Collective Intelligence for Monitoring Innovation and Change in Manufacturing Industry

M. B. Ayhan, M. E. Aydin, and E. Oztemel

***Abstract*—Change monitoring and management become an unavoidable necessity for companies in order to stay competitive in global market.This requires thorough handling models for change management to attain a systematic approach. In this paper, monitoring models for innovation and changes in manufacturing environments are investigated using two collective intelligence approaches. The first approach is based on a multi agent system designed in a tree-structured, where expert operational agents are strictly organised under sub-chair agents. The second approach uses a swarm intelligence approach, namely bee-colony algorithm to achieve collective intelligence for monitoring innovation and change across the manufacturing companies.**

***Index Terms*—Change Management, Collective Intelligence, Innovation Monitoring, Multi Agent Aystems, Swarm Intelligence.**

I. Introduction

CHANGE management is stated as one of the most important factors of successful leadership and management capabilities [1]. Since it does not have a single process structure to be implemented in for all kinds of enterprises, each organization should adapt itself to the change in accordance with own-dynamics.

Manufacturing systems are mostly affected by technological developments yielding cost reduction or minimizing the production times. They also have to follow the changes in customer demands to satisfy their requirements. Furthermore, the recent techniques; Management Information Systems or Enterprise Resource Planning (ERP) systems should also be embedded. In order to fulfil these requirements change elements special for manufacturing systems should be managed essentially. Since the change occurs in global dimensions and management of change needs the visualization and understanding of all components, some change management models have been developed to gain this systematic approach. According to ADKAR [2] model, which is one of the most widely known and used models, comprises of 5 stages; Awareness, Desire, Knowledge, Ability, and Reinforcement to ascertain the change, successfully. Although it is a promising model, the main focus is on the personal perception and implementation of the change, not for the manufacturing functions. Other models including McKinsey 7-S Model, [3] and Kotters Model [4] , sets different factors all working collectively to determine how the company will operate to manage the change. However, a quantifiable metric system is missing to measure the success capability of this change management. Moreover, the main focus is for only the managerial aspect of the change in the existing models, but the manufacturing systems have their unique properties to be considered and monitored for the change management. A general frame work is introduced by Ayhan[5] to embrace a complete enterprises specialised in manufacturing industry. However, the model proposed does not have a computational provision and integrity in the corporate information system. In this study, we developed a computational approach to manage integrity with the enterprise-wise information system based on multi agent systems and swarm intelligence. In the following sections of the paper, (i) the overall framework for monitoring innovation and change management in manufacturing enterprises with highlighting basic fundamentals, (ii) the multi agent systems and swarm intelligence are generally introduced, (ii) and finally, two collective computational intelligence models based on multi-agent systems and swarm intelligence are detailed prior to conclusions.

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II. Change Elements in Manufacturing

There are known and unknown numerous factors leading to change in manufacturing systems, which are categorised into 5 main clusters in this model: Technological, Process Based, Customer Oriented, Managerial and Environmental change elements. The overall model is visualised in Fig. 1 including the main scope of each component and the nature of the relationship among them which lead to monitoring the state of the change.

A. Technological Change

In order to manage the technological change, which can trigger the effectiveness and efficiency of the production processes, it is crucial to decide on the best technology to be invested as the first step of technological change factor. It is important to be aware of the return on investment value of the new technologies prior to investing scarce funds for them. Therefore, forecasts about benefits of the new technologies have to be accurate and precise. This clearly indicates the requirement of Technological Forecasting, which is defined as foreseeing the technological innovation, scientific developments, and estimating the benefits and occurrence time of scientific inventions [6]. Although there are various methods proposed to form successful technological forecasts, they can be classified into 2 types of studies; Numerical Data Based Techniques, and Judgement Based Techniques (See for examples, [7], [8].

