AN INTEGRATED FRAMEWORK FOR SUPPORTING FUZZY DECISION-MAKING IN NETWORKED MANUFACTURING ENVIRONMENTS

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Abstract – In this paper we propose an integrated framework, based on smart objects to support fuzzy decision-making processes applied to manufacturing environments. The processes involved range from factory-production level up to higher decision-making levels, either in the context of traditional single enterprises, up to the one of supply chains and distributed and ubiquitous manufacturing environments. Therefore, the proposed framework promotes contributions for solving different kind of problems, including, among others: networked supply chain management; production planning and control; factory supervision and productivity management; real-time monitoring; data acquisition and processing. The web access via different middleware devices and tools at different process levels, along with the use of integrated algorithms and smart objects, which is possible and will promote an optimized use of knowledge and resources for supporting better decision-making. Moreover, the proposed framework also aims at promoting a wider collaboration process among various groups of stakeholders.

Keywords – Fuzzy decision-making, manufacturing environments

1. Introduction

In recent years, the manufacturing environment has changed from the traditional "in loco" to the decentralized and globally distributed manufacturing networks in the last decades. Companies have established new manufacturing paradigms and carried out strategic relationships with business partners, in order to increase their responsiveness to market changes and to share resources more effectively and efficiently, through integrated manufacturing systems environments. In this context, collaboration among different enterprises becomes less trivial and more critical. Thus, development of appropriate frameworks and approaches, to enable accurate decision-making support along distributed manufacturing environments and at local factories, turns out to be increasingly more important and necessary in order to maximize the overall benefits of businesses and stakeholders within such a networked global scenario.

In this paper we propose an integrated framework for supporting decision-making under the scope of current global market era. The proposed framework is intended to be applied either to traditional local factories or to networked based ones, and it integrates a set of smart objects, for collecting data at the machines and factory level, along with appropriate middleware technology and tools for supporting appropriate data storage and processing and improving decision-making processes. The concept of "Smart Objects" is well known and comes back from the late 1990's [1]. The main focus of the concept is on modeling interactions of smart virtual objects with virtual humans, agents, in virtual worlds".
The proposed framework is based on web technologies, in order to enable dynamic collaboration of distributed enterprises on the Internet, with a proposed data representation model, which does also play a fundamental role in terms of data structure, storage and processing.

Moreover, a fuzzy-based multi-criteria decision-making model is also incorporated in the proposed framework, for enabling to more accurately make decisions, from the factory level, up to the whole supply chain management.

This paper is organized as follows. Section 2 presents a brief contextualization about real-time and collaborative management, including the concept of meta-organizational environments in globally distributed resource markets. Section 3 briefly refers to fuzzy decision-making and data fusion approaches and models, for introducing the concept of the fuzzy information fusion approach to be used in the proposed framework. Section 4 presents a summarized description of the proposed integrated framework, including its general view related to integrated data acquisition and processing. Also in section 4, an industrial application example of the proposed framework, in the context of a clothes factory, is illustrated. Finally, section 5 presents some conclusions and further work.

2. Real-time and collaborative management in the global market era

Real-time and Collaborative Management, at its higher levels, can be viewed as strategies to connect people, processes, data (information), knowledge and decision-making.

In the context of globally distributed markets and Ubiquitous Manufacturing System (UMS) huge amount of complex data urge for frameworks that enable to accurately integrate technology and knowledge for enabling semiotic based manufacturing systems integration (MSI) [2-5]. This is explained due to the nature of distributed and UMS environments [2-6], which are characterized by the possibility of enabling, distributed multiple manufacturing systems or cells, integrating corresponding management support technoligies (UMS Cells). Those cells work all interconnected in a collaborative way, under the supervision of a market-of-resources (MR) manager, which controls the whole UMS, including connections with clients, belonging or not to this Meta-Organization (MO) environment. In this scenario, brokering services also play a fundamental role for accomplishing a trully integrated real-time collaborative management of the whole networked manufacturing environment (Figure 1).

