December 2006

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ABSTRACT

Agile supply chains; characterized by decentralization and dynamism have redefined the performance metrics for gaining competitive advantage for organizations. The extended supply chains of today need a high alignment of the information flow across disparate and decentralized links of supply chains. Peer-to-Peer (P2P) technologies are suitable for enabling the information flow of supply chains. The P2P paradigm supports efficient communication, coordination and computing across decentralized and dynamic networks. In this paper, we have presented a perspective on applicability of P2P to supply chains using supply chain performance attributes and metrics defined by Supply Chain Operations Reference Model (SCOR).

Keywords

Peer-to-Peer, Supply Chain, Performance Metrics

INTRODUCTION

Competition is no more between organizations; it is between the supply chains. Globally, enterprises are forced to decentralize their operations to meet customer demands through extended supply chain. This leads to a paradox! To attain agility and competitive advantage, organizations establish a complex web of partnerships; while on the other hand, it leads to initially centralized supply chain become decentralized and dynamic with numerous enterprises now involved in its operation. Thus, handling this paradox becomes a key factor in ensuring agility and competitive advantage.

Supply chain, constitutes of different flows – physical flow, financial flow, knowledge and information flow. In this paper, we focus on the information flow aspect of supply chain. Information flow determines timely availability of accurate and transparent information for enabling effective decisions. In a traditional centralized supply chain, it was the responsibility of the centralized supply chain management software system to facilitate smooth information flow. However, with multiple partners now being part of the chain, information flow has to be managed not only within an enterprise, but also across multiple enterprises. Simultaneous, Instantaneous, Transparent and Accurate (SITA) (Iyengar and Kulkarni, 2001) information availability is the key for a supply chain. The width and depth of supply chain can be covered by a technology solution but the extent of real time data availability in the context of achieving the pre-defined performance metrics, determines the level of technology needed by the organization.

Peer-to-Peer (henceforth referred to as P2P) is a distributing computing paradigm (Schollmeier, 2002) that facilitates end-to-end communication, coordination and collaboration. In context of this paper, the endpoints are the enterprises participating in the supply chain (and hence the information flow). P2P connects the enterprises in a dynamic manner, facilitating smooth information flows in this decentralized setting. However, given the complex structure of decentralized supply chains, P2P may not prove effective in all types of information flows. So the moot question is: “Where would P2P make an impact on supply chains”. It is this question we try to address in this paper. We have used supply performance metrics and attributes to analyze P2P’s impact on supply chains. To make the analysis generic, we have used the SCOR model (SCOR, 2005). SCOR is an industry neutral supply chain reference model and it provides a rich set of performance metrics and attributes.

The paper is organized as follows: first we give a brief background on supply chain performance metrics and SCOR. Then we describe briefly the P2P technology, its merits and issues. After that, we analyze P2P's role in supply chains using the SCOR performance metrics and attributes. Lastly, we mention the technology components that would form a P2P solution for enabling the identified information flows of a supply chain.

SUPPLY CHAIN PERFORMANCE METRICS

A comprehensive definition (Ayers, 2001) of supply chain is "Life cycle processes comprising physical, information, financial and knowledge flows whose purpose is to satisfy end-user requirements with products and services from multiple linked suppliers". Figure 1 shows the different flows of a supply chain. There are four flows in a supply chain:s

