A DECENTRALIZED PERFORMANCE MEASUREMENT SYSTEM FOR SUPPLY CHAIN

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The growth of the networking possibilities allows extending the monitoring and evaluation processes beyond the walls of a single company to verify the coherence with the global strategy of a supply chain nevertheless diminishing the local control. In this paper we start from the development of the overall architecture of a performance measurement system which reflects the structure of the supply chain under consideration. A preliminary multi-agents model is then discussed enhancing the benefits of such a structure in comparison with traditional systems.

1. INTRODUCTION

A supply chain may have a good measurement system, but unless appropriate action is taken on the basis of the information provided by the measurement system itself, the performance impact will be useless. Furthermore, there are distinct dimensions of performance that have to be measured and managed simultaneously in order to have a global vision of the chain.

The performance measurement systems (PMSs) of the last generation are different from the traditional ones not only because of the different indicators, but because of the way they are used. In fact, usually a PMS have been focused on the financial and economic side of the management giving great importance to the short time targets based on budget problems, and this does not allow the long term vision of the organizations. The new PMSs are strongly involved with customer and worker satisfaction, logistic integration and sustainability of the processes which are evaluated on the same level of importance (Kaplan, 1996).

The PMS of an enterprise has to verify the coherence between the company strategy and the performance of the business units which compose the company. The enterprise has a structure of relationships and integration which should be

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reproduced by the PMS in order to create indicators which operate at different levels of the organization but are linked each other.

More complicated are the relationships in a supply chain where many companies, with many business units, should collaborate and interact, and their performance should be gathered together. The hierarchy in the strategic decisions of the supply chain is due to the fact that the decisions should not be taken with a fully top-down approach with a central decision maker which decides for the whole supply chain. The strategic definition of expanding the business, either introducing a new production line in an existing factory or building up a new factory, should consider also the needs and the requirements of the various plants themselves (Gunasekaran, 2001).

For this reason the strategic decisions should consider also the tactical performances linked to the main issues of the performance evaluation of each single unit involved concerning with cost, quality, delivery and flexibility of their production. Using cognitive maps, cause effect diagrams, tree diagrams and analytical hierarchy processes it is possible to define a performance measurement model for a supply chain (Suwignjo, 2000; Bititci, 2001; Ducq, 2001) where decisions about performance are based on coordination and negotiation activities with a continuous interaction between different levels of the supply chain itself.

Nevertheless some dimensions of performance are non-negotiable and the failure to deliver or adhere to certain standards in one company can result losing power in the supply chain. For the non-negotiable performance dimension the role of the PMS is to ensure collaboration and answer to the requirements of each organization. Ideally, the PMS should be designed to provide an early warning, which makes obvious that unless action is taken, one or more of the non-negotiable performance parameters will be infringed and the whole supply chain can have losses from that.

When considering the negotiable (or co-operation) dimensions of performance the primary role of the PMS is to allow the health of the business to be checked. In this context, measurement enables managers to establish whether the planned actions are being implemented, whether performance is improving, and so far whether the business has a long-term future.

In order to model a PMS for a supply chain, we develop a multi-agent architecture between intelligent components of the distributed system. The focus is on the integration of activities across heterogeneous and decentralized factories and real-time adaptation of the system to environmental changes.

2. THE PERFORMANCE MEASUREMENT SYSTEM

We consider an industrial production environment for white goods where the whole Supply Chain (SC) is composed of many business and productive units geographically dispersed but collaborating in many phases of the production process from the design to the recycling and reuse of the products. We focus our attention on the core of the SC, composed of three main factories producing different parts and components of the compressor for refrigerators.

The management coordinates plants and their innovation process according to the strategic plans (definition of the mission, location of the plants, price policies, production policies,...). To do this, to each plant, or Physical Factory (PF), is associated a Virtual Factory (VF), that is, an environment which allows the

management to test and verify possible solutions before their implementation in the PF (Boer, 1996). The VF and PF co-work on innovation aspects of the production process as defined by the innovation strategy of the SC. The VFs are responsible also for the production planning and scheduling of the production while the PFs have the duty to produce.

