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# A Model for Global Material Management using Dynamic Information

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## ABSTRACT

The supply chain is a world-wide network of suppliers, manufacturing plants, warehouses, distribution centers, wholesalers and retailers where raw materials are purchased, processed and transformed to be sold to customers. Customer satisfaction is highly dependent on the flexibility of the supply chain such as its ability to respond to changes in demand.

Supply chain management (SCM) is currently mainly based on older information retrieval methods. It doesn't take advantage of the 'dynamic' information that is now available due to developments in information and communication technology (ICT) and knowledge management (KM). Consequently, there is a disparity between what is being done and what can be done through the supply chain.

This disparity can be eliminated in supply systems in the future by using the newly available dynamic information that will allow better synchronization of materials and resources flowing through the supply chain. One such system is an updated version of SCM, termed, for the purposes of this paper, Global Materials Management (GMM).

## Keywords

Supply Chain Management (SCM), supply chain networks, Dynamic Information, Real Time Enterprises, e-business, ERP.

## INTRODUCTION

Supply chains and supply networks can be of arbitrary size and complexity. In an e-business environment, enterprises must be capable of rapid reaction in response to dynamic information relating to any changes in constraints or conditions; they must be able to react quickly and flexibly to respond changes in the supply chain (McClellan 2003). Currently, most, if not all, entities in the supply chain use static data such as supplier lead times, factory lead times, and customer due-dates (Lim 2000). These static times are usually statistical averages and have only the appearance of being stable. In reality, these times are usually not stable because situations change and consequently the information changes.

As an example, consider the case of a previous client, a lighting manufacturer whose customers are builders of office blocks (high & low rise), houses or home units. A particular builder may be erecting a 20-storey office block and requires ceiling lights for 2 storeys so an order is given to the lighting manufacturer for the required quantity of lights and a particular due-date. What happens if the construction of the office block falls well behind schedule? If the lights arrive on the due-date, they won't be able to be installed. Instead, they will have to be carefully stored until needed at a place where they won't be damaged. In this situation, the builder might want to move the due-date later. Similarly, if the construction was well ahead of schedule, the builder would like the lights delivered earlier.

Supplier lead times and factory lead times are similarly dynamic in reality because some lead times and due-dates may be shortened and some may be lengthened (Kamalini and Speakman 2000). The changes may be offsetting but currently, no indication is given as to whether or not they are offsetting because dynamic changes to lead times and due-dates aren't handled.

Most studies on supply chain optimization have taken an intra-organizational focus. The growing power of routing electronic information has increased the need to view the entire supply chain or, more specifically, the supply network, of enterprises involved from raw material to finished product (Brynjolfsson and Hilt 1998). Little research has been done on optimizing material flow between enterprises within the supply network using production schedules based on dynamic information although many intra-enterprise tools and methodologies are becoming available. These have generally not been applied for inter-enterprise purposes.

Further, these tools currently use static information, they don't take advantage of the dynamic information that is available due to developments in ICT and the management of the bidirectional flow of dynamic information i.e. back to suppliers and forward to customers e.g. what the impact is on schedules, how to dynamically react to new delivery dates, etc.

The focus of this research is on establishing an underlying theory and suitable models and developing intelligent software that can simplify and possibly optimize the flow of materials through the network, using dynamic information generated as conditions change at any point in the network.

Rather than concentrating on intra-enterprise flows, the attention in this research is on the link between enterprises, using advanced ICT techniques and modern manufacturing techniques to achieve a balanced flow of materials and information (in either direction). Any perturbation in the flow results in the generation of new (dynamic) information. Processing this information at the point of change may result in a spreading activation of changes throughout the network.

## CURRENT SYSTEMS AND METHODOLOGIES

There is a large gap between the information that is available and our usage of that information because most people do not understand what is now available nor how to use it. Even today, many new systems are still being designed to use static information. As an example, most manufacturing systems still use static set-up times, static supplier lead times, inflexible customer due-dates, etc. Almost all our current social, legal, financial and economic systems and methodologies were designed using, and based on, the older static information. Very few systems have been designed or implemented to use dynamic information (Gartner, 2003).

