# A Hybrid Framework for Supporting Scheduling in Extended Manufacturing Environments

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***Abstract* — In the current marketplace, enterprises face enormous competitive pressures. Global competition for customers that demand customized products with shorter due dates and the advancement in information technologies, marked the introduction of the Extended Enterprise. In these EMEs (Extended Manufacturing Environments), lean, virtual, networked and distributed enterprises, form MO (Meta-Organizations), which collaborate to respond to the dynamic marketplace. MO members share resources, customers and information. In this paper we present a hybrid framework based on a DKBS (Distributed Knowledge Base System), which includes information about scheduling methods for collaborative enterprises sharing their problems. A core component of this system includes an inference engine as well as two indexes, to help in the classification of the usefulness of the information about the problems and solving methods. A more structured approach for expanding the MO concept is presented, with the HO (Hyper-Organization). The manner in which MO-DSS can communicate, cooperate and share information, in the context of the HO is also detailed.**

***Keywords - Extended Manufacturing Enviroment; Meta-Organization; Hyper-Organization; Decision Support System; Distributed Knowledge Base System.***

## I. INTRODUCTION

Recently, new production paradigms, such as the extended enterprise, as well as the agile, virtual and networked manufacturing, have appeared in response to the increasingly dynamic conditions of the marketplace. These new concepts prompt geographically dispersed manufacturers to build alliances with their suppliers and customers, in order to work more closely with them. They need to work to build manufacturing networks, which bridge large sections of the supply chain. In the context distributed scheduling, problems are complex optimization problems, which have increased popularity over the years. This is partly attributed to the fact that multi-site production and networked manufacturing environments are increasing [1].

In the actual convoluted marketplace, the scheduling process has become much more complex. Scheduling can be described as the decision making process, that add the final detail to released orders. It can be divided into two phases: allocation, which divides production between the available resources and sequencing, which determines the execution order. Both phases are related and cannot be dissociated.

In the EMEs, schedule boundaries are hard to define. Networked enterprises have to collaborate and coordinate the operations scheduling. Research has focused on the development of tools that can assist MO on the operations scheduling. Developments in information technologies and Artificial Intelligence (AI) have allowed the development of distributed scheduling support systems that learn and self-adapt to the ever-changing manufacturing environment. The HO concept presents a more structural approach to the Ubiquitous Manufacturing System (UBS) network, which is characterized by a tree like hierarchical decision structure, in the administration of the network distributed resources. Each MO enterprise can cooperate with members of other MO, but all communication is done over a central decision-hub to avoid network clutter. Solicitations are treated at the MO decision-hub and will only travel up the hierarchical decision-hubs if no viable solution can be presented at the current hierarchical level. HO structure is similar to the Internet DNS (Domain Name System) hierarchical structure.

In this paper, we propose the framework for the MO-DSS (Decision Support System) that will assist the scheduling process within this distributed production environment. Moreover, the DKBS based MO-DSS will learn from the feedback, and propose scheduling methods that achieved the best result in past solicitations. The remaining sections of this paper are organized as follows: Section II defines the scheduling problem in the context of the EME. Section III presents a literature review about manufacturing scheduling approaches for networked enterprises. Section IV presents the framework for the MO-DSS, and the interactions between several MO-DSS in the context of the HO. Section V demonstrates the MO-DSS capabilities in a problem that required production in two collaborative factories. Finally, the paper presents some conclusions.

## II. EXTENDED MANUFACTURING ENVIRONMENTS

Extended Manufacturing Environments (EMEs) can be defined as complex manufacturing environments, where complexity may arise due to the geographical distribution of the manufacturing resources and/or their autonomy, besides the underlying complexity itself.

In a distributed manufacturing environment, an enterprise consists of equipment that produces the product and is supported by supply chains of materials manufacturers and services [2]. EMEs are increasing nowadays as well as the underlying Agile/ Virtual Enterprise (A/VE) environments, characterized by a dynamically reconfigurable and global networked organization, a networked enterprise, or a network of enterprises, sharing information and/or knowledge, skills, core competencies, market and other resources and processes, configured as a temporary alliance to meet a fast changing market window of opportunity, presenting as main characteristics agility, virtuality, distributivity and integrability [2]. Moreover, an A/VE organizational model can be defined in the context of Ubiquitous Manufacturing System (UMS) network, which is characterized by a market of resources intensively spread through out a globally distributed market [2].

## III. Manufacturing Scheduling Approaches

In most real-world environments, scheduling is a complex process that requires the consideration of an extended set of variables and parameters, which can and be organized and clarified by using ontology for its representation [3]. Generally, an on-going reactive process occurs, where the presence of a variety of unexpected disruptions constantly force reconsideration and revision of pre-established production schedules.