The VF has a fundamental role in the management of the SC since it can be considered as a decision support system based on tools such as Activity Based Cost (ABC) models, Simulation, ERP systems. In particular, the VF we consider has a relevant importance in the SC since it helps:

- the definition of the marketing and sales strategies for the innovation process and for the production planning
- the design of production process with virtual reality, CAD/CAM and 3D simulation of modified and new production modules with suppliers support
- the control and planning of the production (ERP, MPS systems)

The PMS is considered as part of the VF at various decision levels (strategic, tactic and operative) and collects on a common platform the indicators coming from the PF and the various modules composing the VF. The performance measurements are so available from different positions of the SC with different access rights to use targets and real values about the performance. Then, the PMS should consider various dimensions of the SC:

- strategic horizon: the system should consider long and short term evaluation of the performance connecting the operative indicators with the tactical and the strategic indicators of the supply chain;
- process horizon: at each level (SC, factories and departments) some fundamental processes should be defined as, for example, production, maintenance, innovation, distribution, etc.;
- categories: each process should be evaluated with indicators based on four main categories, as time, cost, quality and flexibility.

Figure 1 - Performance indicators hierarchy

As turns out from Figure 1, the VF of the SC defines its mission which should be divided for example in strategies of innovation, of production, of market penetration. For each of the strategic goals some performance indicators and their target values are defined. These strategic goals will be divided in tactical objectives for each factory and then in operative indicators for the business units of the companies (departments, production lines, job shops, ...). The relationships are not only top-down but also bottom-up since the monitoring of the business units and of each plant will be aggregated to understand if the targets are overtaken by the upper levels. Furthermore, there are relationships between productive units at the same level, or between factories which influence the performance of each other and can be monitored through internal benchmarking.

Nevertheless the performance measurements are used not only for static evaluation but also for the management of the SC itself since the interactions between the modules of the VFs, between the PFs and the departments are organized according to some particular performance measurements.

3. A MULTI-AGENTS APPROACH

The PMS provides the potential for access by individuals and organizations to information with which they can make better-informed choices when purchasing, producing, innovating goods and services. However, the lack of refinement and imprecision of some existing measurements systems had some major constraints. Most of the time in an industrial production environment the short time monitoring of the productive units collect information from sensors, PLCs, etc. used in a limited way at the operative level and are not used (after aggregation) to be merged with the long time strategic vision of the company itself.

The development of a multi-agents (or autonomous agents) model is providing better access to information and enhancing the ability of manufactures to communicate each other and to negotiate with suppliers and intermediaries.

Since the mid of the 90s, network and system management has steadily evolved from a centralized paradigm, where all the management processing takes place in a single decision center to a distributed paradigm, where management is distributed over a large number of nodes. Some of these paradigms have been around for several years, whereas some of them, based on mobile code, distributed objects and intelligent agents only recently emerged.

The contribution that a multi-agent system can give to a PMS is due to the properties of the agents themselves:

- autonomy: an intelligent agent operates without the direct intervention of humans, and has some kind of control over its actions and internal state
- communication: intelligent agents cooperate with other intelligent agents to achieve their goals, via some kind of agent communication language
- reactivity: an intelligent agent perceives its environment and the actors with which it should interact and responds in time to changes that occur in it
- pro-activeness: an intelligent agent is able to take the initiative to achieve its goals, as opposed to solely reaction to external events.

Regarding to cooperative systems based on multi agent architecture, several topics have to be considered as system architecture, agent structure, ontology

management, communication problems, conflict resolution, legacy problems (Shen, 1999; Swaminathan, 1998).

The multi-agent structure is already studied for the supply chain management at various levels (Chen, 1999; Fox, 2000), and can be based on coordinated agents which co-work together for some specific targets or on negotiating agents where each of them makes a request and bargain over it with the partners. Usually, a multi-agent architecture system can be modeled according to three different structures: hierarchical, supervised, and, non-supervised architectures according to the level of independence and autonomy of each agent.

In a *hierarchical* multi-agent architecture the agents are organized in a level structure where the autonomy of each agent is subordinate to the upper level agent.

In a *supervised* multi-agent architecture we can distinguish three approaches. First, we have a facilitator agent for a given group of agents. The communications between groups are performed by the facilitator agents that manage the outgoing messages routing and translate the ingoing messages for their own agents. Similarly to the facilitator, in the second case we have a broker agent that have additional functionality. In particular, the broker agent can be contacted from every agent with the aim to identify supplier agent of the requested service. Finally, the mediator agent approach increases the functionality of the facilitator and the broker agents assuming the role of system coordinator and promoting the cooperation between the agents.

