CHAPTER 20
Collaborative Manufacturing

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1. INTRODUCTION

Manufacturing is a constantly evolving field that is strongly driven by optimization of the resources it employs. Manufacturing optimization is showing a shift from processes to businesses in a more systemic analysis of its nature and role in the whole picture. Current economic conditions throughout the world, characterized by the steady growth of local economies, have contributed a good deal to this trend.

This chapter briefly presents the economic principles that drive collaborative manufacturing and the conditions supporting what manufacturing has become nowadays. Later sections of this chapter examine the coordination feature that enables collaborative manufacturing within and between enterprises and discuss several cases that demonstrate the ideas of collaborative manufacturing.

2. MANUFACTURING IN THE CONTEXT OF THE GLOBAL ECONOMY: WHY COLLABORATE?

To understand collaborative manufacturing in its actual form, we must refer to the current world economic conditions that motivate collaborative manufacturing. Many scholars recognize that we are living in the knowledge revolution. As Sahlman (1999) notes, the new economy markedly drives out inefficiency, forces intelligent business process reengineering, and gives knowledgeable customers more than they want. This new economy, based primarily on knowledge and strong entrepreneurship, is focused on productivity and is profoundly changing the role of distribution. Distribution and logistics must be more efficient, cheaper, and more responsive to the consumer. This trend of new, competitive, and open channels between businesses is geographically dispersed, involving highly technical and rational parties in allocating effort and resources to the most qualified suppliers (even if they are part of another company).

One of the key aspects leading the way in this new knowledge-based world economy is science. There is a well-documented link between science and economic growth (Adams 1990), with a very important intermediate step, technology. Science enables a country to grow stronger economically and become the ideal base for entrepreneurs to start new ventures that will ultimately raise productivity to unprecedented levels. This science–growth relationship could lead to the erroneous conclusion that this new economy model will prevail only in these geographic areas favoring high-level academic and applied R&D and, even more, only to those institutions performing leading research. However, as Stephan (1996) points out, there is a spillover effect that transfers the knowledge generated by the research, and this knowledge eventually reaches underdeveloped areas (in the form of new plants, shops, etc.). This observation is confirmed by Rodriguez-Clare (1996), who examined an early study of collaborative manufacturing, multinational companies and their link to economic development. According to the Rodriguez-Clare model, the multinational company can create a positive or negative linkage effect upon any local economy. A positive linkage effect, for example, is created by forcing local companies to attain higher standards in productivity and quality. An example is the electronics industry in Singapore (Lim and Fong 1982). A negative linkage effect is created by forcing local companies to lower their operational standards. An example is the Lockheed Aircraft plant in Marietta, Georgia (Jacobs 1985).

We are therefore facing a new world of business, business of increasing returns for knowledge-based industries (Arthur 1996). The behavior of increasing-returns products is contrary to the classical economic equilibrium, in which the larger the return of a product or service, the more companies will be encouraged to enter the business or start producing the product or service, diminishing the return. Increasing-returns products or services, on the other hand, present positive feedback behavior, creating instability in the market, business, or industry. Increasing returns put companies on the leading edge further ahead of the companies trailing behind in R&D of new products and technologies. A classical example of this new type of business is the DOS operating system developed by Microsoft, which had a lock-in with the distribution of the IBM PC as the most popular computer platform. This lock-in made it possible for Microsoft to spread its costs over a large number of users to obtain unforeseen margins. The world of new business is one of pure adaptation and limits the use of traditional optimization methods, for which the rules are not even defined.

Reality presents us with a highly complex scenario: manufacturing companies unable to perform R&D seem doomed to disappear. One of the few alternatives left to manufacturing companies is to go downstream (Wise and Baumgartner 1999). This forces companies to rethink their strategy on downstream services (customer support) and view them as a profitable activity instead of a trick to generate sales. Under this new strategy, companies must look at the value chain through the customer's eyes to detect opportunities downstream. This affects how performance is measured in the business. Product margin is becoming more restricted to the manufacturing operation, disregarding services related to the functioning and maintenance of the product throughout its life. A feature that is increasing over time in actual markets is for businesses to give products at a very low price or even for free and wait for compensation in service to the customer or during the maintenance stage of the product's life cycle (e.g., cellphones, cable television markets in the United States). According to Wise and Baumgartner (1999), manufacturing companies follow one of four downstream business models (Table 1).