Many enterprises in the supply chain are manufacturers who continue to use systems designed for static information such as Manufacturing Resource Planning (MRPII), JIT, OPT, TOC, Lean Manufacturing, Flow Manufacturing, and some advanced planning systems (APSs). Over 10 years ago, it was shown that these systems are inflexible and inaccurate due to their reliance on the old, static information capabilities (Barker 1994, Goldratt 1994, Barker 2000). When used with SCM, the inherent inaccuracies in quantities and delivery times are magnified and then propagated through the supply chain resulting in an excess of some material and a shortage of other material. As stated in Barker (2000), it is difficult to understand why organisations continue to use static information.

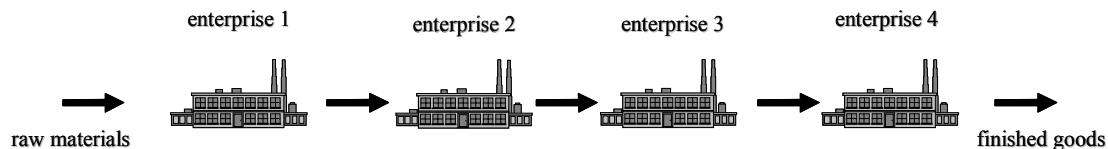


Figure 1: Traditional View of the Supply Chain.

In this paper, we will use the definition of a supply chain as:

“... a connected series of activities which is concerned with planning, co-coordinating and controlling materials, parts, and finished goods from supplier to customer. It is concerned with two distinct flows (material and information) through the organization.” (Stevens 1989).

## THE EXPANDED SUPPLY CHAIN – THE SUPPLY NETWORK

Because of the term ‘chain’, SCM conjures a vision of a linear manufacturing and supply chain. This view is shown in figure 1. In reality, this is not the case. An entity in the chain (a factory or distributor) may have many suppliers and many customers. Each supplier and customer may, in turn, also have many of its own suppliers and customers. Thus, a network of material movement exists, creating a supply network rather than a chain.

Figure 2 shows the supply network as seen by one enterprise (Enterprise A) in the network. Enterprise A has three suppliers and three customers. Each of its suppliers has suppliers and each of its customers has customers. What are not shown in the figure are the other customers of Enterprise A’s suppliers and the other suppliers of Enterprise A’s customers. The figure gets too complex to draw if all the relationships between all the enterprises are shown.

The L notation indicates the level of supplier or customer; the sign before the letter L indicates, in relation to Enterprise A, a supplier (-) or a customer (+). The number after the L indicates how far removed the supplier or customer is from Enterprise

A. For example, the notation -L3 indicates suppliers three levels from Customer A and +L1 indicates direct customers of Enterprise A.

SCM currently deals with -L1 and +L1 enterprises mainly by using EDI. In future, it will deal with multiple levels within the supply network, from -Lm to +Ln.

Silisque et al (2003) noted that supply chains will develop into networks that adapt to consumer demand in almost real time. This will be accomplished by using dynamic information.

