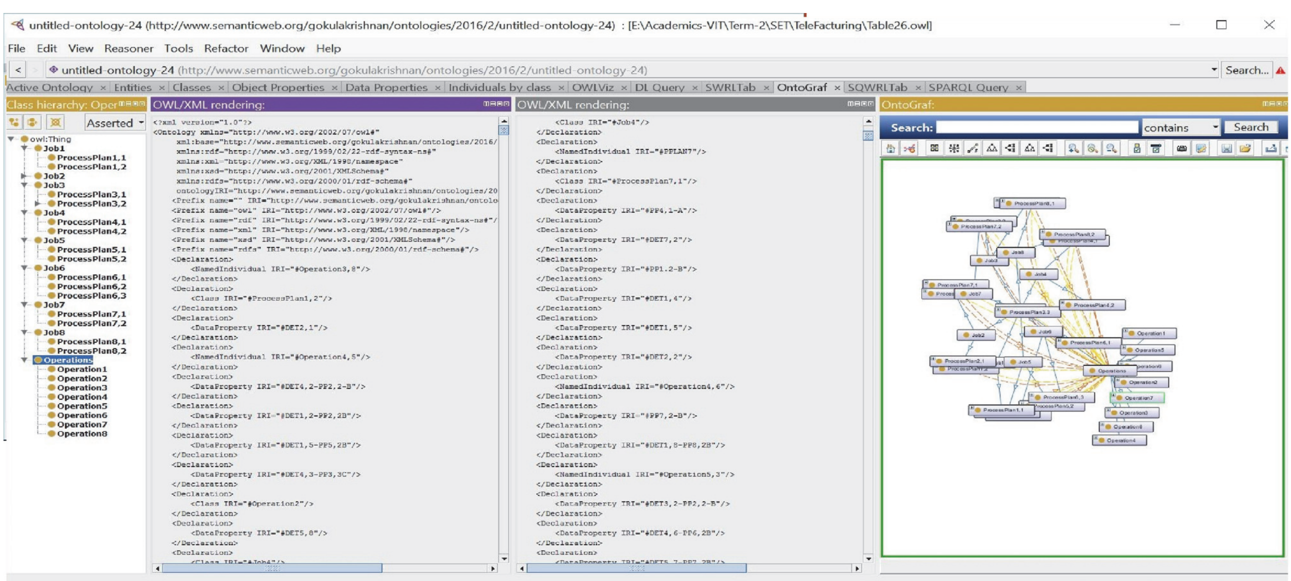


Figure 4: Snapshot of the generated XML file.

hand, another noteworthy aid is that it does not require the installation of any other software for searching and viewing. To assist users in processing their queries, a platform for making queries was developed as shown in Figure 5.

5.2. Minimization of Makespan with Evolutionary Algorithm Based Approach. In this section, the real-time manufacturing scenario as a case and the solution approach for effective solutions are presented. Here, the case study consists of 6 job requests from varied customers and 8 available machines that are assumed to be geographically distributed with the transportation time shown in Tables 1 and 2. In this telefacturing environment, each job has a set of process plans and for each operation a number of geographically distributed machines are available. The data in the curly bracket indicates machine numbers and the data in the square bracket indicates processing time for the particular operation.

In order to obtain good approximate solutions, the most popular, efficient, and widely used genetic algorithm based evolutionary algorithm has been used. The algorithm has

