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Exploring the Scope of Prognosis Agent Technology in Digital Manufacturing

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Abstract
It is an established fact that the last decade is evident for the advancement in manufacturing sector by the use of various digital manufacturing (DM) techniques. Agent technology has contributed far in the DM by simplifying and adding synergy to the various functionaries in form of static and mobile agents. The agents contribute in the paradigms of designing, diagnosis, production, marketing etc. In the international business market, the agent technology has increased the competence by providing fast, error free, customized services. The paper first reviews the work done in the field of applications of agent technology in digital manufacturing including the role of agent technology in prognosis and then the research object is to develop a framework for the prognosis of digital data feeded to the manufacturing facilities of DM system. The paper focus on the introduction and brief description of the manufacturing prognosis agent in context to Digital manufacturing.

Key words: manufacturing prognosis agent, digital manufacturing, prognosis, agent technology, digital data

1. INTRODUCTION

In today's world the manufacturing sector has been revolutionised by the ever increasing competitiveness due to globalization of operation [1] and fables operation of domestic production. This competitiveness has resulted into the increase in competence in International Business Market. To survive in the international market , a manufacturing company has to modernize the manufacturing technique. The scope of Digital Manufacturing has evolved recently to include Computer Aided Process Planning (CAPP); Computer Aided Production Engineering (CAPE) [2]; a Manufacturing Data Base which contains product data, process data, manufacturing resources (PPR); generation of executable programs for automation; the generation of work instructions for workers on the shop floor and the feedback of the manufacturing performance data from the shop floor. Although digital manufacturing has fulfil the industrial need on maximum reduction of failures and degradation of manufacturing systems [3], yet there are the challenge regarding prognosis process enabling to propagate the degradation cause in order to analyse the new degraded situation and to anticipate the manufacturing system failure.

In order to meet this challenge the multi agent technology can play a vital role in digital manufacturing. The multi agents like manufacturability evaluation agent (MEA), manufacturing resource agent (MRA), process-planning agent (PPA), manufacturing scheduling agent (MSA), shop floor agent (SFA), fault diagnosis agent (FDA), etc.[4], can interact coherently for distributed manufacturing. With specific agents having unique functionalities, a manufacturing managing agent (MMA) acts as the centre of this distributed manufacturing system. Along with these agents, manufacturing prognosis agent (MPA) whose paradigms are yet to be explored in the DM sector can have high contribution in making the decision for the type of maintenance used in the system.

Global competition, shorter lead times and customer demands for increasing product variety have collectively forced the manufacturing enterprises to rapidly develop and introduce new products to obtain quick return on their investments [5]. In such conditions it becomes a very necessary aspect for manufacturing sector to minimise the time spent in breakdown condition of machine, tools or other functioning units. Successful realization of predictive maintenance depends a lot on the effectiveness and implementation of a maintenance scheme based on proper diagnostics and prognostics [6]. Prognostic is to detect an undesirable condition before it degrades to a failure. Over recent years, extensive research and development work has been devoted to prognostics and its potential applications in equipment maintenance and utilization. Manufacturing prognosis agent (MPA) facilitates the unit as a decision control tool in analysing the working conditions, predictions of future problems and do the desired maintenance accordingly. It results in the reduced lead time of the product along with smooth, break-free operation of all the units.

This paper is organized in the sections. Section 2 presents the focus study area by reviewing and meta analysis of the work done by application of agent technology in Digital Manufacturing sector followed by research gaps and prognosis agent in Digital manufacturing. Section 3 develops the model for the role of manufacturing prognosis agent (MPA) in digital manufacturing. Conclusions are discussed in section 4.

2. FOCUSSED STUDY AREA

Our main focus study area includes agent technology and it's paradigms in Digital manufacturing before having an overview on the synergy added by the application of agent technology in Digital manufacturing. Various research gaps are identified after conducting exhaustive literature survey. On the basis of identified research gaps, manufacturing prognosis agent (MPA) is introduced and the operational model is developed.