Approaches that solve the static scheduling problem are often impracticable in the real production environments and near-optimal schedules often become obsolete as soon as they are released to the shop floor. Dynamic scheduling models may address a significant number of real-time events and their effects in various manufacturing systems. Real-time events usually occur in such complex manufacturing environments and may be resource or job related [4-6]. Dynamic scheduling for solving real-time events based problems have been defined under three main categories [4]: completely reactive scheduling, predictive–reactive scheduling, and robust pro-active scheduling. Moreover, dynamic scheduling has been solved using different kind of approaches and techniques, such as [7-10]: heuristics, meta-heuristics, knowledge-based systems, fuzzy logic, neural networks, Petri nets, hybrid techniques, simulation, web-based decision support systems, and multi-agent systems and other approaches.

In [11], some interesting features of heuristics and meta-heuristics for solving manufacturing scheduling problems are presented. According to the authors, among several advantages pointed out to these heuristic approaches is the possibility of repeating a huge number of experiences, as this feature facilitates a comparative analysis of the results obtained for different program executions for an given problem. Furthermore, the parameters that control the algorithms are also easily implemented and manipulated in order to more closely being adapted for satisfying more specific requirements of problems arising on different and often quite complex manufacturing scenarios.

An interesting approach to the coordinating mechanism in real world scheduling problems, which uses Genetic Algorithms, is presented in [12] and an approach to resource-oriented scheduling is presented in [13].

Web-based systems are also being used to support the manufacturing scheduling problems [14-16]. In [14] such a system is presented. The system is based on a distributed knowledge base available on computers or peers, integrating a P2P network. Thus, according to the authors, a very large knowledge base, of Industrial Operations Management (IOM) algorithms and mechanisms are made available to users by means of an adequate P2P platform. Moreover, in such a network each peer may supply and receive IOM services. This application explores the use of problems solving algorithms made globally available through the proposed web-based system, which can be easily accessible through the Internet. The authors also refer that in their proposed system, problem solutions can be presented in several formats, namely through Gantt charts, XML files or PDF files. The use of each format depends on what the results are used for, i.e. for simple decision making or for integration with other data for either further problem solving or reporting. In [16] the authors propose a Web Platform for solving MS problems occurring either in intra or inter cellular manufacturing scenarios. Scheduling methods are local or remotely available through web services and can be, easily and continuously, incorporated in a distributed repository, which integrates XML-based components, belonging to a range of business partners, integrating a Virtual Enterprise. The scheduling data modelling and the data transferring processes are based on XML and decision-making is carried out through an interactive approach relying on fuzzy sets.

Several authors proposed approaches using Software Agents to model EMEs, namely distributed manufacturing environments (DME) [17-19]. A DME can be modelled through a set of intelligent software agents that interact in planning and executing processes, each one being assigned to different tasks and responsibilities. A system built upon a set of multiple agents that interact this way is a multi-agent system (MAS). A multi-agent system is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge [20].

Research has focused on the development of tools that can better assist organizations in their convoluted operations scheduling. Advancements in information system technologies and AI (Artificial Intelligence) have permitted the development of distributed scheduling support systems that learn and self-adapt to the ever-changing manufacturing environment. There is also a set of interesting papers based on the application of distinct AI approaches [21-23]. In [21] the author presents an interesting approach about the use of self-organization methods for Scheduling in Agile Manufacturing, which intends to enhance the operations of a scheduling system, by integrating scheduling system configuration and optimization into a single autonomic process requiring minimal manual intervention to increase productivity and effectiveness, while minimizing complexity for users, and conceptualizing real manufacturing systems.