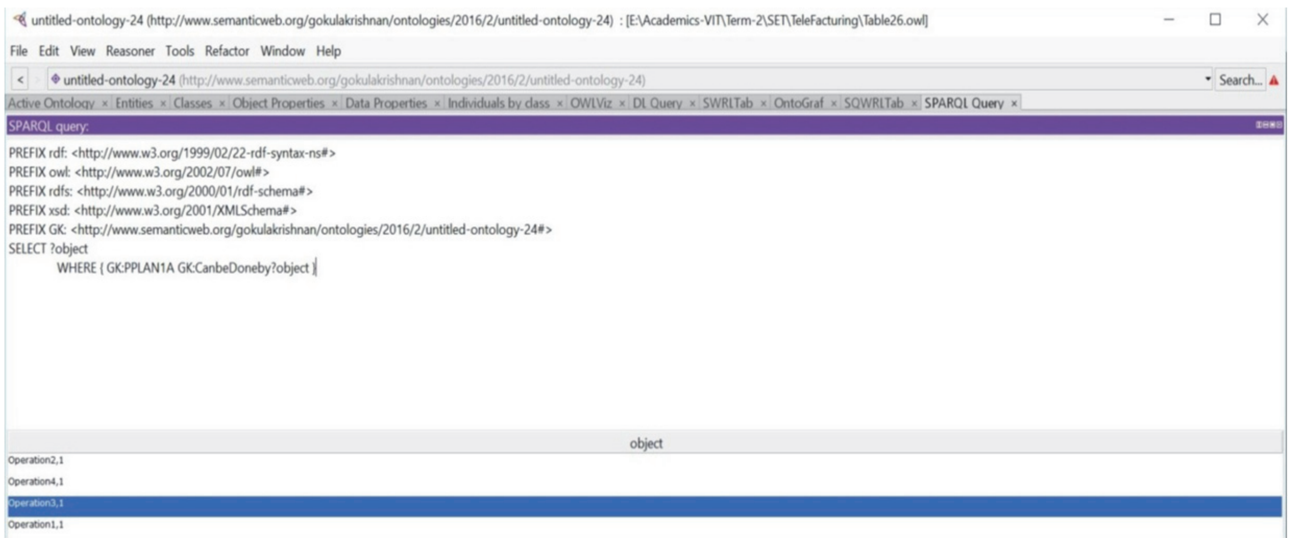


Figure 5: Generation of SPARQL query.

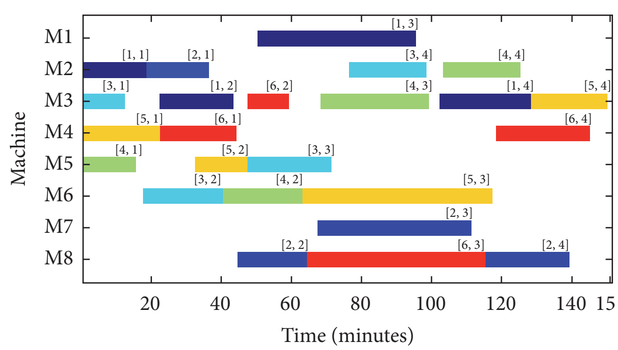


Figure 6: A Gantt chart showing optimal process plan decision for 6 × 8 case.

been coded in MATLAB software, and the problem is tested on Intel® Core™2 Duo CPU T7250 @2.00 GHz, 1.99 GB of RAM. To get a precise conclusion, the problem of this manufacturing approach was solved at an average for 20 simulation results, and the corresponding result was represented as Gantt chart. As shown in Figure 6, it can be understood that average time taken for completion of all the jobs (makespan) is 150 minutes.

5.3. Heuristic Approach to Finding the Total Cost for the Hubs. As mentioned earlier the above-mentioned problem is complicated. Therefore, in order to find our proposed objective, that is, allocating workers to the hub for performing required operations, we have used a heuristic approach as given below in Figure 7.

In Table 3, the average time required for each operation of each job type prior to training has been given. The symbol "/" indicates that there is no operation for corresponding job type. In Table 4, "0" indicates that worker already has required skill for performing that particular operation and the sign of "/" denotes that particular operation is not necessary for the job and hence training is not required. This computational case has been solved using MATLAB programming.

From Table 4, we calculate the total training cost of the worker for each worker. This is shown in Table 5. In Table 6, we have defined the worker-to-hub assignment plan by assigning workers to the respective hubs based on their training costs. In Table 6, number "1" denotes that the allocation exists, and "0" denotes that the allocation does not exist. In Table 7, the difference of total training cost for each worker is illustrated.