After forecasting the expected returns of the related technologies, Product Innovation phase, which is defined as

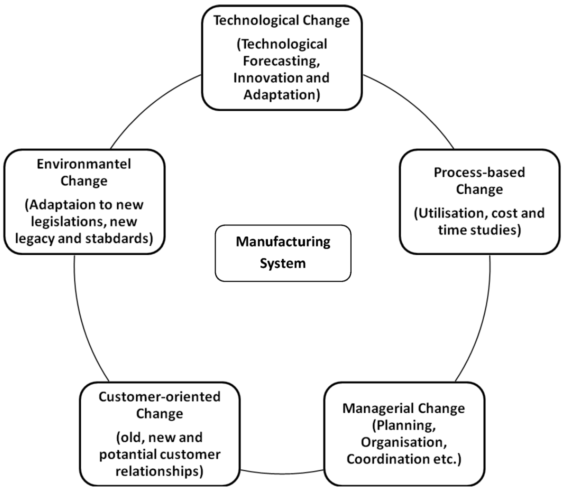

Fig. 1. Change elements for manufacturing systems

implementing technologically new products or significant technological improvements in products [9], should take place to market technologically innovated products. Since creating innovative products is another indication of following the technological change it must be embedded in the change management model.

Once innovative products development considered, Technological Adaptation, which is the penetration of the technological changes within the manufacturing system [10], is responsible for the adaptation of the tools and equipments used, employees working on the manufacturing system as well as the knowledge utilized for the new products. Otherwise, technological forecasts and innovation studies cannot result properly. However, the literature about technology acceptance model [11] and Technology Fit model [12] generally depend on human sociology or the transfer of technologies. By the term of technological adaptation not only the human side but also the adaptation of tools and knowledge should be taken into account.

B. Process Based Change

It is defined as the adoption of technologically new or significantly improved production methods [9] and as important as the technological change. Since, even if new products are developed, they would not have great impact on the market unless the process innovation follows. Traditionally, business process improvement is often measured in terms of lead time, service time, waiting time, and resource utilization [13], [14]. Lee and Ahn [15] propose a different method to assess the process improvement through a set of indicators, which can be adopted for the assessment of the success of manufacturing processes with some modifications [16]. Average Worker Utilization, indicates the performance of manufacturing processes, where the practitioners are always after a more stable labor utilization, avoiding the causes of fluctuations with minimizing the frequencies of both idle-times and overtimes. In addition, it is crucial to minimize the bottleneck times for the manufacturing processes for the sake of better performance such as productivity. This reasonably justifies that the change in Total Bottleneck Time of the system is also to be one of the indicators to monitor the process change. Minimizing Unit Production Cost and Unit Production Time, of a certain production amount is the only way of maximizing the profit margin in a highly competitive market. Hence, evaluating the results of implementing a new manufacturing processes based on these indicators is required for monitoring the process change.

C. Managerial Change

In the era of industrial revolution, management idea was set on a scientific base by the studies of Frederick Taylor, was originally published in 1911 [17]. It is the attainment of organization goals in an effective and efficient manner through planning, organizing, leading, and controlling organizational resources [18]. In addition to these four functions, coordination of entities that form the life blood of the companies, is defined as much important as the previous functions by intra or inter communication channels for the staff and the supplier-customer line. Since the techniques used for management evolve in time [19] due to technological and social changes, there is a need to monitor the changes occur in managerial functions.

Planning is defining goals for future organizational performance and deciding on the tasks and use of resources needed to attain those [18]. Increasing the requirement of complex planning activities bears the transformation of plans. Hence it is important to monitor the changes occur in planning function of the manufacturing systems. Organizing is the activity of matching the tasks to employees. Although there are various organizational structures used throughout the ages [20], it is important to screen this change in management perspective.

Leading is the art of influencing individual or group activities toward achievement of enterprise objectives. Leadership style is widely studied especially by the behavioral and social sciences [21], [22], however, a monitoring scheme is required to analyze the changes occur in management function. Organizational Control is to check if anything happens the way it was planned to happen. Since the manufacturing technologies evolve in time, controlling mechanisms also transforms from the primitive case to the most contemporary techniques. Existing controlling methods can be viewed [18], [20], [23] and the changes in these techniques should be monitored. Coordination, which is required to enhance the attainment of management objectives, can be sustained through the successful use of communication skills of which listed in the literature [24], [25]. Since the changes occur in manufacturing systems, communication styles also advance from the primitive case to the most contemporary ones. To conclude Managerial Change part, the changes occur in each function should be tracked and the outputs of this screening will be an input for collective intelligence system.