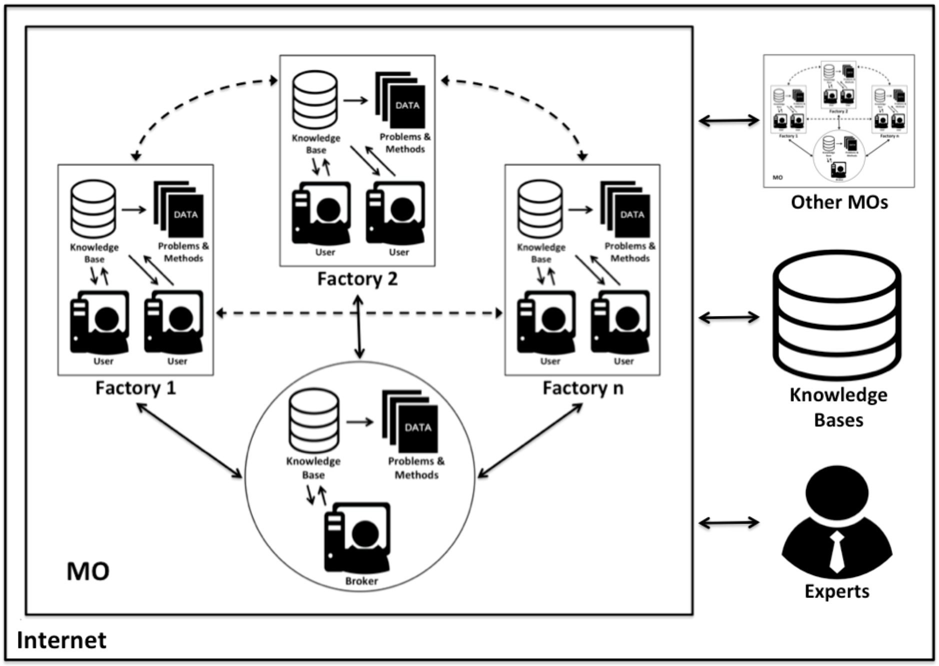


**Figure 1.** DSS Architecture Based on a P2P Network

In [24], the authors detailed the interactions between the manual, human based and automatic, machine assisted, scheduling. Once those interactions have been formalized, the authors, present the framework of a DSS (Decision Support System). In [25] and [26], the frameworks for two Web-Based Dynamic and Distributed Scheduling Systems are presented. Both frameworks are built with Java to insure the platform's independent nature. Several authors have use MAS (Multi-Agent Systems) approaches. The author in [27] proposes the framework for a collaborative production planning and scheduling system; the author in [28] proposes the framework for MAS scheduling system with the concept of the DSB (Dual-Service-Bus); in [29] the authors present the framework for the DIMS (Dynamically Integrated Manufacturing Systems) based on MAS. In [30] a MSA (Multi-Scenario Analysis) model for distributed collaborative decision-making based on the EXASL scrip. Moreover, the authors propose a framework of distributed information bases with centralized analysis process.

In [31], the authors propose a generic library for PSMs (Problem Solving Methods) based on the TMDA (Task-Method-Domain-Application) framework. In their work, the authors define their task-centric ontology on the OCML (Operational Control Modeling Language), which allows the quick construction of new scheduling approaches.

## IV. DSS FRAMEWORK

In the context of collaborative production environments the proposed DSS (Decision Support System) framework, Figure 1, will assist the scheduling process in this distributed production environment. Scheduling methods can be transferred between the business members of this MO (Meta-Organization), which includes the DKBS (Distributed Knowledge Base System) that assists in the decentralized decision process. Each member of the MO will have access to the distributed knowledge base, namely to XML files about scheduling information, either over the BS (Brokerage Service) or through P2P (Peer-to-Peer) connections to other members. P2P connections are also initialized so members of the MO can communicate and coordinate distributed production. Reports about the performance of each method should allow the DKBS to learn which methods achieved better results, and improve its decision support capabilities.

Whenever a client places an order, it is the BS who distributes production between the members of the MO. Once production is distributed between the various members, the BS will initialize P2P connections between members involved and support the scheduling process. Furthermore, each MO member will be able to search in its own knowledge base for satisfactory methods to address the schedule problem at hand. The BS is involved if the member does not know a satisfactory method to schedule operations. The Broker will search its own knowledge base, for satisfactory methods, if none is found, the BS will search among all the other MO members, for one that faced the same problem before and initiate a P2P connection between those two factories. Once the problem is addressed the factories involved need to report back to the BS the performance of the implemented scheduling methods.

In terms of the saved information, each factory should store in their knowledge base the methods implemented in previous problems. The BS will store the problems faced by each of the factories as well as the most requested scheduling methods and other relevant information for the decision support process. Since the storage space is limited, a mechanism that allows the BS and the rest of the MO members, to release methods from their knowledge bases is needed. Methods that are rarely used and methods that were not reliable in the past are candidates for release, in order to free space for new schedule methods and information. For this purpose two indexes are considered, the *iu* (Utility Index) and the *ip* (Performance Index). Each method should have an *iu* and *ip* associated with it, the *iu* representing how many times the method is called upon. Each method *iu* will increase whenever the method is implemented. Lower *iu* method will be deleted to free space for new methods. The *ip* represents the performance index associated with each task and is calculated based on the statistical analyses of the satisfaction of the method solution. The DSS should update the *ip* and *iu* values after each scheduling problem, and indicate methods with higher *ip* values. Moreover, methods that reached a lower threshold in performance should be discarded from the knowledge bases.