Table 8 shows that the number of workers in Hub 1 exceeds 1, as its size is 2. Thus, we have $S_s = \varphi$ and $S_w = \{1, 5, 6\}$. The numbers inside the curl bracket represent Hub 1, Hub 5, and Hub 6, respectively. According to the worker-to-hub allocation plan in Table 6, from step 2 in stage 3, so as to calculate the difference of total training cost, we can remove few workers from Hubs 1, 5, and 6 to Hubs 3, 4, and 2. Hereby, workers were transferred to the hubs that have high workloads on it. Table 8 shows skill levels of each worker before the training was given and it also enlightens where their skills are lacking.

Table 9 is the adjusted worker-to-hub assignment plan which is obtained after optimizing the number of workers in each hub according to the predetermined size. In Table 10, T_c indicates total cost incurred for training all the workers

Table 1: Input data for 6 × 8 problem.

Job	PP	Operations O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8
J_1	$PP_{1,1}$	{1, 2, 7, 8} [6, 5, 5, 4]	{3, 4, 5} [7, 6, 6]	{6} [8]					
	$PP_{1,2}$	{1, 3} [4, 5]	{2, 4} [4, 5]	{3, 5} [5, 6]	{4, 5, 6, 7, 8} [5, 5, 4, 5, 9]				
J_2	$PP_{2,1}$	{2, 7} [4, 8]	{1, 3, 8} [2, 3, 8]	{2, 4, 6} [4, 3, 5]	{3, 5} [2, 4]	{2, 4} [3, 4]	{4, 6} [3, 5]	{1, 3, 5} [5, 5, 8]	{4} [2]
	$PP_{2,2}$	{1, 3, 5} [1, 5, 7]	{4, 8} [5, 4]	{4, 6} [1, 6]	{4, 7, 8} [4, 4, 7]	{4, 6} [1, 2]	{1, 6, 8} [5, 6, 4]	{4} [4]	
J_3	$PP_{3,1}$	{2, 3} [5, 6]	{1, 4, 7, 8} [6, 5, 4, 7]	{2, 5, 7} [5, 6, 5]	{3, 6} [6, 5]	{1, 6} [6, 6]	{5} [4]		
	$PP_{3,2}$	{1, 8} [7, 8]	{3, 4, 7} [8, 8, 11]	{5, 8} [9, 8]					
	$PP_{3,3}$	{2, 3, 8} [7, 6, 8]	{4, 8} [7, 7]	{3, 5, 7} [7, 8, 7]	{4, 6} [7, 8]	{1, 2} [1, 4]			
J_4	$PP_{4,1}$	{1, 2, 7, 8} [7, 8, 7, 8]	{3, 4} [7, 6]	{6} [9]	{1, 7} [5, 7]				
	$PP_{4,2}$	{1, 3, 5} [4, 3, 7]	{2, 8} [4, 4]	{3, 4, 6, 7} [4, 5, 6, 7]	{5, 6, 8} [3, 5, 5]				
J_5	$PP_{5,1}$	{1} [3]	{2, 4} [4, 4]	{3, 8} [4, 4]	{5, 6, 8} [3, 3, 3]				
	$PP_{5,2}$	{2, 4, 7, 8} [5, 6, 5, 5]	{5} [7]	{3, 6} [9, 8]					
J_6	$PP_{6,1}$	{1, 2} [3, 4]	{3, 4} [4, 3]	{2, 5, 7, 8} [5, 3, 5, 4]	{3} [4]	{4, 5} [4, 6]	{3, 6} [5, 4]		
	$PP_{6,2}$	{1, 3} [4, 4]	{2, 3} [5, 6]	{2, 4, 7, 8} [6, 7, 5, 6]	{6} [7]				
	$PP_{6,3}$	{1, 2, 3} [3, 5, 6]	{4, 5} [7, 8]	{3, 6} [9, 8]					

Table 2: Transportation time for 6 × 8 problem.

Machine	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8
M_1	0	3	7	10	3	5	8	12
M_2	3	0	4	7	5	3	5	8
M_3	7	4	0	3	8	5	3	5
M_4	10	7	3	0	10	8	5	3
M_5	3	5	8	10	0	3	7	10
M_6	5	3	5	8	3	0	4	7
M_7	8	5	3	5	7	4	0	3
M_8	12	8	5	3	10	7	3	0

Table 3: The average time required for each operation of each job type before the training has been given to the worker.