D. Customer Oriented Change Stage

The technological revolution has also led the changes in customer behavior. Customers, who were only product buyers without any alternative products or rival companies, now demand products just in the way they want, and additionally flawless customer service. The traditional CRM models [26] are not sufficient to manage the changes in customer profiles; the dynamic changing structure of consuming behaviors should also be regarded. Since the demands and profile of customers change spontaneously, the enterprise cannot control these changes but can follow and foresight future changes. In order to reflect these two aspects, the main aim of a monitoring system for the customer changes, should not only be following the changes but also leading the changes in customer demands [27]. In order to follow the changes in customer demands, enterprises can measure their success through Keeping Customer ratio by comparing two periods. If the company can sustain its previous customers for the next terms then it is called to be successful to monitor the change. To lead the change, companies should also Get New Customers. It provides the success rate to pioneer the change, by comparing the number of new customers with the previous ones. Finally, for both following and leading the change, sales revenues to existing customers can be analyzed to find out the Growth Ratio. Base on these three metrics the success rate of a company to monitor the changes occur in customer demands can revealed.

E. Environmental Change Stage

Manufacturing systems are totally dependent on the ecological environment in which they are operating. Changes in this environment; such as global warming, climate change, decline of the natural resources would then definitely affect the manufacturing systems. Hence it is required to be aware of the environmental changes when trying to be compliant with the change as whole. In order to continue manufacturing operations, they must Comply with Laws, which are assumed to be revised due to the changes in the environment and can be found in the literature [28]. Complying with the legislations will therefore, ensure adaptation to the changes in environment to some extend regarding the manufacturing systems. Otherwise, manufacturing activities should stop. Even though the manufacturing company obeys the laws and the regulations, it is also important to satisfy the international environmental protection standards (e.g. ISO14001), to indicate the capability to protect the environment. Since the standards are evolving, Comply with Standards may indicate the capability of the manufacturing organization to adopt environmental changes in its operations

Furthermore, manufacturing companies should align its Organizational Structure to environmental changes. To fulfill this requirement, the existence of an organizational unit, which deals with the environmental changes, assesses the changes and makes strategic plans depending on the foresights of the changes, is an important indicator for successful environmental change management. Through performing the Voluntary Activities to protect the environment, not only the environmental change can be assessed more effectively, but also the company can increase the customer portfolio reputation by the Environmental Friendliness. Depending on these four factors a monitoring system can be sustained for the environmental changes.

III. Collective Intelligence

Collective intelligence aims to build up and manage computational intelligence achieved by multiple independent homogeneous or heterogeneous actors in a collective manner. The focus remains on how to develop a satisfactory level of intelligence through harmonised collective bodies. Collective intelligence goes through (i) cognition for addressing individual intelligence, (ii) coordination for pointing out how to create collective behavior and (iii) collaboration for clarification of what information to share and exchange. Thus, collective intelligence could be seen as a synergy achieved among individual intelligent entities with sharing and exchanging individual information and intelligence to accomplish missions, that could not been achieved by each individual participant alone.

A. Multi-Agent Systems

The concept of multi-agent systems is a well-known and reasonably mature collective intelligence approach with which a set of agents act individually and collaboratively for solving problems. The idea is to develop the models in a distributed manner and build a certain level of coordination to let each acting individual efficiently collaborate in solving the problems using their distributed intelligence. Multi agent systems are designed to ease the use of artificial intelligence techniques in a more efficient way in which various independent individual agents are implemented separately to make various versions of a single technique or various related techniques available to tackle the same problem source. This is because it is much easier to implement and develop sole algorithms to handle the problem solving process. Each of the agents harvests its own intelligence out of the algorithm equipped in it. Therefore, every individual agent applies the cognition principle of collective intelligence in this way. This is followed by coordination of the agents, which applies the coordination principle of collective. That is a challenging issue despite of many approaches proposed with being domain-specific [29], [30], [31]. Once the group of agents maintained and coordinated, then, the collaboration will be setup. That is required to harvest the synergy among the collection of the agents, where each one contributes proportionally to their own intelligence. The collaboration is fulfilled with letting each agent contribute once an efficient coordination is managed in one way or another.