2.1 LITERATURE REVIEW

In the field of digital manufacturing, literature review is conducted by collecting the highly cited research papers from various journals. Firstly the role of multi-media in manufacturing was explored [7]. In the same year another research emphasized on the integration of several branches of engineering, simulation systems involved in the design & manufacturing of the capital intensive products [8]. Further was the methodology of applying Digital Manufacturing from the initial concept design phase of both product and production processes, through detail design and validation, to both implementation on the shop floor and the constant monitoring the shop floor performance data to support continuous improvement activities [9]. The impact of digital manufacturing on technology management was the next research [10]. Digital planning for manufacturing and validation of the manufacturing data was one of the major concerns of the researchers [11]. After the globalization of the market, the area of interest was to produce more by less available resources [12].For this purpose data integration by the use of application protocols was done [13] which resulted into a more adaptive digital manufacturing environment [14].

With the advancement of computer technology, the human role in the digital manufacturing was replaced by multi-functional agents. Infrastructure for the agent technology was presented along with the function of each component[15]. Also the basic architecture for the manufacturing control was presented [16]. On this platform, the multi-agent based network in global manufacturing supply chain network was introduced [17]. Then presented was an approach that would enable manufacturing organisations to dynamically and cost-effectively integrate, optimise, configure, simulate, restructure and control not only their own manufacturing systems but also their supply networks, in a co-ordinated manner to cope with the dynamic changes occurring in a global market [18]. In the same year, software agent technology was explored along with the applications and opportunities for agent technology in manufacturing [19]. Later an approach based on an integrated decision platform on which planning and control decisions can be considered concurrently with system reconfiguration/restructure decisions was given [20].

Regarding the prognosis of digital data in DM systems, many researchers have been done so far but many aspects regarding the application of agent technology in manufacturing prognosis are still untouched. In the early phase, diagnosis process regarding the detection of error by the installation of monitoring systems in manufacturing system was introduced [21]. Then after diagnosis and prognosis was integrated on a common platform for the proactive maintenance of the manufacturing system [22]. With the advancement of the information technology, web was introduced as the vital enabler for the predictive [23]. As the agent technology became vigilant in the manufacturing sector with the application of multi-agents, further research was done on the intellectualised fault diagnostic system by dividing the systems into sub-systems [24]. Later, the deplovment of extended prognosis process followed a methodology based both on probabilistic and on event approaches [25]. Final introduction of i-diagnosis and i-prognosis was done for the information flow and event handling of the shop floor dynamics [26]. Still the works regarding the introduction of prognostic agent as a key enabler for the decision making of the type of maintenance done in the digital manufacturing system is in is in infantry stage.

2.2 LITERATURE:META ANALYSIS

On the basis of the literature survey conducted on 25 papers in the span of 1990 to 2012, 8 research streams are found on which digital manufacturing is dependent. Each research stream is taken from the various research papers on the basis of literature survey. Table 1 shows that how the trend is following on a particular research stream. In table 1, the lower line shows that duration of the research that which year to which year the research is carrying out in that research stream while upper line shows the peak time of the research in that particular research stream.

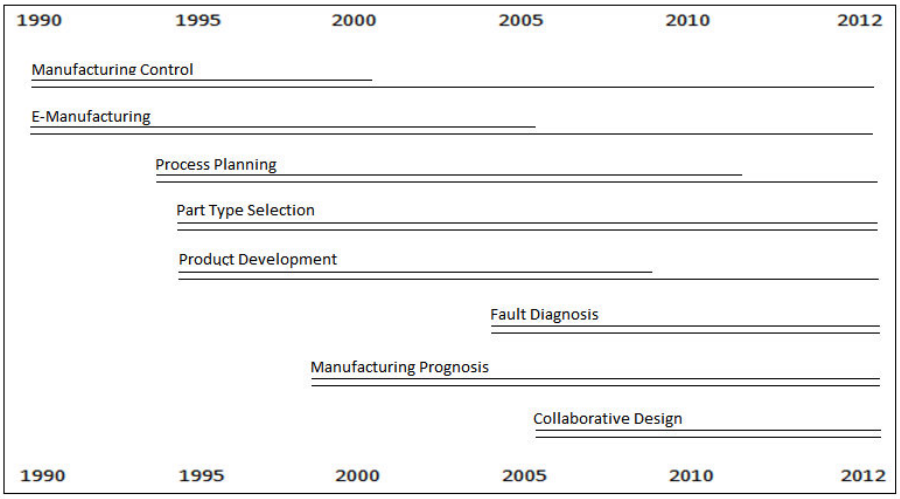

Table 1 – Research trend in various research streams during time span of 1990-2012

The percentage of studies and number of studies on these 8 research streams is given in the table 2, while table 3 represents whether the study was conceptual or empirical.

