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USING "MIRROR WORLDS" TO SUPPORT SUPPLY NETWORK MANAGEMENT

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ABSTRACT

"Mirror Worlds" were suggested by David Gelernter based on a bold assertion: "You will look into a computer screen and see reality." With mirror worlds, managers could be proactive, anticipating what might happen and acting accordingly, instead of waiting till events happen and then reacting. This paper extends the notion of mirrors worlds to supply chain management. In the case of supply chain management, managers could test the impact of making changes in their supply chains to study the impact.

However, mirror worlds could be extended to help actually monitor and manage supply chains to respond and adapt to changes in the world that affected the supply chain. In particular, mirror worlds could be "real" worlds if control for some of the activities between supply chain participants is in effect "turned over" to the mirror world. In that case, the mirror world would show the actual world, with the system making many of the decisions.

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1. INTRODUCTION

"Mirror Worlds" were suggested by David Gelernter based on a bold assertion: "You will look into a computer screen and see reality." With mirror worlds, managers could be proactive, anticipating what might happen and acting accordingly, instead of waiting till events happen and then reacting.

However, Gelernter's view of how mirror worlds could be used in a supply network environment was not elicited in his book. In addition, there have been few contributions to the academic literature focusing on mirror supply network worlds. As a result, one purpose of this paper is to summarize one such vision integrating supply networks and mirror worlds.

In addition, the notion of "mirror worlds" is a bit passive. Rather than just mirroring the "real world," portions of the mirror world might become the real world. For example, rather than just building visibility into a simulation of what could happen in an organization, parts of the mirror world and real world could be merged. If the mirror world is worth its salt as a mirror world then at least parts of it could become parts of the real world and not just mirrors. For some sets of actions, the mirror world would take over decision-making and become the real world.

Is There an Interest in Mirror Worlds for the Supply Chain?

Gelernter's book did not build a mirror world for supply chains. One reason for not building such a model could have been interesting. So, is there really an interest in such a view? Recently, Claus Heinrich of the large enterprise resource planning system software company, SAP, noted (SAP, 2001)

> The ultimate goal is to create a truly adaptive supply network that can sense and respond to rapidly evolving conditions so that partners can intelligently cooperate to keep demand and supply in close alignment and efficiently coordinate the fulfillment process. We believe that intelligent agents will be the key to resolving the increasing challenges companies are faced with in participating and managing global adaptive supply networks.

Accordingly, there appears to be substantial corporate interest in such a model. But, what needs to be embedded in the model?

Dynamic Supply Networks

Teams of companies have announced the development of software designed to attack the problem of supply chain networks. For example,

> … SAP today announced the enhancement of mySAPSupply™ Chain Management (mySAP SCM) to manage adaptive supply chain networks through use of new intelligent agent technology. Adaptive supply networks are an evolution of supply chains and will uniquely combine global visibility, event management, adaptive planning and execution, and dynamic collaboration. An adaptive supply network will provide business partner integration and dynamic collaboration through portals and exchanges. http://www11.sap.com/company/press/press.epx?pressID = 179

This statement also suggests that the technology will not just be designed to mirror the world, but actually be used to support and make critical decisions.

Purpose of This Paper

The purpose of this paper is three-fold. First, it applies the concept of mirror worlds to supply chain management, in order to elicit a mirror world vision of supply chain management. Second, it suggests actually using the mirror world as part of the real world to help better monitor and manage supply chains. Mirror world capabilities can be used in the real world to execute activities in real time. Third, investigates the extent to which mirror worlds or what appear to be mirror worlds have been used in practice to investigate and improve supply chains, by examining a case study about Procter & Gamble (P&G) and SAP.

This Paper

This paper proceeds in the following way. Section 2 provides some background information on mirror worlds. Section 3 investigates the notion of a supply network, in contrast to a supply chain. Section 4 analyzes some of the different types of events needed throughout a supply network, placing them in multiple categories. Section 5 analyzes the use of intelligent agents, using some examples from practice. Section 6 investigates data sources for mirror worlds, including accounting data, radio frequency identification data (RFID), global satellite positioning data, and Internet data. Section 7 integrates supply network events, intelligent agents, and data sources into the notions of mirror worlds. Section 8 brings it all together with an illustration of the concepts using P&G as an example. Section 9 summarizes the paper.