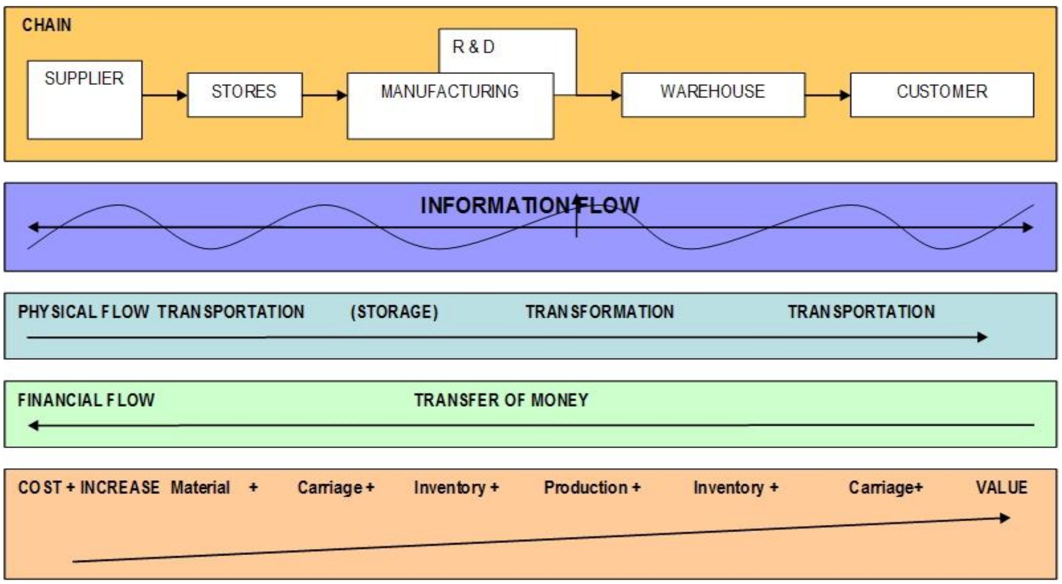

Figure 1. Information flows in a typical supply chain

- **Knowledge flows** are necessarily relevant for R&D. It is a parallel chain, as in case of a New Product development.
- **Physical flows** are the transportation and transformation processes, where the goods move from one location to another as well as undergo a physical change and are delivered to the end customer. The inputs are made available through Inbound Logistics (transportation); Manufacturing converts the input to output (Transformation). Outbound Logistics (transportation) deliver the goods to customer.
- **Financial Flows** occur in
  - Reverse Direction of the physical flow. Money flows from customers in opposite direction of the goods flow
  - Transverse Direction of the physical flow, by operating bodies of the supply chain
- **Information Flows** across the entire chain, typically in multi-directions. The synchronous nature of a supply chain is dependant upon the ability to encapsulate correct data. The application of data to a context becomes "information".

At every stage of the physical flow, a cost is incurred and value is added to the product. Cost is representative for the organization while value is the customer's perspective of the product / service offered. The Value / Cost (V/C) ratio is the key indicator of the health of the supply chain. Technology is the enabler for all information exchange. The advancement of technology has resulted in increasing the integration between the links of the supply chain.

A framework for gauging the contribution of each process to the *holistic* customer *"value"* captured in these factors are the "Performance Metrics" of the supply chain. The paradigm shift towards integration has changed the performance metrics for the organizations. Local Maximum has given way for Global Optimum. Maximization of V/C ratio at every link is now secondary to optimization of V/C of the entire chain.

SUPPLY CHAIN OPERATIONS REFERENCE MODEL

The global performance measures of the supply chain activities of Plan, Source, Make, Deliver and Return are captured in the Supply Chain Operations Reference Model (SCOR) (SCOR, 2005). SCOR, developed by Supply Chain Council (SCC) describes set of standard characteristics of the supply chain.

- SCOR provides standard description of the supply chain management processes and their relationships. The standard description of management processes provides common platform for effective communication across supply chain partners and allows them to measure, manage and control the processes with agreed definitions and scope.
- SCOR provides standard metrics to measure process performance. Standard definition of performance attributes and associated metrics enables technologists to assess the influence of proposed technology on improving the metrics recommended by SCOR
- The unified SCOR framework that links business process, metric and best practices is vertical and technology agnostic; that makes SCOR an exclusive choice for the technologists to use SCOR for technology assessment.

We make use of SCOR specified performance attributes and metrics of the supply chain process framework. Performance attributes provide the characteristics of the supply chain to enable supply chain analysis and evaluation. The metrics represents the parameters through which the implementing organization can measure how successful they are in achieving desired operational results. Performance attributes in conjunction with metrics and the best practices provides a reference framework to analyze how the proposed technology can positively influence SCM common objectives.