The UMS environment illustrated in Figure 1 promotes innovation. Hence, it is also important to enable corporate innovation rather than only focusing on sectorial innovation. Technology integration can enable this kind of corporate innovation, which can be seen as a commodity. Thus, finally giving some concrete shape to the UMS concept. With this work we intend to make a contribution on that direction, by proposing a framework for enabling tecnologies integration for globally distributed enterprises, and which can also be applied to regular "indoor" or traditional enterprises.

In the literature, we find relevant pieces of research which support the current development of this paper. The research project in [7] addresses the emergence of the collaborative manufacturing phenomenon at three levels: sector, system and enabling technology.

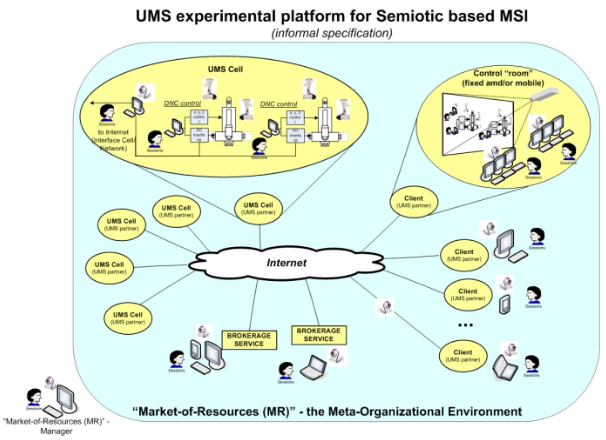

Figure 1: Meta-organizational environment of a globally distributed market of resources [2-5]

Another interesting work in [8] presents a distributed product development architecture for engineering collaborations across ubiquitous virtual enterprises. It provides an integrated framework for product development services to effectively communicate to realize true engineering application integration. In [9] the authors propose the Advanced Resource Connector (ARC), which they describe as a light-weight, non-intrusive, simple yet powerful Grid middleware capable of connecting highly heterogeneous computing and storage resources. ARC aims at providing general purpose, flexible, collaborative computing environments suitable for a range of uses, both in science and business.

3. Fuzzy decision making and data fusion approaches

Fuzzy decision-making processes include ordering, preference and consensus, and multi-objective decisions [10]. In all of these cases, there is a compelling need to incorporate fuzziness in human decision-making, as originally proposed by Bellman and Zadeh [11]. In most decision situations the goals, constraints, and consequences of the proposed alternatives are not known with precision. Much of this imprecision is not measurable, and not random. The imprecision can be due to vague, ambiguous, or fuzzy information. According to [12], imprecision can arise from a variety of sources: incomplete knowledge, inexact language, ambiguous definitions, and measurement problems, among others. Methods to address this form of imprecision are necessary to deal with many of the uncertainties we deal with in humanistic systems [10].

Fuzzy logic [11] has been successfully used to help handle imprecision in decision-making processes, namely in Multiple Criteria Decision Making (MCDM) models [13-16].

Decision Support System (DSS) models frequently lack support for dealing with imprecision, assuming that precise data and preferences are available [17]. This assumption may lead to erroneous decisions, particularly in evolving and fast changing global markets environments. Here are various types of uncertainty that may hamper any decision-making process. In [18] the author distinguishes between three types of uncertainty: (1) Imprecision (associated with the difficulty of determining the score of an alternative on a criterion, due to the absence of relevant information or the inability of a decision maker to express his preferences in a consistent way); (2) Stochastic uncertainty; (3) Indetermination (associated to criteria definition and its interpretation).

On the other hand, when more evaluation parameters are used, along with extended data sets, we may be introducing more imprecision in the decision process, even if criteria are clearly defined and indetermination is avoided. Imprecision may be intrinsic due to the nature of the selected evaluation parameters, such as estimations and/or subjective evaluation parameters, and also by the imprecise human reasoning.

