Proc. of the International Conference on Advances in Mechanical and Automation Engineering - MAE 2016

ISBN: 978-1-63248-102-3 doi: 10.15224/ 978-1-63248-102-3-45

Application of multi-agent system for information flow integration in manufacturing company

Case study

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***Abstract*— Case study of distributed multi-agent system application in manufacturing company information flow integration. Company structure is reflected in set of agents responsible for activities specific to organizational units. Agents interconnect diverse IT systems and integrate information from them, basing on asynchronous message passing communication. Findings: multi-agent systems are analogous to actor model, can work on top of existing IT solutions, utilize power of cloud computing and solve real information flow problems in enterprise applications, assisting in decision-making with high-quality integrated information.**

***Keywords*— multi-agent systems, distributed systems, business management, process engineering, message passing**

I. Introduction

Currently, many manufacturing companies are in the transition from having multiple, independent processes and relying on traditional communication means, like emails and phone calls, to integrated enterprises that can benefit from synergies between different organizational units and business processes and manage issues and risks flexibly. This transition is caused by a common conviction, that information technology may significantly improve the overall company business performance and this effect gets stronger as company grows.

The development of software and telecommunication solutions gives means

Well-developed telecommunication infrastructure and distributed software technologies give solid foundation for companies to implement solutions that integrate all aspects of their operation. The challenge is to make use of IT solutions that already exist in companies, instead of revolutionary developing everything from the scratch. Agent technology may come as a solution to this challenge, as it may operate on top of existing IT systems.

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This paper presents an example of the organization of the manufacturing company and proposes a solution based on multi-agent technology.

II. Theoretical foundations

A. *Multi-agent systems*

The multi-agent systems may be defined as distributed systems, that are based on cooperation of multiplicity of agents. An agent is a program in computer system that is installed in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives [1].

Authors of [2] points out that in multi-agent system all agents jointly act to solve problems which are out of capabilities and knowledge of each particular single agent. This approach improves performance, because each agent is focused on a subproblem with a lower complexity. Also the quality of the resulting decisions is improved, because cooperating agents can together utilize a broader range of knowledge.

In [3] the agent is defined as a background process, that takes some actions on specific events. In the Internet environment the agent is an element of system, that typically resides at user workstation and ingests information on state of this user, then sends this information to management system.

According to [4], agents commonly features with

- Observation - agent perceives dynamic properties of environment in which it operates
- Autonomy - Agent may take actions independently from other agents, it operates in dynamic environment where its ability to communicate with others can be impaired, e.g. because of Internet connection down
- Communication - Agent communicate with user or other agents, accepts tasks from them and notifies progress and completion
- Mobility - Agent cooperate with other agents while dynamically adjusting its actions to actual environment conditions
- Intelligence - Agent interprets events and adapts its decisions on its further actions to achieve its goals

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Depending on the access to the specific knowledge, each agent is programmed to perform different activities. Due to their functions, they can be divided into:

- interface agents - agents supporting employees in their tasks,
- information agents - agents searching and transmitting the required information,
- monitoring agents - agents monitoring selected processes and responding in real time,
- task agents - agents performing specific tasks,
- broker agent - agent routing communication between other agents and enhancing their functionality,
- proxy agent - agent intermediating in communication between other agents.

Multi-agent technology found its application among in energy systems [5], e-commerce [6], troubleshooting of transportation market [7], logistics systems [8]

Communication between agents is based on specific IT protocols. Taking into account the autonomous and asynchronous characteristics of agent operation, the message passing pattern is the approach of choice.

B. Actor model

The multi-agent system can viewed as a distributed environment of simultaneously operating entities - agents, each with specific behavior, capabilities and responsibility as well as types of stimuli it can react on - signals and events it is able to handle. Such stimuli may alter the behaviour of the entity. These entities collaborate by exchanging messages. Additionally, some entities in this distributed environment supervise operation of other entities and may be able to instantiate new ones.

Such characteristics of the multi-agent system match fundamental concepts of actor model [9] which is a mathematical model of concurrent programming. According to this model, an actor is a programmatic entity, which in response to messages can change its behavior, create finite number of actors, send finite number of messages or stop operating.

