

# THE IMPACT OF INFORMATION TECHNOLOGY ON SUPPLY CHAIN PERFORMANCE: THE ERP PHENOMENON

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*The Enterprise Resource Planning (ERP) phenomenon provides an opportunity to drastically rethink supply chain strategies. Recent research on ERP systems aims at understanding the key drivers of the ERP phenomenon, the determination of costs and anticipated benefits, the principal challenges during the implementation project, and the maintenance of the software once it is in place. Such an understanding would provide valuable guidance to managers who are currently undertaking such far-reaching projects. Understanding the ERP phenomenon would equally have more significant longer-term benefits. Current ERP initiatives are aimed at supply chain coordination, viewing the system as a transaction management platform. We believe that ERP will eventually evolve into an infrastructure or a backbone that supports the dynamic view of supply chain design, referred to as capability design. This paper seeks to understand the impact of ERP systems on supply chain performance. Our objective is to establish conditions under which ERP can be a critical enabler or a severe handicap for superior supply chain performance.*

## 1. MOTIVATION

After two decades of streamlining internal operations through initiatives such as Just-in-Time and Total Quality Management, boosting plant productivity, improving product quality, and reducing manufacturing costs, world-class companies have started focusing on supply chain strategies as the next frontier for operational excellence. For example, in 1993, American companies spent \$670 billion on logistics and supply chain-related activities, corresponding to 10.5% of the U.S. GDP. Better coordination along the supply chain is estimated to yield cost savings of over \$30 billion for the grocery industry in the United States<sup>1</sup>. For instance, companies such as Dell, Hewlett Packard, Wal-Mart, and Campbell Soup have demonstrated the profitability impact of innovative supply chain strategies. In Europe, logistics costs range between 6% and 15% of total turnover. Any improvements within logistics would therefore have an immediate impact of profitability.

In this paper, we seek to understand the impact of information technology on supply chain performance. In particular, we focus on the Enterprise Resource Planning

(ERP) systems. Our objective is to establish conditions under which ERP can be a critical enabler or a severe handicap for superior supply chain performance.

A supply chain is a network consisting of suppliers, manufacturers, distributors, retailers, and customers (Figure 1). The network supports three types of flows that require careful planning and close co-ordination: (i) *material flows*, which represent physical product flows from suppliers to customers as well as the reverse flows for product returns, servicing, and recycling; (ii) *information flows*, which represent order transmission and order tracking, and which coordinate the physical flows; and (iii) *financial flows*, which represent credit terms, payment schedules, and consignment and title ownership arrangements. The network, in turn, is supported by three pillars: (a) *processes*, which encompass logistics, new product development, and knowledge management; (b) *organizational structures*, which encompass a range of relationships from total vertical integration to networked companies as well as management approaches, and performance measurement and reward schemes; and (c) *enabling technologies*, which encompass both process technologies and information technologies.

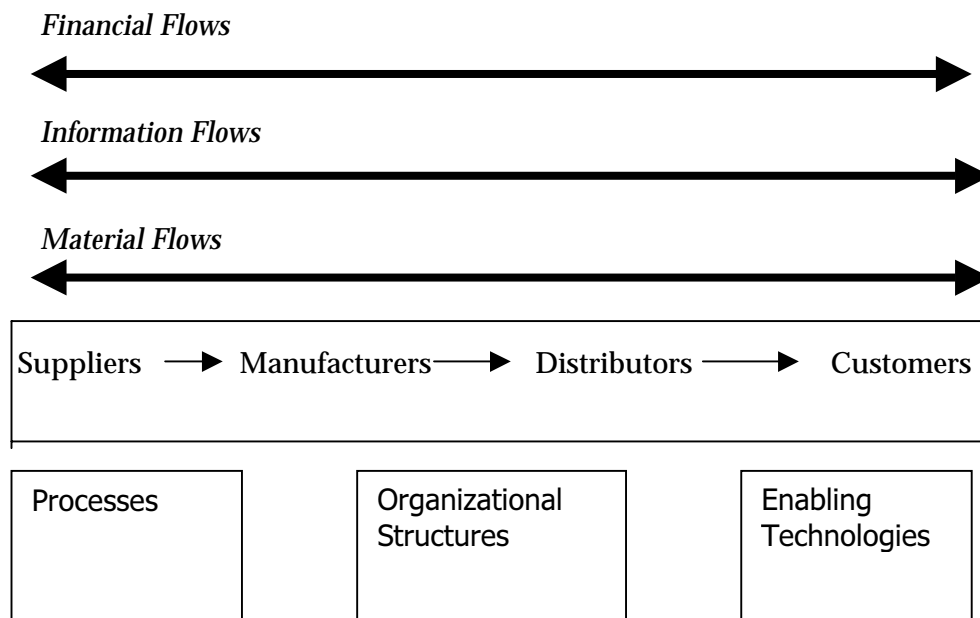


Figure 1. The Supply Chain

Supply chains perform two principal functions<sup>2</sup>: the *physical* function of transformation, storage and transportation, and the *market mediation* function of matching demand and supply. While the physical function has been extensively studied within the production control and inventory management literature, innovative approaches have recently been emerging to the market mediation function. These approaches are classified in Figure 2. Supply chain design is concerned not only with the specification of customer zones, selection of manufacturing and distribution facilities, and allocation of product families to these sites, but also with the prioritization of the capabilities to be developed and retained internally, and the forging of new partnerships with other entities along a supply network. According to Fine, supply chain design ought to be thought of as a dynamic process of assembling chains of capabilities and not just collaborating organizations<sup>3</sup>. This dynamic view is particularly important in a fast-evolving world where new products and emerging distribution channels necessitate a continuous review of supply chain design decisions. Just like product design has an enormous impact on manufacturing performance, superior supply chain design offers significant payoffs in managing and coordinating supply chain activities.