Research Streams	No. of Studies	Percentage of Studies
Manufacturing Control	18	13.2
E-Manufacturing	24	17.6
Process Planning	12	8.8
Part type Selection	27	19.8
Product Development	18	13.2
Fault Diagnosis	17	12.5
Manufacturing Prognosis	09	6.7
Collaborative Design	11	8.0

Table 2 – Research streams and their corresponding percentage of studies

Research Streams	Conceptual		Empirical	
	No.	% age	No.	% age
Manufacturing Control	11	13.9	7	12.2
E-Manufacturing	15	18.9	9	15.7
Process Planning	7	8.8	5	8.7
Part type Selection	14	17.7	13	22.8
Product Development	12	15.1	6	10.5
Fault Diagnosis	9	11.3	8	14.0
Manufacturing Prognosis	6	7.5	3	5.2
Collaborative Design	5	6.3	6	10.5

Table 3 – Research streams and the type of study

Table 4 represents the number of articles and out of those which were statistical and which were non-statistical and their corresponding percentage of studies. From the literature survey it is found that out of total number of studies 23 studies were based on statistical methods which is about 40.3% of the total number of studies while there were 34 studies were non-statistical methods which is about 59.6 of the total number of studies.

Methods	No. of Studies	Percentage of Studies
Statistical	23	40.3
Non-Statistical	34	59.6
Total	57	100

Table 4 – number of studies and percentage of studies of statistical and non-statiscal

Based on the conducted literature survey and the explored dimentions of the Agent Technology usage in Digital Manufacturing, We have introduced two classification schemes to systematically organize the published research papers. The first classification scheme is based on the Problem Configuration along with type of agents used for the DM problem followed by researchers.

The Agent Technology problem in DM can be broadly classified on the avaibility of the data as deterministic and stochastic (figure 1). Within these groups Agent Technology problem can further be classified on the basis of the type of agent used i.e., single agent system, multi-agent system, static agent and mobile agent. According to this series of classification scheme 1, the Agent Technology research problem in DM can be systematically organised into [2X4] = 8 different categories.

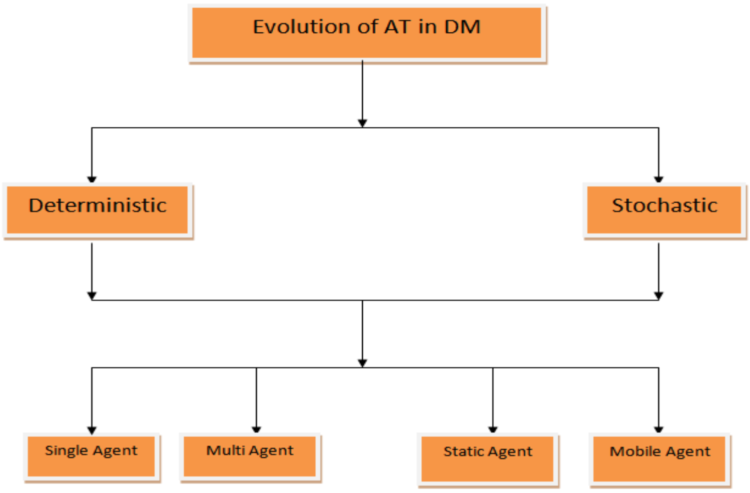

Figure 1 – Classification Scheme on Problem Configuration of AT problem in DM

From the Solution Methodology, proposed in the literature for AT in DM has been grouped broadly into Mathematical Programming Method, Heuristic Method and Simulation Method (figure 2). In case of Mathematical Programming group, the review indicated that so far, few works have been done by the proposal of dynamic programming, Integer Programming and Queuing Model. Mathematical Programming can be used in kind of problem which is short, particular for observation of simple AT effect in the parameters of manufacturing. Mathematical Programming is restricted to the problems with lower number of constraints. As the scope of application of mathematical programming is limited to because of complexity of AT application in DM,many researchers are continuously putting lot of efforts in developing Heuristic methods.Meiruret defined Heristic method as a master set containing three sub subsets (1) Heuristic problem solving (2) Artificial Intelligent (3) Simulation of human thought. Furthermore, many researchers classified the heuristic problems solutions in many ways. These are meta heuristic, simple heuristic and mathematical programming heuristics. These find application in various articles related to application of AT in DM.