PEER-TO-PEER (P2P): A BACKGROUND

P2P represents a key evolutionary phase in distributed computing. P2P envisages harnessing the compute power and resources available on the edges of the Internet; user desktops, mobile devices etc.; and interconnecting them in a massively scalable super-network. A formal definition of P2P networking architecture is found in (Schollmeier, 2002).

The key P2P characteristic highlighted in this definition is the desire of the network participants (peers) to share services, content or resources with each other. The traditional client-server architecture forces us in to quite rigid interaction pattern of request-response, wherein the server responds only on arrival of a client's request. However, application of the P2P paradigm opens newer and interesting interaction patterns:

- **Traditional client-server**: It is pertinent to note that peers retain client-functionality. Hence, a peer can very well participate in a traditional client-server environment.
- **Symmetric pull**: In this pattern, all peers are actively engaged in consuming services/content/resources as well as providing them within the P2P network.
- **Push**: Peers push information/content to all or interested peers within the P2P network.

These interaction patterns build a rich service environment consisting of decentralized and dispersed peers leveraging each other services to realize cooperative computing (Singh and Huhns, 2005).

Features of P2P

Several P2P features enhance information visibility in a business environment. To establish a basis for further discussions, in Table 2 we show the mapping of generic business environment characteristics with P2P characteristics.

No	Business Characteristic	P2P Characteristic
1	Globally dispersed enterprises	Scalability Ability to traverse firewall boundaries Network agnostic service delivery
2	Extensive partnership	Autonomy Ability to traverse organizational boundaries
3	Dynamic	Implicit discovery
4	Collaborative and cooperative inter-business interaction	P2P messaging and negotiation protocols

Table 1. Mapping business characteristics to P2P characteristics

Since P2P paradigm proposes massive decentralization, the architecture is inherently scalable. From a business perspective, the scalability constraints emerge from a high number of collaborating business partners and the resultant impact on the network and computing infrastructure. P2P protocols enable efficient discovery of partners, messaging between them and high-performance computing. In a globally dispersed enterprise, need for dispersed enterprise units and employees to collaborate seamlessly becomes a critical issue. In such situations, collaborative enterprise architectures become very important (Hazra 2004). P2P, with its ability to pierce enterprise firewalls, provides a suitable communication substrate for enabling end-to-end connections for seamless collaboration. Moreover, P2P is network agnostic and as such P2P-enabled applications can run over a wide range of networks including mobile networks. P2P offers an excellent platform for building collaborative environments while still allowing enterprises retain autonomy over their data sources and/or services. E.g., an enterprise can expose its database to its partners without replicating the database at any location outside its organizational boundaries. This feature enables extensive partnership and establishes richer interactions between partners. In cases where business environment is dynamic, P2P provides excellent discovery mechanisms. P2P discovery mechanisms facilitate efficient discovery of business partners facilitating subsequent building of e-partnerships. P2P computing enabled through software agents facilitates automation of complex negotiations between partners for better collaboration and cooperation. Intelligent mix of P2P network functionality and software agents provide a highly efficient P2P application platform (Homayounfar, Wang and Areibi, 2002).

Current limitations of P2P paradigm

While we observe significant benefits from using P2P in contemporary businesses, there are challenges – technical and business – that need to be overcome for wider acceptance of P2P technologies in mission-critical enterprise applications.

- **Interoperability** (White, Peterson and Lheureux, 2003): Traditional application integration architectures use a hub-and-spoke approach with matchmaker and brokers facilitating interaction between endpoints. In case of P2P, such matchmakers and brokers do not exist. The onus of understanding business protocols, message formats and other low-details now lies with the participating business partners. For a controlled environment with known partners, these limitations can be overcome. Using P2P application adapters (Kupsch and Werth, 2005) or agents with integrated business logic alleviates this issue. However, in case of highly dynamic environments, the heterogeneity becomes a severe constraint in P2P's adoption. Technology solutions do not scale well to alleviate this constraint. A business solution for bringing in symmetry in business processes between partners is required. Collaborative Planning, Forecasting and Replenishment (CFPR, 2002) is example of an initiative from the Supply Chain domain.
- **Security**: A decentralized network and application architecture looks scary, since many of the traditional security concepts of authentication, authorization and accounting seem to fail in such scenarios. While traditional security is not a key issue, trust is! When businesses operate in open dynamic environments, it becomes difficult to ascertain the authenticity of one's partners. Several research projects are currently addressing the issue of trust in P2P networks. In fact, JXTA (The JXTA Project), a dominant P2P framework has already incorporated a distributed trust model, Poblano (Chen and Yeager, 2001) in its platform offering. Incidentally, JXTA also offers support for traditional security mechanism such as SSL/TLS and digital certificates.