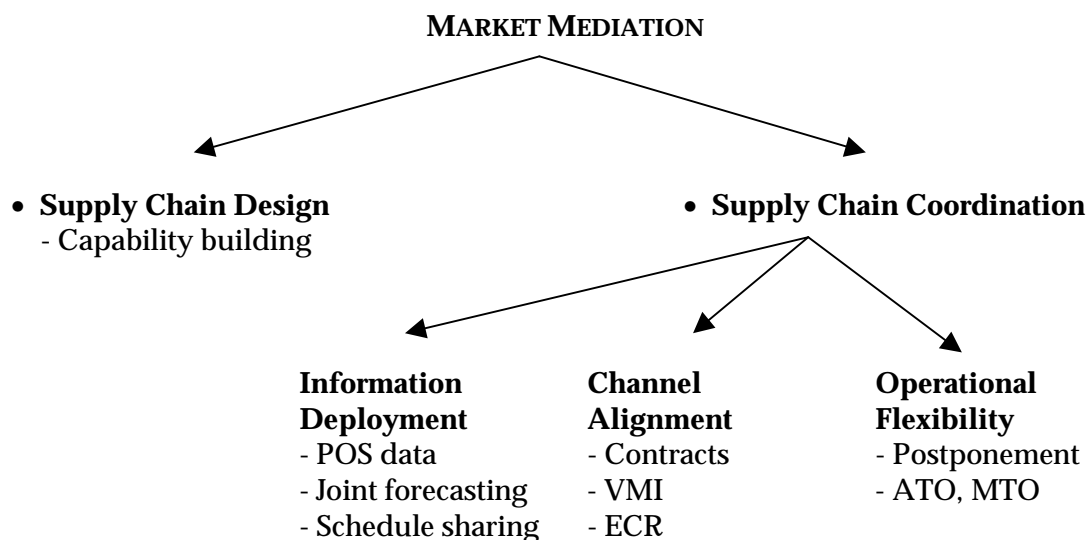


Figure 2. Matching Demand and Supply in a Supply Chain

This dynamic view may necessitate different perspectives (or mappings) for supply chain design. These perspectives include<sup>3</sup>: organizational supply chain, capability

supply chain, and technology supply chain. An organizational supply chain maps all the entities in a company's extended supply chain and illustrates all value-adding activities performed by each organization along the chain. A focus on technology, on the other hand, traces the lines of dependency upstream to the suppliers and downstream to the customers, who provide and use, respectively, key technologies along the supply chain. Finally, a focus on capability aims at identifying the key business process capabilities, which currently exist as well as which are desirable, along the supply chain. A multi-dimensional perspective on supply chain design is critical since building a company or a capability without regard for the chain in which it is embedded is not sustainable<sup>3</sup>. Note that such mappings are also consistent with our thinking on the three pillars supporting the supply chain.

Supply chain management, on the other hand, is concerned with the coordination of the three types of flow once the supply chain design is finalized. Effective supply chain strategies (Figure 2) combine a range of approaches from operational flexibility such as the make-to-order or postponement capability, channel alignment (e.g., vendor-managed inventories), and joint decision making through information deployment (e.g., collaborative forecasting and replenishment planning). These approaches, in turn, typically lead to new forms of organizational structures (e.g., process orientation) and new forms of inter-organizational collaboration (e.g., outsourcing via third-party service providers). This transformation has coincided with the emergence of information and communication technologies facilitating closer collaboration and promoting supply chain transparency. Technological breakthroughs, particularly in information technology, can significantly enhance both the efficiency of the network operations and the effectiveness of customer service on a global basis.

While the World Wide Web and electronic commerce applications have received significant attention, the ERP phenomenon is drastically shaping supply chain strategies, offering both significant operational improvements and strategic risks. Recent research on ERP systems aims at understanding the key drivers of the ERP phenomenon, the determination of costs and anticipated benefits, the principal challenges during the implementation project, and the maintenance of the software once it is in place. Such an understanding would provide valuable guidance to managers who are currently undertaking such far-reaching projects. Understanding

the ERP phenomenon would equally have more significant longer-term benefits. Current ERP initiatives are aimed at supply chain coordination, viewing the system as a transaction management platform. We believe that ERP will eventually evolve into an infrastructure or a backbone that supports the dynamic view of network design, referred to as *capability design* by Fine. The objective of this paper is therefore to provide an appreciation of this ultimate capability in order to give a broader perspective to managers who are undertaking an ERP project.

The paper is structured as follows: The ERP phenomenon is briefly discussed in Section 2. Section 3 identifies the key drivers of ERP implementations and the anticipated benefits. Section 4 classifies immediate implementation challenges. Section 5 considers ERP as a platform to support the dynamic design of supply chains. Section 6 concludes the paper.

## **2. ENTERPRISE RESOURCE PLANNING SYSTEMS**

The ERP phenomenon can be traced back to 1972 when a group of *IBM* engineers devised an integrated Sales & Distribution and Materials Management package for *ICI Chemicals*. This was a logical extension of the MRP thinking. Some of these engineers have later founded *SAP AG* and released the mainframe-based *R/2* package with the large multinational corporations in mind. With minimal marketing effort, some 4,300 copies of the package were sold over the next 20 years. In 1992, *SAP* moved from the mainframes to the client-server architecture by releasing the *R/3*. Today, *SAP* dominates the ERP industry by controlling one third of the market. In fact, one often talks about an “ERP ecosystem” consisting of ERP software developers, consulting firms, hardware developers, specialty software developers, and IT service providers. Table 1 reflects the magnitude of this ecosystem<sup>4</sup>.

J.D. Edwards, an American consulting firm and ERP system vendor, defines ERP as an umbrella term for integrated business software systems that power a corporate information structure, controlling a broad range of activities, from the procurement of supplies to shop floor control and financial accounting. It provides the glue that binds management functions across geographic sites and complex heterogeneous networks. From a more strategic perspective, JBA, a British consulting firm, views ERP as a business approach that starts in the boardroom and permeates the entire

organization; from this perspective, it is a combination of business processes and the supporting or enabling technology.