In this work we use data fusion combined with fuzzy logic and sets to normalize values (enabling numerical and comparable data) and perform data aggregation. Specifically we use a data fusion process, proposed by Ribeiro et al. [19], denoted as FIF – a Fuzzy Information Fusion algorithm. The FIF Data Fusion process is based on fuzzy multi-criteria decision making concepts and techniques, such as fuzzy sets, to normalize the variables and mixture operators with weighting functions to fuse the information into a composite of different kind of parameters, such as measures arising from manufacturing machines, through the use of smart objects. The model is adequate for scenarios where uncertainty is a fact. Further, the criteria weights include parameters that may be fine-tuned, to control the relative importance of criteria when fusing the information. The FIF (Fuzzy Information Fusion) model has successfully been applied man different applications. Among them, we can cite the spacecraft landing on planets scenario, where hazard maps (e.g. "low slope") are the criterion and the candidate alternatives are the target sites (pixels). After the fuzzy normalization of this method, the individual maps (criteria) are fused, generating a composite map, with the aggregated score for each alternative, being each pixel a candidate alternative [19].

The approach we propose in the current work combines the FIF method as in [19], by using data fusion approach with a decision model [20], which dynamically enables to integrate historical, current and future information, to support decision-making at several different planning and control levels, from strategic planning to detailed control in a manufacturing environment. At the machines level in a factory, the data fusion approach along with an aggregation process will enable to accurately support decision making, according to data obtained from smart objects, which will be used for collecting important mesures from the shop floor, which will further be able to be processed for improving decision-making processes from the shop floor level up to the directors strategic planning level.

To generate a ranked list of values, the FIF method [19] uses mixture operators with weighting functions, which allow defining relative importance for each factor or criterion, using a qualitative scale. Further, while evaluating alternatives, we may have different levels of confidence on the data, depending on its availability for each factor or criterion. In our proposed approach we use the metrics proposed in the FIF algorithm [19] both to filter uncertainty and to determine factors or criteria weights.

Finally, by aggregating the final values of each situation, we may obtain a rating for each alternative. The final ranked list of the whole set of alternatives will support an enterprise to make strategic decisions or lower level decision-making, within each factory.

In many computational intelligence applications it is required to analyze multiple sources of heterogeneous information to classify and extract relevant information [21-23]. Data fusion is a suitable technique to combine heterogeneous data sources into a single fused output that combines information of multiple sources [24].

The crux of data fusion is threefold: (i) data must be comparable and numerical, using some normalization process; (ii) imprecision in data must be taken into consideration; (iii) an appropriate aggregation function to combine values into a single score must be selected [24].

Although the capability of precisely decision making processes arising from the possibility of gathering real data from the shop floor, through smart objects, in terms of strategic and even tactic planning, it is also of upmost importance to be able to further predict manufacturing scenarios and strategies, based on future data/ information predictions, regarding higher level decision-making purposes, regarding each individual enterprise, along a supply chain and/ or regarding a whole network of enterprises. Therefore, in this paper we do also consider the integration of uncertainty/ fuzzy and data fusion models with Multi-criteria decision model (MCDM) in the proposed integrated decision support framework.

Therefore, data fusion models do play a fundamental role regarding the necessity of aggregating many different kind of data/ information, arising along the whole hierarchical decision making process, from the bottom or machines/ manufacturing resources level, up to the planning and upper decision-making levels, namely in terms of distributed planning among factories and corresponding stakeholders. Regarding production planning and control, a fuzzy simulated annealing algorithm for supporting the manufacturing scheduling was also implemented, based on previous work in [25].

4. Proposed framework

In this work we propose an advanced manufacturing system framework concept, which is a cloud-based architecture that represents the manufacturing system as a "System-as-a-Service" (SaaS), integrating the services for for real-time data acquisition from the equipment through the embedded intelligent information devices – services type/ group … 'Equipment Intelligent Monitoring Systems', Product Design Services, that integrates four environments: 1) Computer Aided Design, 2) Product data repository with embedded Intelligent System for Decision Making (for accessing all relevant data, actual and historic as well as data analysis) from the equipment in use, and Equipment Operation Services that integrates the following environments [26]:

1) Equipment Data Real-time with embedded Intelligent System for Decision Making, that provides all relevant data, actual and historic as well as data analysis and management suggestions, necessary for the production management.

2) Management environment, for monitoring, planning, scheduling and controlling management activities, with embedded Intelligent System for Decision Making, a Collaborative Environment for supporting management – services; The 'cloud' infrastructure, that will provide the 1) infrastructure for the manufacturing system

applications – of all three types of resources: material processing resources, information processing resources (i.e. computational resources), and knowledge resources – in the form of IaaS - Infrastructure as a Service; 2) platform for the manufacturing system applications in the form of PaaS - Platform as a Service, and 3) manufacturing system software ‘business’ applications in the form of SaaS - Software as a Service.