2. MIRROR WORLDS (GELERNTER, 1992)

Mirror worlds are computer software models of some portion of the world. Mirror worlds gather information from whatever sources they can which can facilitate modeling the real world. Mirror worlds try to model and mimic the way the world works with all of its complex interactions between the different actors. Mirror worlds "mirror" those actors with multiple interacting programs. Mirror worlds are concerned with both the overall view of the interaction and emergent behavior, referred to as "top sight," and the detailed behavior of particular agents, referred to as the "ant's view."

Data are funneled into the mirror world from many sources, since mirror worlds depend heavily on data flow. Data can include classic accounting sources, recently available Internet sources or emerging RFID.

Mirror worlds use computer-based intelligent agents as the actors. Monitoring individual agents provides the ant's view. Agents are designed to follow particular rules of behavior, e.g., "first items in, are the first items out," or "last items in are the last items out." The rules built into the agents in the mirror world often are designed to mimic those in the real world. Alternatively, different rules can be parameterized and studied so that the network can be "optimized." Optimization can occur for either outcomes associated with individual agents or for the entire supply network. Interactions between the agents create the emerged behavior or "top sight," through the development of a network that represents the supply structure.

However, the notion of the mirror world can be extended beyond that of "mimicking" reality. Instead of mimicking, with the right data and the right models, control of the portion of the world under consideration can be delegated to the mirror world. In that setting, the "mirror" world becomes the "real" world.

3. SUPPLY CHAINS OR SUPPLY NETWORKS?

Manufacturing organizations try to manage supplies of raw materials and other manufacturing goods to their firms. Suppliers play different roles, ranging from arms-length third parties to tightly integrated supplier–manufacturer links. That flow of materials from different parties often is referred to as the supply chain.

The importance of the supply chain is being recognized over time. For example, rather than just firm against firm, economic competition increasingly is supply chain against supply chain (DStar, 2001).

However, increasingly, organizations realize that instead of supply chains, organizations constitute supply networks. For example, as noted by P&Gs, director of supply network innovation, "Chain connotes something that is sequential, that requires handing off information in sequence. We believe that it (the supply network) has to operate like a network, like an internet, so everybody has visibility to the information." (Anthes, 2003).

Since chains are sequential, but networks are not necessarily even acyclic, supply networks are combinatorially more complex than supply chains. As a result, supply networks are increasingly seen as an issue for the so-called "complex adaptive systems."

Complex Adaptive Systems

Complex adaptive systems are networks of actors or firms (nodes), each acting on their own behalf. Arcs in the network indicate the movement of goods or information between the nodes or both.

In complex adaptive networks, the networks themselves have emergent behavior, based on the interaction of the behaviors at each of the nodes. This is true even if the amount of intelligence at the nodes is limited. Following even simple rules, systems composed of interacting actors generates behavior for the system, as a consequence of the actor interactions.

Supply networks are complex adaptive networks. The actors are the individual firms and people involved in bringing materials to their customers. Knowing that the supply network is a complex adaptive network means that will have emergent behavior, which we can study to see what rules will generate the kind of outcomes that we are interested in.

Limitations of Supply Network Integration

Unfortunately, sometimes supply networks or portions of supply networks are not integrated. This lack of supply network integration can play a critical role in limiting the flow of information, for a number of those reasons. First, if the systems are not integrated then knowledge of information can be slowed, lost or not possible. Without integration, information cannot flow from one node in the supply network to another. Second, even if systems are integrated, if the same ontology or taxonomy is not used then communication between systems will be slowed, lost or not possible. If one company defines a sale, as on delivery of goods, while another defines a sale on receipt of payment, the sales will not be the same, and information will be confused in the system (e.g., McAfee & McFarland, 2004). Third, without access to multiple different databases could limit the ability of agents, human or computer-based, to make sense out of the impact of information sets. For example, in order to understand the impact of weather would require not only knowledge of the weather, but which, if any, shipments would be affected by the weather. The Internet and the movement toward Internet-based standards has begun to facilitate database integration. Fourth, the lack of integration may influence the ability of a system to be adaptive. If information flows too slowly then adaptations may be insufficient or inappropriate or too late. If adaptive changes are too late, e.g., after a weather storm is over, then the adaptations may not be affective.