The ability to respond quickly and effectively to satisfy customers is what is making the difference among manufacturing companies nowadays. Technological advances such as Internet are facilitating ways for companies to meet their customer needs. As DeVor et al. (1997) point out, agile manufacturing focuses on enhancing competitiveness through cooperation and use of information technology to form virtual enterprises. Virtual enterprises are constructed by partners from different companies collaborating with each other to design and manufacture high-quality, customized products (Chen et al. 1999). Agile manufacturing practices are based on five principles (Yusuf and Sarhadi 1999):

- Identifying and creating value
- Enabling the flow-of-value stream
- Allowing customers to pull value uninterrupted
- Responding to unpredictable change
- Forming tactical and virtual partnerships

TABLE 1 Downstream Business Models

Downstream Model	Characteristics	Example
Embedded services	Embedding of downstream services into the product, freeing the customer of the need to perform them.	Honeywell and its airplane information management system (AIMS)
Comprehensive services	Coverage of downstream services not possible to embed into the product, for example financial services.	General Electric in the locomotive market
Integrated solutions	Combination of products and services for addressing customer needs	Nokia's, array of products for mobile telephony
Distribution control	Moving forward over the value chain to gain control over distribution activities	Coca-Cola and its worldwide distribution network

Agile manufacturing can be considered as the integration of technologies, people, and business processes.

3. COORDINATION AND CONTROL REQUIREMENTS IN COLLABORATIVE MANUFACTURING

An increasing number of companies are basing their future on global markets. The globalization of resources and customers has shifted the focus of industrial companies from resource control to customer-focused control over time (Hirsch et al. 1995). Competitiveness among companies nowadays relies on an increasingly important aspect: time-to-market. Pursuing shorter time-to-market requires faster development cycles for the products and close attention to geographically distributed markets. To cope effectively in this demanding environment, companies frequently engage in collaborative partner relationships, which allow them to focus and coordinate their efforts and improve their position in the market. The collaboration results in an integrated, aligned enterprise composed of several independent companies. Partner companies combine their capabilities in generating new business opportunities to which they could not have access otherwise.

Manufacturing covers a wide range of activities, from early design stages to product recycling. Companies often need to use collaboration between designers, technicians, departments, and divisions, or with other companies, to attain the desired results in an efficient way. As the complexity of the problems in manufacturing increases, concurrent engineering teams have resulted the most effective manner in which to tackle them. Concurrent engineering teams are composed of individuals with a wide range of expertise in different areas. This diversity of knowledge and viewpoints provides the team with the view of the manufacturing process necessary for addressing the complexity of the problems. However, to make from concurrent engineering something more than never-ending meetings, support to coordinate and control the collaboration must be provided. Coordination allows the cooperative operation of two or more systems in the pursuit of complementary objectives, as well as the efficient utilization of resources and allocation of efforts in the organization(s). Much of the support for the collaboration effort required by concurrent engineering comes from the information technologies and the great advances they have experienced in the last decade. Computer-supported collaborative work (CSCW) has been implemented largely for engineering collaboration (Phillips 1998), along with more sophisticated techniques, such as conflict resolution in distributed design (Nof and Huang 1998). The advantages from using information technologies in collaborative manufacturing arise from two sources. First, more information can be acquired from teams having computer support. Second, information availability makes possible a more objective analysis of the problem in a system view. However, some drawbacks should be kept in mind: information overload, lack of knowledge integration, cooperation, and coordination among team members may render the utilization of CSCW tools completely counterproductive.

A key aspect that any CSCW tool must consider is reconfiguration. Adaptation to constantly changing conditions in the manufacturing industry must be attained through tools providing the enterprise with reconfiguration capabilities. Numerous methods for quick reconfiguration of collaborative engineering initiatives have been developed so far. Methods range from those based on integration requirements of the activities being performed (Khanna and Nof 1994; Witzerman and Nof

1995; and Kim and Nof 1997, among others) to those based on concepts taken from disciplines other than manufacturing (Khanna et al. 1998; Ceroni 1999; and Ceroni and Nof 1999, who extend the parallel computing problem to manufacturing modeling).

4. FRAMEWORK FOR COLLABORATIVE MANUFACTURING

The distributed environment presents new challenges for the design, management, and operational functions in organizations. Integrated approaches for designing and managing modern companies have become mandatory in the modern enterprise. Historically, management has relied on a well-established hierarchy, but, the need for collaboration in modern organizations overshadows the hierarchy and imposes networks of interaction among tasks, departments, companies, and so on. As a result of this interaction, three issues arise that make the integration problem critical: variability, culture, and conflicts. Variability represents all possible results and procedures for performing the tasks in the distributed organizations. Variability is inherently present in the processes, but distribution enhances its effects. Cultural aspects such as language, traditions, and working habits impose additional requirements for the integration process of distributed organizations. Lastly, conflicts may represent an important obstacle to the integration process. Conflicts here can be considered as the tendency to organize based on local optimizations in a dual local/global environment. Collaborative relationships, such as user–supplier, are likely to present conflicts when considered within a distributed environment. Communication of essential data and decisions plays a crucial role in allowing organizations to operate cooperatively. Communication must take place in a timely basis in order to be an effective integration facilitator and allow organizations to minimize their coordination efforts and costs.