Mathematical programming is the least used solution methodology to find AT problems in DM. This implies that the multiple parameters of the digital manufacturing on which AT application has a noticeable effect, are not explored. So considering the operaing parameters like lead time, processing time, idle time for the research work and observing the effect of AT on these parameters is one of the relevant areas of further research.

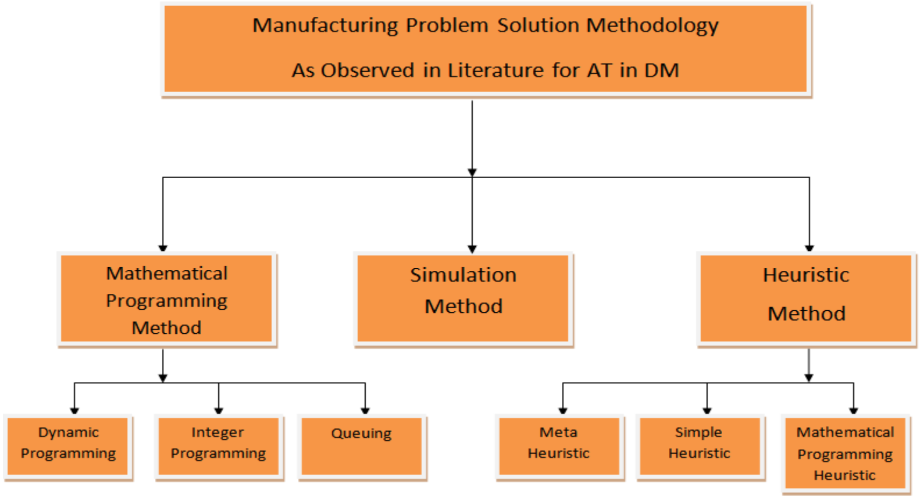

Figure 2 – Classification Methodology on Solution Methodology of AT in DM

In the distribution of articles by classification scheme 1, frequencies distribution of articles according to proposed classification scheme 1 is shown in Table 5 where it is observed that research attention of multi agent technology in DM is equal to research attention of other agent technologies. However most of the research issues addressed on multi agent technology are of stochastic in nature. Finally there are articles in combination of classification scheme 1, proposed in this paper and these are possible areas of new research.

Here, D = Deterministic S = Stochastic

Types of AT in Dm	**D/S**	**No. of Articles**	**No. of Articles in %**	**Total %**
Multi Agents	D	11	16%	38%
	S	15	22%	
Mobile Agents	D	5	7%	16%
	S	6	9%	
Static Agent	D	7	10%	19%
	S	6	9%	
Single Agent	D	8	12%	27%
	S	10	15%	

Table 5 – Distribution on AT research in DM based on classification scheme 1

The Distribution of articles by classification scheme 2. Distribution of research materials as per the proposed classification scheme is given in table 6. Table 6 indicates that simulation method and heuristic method are the two most widely used methods for finding the solution of AT problems in DM. These contribute more widely used methods for finding the solution of AT problems in DM. These contributes more than 85% of the published articles . These observations indicates that as a possible new research direction, there is a tremendous oppurtunity to propose various mathematical programming based methods and integrating them with heuristic approach for AT problems in DM.