<b>ERP Vendor</b>	<b>Revenue (\$)</b>	<b>Service Providers</b>	<b>Revenue (\$)</b>
SAP AG	\$ 4.7 Bn	Andersen Consulting	\$ 990 M
Oracle	\$ 1.9 Bn	Ernst & Young	\$ 968 M
PeopleSoft	\$ 1.4 Bn	Price Waterhouse (*)	\$ 850 M
Baan	\$ 992 M	Deloitte & Touche	\$ 789 M
J.D. Edwards	\$ 990 M	IBM Global Services	\$ 750 M
		KPMG Peat Marwick	\$ 704 M
<i>Others</i>	\$ 4.8 Bn	Coopers & Lybrand (*)	\$ 413 M
		Origin	\$ 400 M
<b>Total Market</b>	<b>\$ 14.8 Bn</b>	Cap Gemini	\$ 390 M
		Computer Sciences Corp.	\$ 375 M

(\*) Merged to form *PricewaterhouseCoopers* in 1998

*Table 1. The ERP Ecosystem*

Technically, ERP is the logical extension of Material Requirements Planning (MRP) systems of 1970's and of Manufacturing Resource Planning (MRP II) systems of 1980's. ERP's impact, however, has been much more significant. Following the American Production and Inventory Control Society's (APICS) "MRP Crusade," sales of MRP software and implementation support exceeded one billion dollars in the United States by 1989. Worldwide sales of ERP packages together with implementation support, on the other hand, are anticipated to exceed twenty billion dollars by the turn of the century with annual growth rates of over 30%<sup>4</sup>.

A recent survey by *Fortune* magazine revealed that seven out of the top ten global pharmaceutical and petroleum companies, nine out of top ten global computer companies, and all of the top ten global chemical companies are using SAP's R/3. In spite of this explosive growth, very little research has been done on the adoption, implementation, and exploitation of ERP systems. The evidence of promised benefits have largely been anecdotal. Popular press and trade journals have been documenting both stellar successes and miserable failures with very little explanation on the causes of success or failure. Given that a typical ERP implementation initiative takes anywhere between one to three years and that typical budgets are in hundreds of millions of dollars, there is urgent need for

understanding the costs and benefits of ERP, the implementation challenges, and the management of the system once it goes live.

ERP is a comprehensive transaction management system that integrates many kinds of information processing abilities and places data into a single database. Prior to ERP, this processing and data were typically spread across several separate information systems. For example, a firm could have separate systems for purchasing, order management, human resources, and accounting, each of which would maintain a separate data source. ERP would subsume these into a single seamless system. Researchers have pointed to information system fragmentation as the primary culprit for information delays and distortions along the supply chain. Information delays and distortions, in turn, cause the famous bullwhip phenomenon<sup>5</sup>. An ERP system could potentially enhance transparency across the supply chain by eliminating information distortions and increase information velocity by reducing information delays. Hence, there is reason to believe that ERP adoption could be associated with significant gains in supply chain effectiveness.

### **3. THE CHALLENGES: SELECTION, IMPLEMENTATION, AND OPERATION**

To understand the key drivers of the ERP growth, we have used a survey instrument adopted from McAfee<sup>6</sup>. The survey consists of four sections aimed at understanding the quality of the existing Information Technology (IT) support prior to the ERP implementation, the motivation for implementation, the impact of the new ERP system, and the project characteristics such as team composition, total budget, and implementation time. In the first three sections, a number of statements are presented and the respondent is asked whether he agrees or disagrees with that particular statement. Further details of the survey are provided in the Appendix.

Quality of the existing IT support prior to an ERP initiative is considered first. Following McAfee, quality is measured along three dimensions. At the individual level, *visibility* focuses on the ability of the system to alert the individual to pending tasks, to prioritize these tasks, to present the individual with the appropriate data, hence to avoid information overload. At the group (function) level, *functionality* measures the capability of the system to enhance the productivity of a group by facilitating and/or eliminating routine or non-value-adding tasks. At the inter-group

level, *commonality* measures the ability of the system to enable and/or facilitate collaboration among different functions.

(n=28)	Avg Score	Std Dev
<b>Visibility</b>		
IT output does not differentiate between important and unimportant information	5.0	1.3
Some tasks go undone since users are not alerted <i>on time</i>	4.9	1.4
There exists information overload for the users	4.0	1.7
Some tasks go undone since users are <i>never</i> alerted	3.5	1.7
IT output highlights critical tasks	3.3	1.9
<b>Functionality</b>		
Processes required functionality not provided by the existing IS	5.9	0.9
Some tasks had to be completed manually	5.5	1.1
Inadequate IS for tasks on hand	5.5	0.9
Some IT functionality was outdated	5.1	1.4
IT provided adequate support for decision making	2.8	1.5
<b>Commonality</b>		
Different steps in a key process use information from different sources	6.0	0.8
People typically ask co-workers for relevant information	5.4	1.5
We lack a common data base for functions working together	5.3	1.6
Access to necessary information was easy	2.6	1.6
Information was communicated to all relevant users	2.6	1.6
We used a common data base	1.8	1.1

*Table 2. Quality of the Existing IT Support*

Table 2 reflects significant dissatisfaction with the existing IT support prior to the ERP initiative. In particular, this is more pronounced for the commonality dimension, as the existing IT systems fail to support close collaboration among the functions along the supply chain. This dissatisfaction can be further detected in Table 3, where the key motivations for ERP implementation are listed. Standardization of business processes is the top driver. This is coupled with the fact that most ERP systems are bundled with a process orientation. Standardization of data, creation of a platform for future IT initiatives, and cost effective IS management all point to the desire to end the fragmentation of the IT infrastructure. It is also

believed that information consistency and increased information velocity would lead to a reduction in cycle times and improved customer responsiveness.