In a *non-supervised* multi-agent architecture, each agent is characterized by the following properties: it is not managed by other agents; it can communicate with other internal or external agent; it has an internal knowledge base about other agents and the external environment; it has a set of local constraints and objectives to reach.

The performance measurements can be used as part of the multi-agent architecture for the negotiation or the collaboration of various agents of the VF where their relationships are managed by the values of specific indicators. The system we want to consider is more concerned with the performance measures themselves. The agents of the VF contain performance measurements which are used for many reasons:

- to evaluate the SC in a integrated and uniform way
- to help negotiation in the sales and purchasing conditions with the external customers and suppliers
- to help collaboration between the factories belonging to the SC.

3.1 A Multi-Agents Approach to Performance Measurement System

A multi-agent structure can be implemented also for the PMS because it permits to organize the SC in many relatively independent agents: this is possible because the structure of the chain is based on modularization.

In our model each VF of the factory (PF) is represented by an autonomous agent (or factory agent), and there exists a supervisor agent, or SC Engine (SC Eng), that provides the SC management with the strategic indicators, monitors the market opportunity and manages the relationships between the SC and the external suppliers. The SC Eng is the mediator agent of the supervised multi-agent

architecture because it co-ordinates the factories network on the basis of the data and indicators aggregating them in strategic level indicators.

Figure 2 shows the communication links between the agents. Each autonomous agent contains evaluation, optimization and decision support tools, in order to take decisions at different level. At a strategic level the SC Eng takes decisions for the whole SC giving targets on the structure of relationships, on the distribution system, on the market share to reach, etc. At the tactical and operative level the factory agents decide the level of production, the delivery plans, etc. However, the tactical decisions are subjected to the strategic constraints provided by the SC Eng.

The overall architecture of the system is based on dynamic information exchange since the SC Eng continuously monitors the data bases to have the real-time updating of the indicators so to take the appropriate actions for further improvements on the system (Kalakota, 1995).

For example e-commerce systems makes suppliers and customers to rely more and more on automated processes to handle the purchasing process. Many real-time auction systems, goods pricing systems, or monitoring systems have autonomous features as well as tight constraints on when and how they can execute specific tasks. These types of applications could benefit from multi-agent system of performance measurements in which agents communicate, coordinate and negotiate to meet their goals within specified timing and quality constraints (DiPippo, 2000).

Figure 2 - Multi-agents model for the strategic level

For example in the relationships with the external supplier such a system might be employed to monitor goods pricing to look for certain changes in the market, and report on these changes within a deadline. The monitoring agent can send alarms to the marketing and sales environment of the VF so that specific actions are taken on human or automatic base using other tools of the VFs.

The SC Eng deploys the performance measurements not only for managing internal relationships (coordination of actions at various hierarchical levels, coordination of actions at the same levels) but also for the management of the

external relationships with suppliers, customers and competitors (negotiation of actions to be taken based on performance parameters). Moreover through the SC Eng, the VF can monitor long term trends in the market that might interest the innovation agent and it notifies to them.

The importance of introducing such a structure based on autonomous agents is due to the freedom that each factory has in managing its own business without overtaking the guide lines given by the SC management and by the external environment trends.

The proposal approach allows us to have a PMS which is:

- modular, so to reflect the structure of the supply chain which is composed of many independent units;
- shareable, so that from each plant it is possible to see what happens in the other plants;
- with homogenous indicators, which consider the needs of each plant;
- in real time with indicators, which are renewed in a short time;
- coherent with the objectives of the strategic decisions, to ensure that goals reached by local performances allows the achievement of the global ones assigned to whole SC.

4. CONCLUSIONS

We have presented a framework model based on autonomous agents to dynamically control the SC strategies through virtual factory. The proposal approach is built upon global interconnection of different companies, where each of them handles specific tasks. Since a supervisor agent continuously monitor all activities of the SC, a quick response will be possible increasing the efficiency of the system.

As future work, this architecture will be used to create the complete model for the PMS also for the tactical and operative levels. It will be integrated in an overall supply chain management system in which the decisions of the autonomous agents are based on indicators and are tested in a virtual factory environment before implementing them in a physical one. Moreover we will compare our system with others already available in the market.

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