4. SUPPLY NETWORK EVENT TYPES

Supply networks need to be adaptive. In order to be adaptive, they need to be able to monitor "events" within the supply network and respond to those events. "Events" are relevant occurrences or happenings in the supply network. Typically events must be responded to, adapted to or linked to other events. For example, receiving goods is likely to link to paying for those goods. In order to monitor and respond to supply network events requires defining the event types and the range of events that the firm will examine as part of their supply network. There are a broad base of potential event types that might be experienced in a supply network, including accounting, delivery interruption, and other types of events.

Accounting Events

Historically, the primary interest has been in "accounting" type events such as "goods delivered," "goods received," "sales," "purchases," and other similar events. Each of those kinds of events has direct and measurable consequences on the firm. Further, these types of events use information of a particular type, that of monetary-based accounting information. Accounting has a well-defined set of actions and activities.

Delivery Interruption

However, accounting events do not cover the range of events necessary if the system is to be adaptive to changing circumstances in the supply network. In particular, the set of events could be expanded to other types of events, depending on what types of intelligent responses are built into the system. For example, events that relate to interruptions of the supply network could be captured. These might be based on the form of travel delivering the goods, including "ship interruption," "train delivery interruption," and "truck delivery interruption." Within each of those types of interruption there can be additional types of information relating to key characteristics of the impact on the goods. For example, within truck delivery, there could be events ranging from "flat tire – minor," to "truck and goods destroyed." The first of those two events would be reflective of a minor shift in delivery time, while the second, would require replenishing the goods. Different types of events would lead to different sets of actions by various actors in the supply network.

Events could also be expanded to anticipate an impact on particular forms of delivery. For example, weather and traffic information could be monitored. Weather, could be broken down into different types that could impact goods delivery. Accordingly, snow, rain, tornados, and hurricanes could be monitored for the potential impact on goods delivery.

Similarly, traffic in particular settings could be monitored for its impact on particular deliveries. Delays could be categorized according to a number of different taxonomies. Factors affecting the traffic quality include "road construction," "special events," and "natural disaster." Other factors could be related to particular local activities. For example, in Los Angeles, "filming" is an event that can clog the highways and limit access to particular facilities during what would be ordinary delivery times.

Carrier, Trailer, and Loading Events (e.g., Maloney, 2005)

There are a number of carrier, trailer and loading-based events. Carrier-related events include, "carrier accepts assignment" and "carrier does not accept assignment." Trailer-related events include "trailer available," "trailer unavailable," "trailer departure," "trailer arrival," and others. Loading-based events can include "loading begins," "loading completed," and other loading events.

Other Types of Events

Other types of events could also be elicited, based in part of the particular supply network and its needs. For example, there can be unloading interruptions. Unloading interruptions could be a function of "inappropriate equipment," "day of week," "hour of day," "contract agreements," and others. Associated with each type of unloading interruptions could be additional sets of events.

Similarly, in contrast to delivery interruption, there could be "receiving interruptions," depending in part on the perspective being taken. Further, identifying, detecting, and eliminating wasted resources in the supply network could also be set as events.

Importance of Event Definitions

Events definitions provide insight into what will be monitored and managed. If the only definitions are accounting-based, then the capabilities will be limited to those accounting events. However, by expanding the scope to a broader base of events allows the supply network to better manage all its resources. Events can be managed early in their life cycle to help solve minor problems before they turn into major problems. For example, determining if an assignment is not accepted by a carrier early will limit problems of a non delivery later.

5. INTELLIGENT AGENTS

In "real life" agents are those who are authorized to act for others (e.g., Croft, 1997). Computer-based intelligent agents are agents that are computer programs, software that typically has a single function.

Radou et al. (2002) argue that intelligent agents have multiple properties, including QA :1

- Cooperation – agents can cooperate with other agents to work toward a goal.

- Autonomy – agents can work without substantial intervention.
- Reactivity – agents can understand their environment and react accordingly.
- Adaptability – agents can adapt to alternative goals.
- Learning – agents can learn, either as an individual agent or as a system.
- Proactivity – agents have goal directed activity.