<b>Motivation</b>	<b>Avg Score</b>	<b>Std Dev</b>
<b>(n=28)</b>		
Standardization of business processes	6.1	0.8
Standardization of data	6.0	1.0
Lack of functionality in current IT	5.6	0.9
Basis for future IT initiatives	5.5	0.9
Improvement in customer responsiveness	5.4	1.2
Improvement in product (service) cost performance	5.0	1.2
Processes incorporated within ERP	5.0	1.4
Cycle time reduction	4.9	1.6
Cost effective IS management	4.8	1.3
Inventory reduction	4.5	1.8

*Table 3. Motivation for ERP Implementation*

There were several other interesting reasons for implementing ERP systems. One respondent views ERP as an efficient way of decentralizing the decision-making process, hence providing workers with more autonomy. For another respondent, ERP enables the implementation of new performance metrics since data can now be collected routinely on these performance characteristics. On-line consolidation of financial data and better reporting across different countries were key factors for a pan-European company on the verge of its initial public offering. The conversion to *Euro* is also a concern.

For those companies that have successfully completed the ERP implementation, the initiative has had an impact on two dimensions. On the operational side, the capability of obtaining transactional information on a real-time basis is reported to have improved the customer interface. As reflected in Table 4, ending the IT fragmentation has allowed different functions to work together more effectively leading to more effective customer service in terms of timely information, on-time order completion, and on-time order delivery.

<b>Impact on Operations</b>	<b>Avg Score</b>	<b>Stde Dev</b>
<b>(n=19)</b>		
Provide customer with required information	5.5	0.9
Different functions working together effectively	5.4	0.6

Improved customer response time	5.1	1.0
Higher percentage of orders completed on time	5.0	1.0
Reduced inventory levels	4.9	1.1
Improved ability to switch among products	4.6	0.7

*Table 4. Operational Impact of the ERP Implementation*

Table 5 captures the organizational impact of the ERP initiative. On the organizational side, respondents are typically happy about the implementation schedule; they are optimistic that the new system will eventually meet their expectations. They also believe that IT was a key catalyst for organizational change; most believe that ERP has spearheaded the re-engineering effort during the implementation. On the other hand, few believe that the organizational structure has changed significantly as a result of the ERP implementation. Such a paradox raises the question of whether companies failed to fully exploit a powerful change opportunity. One should also note that ERP was viewed as a necessary initiative to stay even with competitors.

<b>Impact on Organization</b>	<b>Avg Score</b>	<b>Std Dev</b>
<b>(n=19)</b>		
ERP will eventually satisfy our expectations	5.2	1.0
IT change was vital for performance change	5.1	1.1
ERP has made it possible to stay even with competitors	4.8	1.2
Implementation progress is satisfactory	4.6	1.4
Implementation is proceeding on schedule	4.0	1.6
As a result, organizational structure changed significantly	3.8	1.4
It is BPR, not ERP, that had the biggest impact	3.5	1.4

*Table 5. Organizational Impact of the ERP Implementation*

Table 6 reflects the average scope of the ERP initiatives in our sample. The figures in Table 6 concur with McAfee's findings<sup>6</sup> that ERP implementations are major projects with total budgets of, on average, 2.5% of the sales volume of the affected sites. Implementations involve, on average, more than 8,000 employees and 15 separate locations, and take over two years to complete. The average figures hide the fact that ERP implementations, while uniformly significant projects, are far from being homogeneous across firms. For example, implementation projects in the sample represent a range of 3 to 80 sites across the organizations studied. Implementation took anywhere from nine months to five years.

Table 6 establishes ERP initiatives as major projects with significant risk, extremely high demand on expensive resources, and considerably handsome potential payoffs. Shrewd project management is therefore vital. Two key aspects further complicate the project: process re-engineering and technological constraints. We can therefore summarize the challenges in an ERP initiative in the following categories:

1. *Project Management*: definition of scope, software selection, internal team selection, consulting partner selection, project costing and budgeting, multi-location implementation, implementation sequencing, and progress monitoring.
2. *Process Re-engineering*: standardization around best practices, IT's role in the re-engineering process, organizational change, leadership, resistance.
3. *Technical Requirements*: planning and decision support, interfacing with legacy systems, EDI capability, web capability, incorporation of third-party software packages, software upgrades.

<b>Project Characteristic</b>	<b>Average Value</b>	<b>Minimum Value</b>	<b>Maximum Value</b>
<b>(n=28)</b>			
Total Project Budget (US\$)	20.8 M	0.7 M	107 M
No of sites concerned	15.7	3	80
No of licenses purchased	949	1	5000
No of people affected	8440	50	120,000
Sales Volume affected (US\$)	890 M	260 K	4.1 Bn
Project duration (months)	25.3	9	60

*Table 6. Average Magnitude of the ERP Initiatives*

The management literature offers fragmented insights on these challenges largely based on observations from both successful and abandoned initiatives in various industries. These are synthesized in the next section.

#### **4. IMMEDIATE IMPLEMENTATION CHALLENGES**

##### *4.1 Project Management*

Austin and Nolan<sup>7</sup> propose that ERP projects be structured and managed as new ventures rather than IT projects. They argue that the risk profile of ERP projects,

fraught with technological, organizational and business complexity, closely resembles that of a new venture. In addition, the sheer size of the investment required to implement ERP strongly supports the point to treat such projects as new ventures. Hence, they propose a project management framework built on three factors: staging, risk sharing, and people. *Staging* calls for a modular approach to implementing ERP systems. It would therefore make sense to divide the project into more manageable segments, thus reducing the probability of a write-off. To fully experience the benefits of an ERP system, software vendors emphasize the importance of implementing the system as a whole. The challenge therefore is to identify the smallest self-contained business unit that allows for full-scale implementation within a manageable project scope.