It is relevant to notice that a number of underlying technologies should also be considered within the proposed framework, however it is not the scope of this paper to describe them. Examples of such technologies are: embedded intelligent information devices, real-time management (and design), chaos and complexity management, the theory of sustainability, web 2.0 to web 4.0, and others. Two of the most important problems that have to be taken care at a future stage of this development are: the interoperability, or integration, of the Ubiquitous and Cloud Manufacturing and their adoption in industry [26]. Those are further work topics of the current project.

The proposed framework, as described above should enable better decision-making support and enhance human-human and human-machine interactions, by means of the integration of information and its processing functions. As an illustration, Figure 2 presents a general view about the underlying principal entities and corresponding main interactions considered for data acquisition and processing within a general UMS environment.

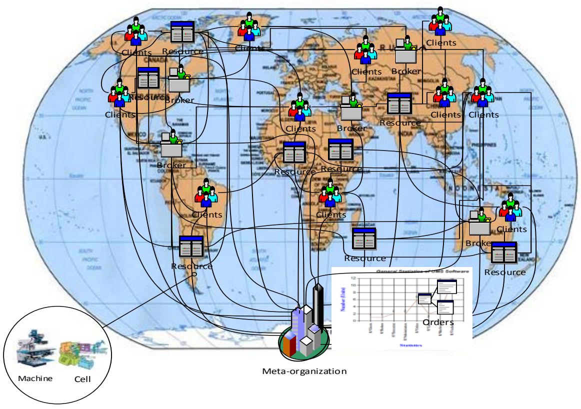

Figure 2: General view of the proposed framework for integrated data acquisition and processing

The platform architecture presented in this paper is a projection of a supporting architecture for Production Systems and Ubiquitous 'Cloud', in which the production system corresponds functionally and from the viewpoint of the business model to a service system [27] and includes the following main entities:

The Meta-Organization (MO) consists on an overall environment to facilitate and manage, in an efficient and dynamic way, systems reconfiguration to ensure dynamic reconfiguration, with low transaction costs, risk of breach of confidentiality and trust management [28]. The MO manages the network environment, since the inscriptions up to the contracts, ensuring the confidentiality of information, trust and ethics present among customers, service providers and products, and 'Brokers', among others. Thus, the manager of the meta-organization to be responsible for managing the trust, total quality management and the MO operations management has at his disposal a set of dashboards to support this process. The Clients record and generate new production orders which can associate 'Brokers' that will inform about the best Resources to accomplish certain order. As is the case with the other modules, it includes a set of management tools and a whole range of communication services (chat, email, video conferencing and other) properly embedded and integrated [29]. The Broker is an agent 'middleware', whose role is to manage the dynamic reconfiguration of agents and has as main characteristics agility for accurately acting between the client and the resource (supplier) [28]. The Broker receives production orders from Clients, makes the best combination of features and has the ability to negotiate with the Resource. For example, negotiate a price reference for a particular order, via chat, email and video conferencing, or other [28,29].

The Resource can be any provider of any service, machine tool type, human agents as service providers (designers, managers, machine operators, planners, schedulers, drivers, vendors, and others), computing resources, software, etc.

The Resources receive the orders from 'Brokers' and then negotiations are triggered (for example via chat, video conferencing, or email). After the approval of the order, the Resource establishes direct relationship with the Client and executes the production order. As stated above, the Resource may give permission for the Client to see the production order to be executed and may allow the Client to control the use of distance (when the resource is a machine, a computer, or software), either from the control room, the PC, or from a mobile device [29].

Our proposed framework has been implemented in Visual Basic (VB) language to prototype an application example for this paper. The VB language enables easy development; as well as user friendly interfaces for data visualization and processing. Data and corresponding processing approaches and applications are managed in different places, which is of particularly importance in the context of a global manufacturing scenario. For instance, if these globally distributed manufacturing environments have their own schedulers developed by different IT stakeholders; their schedules cannot be visualized by a common viewer without particular adapting programs. This actually causes a huge effort on a system’s implementation, and both the cost and the risk of the system, which will be increased. Using interfaces developed through Visual Basic enables end users to have a personalized scheduling viewer, among other interfaces for supporting decision making, within a whole networked environment. Figure 3 shows the corresponding system’s architecture for this industrial application, which aims at enabling integrated, and automatic processes and routines, along with corresponding data acquisition and processing, in a real-time basis.