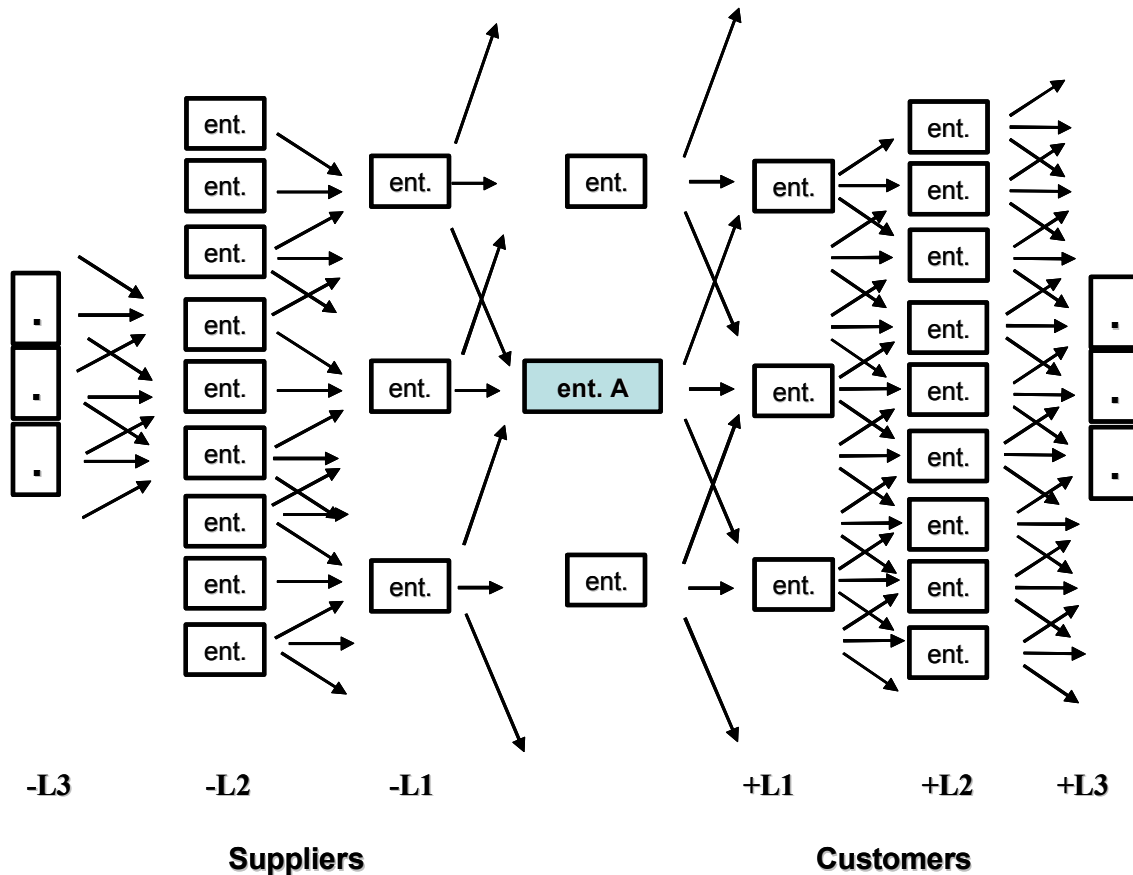


Figure 2: The Supply Network.

The supply network is not a static system. Quantities, delivery times, due dates, start times, etc from various enterprises in the network may change at any time so the supply network is a dynamic system where values are changing continually. Consequently, SCM systems must be updated accordingly so that decisions are based on dynamic information, not static information.

### CURRENT ERP SYSTEMS

Current ERP systems take an intra-organizational focus. They are introducing more inter-enterprise information but it is based on an organisational view not a network view. The growing power of routing electronic information has increased the need to view the entire supply chain or, more specifically, the supply network, of organisations involved from raw material to finished product (see e.g. McClellan 2003, Huhns and Stevens 2001)

Within the supply network, there are 3 flows; viz, information, funds and material. Some commercial research is being done on studying the inter-enterprise gaps in the supply network for information and knowledge generation and the consequential information flow through the supply network. However, current ERP systems concentrate on supply network transactions for

funds, basic trading cases (such as purchase orders and customer orders), collaborative product development and services, etc. GMM targets logistics and manufacturing information. Although some ERP vendors such as SAP ([www.sap.com](http://www.sap.com)) have proposed the use of agent-based technology to support such network operation, little progress appears to have been made in practice and little research has been done on “optimizing” material flow between enterprises within the supply network. Many intra-enterprise tools and methodologies are available (Theory of Constraints (TOC), Lean Manufacturing, Advanced Planning and Scheduling systems (APS), etc) but these have generally not been applied for inter-enterprise purposes.

Rather than concentrating on intra-organisational flows, the attention in GMM is on the link between organisations, using techniques such as intelligent agent technology and the theory of constraints to achieve a balanced flow of materials and information (in either direction). Any perturbation in the flow results in the generation of new (dynamic) information. Processing this information at the point of change may result in a spreading activation of changes throughout the network.

## DYNAMIC INFORMATION

In the past, information was produced and distributed in a static form. After a document was printed for distribution, the printed version couldn't change and the printed information was not global; it could only be accessed locally.

With the development of facilities such as faxes, email and EDI, it became far easier to distribute information both locally and globally. But the information was still distributed via forms or templates and it was “pushed out” from the source to the destination.