*Risk sharing* arrangements should encourage co-operative problem solving in the case of unanticipated events in an ERP implementation process. A well-selected team of *people* is imperative to the success of ERP projects. Austin and Nolan emphasize that the company should place strong people in project management and technical roles to prevent the project expertise from gravitating toward the vendor or system integrator member of the team.

Upton and McAfee<sup>8</sup>, who suggest a path-based approach for ERP initiatives, also share this perspective. This approach is built upon the continuous improvement principles of modularity, accessibility, and inclusiveness. *Modularity* aims at building a system so that, as far as possible, a modification in one element does not trigger changes throughout the system. In addition to easier maintenance and upgrade, modularity allows for local experimentation with selected elements of the system without disrupting the process as a whole. *Accessibility* reflects the ease with which the people in an operation can change parameters of a technology for experimentation or fine-tuning. Systems that operate as black boxes are ultimate examples of inaccessibility. *Inclusiveness* is the principle of involving the people, who will ultimately use the technology, during its design and implementation. It reinforces an awareness of the impact that the changes will have on the existing social system and on the skills of the people.

ERP implementation projects are notorious for time and budget overruns. Even in industries such as petrochemicals where SAP's R/3 has become the industry

standard, Davenport quotes a CEO that competitive advantage might just come from implementing *SAP* in the best and cheapest way<sup>9</sup>. Slater identifies five areas that may greatly inflate project costs<sup>10</sup>: training, integration and testing, data conversion, data analysis, and consulting services. Training is expensive since workers typically have to learn a new set of processes, not just a new software interface. *Gartner Group* estimates that successful training will account for 10 to 15% of the total project budget.

As in the implementation of MRP systems, data clean up and conversion is a vital part of an ERP implementation. Invariably, the same part will have different part numbers at different plants; the Sales Department will have various renderings of the same customer's name and coordinates. ERP implementation is a good opportunity to eradicate such inconsistencies. Data clean up has created a set of niche players within the ERP ecosystem. *Conversion Sciences* or *Evolutionary Technologies International* claim to reduce conversion costs by as much as 75%.

Consulting expertise must be deployed wisely both to avoid overtime costs and to ensure the transfer of the necessary know-how to run and maintain the system internally. Under pressure to simplify –hence, expedite- the implementation process, many consultants use business process templates that prescribe best practices for particular industries. Examples of such standardized approaches include *Oracle Fast Forward* and *ASAP*, typically provided by local resellers. *Siemens's R/3 Live Express* is a fixed time-scale, fixed-cost implementation service for medium sized companies. The German electronics group has experience with some 1,400 ERP projects, making it the largest customer for *SAP*. Based on this experience, *Siemens* has developed its own expert system, which produces a software system configuration based on an interactive questionnaire. This, in turn, shortens the design phase and enables system implementation to be completed within three months.

The big advantage is that many of the glitches that had to be laboriously detected and fixed are eliminated. Templates, however, remain the property of the consulting firm; competitors can therefore get most of the same benefits. Moreover, such convergence around a single software and process templates might create uniform information flows and process structures within a particular industry, which, in turn might undermine the differences between a company and its competitors.

Another cost cutting measure widely adopted by companies lacking the critical resources for ERP projects is to outsource both the implementation and the management of the system to third party IT service providers. *Origin* has pioneered the service, which has attracted competition from such giants as *IBM* and *HP*. While outsourcing the IT function is not new, viewing the ERP system as another piece of IT may have serious consequences for the company.

#### *4.2 IT-led BPR and System Standardization*

ERP systems are designed to eliminate information fragmentation in large organizations. Since an ERP system streamlines data flows and provides access to a wealth of operating information, gains in productivity and speed can indeed be realized. Problems arise when the ERP system does not fit exactly with the company's specific business context. Some customization of the system is possible, but often not very appealing for various reasons. First, major modifications are time-consuming and expensive, both to implement and to maintain. Second, more customized systems become less able to communicate with systems of suppliers and customers. Most importantly, however, within the implementation, the business becomes modified to fit the system and the underlying best process, with the vendor defining what is "best".

Davenport points out that ERP systems typically fail due to business problems and not technical challenges, however great the latter may be<sup>9</sup>. If the logic of the ERP system conflicts with the logic of the business, implementing ERP may actually weaken important sources of a company's competitive advantage. Successful companies view their systems primarily in strategic and organizational terms, implying that certain strategic questions should be answered before any decisions are taken. These questions should include the system's impact on the organization and its competitive position as well as the scope of the implementation in terms of needed modules, functions, geographic locations, and timing. A celebrated example, *Dell Computers*, has suspended the *SAP* implementation with the corporate goal of "running Dell on Dell [hardware]"<sup>11</sup>. Another example is *Compaq*, which uses its proprietary modules for forecasting and materials management while using *SAP's R/3* for other processes. On the other hand, Davenport reports that, in the petrochemical industry, ERP systems have improved the flow of information

through the supply chain to such a degree that they have become a *de facto* operating standard<sup>9</sup>.

It is therefore necessary to understand IT's delicate role in business process re-engineering (BPR). On the one hand, IT cannot enhance productivity significantly unless management processes, including the organizational structure, job characteristics, performance measures, and the reward system, are redesigned. On the other hand, BPR relies on the use of IT to create radically different working methods to deliver significant improvements. Furthermore, BPR can also be viewed as a channel through which IT solutions can be evaluated and selected. Soliman and Youssef highlight the role of SAP's *R/3* in guiding process re-engineering efforts<sup>12</sup>. Companies in our survey share the same view by declaring ERP a key catalyst for organizational change; for instance, ERP makes it possible to adopt a new set of performance metrics by enabling routine data collection on those metrics. In its ERP initiative, a European consumer electronics giant has budgeted one year for BPR and four months for software implementation for each organization.