Jobs	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	Operation 8
Job 1	81	50	95	93	87	67	79	74
Job 2	/	73	/	78	69	95	/	93
Job 3	84	82	63	/	69	/	/	/
Job 4	86	/	70	66	71	54	89	58
Job 5	92	88	88	63	50	63	56	79
Job 6	82	63	86	95	/	67	61	80

Table 4: The cost incurred for training each worker for each operation of each job type.

Job	Worker	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	Operation 8
Job 1	1	0	30	56	/	20	62	/	36
	2	62	0	158	/	109	92	/	54
	3	53	1	0	/	50	49	/	90
	4	102	145	151	/	62	87	/	96
	5	80	90	43	/	0	132	/	77
	6	15	67	67	/	122	0	/	118
	7	96	146	32	/	167	135	/	55
	8	49	10	101	/	169	123	/	0
	9	147	136	23	/	83	104	/	132
	10	61	81	31	/	140	161	/	105
Job 2	1	0	11	105	9	70	/	176	84
	2	48	0	179	90	106	/	6	122
	3	63	167	0	64	146	/	68	67
	4	110	39	23	0	123	/	133	8
	5	130	109	62	55	0	/	87	136
	6	86	60	60	45	86	/	78	46
	7	103	176	73	83	139	/	0	175
	8	91	33	18	130	167	/	76	0
	9	60	64	56	12	55	/	85	50
	10	55	153	120	2	13	/	10	21
Job 3	1	0	/	95	71	53	/	134	141
	2	55	/	94	125	107	/	79	60
	3	86	/	0	38	52	/	9	73
	4	66	/	138	0	65	/	72	110
	5	82	/	89	113	0	/	40	80
	6	167	/	61	80	71	/	101	106
	7	65	/	1	85	52	/	0	179

Table 4: Continued.

Job	Worker	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	Operation 8
	8	128	/	131	90	31	/	60	0
	9	73	/	2	6	104	/	101	137
	10	131	/	169	12	31	/	119	21
Job 4	1	0	132	117	/	14	133	23	/
	2	49	0	94	/	19	163	71	/
	3	112	173	0	/	161	87	114	/
	4	154	115	77	/	8	131	7	/
	5	97	113	174	/	0	78	163	/
	6	5	119	117	/	100	0	45	/
	7	173	40	118	/	12	146	0	/
	8	43	178	19	/	137	75	63	/
	9	3	164	164	/	43	73	162	/
	10	55	58	46	/	18	109	40	/
Job 5	1	0	/	4	6	11	/	2	112
	2	120	/	26	160	150	/	126	64
	3	5	/	0	104	35	/	121	130
	4	107	/	59	0	5	/	76	77
	5	139	/	177	157	0	/	127	29
	6	61	/	48	105	18	/	112	154
	7	5	/	17	63	91	/	0	72
	8	80	/	123	111	104	/	21	0
	9	81	/	25	177	84	/	128	57
	10	129	/	20	166	63	/	26	33
Job 6	1	0	130	74	/	131	80	/	129
	2	136	0	127	/	5	74	/	126
	3	148	99	0	/	116	9	/	58
	4	15	72	62	/	131	165	/	4
	5	105	68	116	/	0	30	/	44
	6	43	163	112	/	92	0	/	5
	7	5	2	23	/	161	102	/	159
	8	152	30	26	/	140	106	/	0
	9	141	133	128	/	167	18	/	141
	10	21	61	146	/	57	145	/	29