Solution Methodology	**No. of Articles**	**No. of articles in %**
Mathematical Programming	8	14%
Simulation Method	25	45%
Heuristic Method	23	41%

Table 6 – Distribution on AT research in DM based on classification scheme 2

Table 7 shows the number of articles and number of researches contributed in the area of research problem of AT in DM. Is is observed that the no. of published articles between the periods 1991 to 1996 is very meagre, so it can be concluded that the year 1997 is the starting point for the evolution of agent technology research in digital manufacturing . In the period between 2003 to 2012, high research activities has been done on AT problem in DM. Then after, the research has been continued at an accelerated rate. The advancement of information technology has led to the new research in the field of agent technology by integrating agent technology with information technology. Also, with emergence competence in the international business market, manufacturing industries are investing in the research and development of manufacturing facilities to get the competitive advantage over other industries.

Year	**No. of Articles**	**No. of Researchers**
1990-1992	1	2
1993-1995	52	4
1996-1998	11	23

1999-2001	6	19
2002-2004	11	31
2005-2007	20	43
2008-2010	12	33
2011-2012	8	27

Table 7 – Statics on number of articles and number of authors Contributed tri-anually

2.3 CONCEPTUALIZING THE PROGNOSIS AGENT TECHNOLOGY

Prognosis agent technology is the concept of the prognosis of the data injected into the manufacturing system by a static or mobile agent. This technology can contribute in predictive maintenance of the manufacturing system. Predictive maintenance, which monitors the performance of equipments, predicts the remaining health life and conducts the maintenance before breakdown occurs, can efficiently prevent automation equipment from breakdown occurrence [27]. As maintenance cost accounts for 15%-40% of the cost of manufactured goods, so by the application of prognosis agent technology in manufacturing system, the unwanted costs in maintenance and breakdown can be eliminated which leads to the increase in productivity of the unit. By increased productivity, a manufacturing company can enter into the International Business Market smoothly. Thus it can be assumed that prognosis agent technology is a key enabler for the manufacturing sector to provide competence in International Business Market. Also other aspects of manufacturing like lead time, effectiveness are also improved by the usage of prognosis agent technology.

2.3 THEORIZING THE RESEARCH ISSUES IN MANUFACTURING PROGNOSIS AGENT

On the basis of the exhaustive literature survey conducted on 25 papers in the span of 1990 to 2012, the research gaps are identified. These research gaps are shown in table 8.

Here, Add. = Addressed

Unadd. = Unaddressed

EXPLORED VARIABLES	YEAR SPAN							
	1990-1995		1996-2000		2001-2005		2005-2012	
	Add. issue	Unadd. Issue	Add. Issue	Unadd. issue	Add. issue	Unadd. issue	Add. issue	Unadd. Issue
1.Diagnostic system	✓		✓		✓		✓	
2.Multi agents-resource agent		✓	✓		✓		✓	
3.Machine agent	✓							
4.Worker agent		✓	✓		✓		✓	✓
5.Integration of monitoring, diagnosis, prognosis		✓	✓		✓	✓ ✓	✓	✓
6.Proactive maintenance,			✓					
7.Virtual manufacturing organizations		✓	✓					
8.Multimedia; Internet;		✓			✓		✓	
9.Global manufacturing,		✓	✓	✓	✓		✓	
10.Digital manufacturing,			✓	✓	✓		✓	
11.Decision support tool		✓	✓		✓		✓	
12.Prognostic agent .	✓	✓	✓		✓		✓	

13.Multi-agent co-0peration					✓	✓		
14.Agent technology		✓		✓			✓	
15.Internet enabled predictive maintenance		✓	✓	✓	✓			
16.Prognosis of DM systems	✓		✓		✓		✓	
17.Integrated manufacturing system		✓			✓		✓	
		✓						
		✓			✓		✓	
							✓	
							✓	
					✓			

Table 8 – Addressed and Unaddressed issues during the time span of 1990-2012

On the basis of identified research gaps, it can be stated that prognosis agent technology is the area under exploration and has the scope for further research.

2.4 BRIDGING RESEARCH GAPS

Prognosis agent technology and its application in digital manufacturing is identified as the research gap which require more attention. The main issue we attempt to bridge the research gap is to develop an informational framework which has efficient co-ordination to cover prognosis of digital data in product design, manufacturability evaluation, process planning, scheduling, and real-time production monitoring. All the earlier proposed systems have in different ways addressed specific issues like using multiple-way and multiple-step negotiation, using black boards, sub-contracts, conflict resolution and so on [27]. However, in this paper we have proposed a framework to incorporate the prognosis agent in a flexible system for multiple co-ordinated tasks starting from part design to final scheduling. The system has the capability to be upgraded by incorporating additional functional agents for manufacturing related tasks.

