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Real-Time Business Intelligence in Multi-Agent Adaptive Supply Networks

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Abstract

The increasing speed and complexity of inter-organisational communication in supply networks requires effective automation. Multi-agent systems have been proposed as a possible solution. However, the information needs of the agent, particularly in responding to any variation from the norm, are similar to a human in the same position.

This paper reviews the concepts of Business Intelligence (BI) and Real-Time Enterprises (RTE) and looks at the need for BI in dynamic information management. A multi-agent framework is described and case-based reasoning investigated as a reasoning paradigm capable of responding to the need for business intelligence. A CBR approach is proposed with Key Performance Indicators defining the case problem and BI operations the case solution.

1. Introduction

The traditional supply chain assumes a regular and virtually linear flow of information and materials from raw material source to customer. With the increasing speed of information movement this has been extended to a supply network concept with multiple sources and destinations.

Agent-based approaches have been put forward for supply chain management e.g. [1,2,3,4]. This paper will discuss the information needs in an agent-based approach for intelligent automation of inter-organisational interaction in the supply/demand network. At an operational level this information will relate to the management of a specific transaction e.g. in purchasing there will be information on order size, due date, etc. At a planning/informational level, information is needed to select specific trading partners, monitor trends in specific product classes, identify declining margins, etc.

Any organisation will have some history of dealing with problems relating to orders and perturbations in the network and solutions applied, as well as formal processes for dealing with these. Agent information can come from a variety of sources, including analysis of historical information at the informational or planning

level. In traditional management, the use of key indicators and performance metrics based on historical analytics is considered business intelligence. In a real-time enterprise, collection of information and use of the analytics needs to move to a real-time business intelligence environment.

2. Business Intelligence

Despite the technology being available since the late seventies, it is only in the last decade that business intelligence has moved into mainstream business conscience, helped in part by the increasingly competitive business environment.

The focus in BI has traditionally been on analysis of cleaned historical data in a data warehouse that is updated periodically from operational sources e.g. daily, weekly or monthly. The data is largely static and updating is usually scheduled for low use periods. The data warehouse is quarantined from the operational databases.

The increased use of the web and interactive business has driven the need for web site analysis, including click-stream analysis and real time response, which has led to increased interest in real-time business intelligence. Given that traditional BI has usually relied on batch updating, at best daily, "real-time" has tended to be considered as anything better than that. The Data Warehousing Institute notes "it is more practical to focus on "right time" than "real time"" The terminology is further confused by the concept of Business Activity Monitoring (BAM) which refers to the automated monitoring of business-related activity affecting an enterprise. Some vendors refer to BAM as Real-Time BI while others separate the issues. BAM applications monitor and report on activities in the current operational cycle.

3. The Real-Time Enterprise

The real-time enterprise (RTE) (Gartner [5]) essentially describes an organization that applies technology to reduce the gap between when data is recorded in a system and when it is available for information processing. The aim is to get relevant information into the hands of decision-makers (or decision making agents) as soon as possible. If one views

Δt as the time difference between initiation and completion of information processes, the RTE is attempting to reduce this gap to zero i.e. $\Delta t \rightarrow 0$.

In order fulfilment, it is typically called cycle time and represents the time difference between submitting an order and receiving the order. In industrial engineering, it is the cycle time between 2 discrete units of production. In manufacturing, it is the throughput time from when material enters a production facility to when it exits.

As with “real-time” business intelligence, a “real-time enterprise” does not necessarily operate in genuine real-time and often uses the same “within a day” measure to be as good as real time. If the data is received within adequate time to respond to the event it could be considered effective. The “adequate time” will, of course, vary from product to product and industry to industry. For high volume production industries, adequate time is typically hours or days but it may be as small as minutes e.g. bottle-top manufacturing, or beer production. For very low production industries, adequate time is usually measured in weeks or months but it may be as large as years e.g. ship building and highway construction.

4. Using BI for Dynamic Information Management in Real-Time Enterprises

A successful real-time enterprise (RTE) needs the ability to learn and adapt reasonably quickly i.e. it needs to be able to determine new trends, identify deficiencies and problems, adjust supply network needs and adapt to new business conditions. A real-time enterprise will need business intelligence based on real time data. However even current real-time BI products assume that the consumer of the information (the decision-maker) is human. Current research in multi-agent systems for supply network management suggests the need for real-time BI for agent decision making. The use of RFID’s (Radio Frequency Identification tags) adds another

dimension to the need for real-time intelligence data. With intelligent products in the supply network, agents will need to be able to respond on the basis of real-time location information.