Generic Supply Network Roles

Within supply networks there are a number of generic roles for intelligent agents, including the following:

- Sorting agents determine to which agent different events should be funneled to.
- Demand agents determine how much product should be funneled to a particular location. These agents take demand signals and couple it with other events, such as advertising, and predict demand.
- Auction bidding agents, determine what bid is appropriate for some auction and act on executing that auction.
- Interruption analysis agents take in information about shipping interruptions and analyze that interruption to first determine if the interruption will impact the supply network, and if necessary, develop alternative approaches to mitigate the impact of the interruption.

Other roles can be developed based on the particular needs being addressed. For example, if the model has carrier interaction, agents could be concerned with choosing carriers, rescheduling carriers, etc.

Example – Cisco

One of the most visible adopters of intelligent agents into their customer relationship has been Cisco, who actually purchased a company that made agents to facilitate their own use. Cisco has introduced a number of agents including the following:

- Configuration agents that verify router configurations.
- Pricing agents that help customers view prices.

- Lead Time agents that check expected lead times.
- Status agents that monitor the status of orders.
- Orders Extract agents that take order information at Cisco and download it for local use.

6. MIRROR WORLD DATA SOURCES FOR SUPPLY NETWORKS

Mirror worlds are heavily data driven, using the data to drive agent decision-making where feasible. In a supply network environment, mirror world data sources for supply networks are likely to be from a number of sources, including accounting data, Global Positioning System (GPS) and RFID, Internet-based data, and other sources.

Accounting Data

Accounting data can provide substantial input to a supply network mirror world. Supply network data accounting data generated includes

- When, what, and where goods were shipped.
- When, what, and where goods were received.
- When, what, and where goods were recognized as a sale.
- When, what, and where goods were recognized as a purchase.

Throughout, accounting data is focused on economic transactions that occur throughout the supply network. However, that is not to say that other data in the supply network does not have economic consequences, and should not be gathered. Much of this other data can provide the ability of the networks to be adaptive.

GPS and RFID

RFID and GPS have become an increasingly, important source of information about the location of particular materials, or shipments of materials. Information about location can provide improved visibility about shipments or goods. RFID can provide different objects of interest with their own identity. For example, RFID can be used at the individual item level, the case level, the pallet level or even the truck or other form of shipment level. Using RFID and GPS we can facilitate location of those particular objects.

Data generated by GPS and RFID can provide much data to understand what is going on in a supply network, e.g., where are shipments or how long have they been "stuck"? Using GPS and RFID supply network participants can keep track of particular units, knowing where they are located, and keeping track of that location. With that kind of knowledge, goods can become visible to the entire supply network. Such visibility can make the goal of adaptation clear, and even provide data for generation of strategies.

Internet-Based Data

The Internet can provide a number of different kinds of data, such as weather and traffic data. For example, http://www.weather.com provides ongoing information about weather that could be used, while http://traffic-info.lacity.org/ provides traffic information for Los Angeles. Intelligent agents gathering such data can be used to anticipate the flow of goods through the supply chain. In order for agents to fully employ weather and traffic data, they would need to integrate that information with accounting data and GPS and RFID data about supply location. As a result, it would be necessary to integrate the computer-based agents, the events being monitored and the corresponding data sources.

7. INTEGRATING INTELLIGENT AGENTS, EVENT MONITORING, AND DATA SOURCES

Key building blocks in the development of mirror worlds are intelligent computer-based agents, event monitoring, and a keen focus on the appropriate data sources. However, those building blocks do not stand alone, but need to be integrated with each other.

Intelligent Agents and Event Monitoring

In an integrated system, the events would be captured and funneled to intelligent agents that would monitor and sort the events. Intelligent agents would monitor the events, for example, to determine if the events were nonroutine and problematic or routine and non-problematic. Those same intelligent agents could provide responses to routine problems and funnel problematic events to the appropriate source. After events were sorted then they could be sent to the next layer of agents.

Routine problems could be attacked using rules, or sets of rules as part of a rule-based knowledge-based system. In addition, agents could process simulations or other mirror worlds under different scenarios to address different event types. For example, based on the events discussed earlier, different interruption types could be addressed by different agent types. Accordingly, agents could specialize in truck shipping or train shipping. As a result, agents could have knowledge of alternative trucking options or alternative shipping options. Such agents would have knowledge of alternative shipping opportunities. This also would require intelligent agents to access the appropriate data.