- **Manageability**: Decentralization has some negative impact on the manageability of the P2P applications. Specific application management systems need to be built in order to address management issues arising out of the dynamicity and heterogeneity of a P2P infrastructure. It is the responsibility of the P2P platform to provide raw management capabilities. These can be further leveraged by enterprise network/application management applications. E.g., JXTA has incorporated a metering and monitoring capability (JXTA Metering and Monitoring Project) within the core platform that allows monitoring of key JXTA services and applications.
- **Legacy systems**: Existing legacy system and their integration in to the new P2P-enabled collaborative environment is another key issue. However, it is possible to achieve this integration without too much legacy application reengineering, using appropriate application adapters.
- **Napster effect**: Unfortunately, use of P2P in enterprise context is often marred by the notoriety of Napster! The initial Napster offering allowed millions of users to upload and download illegal music. The tags that P2P allows only music sharing and that P2P is illegal have stuck to P2P technology. However, as we will see next, P2P is being widely used in the enterprises in non-music scenarios too.

Using P2P in the enterprise

Beyond just being music sharing platform, P2P has made significant inroads in enterprise applications. The primary P2P application area is collaboration. P2P's firewall traversal ability makes it highly suitable for collaboration across networks and organizations. Collaboration workspaces – e.g. Groove (Groove) - provide users with a rich set of collaboration tools such as voting, IM, file sharing etc. Incidentally Groove has been taken by Microsoft with plans for integrating Groove platform in to future Microsoft products for enterprise collaboration. Knowledge Management is another area where P2P makes a significant impact. Distributed Knowledge Management is critical to harness the informal knowledge sharing occurring at the organizational edges (i.e. its people). The implicit support of P2P for distributed applications makes P2P-enabled knowledge management an imminently feasible solution. (Bonafacio, Giunchiglia and Zihrayen, 2005) discusses the state of art of knowledge management and P2P and illustrates how P2P helps in implementing enterprise Knowledge Management.

Beyond collaboration, P2P is being used in mission critical applications such as network management. Nokia is using P2P technology based on JXTA for server monitoring. Whenever, a server fails, JXTA notifies other servers of this failure, enabling the other servers to balance the load across them. P2P technology is also used in Grid services. The implicit discovery of P2P helps in identifying availability of resources in Grid networks (Talia and Trunflo 2003). P2P paradigm also finds applicability in enabling pervasive service oriented architectures. Currently P2P is used for federating UDDI service registries and federated lookup of web services. Going ahead P2P will have significant impact on web services, with P2P Web Services becoming an important facet (Schmelzer, 2005). P2P is also applicable to ad hoc workflow systems. P2P's inherently distributed computing paradigm makes it highly suitable for implementing ad hoc workflow systems (Fakas and Karakastos, 2004) and (Kaulgud, 2006).

These are only a few examples which go to show that P2P is applicable in the enterprise too. We believe that P2P is not limited to file sharing applications. It has to be realized that P2P is a distributed computing paradigm and it is applicable in numerous distributed applications.