The actor model computing is gaining popularity together with functional programming paradigm, as it helps splitting complex computational problems into smaller, well-defined pieces[10]. This results not only in cleaner software architectures based on elegant mathematical foundations[11], but also in computational performance improvements. Actors communicate with each others by message passing, thus they are highly decoupled. An actor can be easily replaced by another one in a running systems, without a need for discontinuing its operation. The decoupling by asynchronous message passing also helps solving subtle concurrent programming issues, like dead locks, exhaustion or starvation: as behavior of an actor is encapsulated behind message queues, they share no common state (shared-nothing architecture) and never have to synchronize their accesses to such state variables.[12]

In the message-passing based communication scheme, there are no traditional request-response transactions between actors. Instead an ask pattern is commonly applied. When some actor in its operation needs some information from another actor, it sends a message to that actor asking for the information. Then, instead of waiting for a response (as it was in the request-response pattern), this actor continues its activity - processes further incoming messages. Meanwhile, the actor which received the ask-message, computes the information it was asked for, and sends it as a message to the asking actor. Finally, the asking actor will encounter this message and processes it as it was designed for.

For reasons described above, the actor model may be a useful way to implement multi-agent systems. There exist many solutions realizing such paradigm. Erlang programming language concurrency model is based on actors. Akka is a dynamically evolving actor framework for Scala and Java. Other major software technologies offer libraries for actor programming: Pykka for Python, Actor Framework for Windows Azure, ActorKit for Objective-C, Haskell-Actor, etc. Also some trends observed in cloud computing technologies fits in the actor programming model, including AWS Lambda, Google Cloud Functions and Azure Functions. Such products may constitute a basis for cloud agents.

III. Problem statement for an agent system

Analysis was conducted for an exemplary international manufacturing company, which operates in the B2B model. It has a distributed structure with location in many premises, which is caused by optimization of costs of production of goods and access to intermediates.

A. Manufacturing company – case study

The company have implemented many IT systems, separated per locations and organizational structure units. On the top level, the information is shared between units in form of emails and periodic report documents; EDI is used seldom.

The analyzed company consists of Top Management, Analysis Department (Internal Analysis Department, Market Analysis Department), Sales Department, Manufacturing Department (Production process designing, Production, Quality control), Procurement Department, Storage Department, HR Department, Finance department and Distribution Division Department.

Top management combines the entire structure. The employees of this department take strategic decisions related to the functioning of the entire company. Based on the data from the Analysis and Finance Departments, global decisions are taken as to the planned production, employment levels, quantity, quality or the location of a branch office, and so on.

Analysis department is divided into two units. The department of internal analysis collects and analyzes data related to production, quality, human resources, cost

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effectiveness of implementation of innovations proposed by the R&D. Unit of external analyses studies the market using benchmarking tools, seeks to capture and describe the trends prevailing on the market. In addition, it examines the level of satisfaction of the existing customers.

Sales department is responsible for the acquisition of new orders and servicing of the existing accounts. They change, though, both in terms of quality and sales volume, depending on variations in demand associated with the seasonality.

Manufacturing department is responsible for the production of the offered assortment. This department is divided into units designing and adapting the production line, units responsible for the production and units responsible for quality control. Inside their own structures, it is also responsible for handling events related to issues arising in the course of production (equipment failures including).

The main task of the Procurement Department is to provide the manufacturing department with raw materials and intermediates. As part of its activities, this department is responsible for obtaining new suppliers (eg. in a situation where there is a need to increase production or its alteration as well as to diversify sources of supplies), and also for negotiating prices. Moreover, the department also fulfill orders of other departments.

Storage department is responsible for the storage of semi-finished products and raw materials for the production, and the prepared batches of goods to handle contracts.

HR is responsible for ensuring and optimizing human resources for the enterprise to function properly. This department should react in situations of changing demand for production workers and should maintain employment for specialist positions. It is also responsible for providing and maintaining an appropriate level of qualifications of employees. The department also conducts analyses related to the performance of both individual employees and business units based on employee evaluations.

The finance department is responsible for the control of financial condition of the company. On the basis of the obtained analyzes and orders, it allocates funds between various divisions and departments of the company.

The company does not have an extensive distribution department. To optimize the cost, distribution is outsourced instead. This department is responsible only for cooperation with carriers.

B. *Manufacturing company – problem identification*

The company suffers insufficient information flow between departments. Human factor is a cause of erroneous data. This causes suboptimal decisions taken on many management levels up to strategic planning and risk management, making it hard to achieve expected business performance. Poor communications additionally undermines staff morale and causes rotation of employees, resulting in temporary deficiencies of qualified workers. Furthermore, inefficient communication between Storage, Manufacturing and Procurement Departments cause severe wastes of resources, such as raw materials and storage space.