The organizational distributed environment has the following characteristics (Hirsch et al. 1995):

- Cooperation of different (independent) enterprises
- Shifting of project responsibilities during the product life cycle
- Different conditions, heterogeneity, autonomy, and independence of the participants' hardware and software environments

With these characteristics, the following series of requirements for the integration of distributed organizations can be established as the guidelines for the integration process:

- Support of geographically distributed systems and applications in a multisite production environment and, in special cases, the support of site-oriented temporal manufacturing
- Consideration of heterogeneity of systems ontology, software, and hardware platforms and networks
- Integration of autonomous systems within different enterprises (or enterprise domains) with unique responsibilities at different sites
- Provision of mechanisms for business process management to coordinate the information flow within the entire integrated environment

Among further efforts to construct a framework for collaborative manufacturing is Nofs' taxonomy of integration (Figure 1 and Table 2), which classifies collaboration in four types: mandatory, optional, concurrent, and resource sharing. Each of these collaboration types is found along a human–machine integration level and an interaction level (interface, group decision support system, or computer-supported collaborative work).

5. FACILITATING AND IMPLEMENTING COLLABORATION IN MANUFACTURING

During the design stages of the product, *codesign* (Eberts and Nof 1995) refers to integrated systems implemented using both hardware and software components. Computer-supported collaborative work (CSCW) allows the integration and collaboration of specialists in an environment where work and codesigns in manufacturing are essential. The collaboration is accomplished by integrating CAD and database applications, providing alphanumeric and graphical representations for the system's users. Codesign protocols were established for concurrency control, error recovery, transaction management, and information exchange (Figure 2). The CSCW tool supports the following design steps:

- Conceptual discussion of the design project
- High-level conceptual design
- Testing and evaluation of models
- Documentation

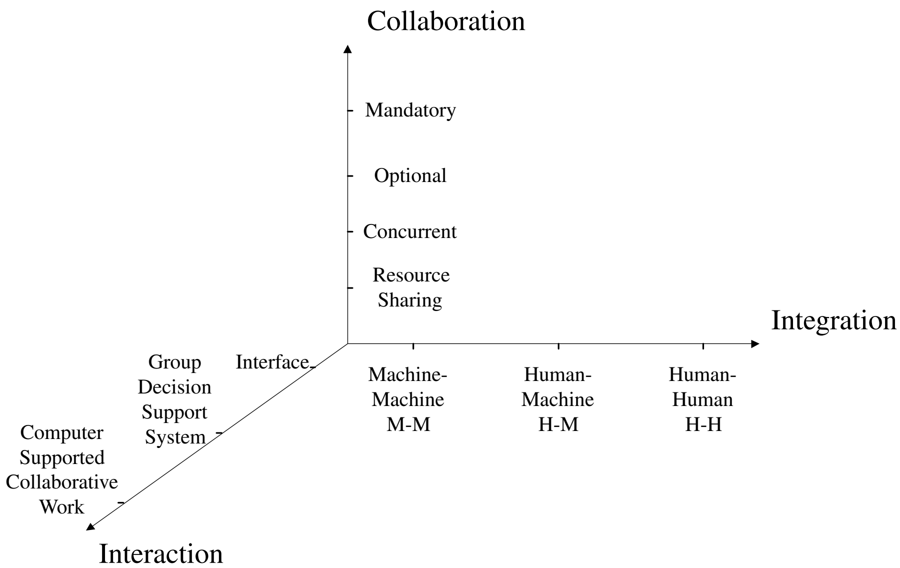


Figure 1 Integration Taxonomy. (From Nof 1994)

When deciding on its operation, every manufacturing enterprise accounts for the following transaction costs (Busalacchi 1999):

1. Searching for a supplier or consumer
2. Finding out about the nature of the product
3. Negotiating the terms for the product
4. Making a decision on suppliers and vendors
5. Policing the product to ensure quality, quantity, etc.
6. Enforcing compliance with the agreement

Traditionally, enterprises grew until they could afford to internalize the transaction costs of those products they were interested in. However, the transaction costs now have been greatly affected by