Now, due to developments in ICT, information can be retrieved from around the globe when required, security access permitting. Information can be gathered using both push technology (emails, EDI) and pull technology (intelligent agents, web pages).

Not only is a lot more information available, more easily accessible and global, it is also delivered much faster. As soon as information is updated, it is available virtually instantly to all those accessing it. It is not necessary to check if information has been updated, as it is possible to be notified automatically. Verification checks may have to be implemented in such cases.

So the nature of information has changed. Information now is:

- much greater in quantity
- global rather than ‘local’
- far more accessible
- much faster in delivery
- **dynamic rather than static.**

### The Importance of using Dynamic Information.

Within the supply network, information is constantly changing. Customers may wish to change an order's due-date or change the requested quantity. Similarly, due to unforeseen circumstances, suppliers may like to change dates or quantities on purchase orders. An example of a customer wishing to change the due-date of an order was given above.

Referring to the traditional supply chain depicted in figure 1, consider the following three situations as handled with static information:

- the raw materials to enterprise 1 are late,
- enterprise 3 wants material from enterprise 2 to be delivered later (or earlier),
- enterprise 4 cancels an order to enterprise 3.

1) The raw materials to enterprise 1 are late. Assume that the raw materials to enterprise 1 are 2 days late. Then it can be shown that, unless extra resources are added somewhere in the manufacturing chain, the delay to a customer at the end of the chain will be at least 2 days. In most cases, it will be much greater than 2 days.

All the enterprises shown in the figure would have to change their *expected receipt dates* of all affected material.

2) Enterprise 3 wants material from enterprise 2 to be delayed. In this situation, the *due dates* of all affected materials on the supply side of enterprise 3 will need to be altered and the *expected receipt dates* of all affected materials on the customer side of enterprise 3 will also need to be changed.

3) Enterprise 4 cancels an order to enterprise 3. In this situation, all the enterprises would have to change the *due dates* of all affected materials.

Handling the above situations with static information and current versions of SCM can be very difficult because, as has been shown in the past:

- the values generated by enterprises using static information systems are usually incorrect,
- the time taken to make the changes is too long,
- a lot of manual intervention is required, and
- each enterprise usually has to wait to be notified by an ‘adjacent’ enterprise in the chain.

Recall that the manufacturing chain given in figure 1 is a simple linear chain. As mentioned above, the chain is a network in reality. Consequently, the task is much more complicated than that presented in this simple example.

The assumption has also been made that all the enterprises in the simple chain are make-to-order. Although an increasing number of manufacturers are moving to make-to-order (demand pull), if one or more enterprises are make-to-stock, then the above example may also involve increased stock holdings in one or more of any make-to-stock enterprises in the chain.

Using dynamic information, each enterprise in the network is automatically given the updated information within minutes using information push and pull technologies.

## INTELLIGENT AGENTS

Intelligent agents gather information 24 hours a day, seven days a week, 52 weeks a year and are the principle source of dynamic information.

Beck and Fox (1994) did some early work using a global perspective mediating agent which gathers information on commitments from other agents when there is any event which disrupts supply. The role of agents in SCM was investigated in the AARIA project (Baker, Parunak et al. 1997; Baker, Parunak et al. 1999; Parunak, Baker et al. 2001). An agent based framework which simulates the supply chain with agents at each station was defined by Fox, Barbuceanu et al (2000). Huhns and Stephens (2001) describe a multi-agent system (MAS) where each agent manages a part of the B2B supply-chain for the enterprise. An MAS for dynamic information processing in supply chains was proposed by Sadeh-Konieczpol, Hildum et al. (2001). In the system, called MASCOT, each agent uses a blackboard architecture for coordination and control and an agenda to drive activity.

To be useful in the dynamic supply network, agents must learn to actively respond to changes in the supply network. Several learning techniques have been considered including case-based reasoning (CBR) (Dorn 1996, Cunningham and Smyth 1996, Corchado 2001, Olivia et al 1999, Finnie and Sun 2003), artificial neural networks (ANN) (Wermter, Arevian and Panchev, 2000), reinforcement learning (Arai, Sycara and Payne, 2000) and others.