This provides flexibility for visualizing distributed schedules everywhere through the Internet. Therefore, the proposed data representation and processing model can be seen as a general modeling schema, for problem data specification and processing for enabling to better supporting decisions at different decision levels intra and/or inter factories and stakeholders.

Our illustrative example of the proposed integrated framework implements an application in the context of a clothes factory in Portugal.

Figure 4 shows a general view of the main technologies and system's interfaces at the factory and director's management levels, which has access to integrated panels about data processing for strategic actions planning support.

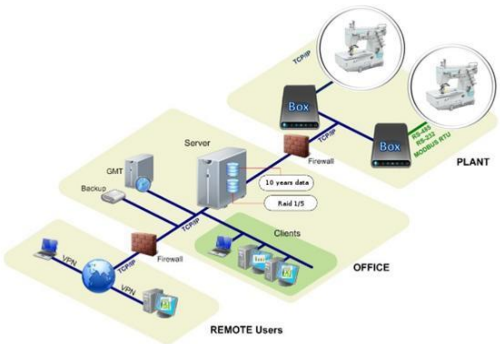

Figure 3: industrial application architecture of the processes of a factory of clothes

Figure 4: General technologies and systems integration view of the processes of a factory of clothes

Moreover, the proposed integrated framework is intended to enable supporting fuzzy decision-making either in the context of local factories or in the context of distributed and networked manufacturing environments. One important aspect of the proposed integrated framework is its capability for enabling to acquire real data from the machines and other manufacturing resources, at the factory level, through smart objects technology, in a precisely and real-time basis [30-34].

These smart objects have the capability to collect and store data in real time, to identify themselves and to make decisions, in a automatic and autonomous way, thus they play a crucial role in terms of real-time management functions, for supporting manufacturing, as they enable to update data to the second, instead of the traditional reports, which take sometimes days or even more time periods to enable to use updated data for manufacturing decision-making support.

Therefore, the smart objects are programmed with the proposed functions in order to enable to manage, in real time, machines and products, sending accurate, timely and reliable information, to workers responsible for production planning and scheduling, machining, assembling and maintenance. The functions are presented by modules, where each one represents a type of data that a smart object can capture.

Moreover, there is a higher level requirement about a need to distribute the whole data by the existing hierarchical levels in the enterprise, since each job title requires singular responsibilities and decision making, and the smart objects' architectures are presented through different technological levels.

5. Conclusions

This paper described a proposed integrated framework for supporting decision-making either in local enterprises or in networked manufacturing environments, which is being developed using VB language. For its implementation a standard format to exchange data among different manufacturing enterprises were used, which is an important aspect, as many ICT applications including distinct backend systems are to be integrated. An illustrative example of the application of the proposed framework in a real world manufacturing environment was illustrated.

Moreover, the effectiveness of the integrated technologies and approaches was briefly described an illustrated through the application example provided, namely regarding smart objects, which play a very important role in the proposed framework, namely at the shop floor level. An important aspect is that data can be generated and visualized by computers and other devices, including the smart objects, in appropriate and distinct ways and it is also important to notice that the data representation schema is general for distinct kind of manufacturing enterprises requisites.

Moreover, we can state that this underlying standardization, through a general data representation model will bring us to more valuable future business models, by using the Internet. Besides that, collaboration issues among different kind of entities through the proposed framework will provide better applications integration infrastructure for all manufacturing enterprises, within a networked manufacturing environment.

For being able to fully implement the overall characteristics of the proposed framework, for working along a whole network of enterprises and enabling all underlying stakeholders to interact at each level of the

decision-support system, there is still some need to further work to implement additional functionalities, namely for supporting collaborative inter-enterprise negotiation and management processes.
Moreover, at the shop floor level there is also some further work to be carried out, for fully implementing fuzzy data aggregation, regarding alternative methods, which are going to be further analyzed.

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