Intelligent Agents and Data Sources

Just as events are often tied to particular data sources, intelligent agents must be given access to the appropriate data sources. For example, intelligent agents funneled events related to shipment interruption would need access to data about the interruption. In order to fully respond to a particular type of weather, agents would need access to potential impact of weather on particular locations and the corresponding location of the transport media. As a result, information from satellite-base GPS and RFID could be integrated with information about weather. Further, in order to fully leverage direct links with data sources, agents could be specially designed for particular data sources.

Event Monitoring and Data Sources

Monitoring of specific events (e.g., delivery interruptions in a particular location) can often be traced to monitoring particular data sources for particular outcomes (e.g., traffic web site for slowed traffic levels). Accordingly, there is a close coupling of events and data sources. Agents could be designed to leverage information about accessing particular databases. Event monitoring could leverage xml data exchange or generate direct links with particular data sources in order to fully leverage integration with data sources.

8. BRINGING IT ALL TOGETHER: PROCTER & GAMBLE

There have been reports of the use of these technologies for supply network integration. Throughout, P&G have played an active role in extending supply network concepts. Anthes (2003) reported on how six different companies were using agent-based software for a wide range of tasks, including P&G. P&G was reported to save $300 million annually because of its ability to transform its supply chain. In addition, mirror world-type of capability was being reportedly studied by SAP, the large enterprise resource planning software firm, whose software was being used by P&G. Now a prototype, mirror world-like capabilities apparently are being built into SAPs supply chain software, to meet the needs of P&G and other advanced supply network firms.

Procter & Gamble's Modeling Supply Networks

Melymuka (2002) reported on P&Gs development of what appeared to be "mirror-world" capabilities: "companies are beginning to use complex adaptive systems to plot future business scenarios." P&G built an agent-based model to simulate their complex supply network. P&Gs model of their supply chain was designed to address questions, such as "What if supermarkets and other customers shared information about planned product promotions that might change their supply needs?" Using this model, and asking key questions supposedly has led to the finding of millions of dollars of potential savings.

According to Radjou, Orlov, and Nakashima (2002), the simulation allowed P&G to include in the model planning, sourcing, production, and delivery policies employed throughout the supply network. Agents were used to represent the many actors in the network. The modeling found counter intuitive results. Inventory could be decreased, stock-outs could be decreased and product could be sped through the network using so-called "less than truckload" (LTL) shipments and by combining multiple stock-keeping units (SKUs) in the same shipments. As reported in NuTech (2003) there was a 50% savings in cycle time and inventory, ultimately leading to a $300 million annual savings, on an investment of less than $3 million.

Procter & Gamble's Proactive Use of Intelligent Agents

Anthes (2003) provides a glimpse of P&Gs supply chain of the future, based on P&G and Forrester Research's example of the use of intelligent agents to proactively manage supply networks. In that vision, by the year 2008, P&G shortens the end-to-end cycle of replenishing a box of their detergent "Tide" from four months to one day. In the example, specialized production plants are replaced with flexi-plants and agents interact with each other and have a number of uses. First, intelligent agents monitor weather to determine when weather might impact the delivery of shipments, either by boat, train or truck. Second, intelligent agents are used to create alternative delivery schedules should they find problems with existing schedules due to issue such as the weather or problems with the delivery media, such as flat tires. Third, intelligent agents are used to bid for different production opportunities, based on availability particular production facilities. Fourth, intelligent agents gather real-time data from stores and warehouses, and use that data to estimate production requirements. Fifth, intelligent agents monitor shelves in stores to determine stocking needs, alerting stockers when to stock product on the shelves.

9. SUMMARY

This paper has examined and applied the use of mirror worlds in a supply network environment. It extended the concept of mirror worlds to be in the real world, suggesting that parts of the mirror world integrate with the "real world." If the mirror world capabilities are strong enough to really "mirror" the real world, then in many cases it is likely more effective to let the mirror world merge with the real world. The paper also illustrated the discussion with the analysis of a real world design by P&G, SAP, and BiosGroup.

Selected Web Addresses

BiosGroup	http://www.biosgroup.com/
SAP Supply Chain Management	http://www.sap.com/solutions/business-suite/scm/index.epx
Sante Fe Institute	http://www.santafe.edu

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