When not solicited the BS should anticipate further scheduling problems. Moreover, the MO's knowledge base can be incremented with the collaboration with other MOs, independent experts and open knowledge bases. In this HO (Hyper-Organization), the MO will search among their partners for new scheduling methods to be introduced into its knowledge base. The MO should report to the provider with the performance of the method whenever it is used. This will allow the HO's members to have a better overview about their methods performance and update their *iu* and *ip*.

## V. CASE STUDY

The illustrative example will demonstrate the MO-DSS capabilities in the makespan minimization problem that required production in two factories. In the example there are 10 tasks that need execution in two parallel-machines based factories. The problem can be divided into $P_m||C_{max}$ in the first factory and $P_m|r_j|C_{max}$ in the second. Furthermore, tasks take 1 *t.u.* to be transported between the factories and should do so in batches of 4. Table I shows the problem execution times. The problem can be described as a multi-site non-proportional, flexible-flow shop makespan minimization problem, $FF_c||C_{max}$. Production flows between factories, each responsible for one operation that can be executed in one of the identical parallel-machines, as seen in Figure 2.

TABLE I. THE ILLUSTRATIVE EXAMPLE EXECUTION TIMES

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **F1** | 7 | 8 | 0 | 5 | 7 | 9 | 1 | 5 | 5 | 8 |
| **F2** | 6 | 3 | 3 | 0 | 4 | 8 | 9 | 2 | 1 | 0 |

When the order arrives, the BS is responsible for the allocation between the members of the MO. It should take into consideration the capability, the capacity, the load and the performance of each factory, which should be reported after each production order is completed. In this case, factories are held accountable for their performance, which will determine their future priorities. In the example, let us consider that the selected factories have the best performance between all factories that are under capacity. These performance indexes should be updated based on the factors that can impact production, such as the execution times, machines breakdown indexes and product defects. The BS preference for more reliable production will incentivize the continuous improvement from all MO members.

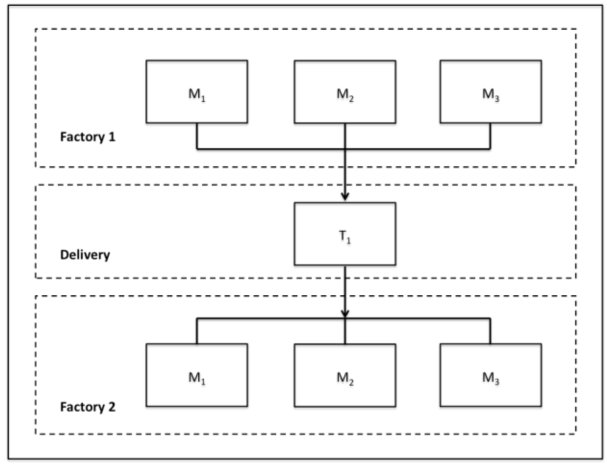


**Figure 2.** The Illustrative Example Model

Once the factories have been selected, the BS will initiate a P2P connection between both factories, since the sequence in which tasks are released from the first factory can impact the production schedule on the second one. In the example, let us assume that one of the factories faced the $FF_c||C_{max}$ problem before and has the Johnson Rule as the method with the highest *ip* for the sequencing problem in proportional flexible flow shops. Once this method is proposed the other factory can accept the method or ask the BS for alternative methods. In the example let us consider that both factories accepted the Johnson rule for the sequencing problem. Both factories will search in their knowledge bases for methods to allocate operations. Let us consider that the first factory used LPT (*Longest Processing Time*) with success for the $P_m||C_{max}$. In this case the first factory will not query the BS and will immediately implement the LPT rule to allocate production. The second factory does not know any allocation method for the $P_m|r_j|C_{max}$ and contacts the BS for assistance, which will search on its own knowledge base. When no method is found, the BS, will search among all MO members for one that faced the same problem before and establish a P2P connection between factory 2 and factory *n* that used the RLPT (*Released Longest Processing Time*) [32], so the method can be transmitted between both factories. The scheduling solution can be analyzed in Figure 4.

Once the schedule has been implemented, the methods applied need to be reevaluated in terms of their *iu* and *ip*. In the example LPT, RLPT and the Johnson rule *iu* need to be updated, these updates need to be communicated back to the BS. Both factories need to inform the BS about how satisfied they were with the scheduling solution provided by the given method, so the *ip* can be updated. The BS should use this information to learn how to better assist in the scheduling process. Let us assume that the second factory was not satisfied with the RLPT, in that case the method *ip* should decrease, and if it reaches a lower threshold it should be deleted. The sequence diagram can be seen in Figure 3.