Research is currently being done investigating two levels of customer side and vendor side agents (Finnie and Barker 2004, Finnie et al 2004) and CBR learning techniques for MAS (Finnie and Sun 2003, Finnie et al 2004).

## PARTNER INTERFACE PROCESSES (PIP)

Before defining the model and explaining how it works, it is necessary to

Intelligent agents will provide updated information and assist in relevant decision-making but they won't carry out the relevant trading transactions between enterprises (purchase orders, customer orders, etc). These will be handled by PIPs.

“RosettaNet Partner Interface Processes® (PIPs®) define business processes between trading partners.

“PIPs fit into seven Clusters, or groups of core business processes, that represent the backbone of the trading network. Each Cluster is broken down into Segments - cross-enterprise processes involving more than one type of trading partner. Within each Segment are individual PIPs.

“PIPs are specialized system-to-system XML-based dialogs. Each PIP specification includes a business document with the vocabulary, and a business process with the choreography of the message dialog.” (RosettaNet 2004)

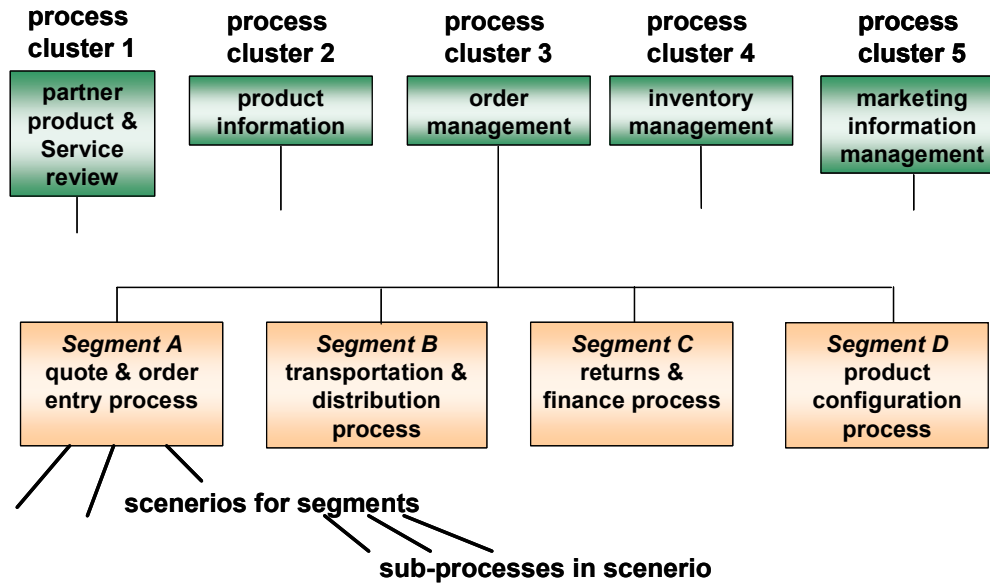


Figure 3: Clusters 1 to 5.

The seven clusters are:

Cluster 0: RosettaNet Support which provides administrative functionality.

Cluster 1: Partner Product and Service Review which allows information collection, maintenance and distribution for the development of trading-partner profiles and product-information subscriptions.

Cluster 2: Product Information to enable distribution and periodic update of product and detailed design information, including product change notices and product technical specifications.

Cluster 3: Order Management which supports full order management business area from price and delivery quoting through purchase order initiation, status reporting, and management. Order invoicing, payment and discrepancy notification is also managed using this Cluster of processes.

Cluster 4: Inventory Management to enable inventory management, including collaboration, replenishment, price protection, reporting and allocation of constrained product

Cluster 5: Marketing Information Management to enable communication of marketing information, including campaign plans, lead information and design registration.