APPLICABILITY OF P2P TO SUPPLY CHAINS

From the discussion in the previous section, it is clear that P2P offers significant benefits if used judiciously in enterprises. It should be noted that P2P is not a panacea for solving all ills of a distributed enterprise. Hence, it is necessary to evaluate applicability of P2P to specific enterprise systems and requirements. We argue that P2P is poised to be an important facet in the multi-faceted technology solutions for supply chain management. Many times people misconstrue P2P to be a replacement for existing ERP or similar applications. However, P2P is and will remain a technology enabler and will coexist with the current supply-chain management solutions. Some components will be *replaced* by P2P-enabled features, while in most cases, P2P-enabled features will *wrap around* existing components, further augmenting their usability.

For evaluation of P2P to supply chain context, we have used SCOR (SCOR, 2005), the performance attributes, and metrics defined in the model. In the subsequent discussion, we first analyze applicability at a high-level using SCOR performance attributes and then drill down using SCOR performance metrics.

P2P and SCOR (SCOR, 2005**) model**

SCOR specifies performance attributes for supply chain analysis and optimization. We have considered these performance attributes for analyzing at a high-level applicability of P2P in supply chains. The SCOR **performance attributes** are:

- **Supply Chain Reliability**: Supply Chain reliability focuses on the delivery capabilities of the supply chain. It is obvious that a supply chain needs to deliver a product to the enterprise's customer. Ability of the enterprise to deliver the right product at the right time and right customer is critical to the chain's reliability!
- **Supply Chain Responsiveness**: Not only should the supply chain be reliable, it should be responsive as well. With increasing market competition, time-to-market becomes crucial – not only for the enterprise but also for its customers. Hence, a supply chain should be optimized to deliver products fast.
- **Supply Chain Flexibility**: Businesses operate in a highly competitive and dynamic environment. To gain and retain its competitive edge, supply chain of an organization needs to adapt continually itself to changing customer profile and demand. Furthermore, a supply chain needs to seek continually suppliers who help fulfill customer demands and bring better value-for-money on table.
- **Supply Chain Asset Management**: We believe that the cost of operating a supply chain also includes the cost of owning the assets of an extended digitized supply chain. E.g., if an enterprise extends its ERP to its channel partners, cost of owning this extended supply chain increases the overall costs. Hence, the spread of the supply chain and degree of centralization of ownership are critical factors here.

We observe the following common threads running through the above four attributes:

- While physical flow is critical to meet the performance attributes, the underlying information flow is crucial. The information flow determines the availability of information at the right time, to the right person in the right form (the R's of information flow). Only if these conditions are satisfied, will decisions influencing the physical and financial flow be efficient and effective.
- Information flow itself needs to be dynamic. While an efficient information flow is easy to implement between a static set of partner organizations, dynamism at both upstream and downstream, requires implementation of a "dynamic" information flow enabler.
- Finally, the information flow has to be cost-effective. If implementing high-performance information itself leads to high cost of ownership, any benefits accruing due to it would be negated by the costs!

P2P can play a role in addressing these concerns relating to high-performance information flow across the supply chain.

- P2P eliminates the need for traditional portal-based information flows. Portals (e.g. web sites) represent a break in a smooth information flow. It is akin to passing of the baton in relay race! Speed through which information is passed from say Enterprise-A to Enterprise-B depends on how frequently does a human entity / software entity in Enterprise-B check the portal for new information. P2P obviates this delay by a direct connection between applications and/or business processes. P2P allows direct injection of messages from an application say in Enterprise-A in to a corresponding application in Enterprise-B.
- P2P inherently supports dynamism and scalability. It has excellent resource discovery mechanisms. Moreover, P2P supports massive decentralization. Using P2P, integrating the decentralized upstream and downstream partners becomes easier.
- Moreover, since P2P encourages autonomy, the spread of the digitized supply chain can be confined within organizational boundaries. The e-SCM components remain autonomous and within the enterprise. P2P integration channel then interconnects these autonomous e-SCM silos. The cost of ownership of the digitized supply chain is limited making the information flow cost-effective

In Figure 2[1], we show various interfaces in the supply chain network and those that are influenced by P2P are marked with tags. While, we have discussed P2P applicability to the generic performance attributes, it is worthwhile to analyze further the