#### *4.3 Technical Requirements*

Standard ERP packages do not include data analysis and decision support tools. Required capabilities such as data warehousing, advanced forecasting, and simulation should be explicitly factored into the project budget, as they are typically supplied by third-party vendors. Furthermore, appropriate interfaces have to be built between such modules and the standard ERP implementation. In most cases, standard ERP modules have to be interfaced with legacy systems and software from other vendors, necessitating a case-by-case building and testing the necessary links.

In fact, within the current generation of the ERP systems, companies are combining software packages from various vendors. While the ERP systems provide the platform for transaction management, Advanced Planning and Scheduling (APS) capabilities are typically provided by *i2 Technologies* or *Manugistics*. For example, many companies report the implementation of SAP's *R/3* as the ERP backbone supplemented by *i2 Technologies'* *Rhythm* pull scheduling system or *PeopleSoft* as the backbone complemented with *Manugistics5*. This has been possible largely due to the development partnerships created between ERP vendors and third party software developers. In the absence of such arrangements, middleware vendors

such as *Crossworlds* who write customized interfaces between different application programs provide crucial integration solutions.

The cost and complexity of middleware will become too heavy to support in the long run. The only viable alternative is to adopt fully open and modular systems, where different modules can be updated or modified without paralyzing the entire system. The transition in hardware platforms from monolithic and closed mainframe computers to powerful personal computers for client-server computing provides a useful benchmark. On the software side, object-oriented programming is necessary to ensure modularity of application programs. What is needed are open standards, which allow hardware and software products from different vendors to be combined effortlessly. One such initiative, the Open Systems Interconnect Group (OSI) has agreed upon a multi-level open system model. At the lowest level, the system is concerned with the physical connection of the devices, whereas the higher levels define the addressing and the delivery of a message, and the encoding of information. There exist many open standards at each of the seven levels. The best-known open system is the *Internet*. An example of a modular portable programming language is *Java* of *Sun Microsystems*.

ERP vendors have also started adopting some of the open standards. The new version of *SAP's R/3* system expands features such as Application Link Enabling (ALE), Business Objects, business application programming interfaces (BAPIs) to incorporate standard object-oriented techniques and to better interface with Internet and intranet applications. *SAP* has also announced that future versions of its software will separate logistics and human resources functions from the remainder of the system so as to treat them as individual (hence, substitutable) components.

## **5. THE ROLE OF ERP IN DYNAMIC SUPPLY CHAIN DESIGN**

Recall that Fisher<sup>2</sup> defines market mediation as one of the key functions of a supply chain. Figure 2 summarizes the principal approaches to match demand and supply in a dynamic, uncertain environment. Most ERP initiatives appear to focus on supply chain coordination initiatives. In other words, the bulk of the effort is spent in creating an information technology infrastructure –or a transaction system– to facilitate information deployment, channel alignment, and operational flexibility. However, we believe that the most significant impact of ERP systems will be on the

capability of dynamic supply chain design, as defined by Fine<sup>3</sup>. In other words, ERP will furnish the necessary platform for dynamically reconfiguring the supply chain as a function of acquired capabilities and emerging technologies.

On the technology dimension, there are some important prerequisites in terms of capabilities offered by the software package such as memory-resident processing. On the business capabilities dimension, a balance between business process re-engineering and continuous improvement will be necessary. These long-term challenges are discussed next.

### *5.1 ERP Evolution*

The ERP industry is now a tightly-knit ecosystem of software vendors, middleware vendors, supply chain experts, specialty-software houses, and hardware vendors. The ecosystem is also evolving fairly rapidly. It is therefore important to understand the capabilities afforded by the current technology and identify the desirable features of future versions.

#### *ERP: Transaction Management – “Can I take your order?”*

Most of the companies in our survey have implemented a transaction management system. This was a necessary investment in infrastructure to end the IT fragmentation. Hence, it is no longer necessary for a salesperson to write down a customer request taken over the telephone and spend the following two days figuring out whether the customer request can be satisfied. The new system makes the supply chain fully transparent, enabling the salesperson to answer the customer inquiry right away. The system is also capable of figuring out the best way to deliver the product to the customer, invoice the customer, and credit the salesperson. Davenport reports on how ERP ended not only the IT fragmentation, but also the business fragmentation at *Elf Atochem*: prior to implementing *SAP's R/3* system, the company's twelve business units were autonomous entities<sup>9</sup>. Not only inventory consolidation and manufacturing coordination could not be done at the corporate level, many (common) customers had to contact the business units separately to place their orders. ERP implementation ended this fragmentation by enabling the creation of a single customer service department, providing each customer with a single point of contact *within Elf Atochem*. Such a system, however, still reflects the traditional MRP thinking, heavily relying on accurate forecasts, although information

distortion induced by fragmented IT systems and isolated departments has been largely eliminated. The resulting capability can be summarized as: I can take your order if the material exists somewhere along the supply chain.

*ERP+: Available to Promise – “Should I take your order?”*

Available to promise (ATP) is an emerging concept within the ERP circles. The challenge here is not to figure out whether the customer order can be satisfied with the goods available *somewhere* along the supply chain, but to decide whether it is economically meaningful to allocate supply chain capacity to this potential order. In a way, this capability is analogous to *yield management* that provides significant revenue enhancements to service companies such as the airlines. Smith et al.<sup>13</sup> estimate that yield management generates additional annual revenues of over \$500M for *American Airlines*. This may be the key enabler for a truly make-to-order (MTO) system that evaluates the feasibility of an incoming customer request with respect to both physical capacity constraints and the economic value of the available capacity. This capability can be summarized as follows: does it make business sense for me to accept your order?