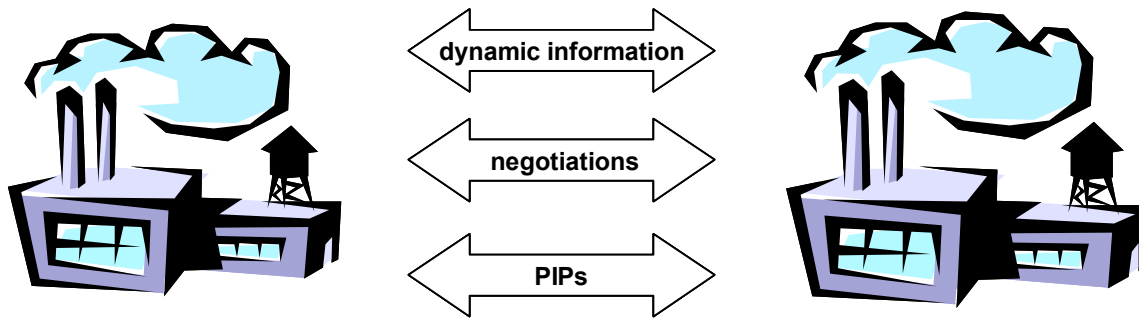
Cluster 6: Service and Support which provides post-sales technical support, service warranty and asset management capabilities.

Cluster 7: Manufacturing to enable the exchange of design, configuration, process, quality and other manufacturing floor information to support the "Virtual Manufacturing" environment.

PIPs rely on an amount of standardization which has been accepted by the participants and users of RosettaNet. As a consequence, many of RosettaNet's standards have been accepted universally, so much so that Universal Code Council (UCC 2004) and its affiliate EAN International, purchased RosettaNet.

## GLOBAL MATERIAL MANAGEMENT MODEL

GMM is an updated version of SCM that will take advantage of the developments in ICT where dynamic information is exchanged between enterprises, agent negotiations determine suppliers and customers, and PIPs carry out the required actions (see figure 4).



**Figure 4: Exchanges between enterprises.**

#### **Inter-enterprise co-operation and negotiation.**

Assume that the enterprise is a manufacturer and is enterprise A in figure 2. Then, generally, the following order fulfillment steps between enterprises will occur. More details are given in the next section.

1. The customer-finding agents of enterprise A search 24 hours a day, 7 days a week, for potential +L1 customers and negotiate with their supplier-finding agents.
2. If any orders are taken due to successful negotiations, enterprise A's "brain" uses its algorithms, the dynamic data, knowledge from its knowledge engine and any relevant patterns or trends from data mining to create an updated version the production schedule (which incorporates the Master Production Schedule (MPS)). This updated version is not yet released to the shop floor or to the supply chain.
3. Enterprise A's supplier finding agents search for potential -L1 suppliers and negotiate with their customer-finding agents.
4. Once all negotiations are concluded satisfactorily and the updated version of the production schedule has been modified accordingly, it becomes the production schedule and is released to the shop floor and to the supply chain.
5. The appropriate PIPs then carry out the required trading transactions between enterprise A and the +L1 customer and between enterprise A and the -L1 suppliers. The PIPs are like worker ants carrying out the instructions of the brain.
6. If any changes are made to customer due-dates or to supplier delivery dates (see examples above under "The importance of using Dynamic Information"), the production schedule is modified accordingly.

Figure 5 shows the steps as described above.