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[1] InFlux™ Workbench has been used to draw the Illustrative high-level information Architecture depicted in this paper. InFlux™ is registered trademark for the framework developed by Infosys Technologies Ltd

applicability using SCOR performance metrics. We discuss here the approach to assess the role of P2P for enhancing Supply Chain Metrics based on SCOR framework. For example in the supply chain network depicted in Figure 2, the 'Reserve

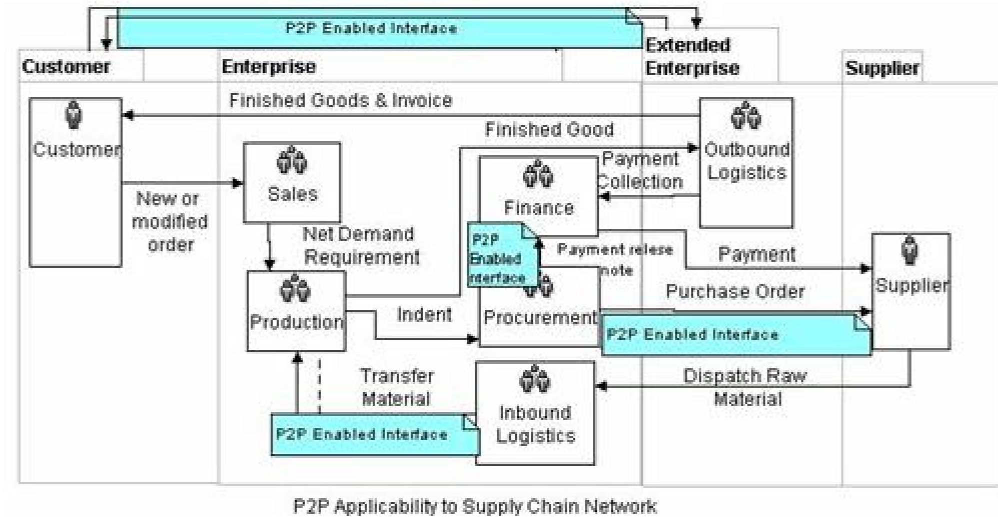

Figure 2[1]. Illustrative high-level information Architecture of a supply chain

Inventory and Determine Deliver Date' is the process for the stocked products, where in the Inventory and/or planned capacity (both on hand and scheduled) is identified and reserved for specific orders and a delivery date is committed and scheduled (SCOR, 2005). SCOR recommends Reliability as the performance attribute and Perfect Order Fulfillment as the measure for this process. As a part of best practice to deliver right product at right time at right place to correct customer SCOR recommends links between manufacturing and Distributor to gain visibility on finished goods inventory and expected shipments. The visibility on the inventory across supply chain partners is the key in achieving on time delivery. Therefore the technology that can influence the reliability of the process should have the ability to traverse through organizational boundaries and should provide scalable solutions across multiple supply chain partners. Similarly the best practices for priority based inventory reservations for key clients and FIFO based allocations for others will require the technology features such as dynamic discovery, negotiating and messaging protocols. P2P satisfies both the needs of cross organizational information flow and the dynamic discovery across dispersed network.

Table 2 maps the performance metrics with key indicators, SITA characteristics and relevant P2P feature.

Performance Metric	Key Indicators	SITA characteristics	P2P features
Perfect Order Fulfillment	Right Product at right time at right place to correct customer	Instantaneous Accurate	Direct communication between entities Non-existence of data duplication by humans
Order Fulfillment Cycle Time	Response time for delivering the product	Simultaneous Transparent Accurate	Dissemination of information with in peer groups
Downside / Upside Supply Chain Flexibility and Adaptability	Ability to respond to customer demands by integrating the supply side with the demand side	Simultaneous Instantaneous Transparent Accurate	Support for Dynamic environment Ability to cross organizational boundaries Capability to create complex partnerships Messaging & co-ordination between dispersed enterprises
ROI on Asset	Meet demand through optimal asset utilization	Transparent Accurate	Reduced cost of owning the extended digitized supply chain