The key pre-requisite for true MTO capability is memory-resident processing that considers material and capacity simultaneously. This approach, typically referred to as Advanced Planning and Scheduling (APS), represents a significant diversion from the traditional MRP thinking. While ERP is the transaction backbone, APS systems provide decision support functionality. ERP planning components such as master production scheduling, MRP, distribution requirements planning, and capacity requirements planning will be replaced or redesigned.

Most manufacturing companies implement both ERP and APS systems, and turn off parts of their ERP implementations. For example, *SAP's R/3, Baan or Peoplesoft* can be implemented as a transaction management backbone in conjunction with APS systems from *i2 Technologies, Logility, Numetrix or Manugistics* as a planning and decision support tool.

Many ERP vendors, however, have recognized the need to re-engineer planning components of their systems. *SAP's SCOPE* (Supply Chain Optimization, Planning and Execution) is the most notable initiative in this direction. *SAP APO* (Advanced

Planning and Optimization) is a real-time decision support tool for demand planning, supply network planning and deployment, production planning and detailed scheduling, and global ATP. Supply Chain Cockpit, on the other hand, is a graphical interface for network configuration.

ERP+ represents a seamless integration between ERP and APS systems. It can therefore provide full transparency along the internal supply chain of a firm, providing real-time ATP capability.

*ERP++: Extended Supply Chain Design – “Should I mobilize my supply network to satisfy your order?”*

The next challenge is to extend the real-time ATP capability upstream to include a firm’s suppliers. Fine<sup>3</sup> advises that products, processes, and supply chains be designed concurrently. He refers to this joint development effort as three-dimensional concurrent engineering (3-DCE). A crucial decision within the 3-DCE process is the on-going make/buy evaluations. In other words, companies must dynamically decide which competencies to harbor and develop in-house and which others to outsource. For example, *Solectron* has emerged as a *Fortune 500* company by providing subcontracting services (both in design and manufacturing) for electronics manufacturers. In the automobile industry, traditional suppliers such as *Solvay Automotive* and *Valéo* are quickly becoming system developers for a specific car model or business venture.

The coordination of various partners along the supply chain necessitates not only a transaction management infrastructure, but also a system for sharing engineering and design data. For example, the launch of a new product can be triggered by the introduction of a new version/model or by the modification of the current product to better meet the needs of a specific customer. Hence, an engineering change order (ECO) initiated by the Engineering Department has to be broadcast along the supply chain, updating all associated system parameters. A California software vendor, *Agile Software*, has implemented the capability of cascading ECOs throughout the supply chain. Such an infrastructure enables the extended supply chain to respond quickly to a design change triggered by a customer who wishes to purchase a slightly different variant of a standard product. This capability may be a key

ingredient for “customer-centric profitable mass customization” promoted by *Manugistics*.

*TurboERP: Engineer to Order* – “Should I configure a new supply chain to design, manufacture, and deliver your order?”

The logical next step would be the engineer-to-order systems, where the customer is involved throughout the design and manufacturing phases of a product or service. A plausible scenario is one where the customer submits a product request (through a web-based interface, of course). The request is automatically translated into product and process specifications; the specifications are used to identify a capable supply base for the required components. The specifications are then electronically released to the selected supply base as manufacture and purchase orders, and the request is delivered through the appropriate logistics channels to the customer with all the accompanying financial transactions. There have been recent reports in trade journals on initiatives of grouping CAD/CAM, Workflow, and ERP capabilities under a single software umbrella<sup>14</sup>.

*GE Plastics* is famous for its “thriller auctions” conducted on its Internet-based *Trade Partner Network*. In these auctions, *GE* posts a product and invites its suppliers to bid for the purchase contract within a certain period of time. *TurboERP* might provide the necessary infrastructure for a vendor to dynamically configure a capable supply network for effective and efficient response in such a thrilling environment.

*i2 Technologies* has recently launched their *Intelligent eBusiness* structure, which enables a marriage between electronic commerce, supply chain planning, and supply chain coordination activities. The structure consists of four elements: a customer-facing store front on the web, a back end with ERP+ capability, an integrator between the front and back ends (e.g., the *Internet Fulfillment Server*) and a trading community or exchange consisting of the supplier base. The last element is the public analog of *GE*'s private *Trade Partner Network*.

## 5.2 Process Capability Development

As depicted in Figure 1, supply chain design is facilitated not only by a set of enabling information technologies, but also by a set of new and/or redesigned processes. On the one hand, IT cannot enhance supply chain performance unless

processes and organizational structures are redesigned. On the other hand, process re-engineering relies heavily on the use of IT to create innovative processes to enhance supply chain performance. One of the most important opportunities offered by the ERP evolution is radical business process re-engineering along the supply chain. In an effort to contain the implementation costs and complexity, however, many companies adopt a process re-engineering approach defined by the selected ERP system. This approach typically entails the use of business process templates that reflect best practices in a particular industry. As indicated earlier, such a convergence around process templates might create uniform information flows and process structures within an industry. On the one hand, such convergence may facilitate the dynamic reconfiguration of a supply chain within that industry, as defined by Fine<sup>3</sup>. On the other hand, if processes that are being standardized represent a unique source of competitive advantage, then the ERP implementation will increase the strategic risk of losing such a competitive advantage.

Another long-term disadvantage might stem from the very nature of re-engineering initiatives. Such initiatives, typically aimed at strategic leaps, require a major expenditure of funds and considerable outside expertise. Lower-level employees are affected by the decisions made, since they are the end users of any new process, technology or equipment. However, they are not typically involved in the decision making process and the implementation, since these are considered the domain of experts. In other words, lower-level employees are trained on the use of the new technology, but they are not consulted during the selection and implementation phases.