There are a number of critical metrics for managing supply chain and supply network performance e.g. Demand forecast accuracy, perfect order fulfilment, supply chain cost, and cash-to-cash cycle time [6]. The bigger picture also needs to be considered e.g. for sales analysis a company needs to know customer, product and time profitability. From a marketing perspective, it needs to know where to focus its efforts. There must be some assessment of agent effectiveness for agents in the supply network (whether human or not) i.e. a suitable set of metrics is needed to evaluate performance.

All of these require access to BI based both on current and historical information that essentially defines the context in which the agent can operate. It is likely that each enterprise would retain its own BI system and it would probably be most effective if all its agents could access a single centralised copy of this information. The system would be updated in (at least) near-real time as the drive to reduce Δt to zero continues.

5. A Multi-Agent Model

A significant number of multi-agent systems (MAS) approaches to supply chain management have been proposed in the last decade (e.g. [4,7,8]), although actual working applications are few. The IBM Research Sense and Respond (SAR) Blue Enterprise model [8] is probably the closest research to our model below.

Figure 1 gives a model of our MAS approach to supply network management. This model and the use of case-based or experience based reasoning (CBR) in the agents has been described in [9]. This model distinguished buyer agents and buyer manager agents. *Buyer agents* control the interface between an organization and its suppliers, with each of the buyer

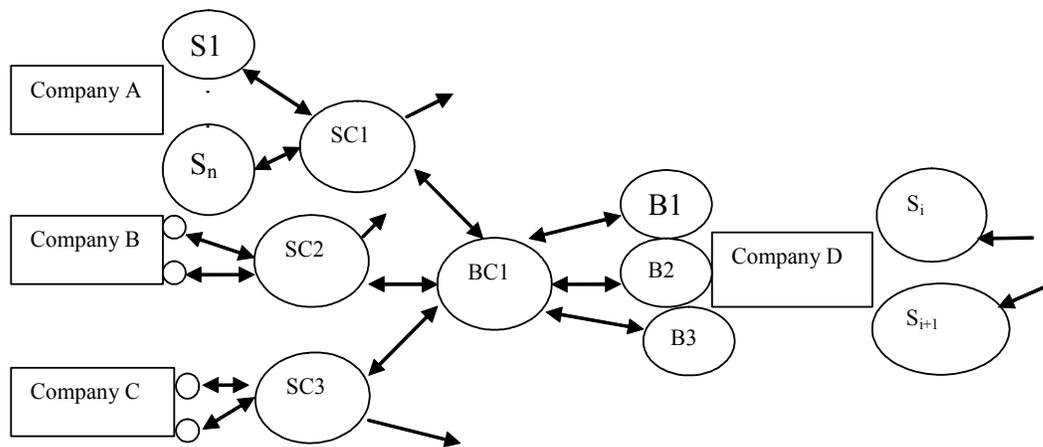


Figure 1: Multi-agent cooperation and negotiation in a supply network

agents using CBR to provide intelligent processing of supply needs on the basis of prior experience. A *buyer manager (control agent)* coordinates and controls the activation and operation of the buyer agents utilizing CBR. It also uses CBR to select a suitable strategy for finding all components required for a particular product i.e. it will review or revise the bill of manufacture, decide on suitable suppliers and set up agents to control the interaction with each supply agent.

The model can be extended to allow agents to extract relevant decision support information from a BI system as well as provide real-time updates for the BI system. Which level of agent needs to utilise BI information? Buyer agents are intended as relatively low level controller agents that effectively monitor the buying activity with a particular supplier. Supplier agents serve a similar role. It is likely that the buyer and supplier managers (as one would expect in their human counterparts) would utilise and modify BI. In order to reduce the complexity of the manager agents, it might in turn be necessary to subcontract the analysis of the BI to specialist BI agents.

With the trend towards real-time enterprises, there is a need not only to deal with shorter response times but an increase in complexity with the growth of the supply network. It is no longer possible to deal only with suppliers and customers but an RTE needs current information for suppliers of suppliers and customers of customers. This complexity needs automation and intelligence. A MAS system must be capable of dealing with networks of arbitrary size and complexity.

6. The Role of Learning in Real-Time BI

The use of business intelligence by human users requires the application of learned skills i.e. which models to apply, which dimensions of data to consider, etc. If business intelligence is to be used automatically in an agent environment, it will be necessary to include the capacity to learn which aspects of the business intelligence toolset are to be used for a particular class of problem.