B. Swarm Intelligence

Swarm intelligence is linked to artificial intelligence (AI) systems where an intelligent behaviour can emerge as the outcome of the self-organisation of a collection of simple agents, organisms or individuals. Simple organisms that live in colonies; such as ants, bees, bird flocks etc., have long fascinated researchers with their collective intelligence that is manifested in many of the things that they do. A population of simple units can interact with each other as well as their environment without using any set of instruction(s) to proceed, and compose a swarm intelligence system. The swarm intelligence is achieved with managing collaboration among the agents with nature-inspired approaches, which are simulating the collective behaviour of social in- sects in performing specific duties; it is all about modelling the behaviour of those social insects and use these models as a basis upon which varieties of artificial entities can be developed. The behavioural model inspired of social insects implies exploiting simple capabilities of each social agent, which makes up the swarm. The motivation is to model the

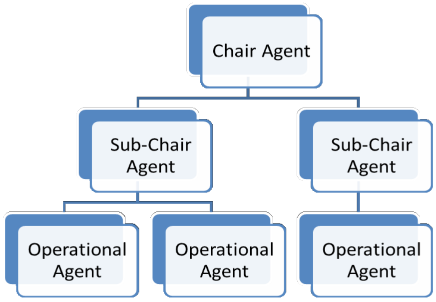

Fig. 2. The hierarchy of multi agent system model

simple behaviours of individuals and the local interactions with the environment and neighbouring individuals, in order to obtain more complex behaviours that can be used to solve complex problems, mostly optimisation problems [29], [30].

Bee colonies-based algorithms are of swarm intelligence algorithms, recently developed, inspired of the social behaviour of the natural bee colonies. This family of algorithms has been successfully used for various applications such as modelling on communication networks [31], manufacturing cell formation [32], training artificial neural networks [33] etc. The main idea behind a simple bee colony optimisation algorithm is to follow the most successful member of the colony in conducting the search. The scenario followed is that once a bee found a fruitful region, then it performs the waggle dance to communicate to the rest of the colony. Once any member of the colony realises that there is a waggle dance performance by a peer fellow, then it moves to that members neighbourhood to collect more food. Inspiring of this natural process, bee colony optimisation algorithms are implemented for efficient search methodologies borrowing this idea to direct the search to a more fruitful region of the search space. That would result a quicker search for an appropriate solution to be considered as a neat near-optimum.

IV. Collective Intelligence for Change Management

As explained in the previous sections, change management is crucial monitoring process for the performance of companies. Monitoring the change is a very fundamental action to be made by the companies in an efficient way. There are approaches brought forward for this purpose in various perspectives, but, there is a significant gap in handling changes in an automatic way. Computational systems are believed that would help in handling this process in a very efficient way.

The collective intelligence aimed to be used is expected of a multi agent system model established for the purpose of monitoring innovation status of manufacturing companies. The architecture is decided to be a tree like architecture, where the agent on the top node acts as the root of the tree. As sketch in Fig. 2, the multi agent system is architecture to work in hierarchical way so as to fit in the structure of monitoring process of the performance of a manufacturing corporate. There are mainly two types of agents taking three different roles; chair agents and operational agents take chair, sub-chair and operation roles, respectively. The chair position is to manage the coordination among the agents fulfilling

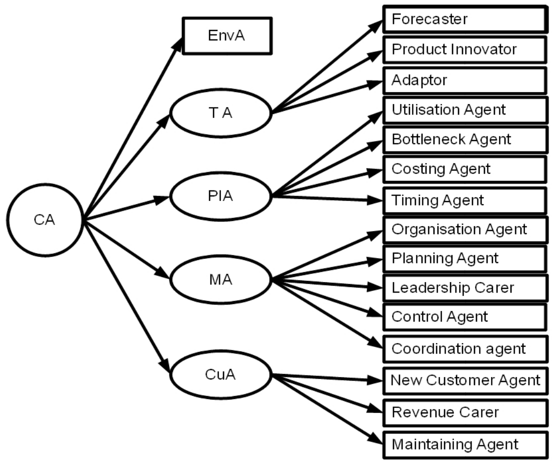

Fig. 3. Tree structure of agents hierarchy for Scenario 1.

sub-chair duties, deployed on immediate next level in the tree, while the operation role is to deliver the duties and to report to sub-chair level.

The root agent is called as the Chair Agent, which aims to organise the rest of the team (tree) to work in harmony and collaborate on purpose and in a timely manner. It also produces the final reports and presents to corresponding stages. The next level of agents consists of four Sub-Chair agents and one Operational agent, as reflected on Fig. 3, where each Sub-Chair agent conducts both some organizational and operational duties. The operational agents are designed to search for relevant information through out of the resources/ infrastructures and produce the information expected from each of them. For instance, the Costing Agent, responsible to the sub-chair called PIA, will gather cost inputs from the information system used by the corporate and will calculate related measures using all functionalities and intelligence built in it.