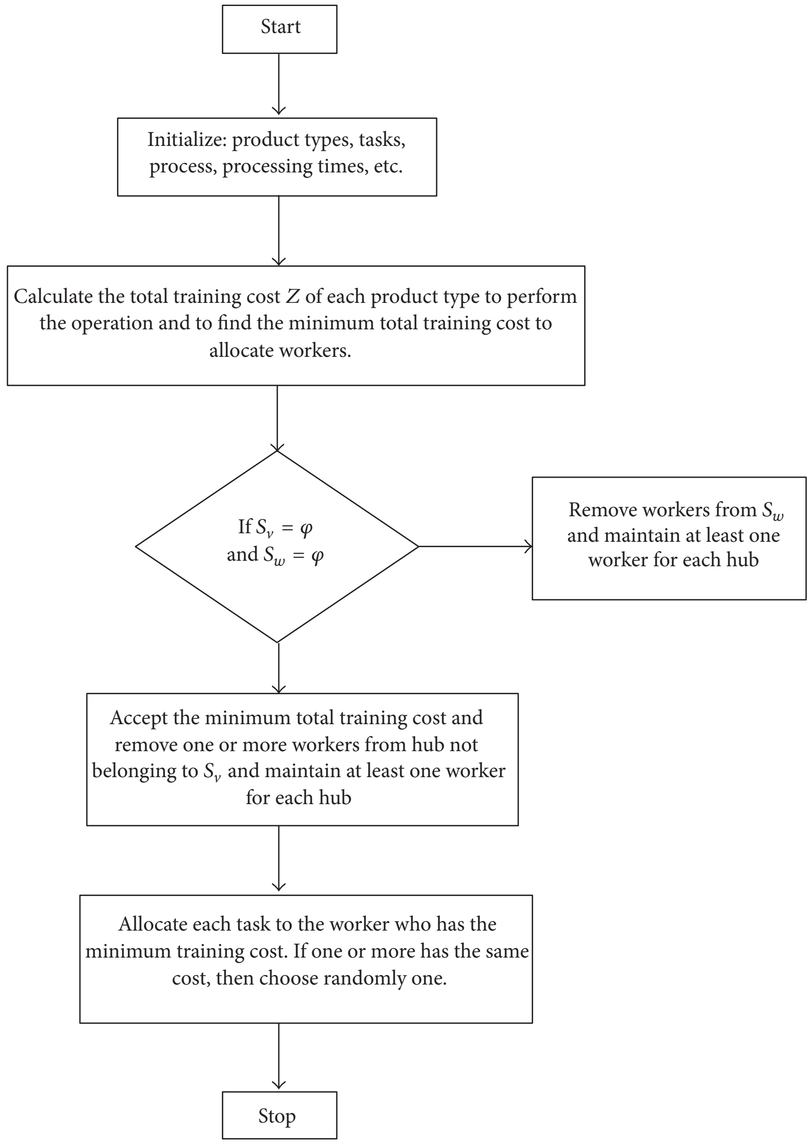


Figure 7: Flowchart of a heuristic approach for assigning jobs to workers.

Table 5: The total cost incurred for each worker on training each job type.

Worker	Job 1 (Hub 1)	Job 2 (Hub 2)	Job 3 (Hub 3)	Job 4 (Hub 4)	Job 5 (Hub 5)	Job 6 (Hub 6)
1	434	497	702	528	233	719
2	562	606	734	668	824	615
3	374	729	344	896	545	639
4	785	553	575	675	391	688
5	537	685	607	716	825	496
6	504	605	713	551	550	647
7	873	801	443	539	341	539
8	684	575	569	773	608	543
9	724	450	501	671	646	742
10	604	374	629	367	487	519

Table 6: The worker-to-hub assignment plan.

Worker	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6
1	0	0	0	0	1	0
2	1	0	0	0	0	0
3	0	0	1	0	0	0
4	0	0	0	0	1	0
5	0	0	0	0	0	1
6	1	0	0	0	0	0
7	0	0	0	0	1	0
8	0	0	0	0	0	1
9	0	1	0	0	0	0
10	0	0	0	1	0	0

Table 7: The difference of total training cost for worker i.

Worker	Hub 3	Hub 4	Hub 2
1	469	295	264
2	172	106	44
4	184	284	162
5	111	220	189
6	209	47	101
7	102	198	460
8	26	7	32

in the particular hub, and Dj represents the sum of squares of deviations from the mean of operating times among the workers in the respective hubs. After completion of training, there is a gradual decline in operating time of each worker when compared to the period workers were trained.