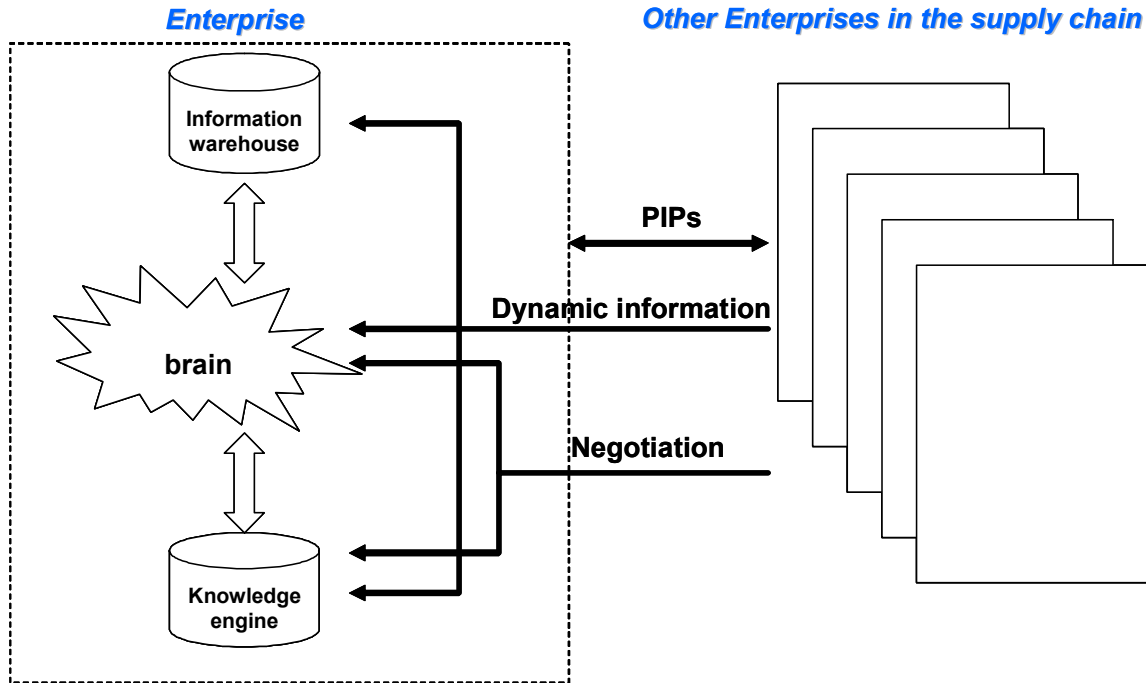


Figure 5: Input of exchanges between enterprises.

#### Intra-enterprise Model.

Figure 6 illustrates the model within the enterprise (enterprise A above).

##### *Constant monitoring and adjusting.*

Dynamic information is retrieved from the supply network through various channels (web, email, telephone, fax, conversations) but principally via the enterprise's agents. The information may be changes in delivery times, changes in due dates, changes in quantity, cancellation of an order, design changes, requests for information, marketing information, sales opportunities, etc.

Depending on the nature of the information, it may be stored in the data warehouse, used by the optimizing algorithms and/or used in the knowledge engine.

The data warehouse stores information in much the same way as most modern ERP packages store information. The information can be used directly by the optimizing algorithms and the knowledge engine. It can also be used by data mining to extract other information (correlations, trends, patterns) which can be used by the algorithms and the knowledge engine.

##### *Negotiations with customers and suppliers.*

As noted above, negotiations with customers and suppliers are via agents. The agents learn from a learning technique (see above) using knowledge from the knowledge engine and information, directly or via data mining from the data warehouse. They also learn from their own experiences.

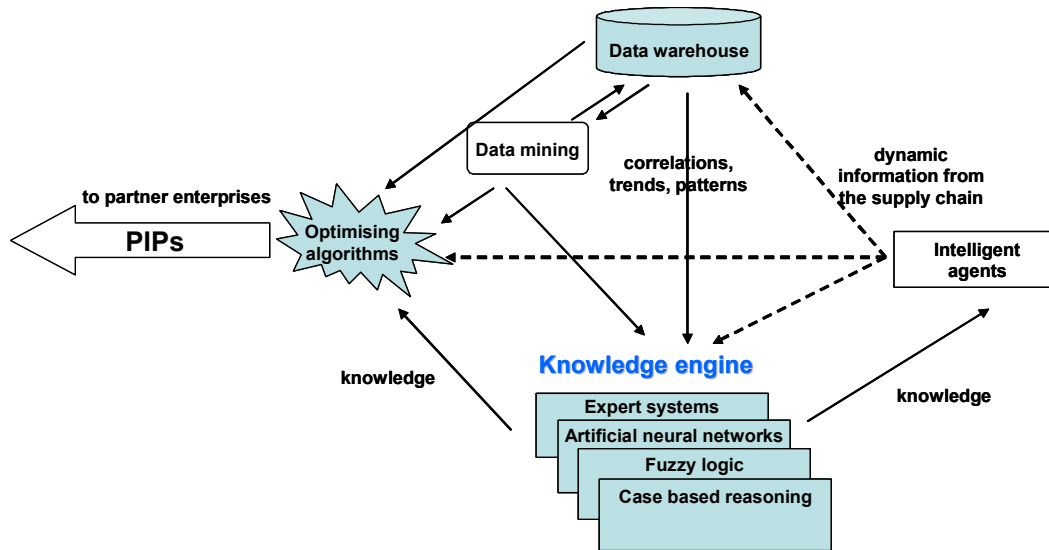


Figure 6: Enterprise intelligence.