Table 2. Mapping of Supply Chain performance metrics to P2P features

Thus, we see P2P making a significant impact on the information flow and consequently on the performance metrics. Throughout the paper, we have concentrated on the physical flow and information flow. However, knowledge flow is equally important for an enterprise to retain competitive advantage. Moreover, efficient knowledge flow influences product design and development and consequently time-to-market and supply chain attributes. Since, knowledge flows is not the focus of this paper, we do not discuss it further. However, we direct the reader to (Hart, 2004) for more details. Using arguments similar to information flow, we believe that P2P-enabled implementation of intra-enterprise and especially inter-enterprise knowledge flows would make them very efficient, flexible and scalable. We direct the readers to (Tsui) for further information on P2P knowledge management.

TECHNOLOGY COMPONENTS

Implementation of P2P-enabled digitized supply chains would require three technology components:

- P2P platform: P2P platform provides the low-level P2P communication semantics. This layer provides representation of entities in the digitized supply chain, their discovery and virtual paths for end-to-end communication across firewalls. JXTA is a classic example of a modular and extensible P2P platform, which can be leveraged for building complex P2P applications.
- P2P computing and coordination entities: While the platform forms the communications base, software agents provide the computing and coordination capabilities. Since agents inter-communicate and inter-operate directly between each other, they are inherently P2P. Software agents are best used for implementing process logic or business protocols. They complement the P2P platform component well. While agents provide compute and coordination capabilities, the platform provides the agent low-level discovery and transport semantics.
- Service invocation entities: The final issue that remains is how is a remote agent's functionality invoked? While agent platforms do provide this capability, it remains proprietary to the agent platform used. Peer-to-Peer web services (Schmelzer, 2005) seem to be a candidate technology alternative for a standards based service invocation layer. P2P web services would wrap an agent to expose agent's functionality via web-services interface. Other peer services will invoke the agent functionality via the exposed web-services interface. With the use of web services, the solution becomes ubiquitous as almost every software development environment supports web services. Again, the P2P platform provides discovery and transport semantics to the P2P web services. As long as an enterprise knows the web-service interface of a partner's P2P-enabled supply chain system, it can connect and invoke that services directly. However, a P2P web service is an upcoming paradigm and it will take some time for it to mature.

Thus, using the three tier model, we not only get the benefits of P2P in the communication substrate, but we also leverage proven software paradigms of agents and web services for realizing the P2P computing services.

CONCLUSION

In today's dynamic environment, the competitive advantage is driven by the agile supply chains. The agile supply-chain demands for the minimum latency in the response, at lower risk of failure and within affordable costs spread across the network. In order to seek competitive advantage, today organizations are increasingly becoming conscious towards consistently analyzing and evaluating their supply chain performance. Technology being the enabler needs to be prudently adopted to achieve optimally the performance metric.

The applicability analysis finds that P2P can play an important role in optimization of decentralized and extended supply chains. P2P is particularly applicable where the interfaces of an enterprise with external supply chain partners are many and dynamic. P2P enables enterprises to confine the spread of e-SCM components within the enterprise and effectively integrate disparate partner systems to create a cohesive digitized supply chain. In the paper, we have noted the current constraints in P2P adoption. We observe that technology solutions exist to overcome the technical constraints. Moreover, there are business initiatives as well, focusing on development of collaborative business frameworks. Hence, for P2P's widespread adoption, following become critical:

- Development of an enterprise-grade P2P platform
- A framework for integrating P2P applications with legacy enterprise systems
- Negotiation between business partners to understand business processes and establish the need for collaborative business environment

A note of caution is found in (Bitran, Gurumurthi, and Lin Sam, 2006). While the report conjectures on the applicability of agents residing within supply chain, it warns of the chaotic condition that may emerge if supply chain is heavily decomposed and relies too much on external partnerships. The report feels that eventually certain decentralized functions would reintegrate in to specialized supply chain services and service providers who would mediate in the decentralized supply chain.

We believe that judicious decentralization of supply chains would help enterprises gain competitive advantages. P2P-enabled solutions will eventually form the backbone of information systems supporting these supply chains.

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