6. Conclusions and Future Work

In this paper, we have proposed a distributed manufacturing based telefacturing approach for better collaboration and coordination of enterprises which are geographically distributed and for the proper allocation of hubs (Common work places) for the workers who are capable of performing multiple jobs in a single work place. In order to achieve this and to enhance the interoperability, this research work is carried out in two phases. Firstly, by using Protégé software, Ontology-based knowledge was created where the meaningful information is sent across the platforms in an effective manner. In addition, this tool has the capability to transform stored Ontology data into XML/RDF files. The generated XML files enable the possibility of sharing information within the heterogeneous network system without any conflicts. With this transferred information, the Integration of Process Planning and Scheduling has been performed by minimizing the makespan as one of the objectives for effective and efficient manufacturing system. Moreover, through queries, a platform for accessing large database in real time was developed. Secondly, in the proposed environment there is flexibility to work for multiple operations in a single work place, and this can be supported with the help of multiskilled workers. Therefore, prior to working in the actual environment workers are given training that enhances their capability into semiskilled to multiskilled workers. It is necessary to validate the proposed approach; thus a real case with an illustrative example is taken, and it has been applied in an actual manufacturing environment. Here, minimization of the processing time of the workers thereby achieving total cost reduction in the hub is considered as our second objective. As the problem is complex in nature, we have used an evolutionary algorithm based approach and also developed a heuristic algorithm to find the best possible results for the above-mentioned objectives. Finally, the results indicate the effectiveness of the proposed approach on the considered manufacturing system and also readiness to implement the hubs in the near future. In future, this approach can be implemented in geographically located small and medium scale enterprises and also the possibility of creating more hubs can be investigated. In addition, one can use mobile agent-based approach to solve this approach more effectively.

Notations

N: Total number of jobs
K: Total number of machines
G_j: The total number of alternative process plans of job j
U_{jop}: The oth operation in the pth alternative process plan of job j
Q_{jp}: The number of operations in the pth alternative process plan of the job j
Tj: Makespan of the jth job from the set of possible process plans
Prt_{jopm}: The processing time of the operation $Ujop$ on machine m
Trt: Transportation time
M: Any machine
V: The maximal number of generations
W: Number of generations for job scheduling game
$\mathrm{st}(j, o, p, m_1)$: Starting time of operation jth job and pth process plan and oth operation on machine 1 (one of the machines on which oth operation of pth process plan of jth job is done)

Table 8: The data of workers' level of skill before training the workers (β_{ni}).

Workers	Job types					
	1	2	3	4	5	6
1	5	6	7	10	9	8
2	5	9	5	5	8	5
3	9	6	9	6	5	10
4	6	8	8	9	5	10
5	5	6	9	6	7	7
6	10	5	10	7	6	5
7	10	9	10	10	9	8
8	6	5	7	10	6	5
9	9	10	6	6	5	8
10	10	7	7	8	6	9

Table 9: The adjusted worker-to-hub allocation plan.

Worker	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6
1	0	0	0	0	1	0
2	1	0	0	0	0	0
3	0	0	1	0	0	0
4	0	1	0	0	0	0
5	0	0	0	0	0	1
6	1	0	0	0	0	0
7	0	0	0	0	1	0
8	0	0	0	0	0	1
9	0	1	0	0	0	0
10	0	0	0	1	0	0

Table 10: All feasible operation-to-worker training plans.

	Worker	Op-1	Op-2	Op-3	Op-4	Op-5	Op-6	Op-7	Op-8	Op-9	Op-10	Total cost
Hub 1	2	0	1	0	0	1	0	0	1	1	0	326
	6	1	0	1	0	0	1	0	0	0	1	
Hub 2	4	0	1	1	1	0	0	0	1	0	0	338
	9	1	0	0	0	1	0	1	0	0	1	
Hub 3	3	1	0	1	1	1	0	1	1	1	1	344
Hub 4	10	1	1	1	0	1	1	1	0	1	1	367
Hub 5	1	1	0	1	1	1	0	0	0	0	1	109
	7	0	0	0	0	0	0	1	1	1	0	
Hub 6	5	1	0	0	0	1	1	0	0	0	0	280
	8	0	1	1	0	0	0	0	1	1	1	

$\text{trt}(j, p, m_1, m_2)$: Transporting time for jth job and pth process plan from machine 1 to machine 2

$\text{wt}(j, o, p, m)$: Waiting time of operation jth job and pth process plan and oth operation on machine

$f(j, t)$: Fitness function for each individual in the population

A: A very large positive number

C_j: The completion time of job j

C_{jopm}: The earliest completion time of operation U_{jop} on machine m

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] B. Khoshnevis, "Telefacturing—a Paradigm for the 21st century," *Industrial Engineering*, vol. 47, no. 11, 2015.