#### Creating a dynamic production schedule.

More and more manufacturing software packages are incorporating APS packages. However, most of these packages use static data. In the GMM model, dynamic data would be retrieved from both suppliers and customers before a production schedule is created. Expected delivery times are calculated from information retrieved by agents from the production schedules of suppliers and required due dates are calculated from information retrieved by agents from the production schedules of the customers.

This dynamic information is then used with information from data mining and with knowledge from the knowledge engine to determine an optimal production schedule for the enterprise which is, in turn, visible to both suppliers and customers. Note that the agents retrieving the information are not limited to  $-L1$  and  $+L1$ , i.e. first level suppliers and customers. Where and when required, they can go to many levels up the suppliers side ( $-Lm$ ) and many levels down the customer side ( $+Ln$ ).

The “optimizing” criteria for the schedules may differ for each enterprise. Generally, however, the schedules should incorporate the principles of schedule based manufacturing (SBM) (Barker 1994, Barker 2000), Lean Manufacturing and TOC (Goldratt 1994 and many others).

The resulting schedules are available, through push and pull techniques including agents, to the enterprise’s suppliers and customers on an ‘on-demand’ basis. Required material information (quantities, shortages, availability, delivery dates, shipping information, related documentation, payments, etc) will thus pass between enterprises very rapidly and will allow, in turn, better production schedules to be generated by each enterprise within the network since the information used to produce such schedules is virtually real-time.

In effect, production schedules (and delivery schedules) throughout the supply network will be visible to each other thus enabling them to be better synchronised due to the up to date information on changed delivery times and the resultant modified lead times and due dates. This will result in:

- greater flexibility with dates and quantities
- shorter lead times
- timely notification of supply problems within the network
- alternative supply options
- less inventory being stored throughout the supply network
- reduced ordering overheads
- possible elimination of set-up times due to supply auctioning (see below)

Other as yet unforeseen benefits may also occur. Note that the above benefits will occur across the whole supply network but not all enterprises within the network will experience all, or even any, of the benefits.

To demonstrate how one of the above benefits will be implemented in GMM, viz flexible due-dates, consider the example given in the introduction. Assume that the builder wishes to change the due-date of his order for lights to 2 weeks later than the date given on the order originally. The builder will simply change his own schedule to reflect the progress of the building; he does not need to explicitly contact the lighting manufacturer. The intelligent agents of the lighting manufacturer will pick up the change in due-date from the customer's schedule (i.e. the builder's schedule) and then determine if any other customers would like their lights delivered earlier by checking their schedules. If so and if the delivery dates of the suppliers could also be changed, then the lighting enterprise's production schedule would be changed, if feasible, to reflect these requirements. If no other customers wanted their lights earlier, if it wasn't feasible to change the lighting enterprise's production schedule or if it wasn't possible to change the delivery dates of the suppliers, then it wouldn't be changed.

#### *Exchanging processes.*

When the production schedule is updated, negotiations completed or other inter-enterprise decisions finalized, the PIPs (RosettaNet 2004) would then be used to carry out the required trading transactions.

### **CONCLUSION**

The modern supply network is not a static structure; it is a volatile, dynamic structure requiring decisions to be made quickly, automatically and effectively. Consequently, intra-enterprise and inter-enterprise decisions and business processes will therefore need to be based on dynamic information and associated generated knowledge. Modern ICT techniques such as agents, knowledge management and data mining can be used to access dynamic information.

Updated versions of SCM, such as GMM, acknowledge the dynamic nature of the supply network. They will use dynamic information and generated knowledge to shorten the time between the receipt of a customer order and the delivery of the required product(s), to allow due-dates and lead times to be flexible rather than fixed and to considerably reduce inventory holdings throughout the supply chain.

The model defined here requires further research in some areas such as the structure of the agents, the learning techniques of the agents and the negotiation capabilities.

Due to space limitations, important discussion issues such as trust, customer service levels vs costs, etc, have not been covered in this paper. Please contact the authors on these issues.

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