Case-based reasoning is a practical subset of experience based reasoning which learns by recording past cases and attempting to reuse past experience when faced with a new problem. As an example, consider metrics of supply chain costs. If a human agent detects an unforeseen rise in costs, they would normally do several types of analysis e.g. is this part of a trend, what is the cause (possibly with some multidimensional analysis), is this likely to be temporary or should the costing of the product be reviewed, etc? A similar response would be required irrespective of the specific components involved. A human agent would normally learn the most successful forms of investigation from experience and training.

In the system outlined in Figure 1, a buying agent for a company will notify the buyer agent manager of a

specific transaction. The agent manager checks whether this transaction is any cause for anxiety e.g. is there a longer term trend to increased prices or is the margin for this specific product becoming eroded relative to others in the product class. This might require some multidimensional analysis and drill-down to establish a cause.

Initially it would be expected that such systems would be predominantly advisory, retrieving a probable sequence of action to be followed by the human analyst. As the move towards a genuine RTE increases, this type of operation would be increasingly automated with certain safeguards and limits built in as well as requiring occasional human intervention for difficult cases and updating of the case base.

For example, assume a company puts together subassemblies with a number of components sourced from several countries. With a fluctuating but steadily weakening exchange rate, these components become more expensive. However the impact of changes might not be immediate, although the cumulative effect should eventually trigger some action. This type of situation is difficult to track looking at single events as they occur. A better (in the sense of more informed) decision can be made by including the historical context.

A case is a set of factors or metrics describing a specific problem scenario and a solution consisting of a set of operations to try to identify a cause. A Key Performance Indicator (KPI) is a measure designed to track a critical performance variable over time. Example KPI's could be in functional costs (warehousing, transportation, inventory, etc.), or channel costs (institutional, retail, mass merchants, government, etc.) Actual metrics would be the specific costs, proportions, preset limits and others.

KPI's are considered to be of two types: lagging indicators which are typically financial and show how the organization has performed in the past and leading indicators which show how the organization is performing now. Obviously in an RTE we are concerned with leading indicators. A particular KPI will trigger a specific type of response. Case based reasoning (CBR) provides a possible means of automating this response.

CBR is similarity based reasoning i.e. for a specific problem, it performs a similarity based match on the KPI's and retrieves those cases that are most similar to the current scenario. The cases can be generic i.e. applicable to a specific product class or all products. The solution for any similar case would be a sequence of analytical operations e.g. a trend analysis of key components, a slice and dice view of the product inputs to identify key cost variances, etc. The output may be an information presentation for review by a human or may trigger an automated response – the extent of automation will be defined by a specific RTE.

7. A Case Base for Business Intelligence

As an example, a set of KPI's might relate to deliveries and orders per company. If one or more of these is triggered by a specific order transaction, it would in a human driven real-time BI or dashboard situation suggest the need for analysis. A human operator would normally do some analysis such as historical trend of dealings with the company and an analysis of total dealings with breakdown by category, critical status and location. This in turn might suggest a review of alternative suppliers or a negotiation of a longer-term contract.

A specific set of KPI's might be

- Delivery on time
- Delivery in Full
- Delivery on time and in full
- Out of stock frequency (material)
- Production service level

Processing of a particular order may show that the percentage of perfect orders (on time and in full) has dropped below a critical point for a particular supplier. A search of the case base for similar KPI cases should retrieve one or more similar cases i.e. past responses to a variation in the KPI. Taking the most similar case might give a particular sequence of information requests e.g.

- Trend on orders for this supplier over time (which require consolidation of orders for the customer)
- Comparison to other vendors of similar products
- Variance report on difference from agreed norms
- Slice and dice to identify location of problem e.g. a particular distribution centre or production facility.

If there is no similar case it will be necessary to request human intervention. Once a specific response has been determined, it is entered in the case base as a new case.

The level of automation of response will depend on the level of trust by human operators. Initially it would be expected that such a system would act in a predominantly advisory role. However as the speed and complexity of information flow increase the response will need to be increasingly automated i.e. following the trend of $\Delta t \rightarrow 0$.

8. Conclusions

Demand networks in a real-time world will increasingly need to operate as intelligently managed systems. Although the use of agents has been fairly widely proposed and a number of models put forward, the type of information which will need to be utilised by the agents has usually not been considered beyond automation of conventional transaction management.

This paper has considered the trend towards real-time enterprises with the consequential rise in speed and

complexity of information flow. To operate in this environment, agents will need to move beyond operational responses to applying planning and control information. We are proposing that such agents will increasingly need the type of information which is becoming more widely used by human managers i.e. business intelligence.

Intelligent agents operate with several paradigms of intelligence, including case based reasoning. We believe that CBR offers a useful tool to capture the BI framework and are investigating this approach in an experimental environment.

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