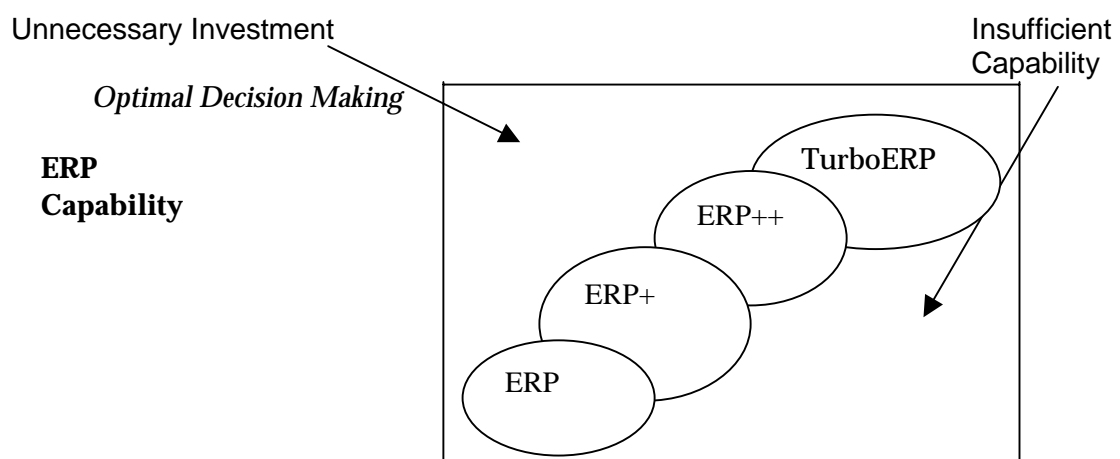
This is in stark contrast with the experience in the manufacturing sector that spent the last two decades adopting a continuous improvement approach within the Just-in-Time and Total Quality Management philosophies. Continuous improvement demands considerable involvement at the lower and middle levels of an organization, relying upon their intimate, on-going knowledge of the operation. While the purpose of this paper is not to rekindle the BPR versus the continuous improvement debate, a better balance between the two approaches is needed for effective ERP implementations. For instance, a European maker of process equipment for microprocessor manufacturing complains that continuous

improvement initiatives such as just-in-time manufacturing, kanban control, and set up time reduction severely stagnate during and after the ERP implementation.

ERP coupled with APS may represent the best opportunity to strike a balance between BPR and continuous improvement. While ERP follows the lowest common denominator in efficiency, APS focuses on being effective with enterprise data. APS is an innovation-driven concept that requires unique solutions, which can only be generated through deep process knowledge. In other words, while ERP-led BPR eliminates most of the inefficiencies along the supply chain due to fragmentation and information distortion, APS, based on continuous improvement, may prove to be a source of competitive advantage. For example, MIMI of *Chesapeake Decision Sciences* (recently acquired by *Aspen Technology Inc.*) is a flexible APS framework that allows the modeling of supply chain activities in terms of capacity, material flows, and order fulfillment.

### 5.3 Matching ERP Capabilities with Supply Chain Strategies

We view enterprise systems as a key infrastructure to develop the capability of dynamic supply chain design. The features of this infrastructure should therefore match the desired characteristics of a supply chain. Fisher<sup>2</sup> argues that the characteristics of a supply chain should be determined by the type of products and services to be delivered along that chain. For instance, “functional products” with stable demand patterns and thin margins would necessitate physically efficient supply chains in order to minimize total landed costs. “Innovative products,” on the other hand, with highly unstable demand and potentially high margins, would necessitate responsive supply chains that are capable of responding to emerging trends in the market.



*Transaction Management  
Backbone*

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*Physical Efficiency*

*Responsiveness*

**Supply Chain Strategy**

*Figure 3. Supply Chain Strategy versus ERP Capability*

These two types of supply chains require radically different information infrastructures. While a reliable transaction management backbone might be sufficient for a physically efficient supply chain, more advanced planning and execution functionalities would be needed to support a responsive supply chain. Figure 3 summarizes this view. For example, it may be sufficient for *Elf Atochem* to implement a robust ERP system for enhancing supply chain efficiency in the highly competitive petrochemical industry<sup>9</sup>. A global car manufacturer, on the other hand, may require an ERP+ infrastructure to acquire the flexibility to switch production from one facility to another with changes in global demand patterns and economic conditions. To support its direct channel and built-to-order strategy, *Dell* may require an ERP++ infrastructure. Finally, suppliers such as *Solectron* and *Valéo*, who provide design, engineering, and manufacturing services, may ultimately need a TurboERP infrastructure.

## **6. CONCLUDING REMARKS**

Many companies currently focus on transaction management. Time and budget pressures lead to black-box standard set-up implementations. Such an approach may prove to be highly inflexible –hence, risky- as the company is forced to rethink its supply chain strategy by competitors, emerging technologies, or new products. Such a dynamic environment would require dynamic supply chain design capabilities.

Our current research is aimed at providing empirical support for this framework. In particular, we are analyzing supply chain performances of a large number of European companies with a particular focus on their information infrastructure.

## **APPENDIX I: THE ERP SURVEY**

A survey instrument, originally developed by McAfee<sup>6</sup>, was administered to managers from European companies attending executive education programs on manufacturing and logistics at INSEAD. The survey consists of four parts: the quality of the existing IT infrastructure (i.e., pre-ERP era), motivation for ERP implementation, impact of the ERP system (i.e., post-ERP era), and the overall magnitude of the project (e.g., number of licenses purchased, number of sites covered, project schedule, etc.) Each section of the survey presents the respondent with a set of statements and asks the respondent whether he agrees or disagrees with that statement. The response is recorded on a Likert scale (1=strongly disagree, 7=strongly agree). The objective is to compare the pre- and post-ERP eras to assess the impact of ERP systems on the dimensions of visibility, functionality, and commonality.

While our data set contains responses from 60 companies, we have chosen to present the subset that consists of managers with supply chain management responsibilities. Our respondents are evenly divided between process industries (e.g., petrochemical) and discrete parts manufacturing (e.g., automotive suppliers).

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