[2] P. Leitão and F. Restivo, "A holonic approach to dynamic manufacturing scheduling," *Robotics and Computer-Integrated Manufacturing*, vol. 24, no. 5, pp. 625–634, 2008.

[3] J. Zhang, L. Gao, F. T. S. Chan, and P. Li, "A holonic architecture of the concurrent integrated process planning system," *Journal of Materials Processing Technology*, vol. 139, no. 1–3, pp. 267–272, 2003.

[4] C. Saygin and S. E. Kilic, "Integrating flexible process plans with scheduling in flexible manufacturing systems," *International Journal of Advanced Manufacturing Technology*, vol. 15, no. 4, pp. 268–280, 1999.

[5] G. Chryssolouris, S. Chan, and N. P. Suh, "An integrated approach to process planning and scheduling," *CIRP Annals—Manufacturing Technology*, vol. 34, no. 1, pp. 413–417, 1985.

[6] G. Chryssolouris, S. Chan, and W. Cobb, "Decision making on the factory floor: an integrated approach to process planning and scheduling," *Robotics and Computer Integrated Manufacturing*, vol. 1, no. 3-4, pp. 315–319, 1984.

[7] V. K. Manupati, S. Deo, N. Cheikhrouhou, and M. K. Tiwari, "Optimal process plan selection in networked based manufacturing using game-theoretic approach," *International Journal of Production Research*, vol. 50, no. 18, pp. 5239–5258, 2012.

[8] X. Li, C. Zhang, L. Gao, W. Li, and X. Shao, "An agent-based approach for integrated process planning and scheduling," *Expert Systems with Applications*, vol. 37, no. 2, pp. 1256–1264, 2010.

[9] G. Zhou, Z. Xiao, P. Jiang, and G. Q. Huang, "A game-theoretic approach to generating optimal process plans of multiple jobs in networked manufacturing," *International Journal of Computer Integrated Manufacturing*, vol. 23, no. 12, pp. 1118–1132, 2010.

[10] V. K. Manupati, J. J. Thakkar, K. Y. Wong, and M. K. Tiwari, "Near optimal process plan selection for multiple jobs in networked based manufacturing using multi-objective evolutionary algorithms," *Computers and Industrial Engineering*, vol. 66, no. 1, pp. 63–76, 2013.

[11] V. K. Manupati, G. D. Putnik, M. K. Tiwari, P. Ávila, and M. M. Cruz-Cunha, "Integration of process planning and scheduling using mobile-agent based approach in a networked manufacturing environment," *Computers and Industrial Engineering*, vol. 94, pp. 63–73, 2016.