The entire system consists of 3-layer tree structure in which middle layer includes 1 operational agent, which is called Environmental Agent (EnvA) and 4 sub-chair agents, which are namely Technology Agent (TA), Process Innovation Agent (PIA), Managerial Agent (MA), and Customer relation Agent (CuA). Each of sub-chair agent organises the set of agents under its supervision to deliver the duties, which are aimed to calculate a set of particular measures that described in corresponding subsection of Section 2. The details of each branch of the tree corresponds to each sub-chair is detailed in Fig. 3.

The groups of agents deployed beneath sub-chair layer are the operational agents, which are mainly furnished with information retrieval functionalities by default in order to enable them to search for the information needed through out of the corporate information systems. Every individual agent is also designed with a set of aims and objectives specific to the functionalities embedded in.

The implementation of operational agent level can be organised in two ways. Scenario 1 imposes developing expert agents specialised in functionalities, where each is furnished with mechanisms to handle a particular functionality. For instance, Bottleneck agent is responsible to PIA sub-chair,

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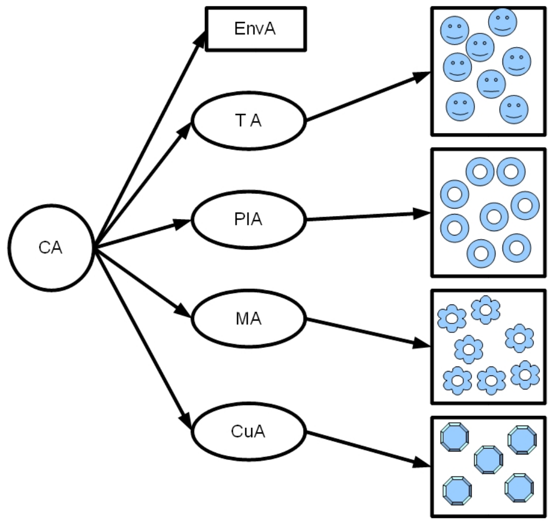

Fig. 4. The agents architecture for Scenario 2.

namely Process Innovation Agent, and is developed to calculate the bottlenecks within the process and makes up corresponding measure to be reported back to the sub-chair in line. Fig. 3 presents the complete architecture of the multi-agent system designed with expert operational agents and organised in a hierarchical tree structure. All operational agents are linked to corresponding sub-chairs and named to highlight the specific expertise built in it. The collective intelligence cultivated and harvested in this architecture originates through the complete tree structure, where the cognition/ intelligence produced by each expert operational agent collected by sub-chairs and finalized by the Chair agent.

Scenario 2 is generated to reflect the second way of organizing the operational level agents. The idea here is to make use of swarm intelligence approaches in coordination and collaboration. Each sub-chair agent is given with a swarm of agents, which are furnished to conduct any functionality needed for each corresponding immediate branch of tree. The architecture of this approach is sketched on Fig. 4. The swarms identify the information needed first and find out the source of this information next. Once found by any member of swarm, the rest is called to fulfil the duties required and generate the measure via a collaborative effort. Bee colony-algorithms is one of well-fitting family of swarm intelligence techniques, which can be implemented for this purpose, where each swarm will be formulated as a bee colony guided by sub-chair agent. The source for information needed to calculate the innovation measure will be digged down by the bee-colony and will be collectively produced and submitted to the sub-chair agent, then will be fed-back to the chair agent. Therefore, a multi swarm approach will be implemented and used to reveal the complete innovation attained by the manufacturing company

V. Conclusion

In this paper, two collective intelligence approaches introduced for monitoring innovation and change of manufacturing companies. The first approach is based on a multi agent system designed in a tree-structured, where expert operational agents are strictly organised under sub-chair agents. This approach imposes deep expertise for each particular operational agent and then makes up collectivism with the role of sub-chair agent. The main advantage is to exploit individual expertise. Once an expertise is not required, corresponding individual agents will remain redundant. The second approach uses a swarm intelligence approach, namely bee-colony algorithm to achieve collective intelligence for monitoring innovation and change across the manufacturing companies. Each member of bee-colony has wide-range shallow knowledge and skills to fulfil the duties in collaboration with the rest of swarm. Once a task is acknowledged by the sub-chair, the whole colony will take part of the fulfilment. Further implementations of this collective computational intelligence model based on various other multi-agent system as well as swarm intelligence approaches will be studied in the future.

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