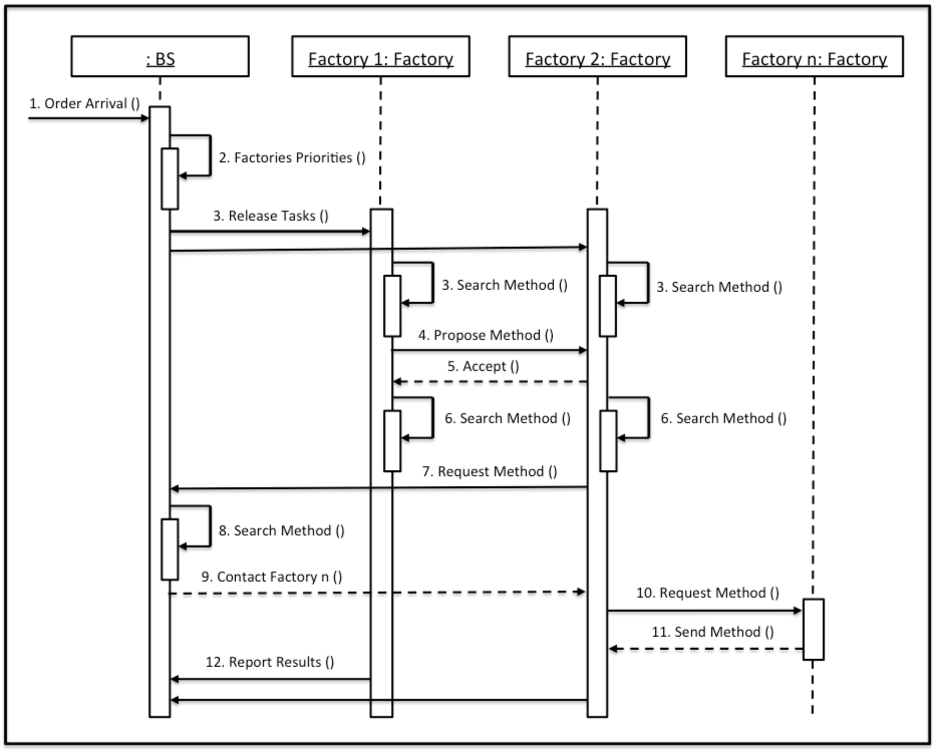


Figure 3. MO-DSS Sequence Diagram

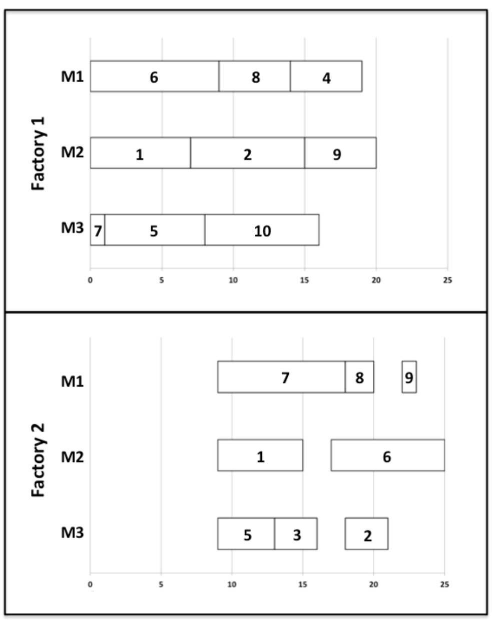


Figure 4. The Illustrative Example Schedule

If RLPT is deleted from the DSS and the BS expects the $P_m|r_j|C_{max}$ to appear in the future, based on a historical analyses and known prevision methods, it should search within the HO for other MOs that faced the same problem before, experts or open knowledge bases, for methods that the MO-DSS does not know.

## CONCLUSIONS

In the EMEs, lean, networked and distributed enterprises form MOs, which collaborate to respond to the dynamic marketplace. For MOs, schedule boundaries are hard to define, as the extended enterprises need to coordinate their production schedules with its partners. In this paper we proposed a framework for the MO-DSS that will assist extended enterprises in the coordination of their production scheduling process. The proposed framework is based on the DKBS that will learn and self-adapt according to a convoluted and complex production environment. In the context of the HO, the framework will share information with the partners outside the MO scope, such as other MOs, independent experts or open information bases. The HO will constitute a platform in which several MO can cooperate to build win-win relations and answer the marketplace constant perturbations and disruptions.

The proposed framework was demonstrated through an illustrative example and further work will focus on the full development and implementation of the MO-DSS.

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