3. ROLE OF MANUFACTURING PROGNOSIS AGENT IN DIGITAL MANUFACTURING

In manufacturing systems, manufacturing prognosis agent (MPA) plays a vital role in prediction, forecasting, co-operation and co-ordination among the agents, a manufacturing prognosis agent (MPA) is introduced and considered to be logically before every step in multi-agent technology.

3.1 MANUFACTURING PROGNOSIS AGENT (MPA)

In this section, manufacturing prognosis agent (MPA) is discussed. The manufacturing prognosis agent (MPA) is a computer system that replace the work of a human being and is effective to realise the future problems related to product design, manufacturability evaluation, process planning, scheduling and real-time production monitoring. Before introducing manufacturing prognosis agent, it is important to describe the system framework (Fig.1) for reaching an overall desired goal when multiple agents with their own competence are all trying to achieve specific objectives[27]. Process planning and scheduling are rather complex tasks. On the basis of their corresponding specialization in functionalities and complexity, these tasks are decomposed into sub-tasks. The sub-tasks may involve design, feature extraction, suitable manufacturing model, manufacturability evaluation, process planning, etc[4]. In the proposed system, these sub-tasks are often distributed over different geographical locations to facilitate prediction and forecasting.

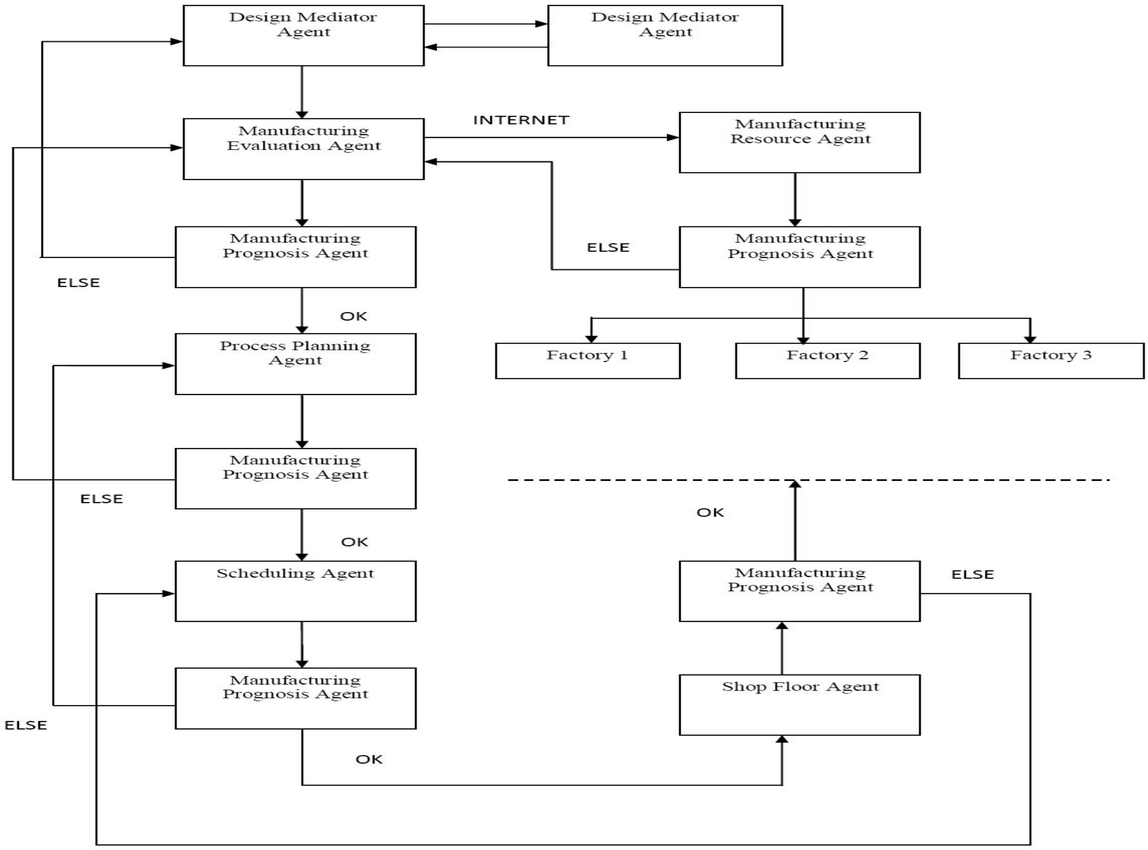

Figure 3 - System framework for MPA

3.2 SYSTEMATIC FRAMEWORK FOR MANUFACTURING PROGNOSIS AGENT (MPA)

An agent is defined by its characteristics, and researchers propose various characteristics for agents. In General, it includes four key characteristics: autonomous, communicative, goal oriented, proactive, rational and reactive [27]. Fig.3 shows the detailed system framework for the function of MPA in digital manufacturing systems. The multi-agent function in the whole manufacturing operation is broadly divided into six dimensions- design mediator, manufacturing resource, manufacturing evaluation, process planning, scheduling and shop floor.

Six basic types of agent are considered in the system framework- Design Mediator Agent (DMA), Manufacturing Resource Agent (MRA), Manufacturing Evaluation Agent (MEA), Process Planning Agent (PPA), Manufacturing Scheduling Agent (MSA) and Shop Floor Agent (SFA). Along with these agents, Manufacturing Prognosis Agent (MPA) is introduced before each agent for constant monitoring of the manufacturing process. Considering the limited types of agents with knowledge of their specific stages/functions in a product life cycle, a prognosis mechanism is adopted for our system. The MPA assumes the role of feedback control in being responsible for predicting problems relating to functionality of agents, while the other agents are responsible for solving specific problems, such as manufacturability evaluation, process planning, etc. Each time an operation is completed, the MPA will be notified and it correspondingly acts to do the prognosis and instruct the appropriate agents accordingly. The MPA is designed to be the logical feedback part and thus can analyse the operation and has the right to decide on how to react to it. The MPA may simply forward the message to another agent or instruct it correspondingly. The functions of each agent are given below.