IV. The proposed solution

The extensive organizational structure of the analyzed company enforces implementation of a distributed IT solution. It shall base on existing, stable IT infrastructure on company premises and should also have enough capabilities to assist the staff in decision-making processes at different levels.

A. *Agents definitions and responsibilities*

In the proposed solution each department has an agent responsible for collecting, processing and sharing information.

Depending on the access to the specific knowledge, each agent is programmed to perform different activities. Due to their functions, they can be divided into:

- interface agents - agents supporting employees in their tasks,
- information agents - agents searching and transmitting the required information,
- monitoring agents - agents monitoring selected processes and responding in real time,
- task agents - agents performing specific tasks,
- broker agent - agent routing communication between other agents and enhancing their functionality,
- proxy agent - agent intermediating in communication between other agents.

1) HeadquarterAgent

HeadquarterAgent supports Top Management in taking strategic decisions. It provides information on occurring business events and proposes ways to handle them. It calls the AnalyticsAgent (information agent), which, in response, returns the reports on key performance indicators (KPI) of the company, including the results of the Analysis Department, information on production, quality of the manufactured product range, performance of human resources and financial reports of the company.

The decisions are communicated to the other departments also with the use of this agent, which assigns tasks, and thus, sends the appropriate requests by the DispatcherAgent.

2) AnalyticsAgent

AnalyticsAgent is an interface agent which aggregates information from other agents and supports the work of the Analysis Department. It collects information needed to prepare the internal analysis of the company, including sales analysis, prediction of the volume of production (including the demand for semi-finished products), taking into account the recoil on the basis of data from the Quality Control Department.

3) InventoryAgent

InventoryAgent is a monitoring agent, which aims to support the company's Storage Department. It controls the inventory and is responsible for communication with both SupplyAgent and LogisticAgent. In both cases, the

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communication is performed indirectly through Dispatcher Agent. To maintain continuity of production, InventoryAgent receives information about the planned production volumes at specified time intervals, and the foreseen amount of semi-finished products to be stored. The problem of storage of manufactured products which must be stored until their collection by an external company was solved in a similar way.

4) LogisticAgent

LogisticAgent supports coordination between the company and third party carriers (interface agent). It is designed for the needs of the Distribution Department.

5) SupplyAgent

Supply Agent is an interface agent supporting the work of the Procurement Department. It is designed to respond to the demands filed by DispatcherAgent on behalf of i.a. ManufacturingAgent and referring both to production (necessary intermediates) as well as to the company's other departments. It processes information on the planned investments and the planned budget, as well as supports staff in the implementation of these plans. It also supports activities referring the current operation of the company (office supplies, etc.)

6) HumanRecoursesAgent

Human Resources Agent is a monitoring agent which is supporting activities of the HR department. It is designed to respond quickly to situations occurring in the current functioning of the company. One of its common task is to find a smart replacement for an absent employee. In addition, it analyzes the level of qualification of the crew at all organizational levels and informs the need for carrying training or for starting the recruitment process for positions requiring specialized skills. In the case of organizational changes, resulting from e.g. the change in the production profile or the withdrawal of certain technologies, it tries to determine whether an employee can be valuable for another organizational unit.

7) FinancialAgent

Financial Agent is an interface agent that is designed to actively support the company's Finance Department. This agent analyzes the current financial condition of the company. Its main task is to prepare the financial reports of the company (financial statements, balance sheets, cache flow reports, etc.). Additionally, it supports the staff in the Finance Department in defining the financial liquidity of the company, determining its investment opportunities and the allocation of assets due to the planned investments or the increase in employment.

Due to the numerous responsibilities of this department, it is also supported by additional agents.

8) SalesAgent

Sales Agent is a mobile agent supporting actions of the sales staff. The agent informs them about the statuses of orders, possibilities and time limits for potential new orders and inventories status.

9) ProductionAgent

Production Agent is an intermediary agent and is designed to support the manufacturing process. It is the only production agent which communicates with the rest of the system.