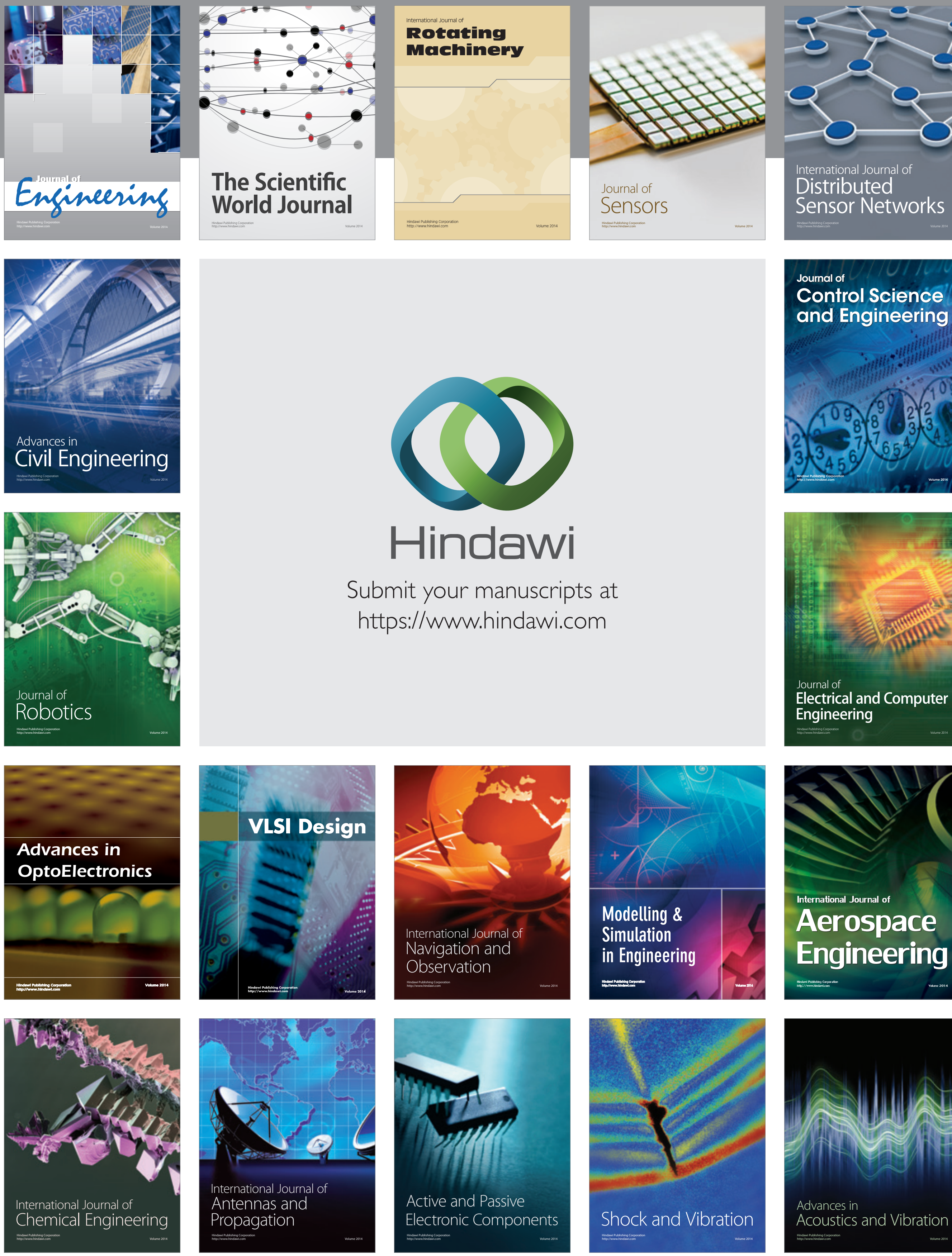
[12] C. Agostinho and R. Jardim-Goncalves, "Sustaining interoperability of networked liquid-sensing enterprises: a complex systems perspective," *Annual Reviews in Control*, vol. 39, pp. 128–143, 2015.

[13] R. Jardim-Goncalves, C. Agostinho, J. Sarraipa, A. Griloc, and J. P. Mendonca, "Reference framework for enhanced interoperable collaborative networks in industrial organisations," *International Journal of Computer Integrated Manufacturing*, vol. 26, no. 1-2, pp. 166–182, 2013.

[14] H. K. Lin and J. A. Harding, "A manufacturing system engineering ontology model on the semantic web for inter-enterprise collaboration," *Computers in Industry*, vol. 58, no. 5, pp. 428–437, 2007.

[15] D. Diep, C. Alexakos, and T. Wagner, "An ontology-based interoperability framework for distributed manufacturing control," in *Proceedings of the 12th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA '07)*, pp. 855–862, IEEE, Patras, Greece, September 2007.

[16] L. Tian, J. Chen, Q. Wang, W. Hao, and B. Tong, "CoDesign Space: a collaborative design support system in a network environment," *International Journal of Computer Integrated Manufacturing*, vol. 20, no. 2-3, pp. 265–279, 2007.



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