- MEA - The work engine of MEA is an inference-reasoning engine connected with two rule-based knowledge pools. The first pool stores the rules based on manufacturing experience and principles and is used to analyse typical design configurations and detect features that may cause manufacturing difficulties [27]. The rules in the second pool are used to infer machining processes for individual features and evaluate the capabilities of the manufacturing resources for carrying out the processes.
- MRA - The work engine of MRA is a forward-searching engine, which compares the available factories with the required manufacturing resources to identify eligible factories[27].
- PPA - The PPA employs a genetic algorithm-based engine to perform process planning for a feature-based part. The process plan that is generated will specify the machines that will process the features and the cutters required[27].
- MSA - The MSA work engine uses an integrated genetic algorithm and Gantt chart approach to determine an optimal production schedule in a selected factory. Various objectives can be made, such as minimizing cost or make-span[27].
- DMA - The DMA works in the field of initial design of the specimen, validation of design by optimum design parameters and manufacturing system design.

4. FUTURE WORK AND CONCLUSION

This paper first review the application of agent technology in digital manufacturing, then introduces manufacturing prognosis agent (MPA) and lately a system framework to enable predictive maintenance of the digital manufacturing system. This systematic framework presents the role of MPA in different paradigms of manufacturing – design, shop floor, process planning, scheduling etc. MPA can play a vital role in real-time predictive maintenance along with minimizing the maintenance cost towards achieving zero down-time.

A systematic frame work for the application of application of MPA in integration with MEA, MRA, PPA, MSA, DMA and SFA is presented. By the application of MPA, competence in manufacturing sector can be boosted in accordance to International Business Market.

However there are still some challenges for our future research. In current time, not much research has been done in the application of MPA in industries by considering the parameters like lead time, down time, performance testing etc. Therefore our future research is to verify the prognosis agent in a manufacturing system and validate MPA's effect on real time manufacturing parameters along with exploring it's effect on International Business Market.

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