The Production Department is relatively autonomous and has the authority to control the entire manufacturing process. It is responsible for the design process, adapting technological solutions, production itself, quality control, and event handling. The presented solution had to be adapted to the department's operation model. Accordingly, a division of supporting agents has been designed:

- DesignAgent (interface agent) - a smart agent supporting the production design process, including modelling of the production line,
- QualityAgent (monitoring agent) - agent monitoring all stages of quality control; on the basis of information collected, it creates statistics and reacts in case of any deviations from the defined standards,
- ProcessAgent (monitoring agent) - agent responsible for the control of the production process; its task is to immediately inform the ProductionAgent of any issues and to determine their causes,
- TaskAgent (task agent) - agent for orders queuing.

Supporting agents have a convenient possibility to communicate with each other and, in some relationships, to control each other (as a reaction to events during the monitored processes).

B. System conceptional project

In the top level design, the agents communicate with each other via a dispatcher agent, which resides in a very core of the whole multi agent system concept. It acts as a message broker and router, that other agents directly or indirectly communicate with. The main responsibility is to direct information to appropriate recipients. Dispatcher agent may also activate other agent when it is requested.

With such approach the details of the multi-agent system structure, i.e. existence of receiving agents, can be hidden from the agents that issue messages. E.g. when production agent encounters an event that have to be communicated to other agents, like exhaustion of some raw material, then it only sends a message to the dispatching agent, instead of notifying InventoryAgent, SalesAgent and ProcurementAgent, which are interested in receiving such messages (Fig. 1). This approach simplifies design of many agents in the system.

The DispatcherAgent responsibility is to maintain information on other agents that exist in the system and their willingness to receive various types of messages. Therefore the dispatching agent plays a supervisory role with regard to other agents.

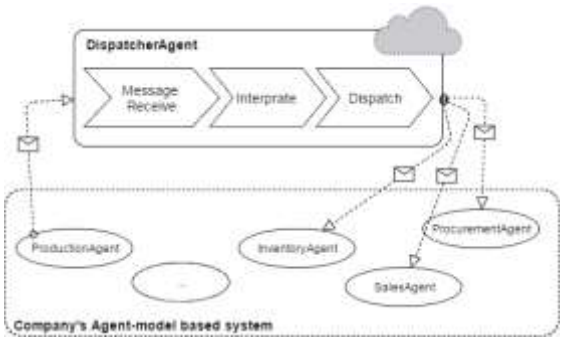

Figure 1. Example use case for DispatcherAgent

ISBN: 978-1-63248-102-3 doi: 10.15224/ 978-1-63248-102-3-45

To make the DispatcherAgent scalable, higly available and premise location agnostic it is deployed in a cloud infrastructure. Thanks to this, the DispatchingAgent can directly benefit from Big Data capabilities of the cloud computing, furthermore these capabilities are also exposed to all other agents (indirectly).[13]

V. Summary

The multi-agent technology can satisfy requirements of the manufacturing market. It can integrate with existing processes, collect and analyze data, and thus, facilitate decision-making at various levels. It can also detect problems and suggest solutions not only within its own environment.

The multi-agent technology can be scaled horizontally and vertically. Within the described technology, there is no need to rebuild the entire system. Due to the autonomy of actions, the agent can be created independently of the other existing agents, including even other runtime environment, whereas it can communicate with the whole system on the basis of specific protocols used by its supervisor.

Multi-agent systems can naturally be implemented with actor model, taking advantage from its conceptual simplicity, concurrent performance, flexibility and maintenance ease. It is easier to manage a larger number of small, well defined actors, than a cumbersome monolithic system with complex transactional semantics spanning across distributed environment. Such an infrastructure enables the disconnection of an unnecessary agent or its modification and adaptation to newly arisen requirements at a relatively low cost. Despite the advantages of its capabilities presented in the article, the technology is not free from drawbacks. Still, this is an expensive technology both at the stage of development and deployment at various levels.

In the described application the multi-agent technology helps company in integrating information flow and management, as well as improve information quality by eliminating human factors. This technology also enabled company to keep the IT solutions which were implemented beforehand, so the well established business processes could run smoothly during transition period and the existing infrastructure could still be monetized.

As multi-agent systems are distributed by design, its parts can naturally be deployed in cloud environments. The benefits are in scalability and high availability of cloud-based deployments and significant savings in infrastructure costs are not uncommon. Implementation of agents with actor model fits in specifics of cloud environments. Therefore the multi-agent systems give an additional advantage of complementing on-premise solutions with cloud computing[14] and big data technologies[15].

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