TABLE 2 Example of Collaboration Types for Integration Problems

	Integration Problem	Example		Collaboration Type
1	Processing of task without splitting and with sequential processing	Concept design followed by physical design	H-H	Mandatory, sequential
2	Processing of task with splitting and parallel processing	Multi-robot assembly	M-M	Mandatory, parallel
3	Processing of task without splitting. Very specific operation	Single human planner (particular)	H-M	Optional, similar processors
4	Processing of task without splitting. General task	Single human planner (out of a team)	H-M	Optional, different processors types
5	Processing of task can have splitting	Engineering team design	H-H	Concurrent
6	Resource allocation	Job-machine assignment	M-M	Competitive
7	Machine substitution	Database backups	M-M	Cooperative

From Nof 1994.

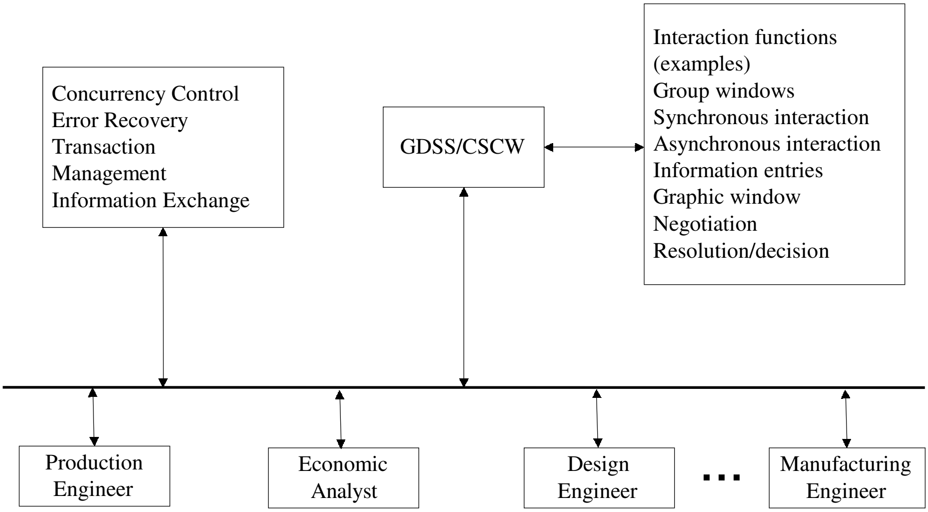


Figure 2 Codesign Computer-Supported Collaborative Work (CSCW) System.

technologies such electronic data interchange (EDI) and the Internet, which are shifting the way of doing business, moving the transaction costs to:

1. Coordination between potential suppliers or consumers
2. Rapid access to information about products
3. Means for rapid negotiation of terms between suppliers and consumers
4. Access to evaluative criteria for suppliers and consumers
5. Mechanisms for ensuring the quality and quantity of products
6. Mechanisms for enforcing compliance with the agreement

6. MOVING FROM FACILITATING TO ENABLING COLLABORATION: E-WORK IN THE MANUFACTURING ENVIRONMENT

We define e-work as collaborative, computer-supported activities and communication-supported operations in highly distributed organizations of humans and/or robots or autonomous systems, and we investigate fundamental design principles for their effectiveness (Nof 2000a,b). The premise is that without effective e-work, the potential of emerging and promising electronic work activities, such as virtual manufacturing and e-commerce, cannot be fully realized. Two major ingredients for future effectiveness are autonomous agents and active protocols. Their role is to enable efficient information exchanges at the application level and administer tasks to ensure smooth, efficient interaction, collaboration, and communication to augment the natural human abilities.

In an analogy to massively parallel computing and network computing, the teamwork integration evaluator (TIE) has been developed (Nof and Huang 1998). TIE is a parallel simulator of distributed, networked teams of operators (human, robots, agents). Three versions of TIE have been implemented with the message-passing interface (on Intel's Paragon, on a network of workstations, and currently on Silicon Graphics' Origin 2000):

1. TIE/design (Figure 3) to model integration of distributed designers or engineering systems (Khanna et al. 1998)
2. TIE/agent (Figure 4) to analyze the viability of distributed, agent-based manufacturing enterprises (Huang and Nof, 1999)
3. TIE/protocol (Figure 5) to model and evaluate the performance of different task administration active protocols, such as in integrated assembly-and-test networks (Williams and Nof 1995)

7. CASE EXAMPLES

Global markets are increasingly demanding that organizations collaborate and coordinate efforts for coping with distributed customers, operations, and suppliers. An important aspect of the collaboration

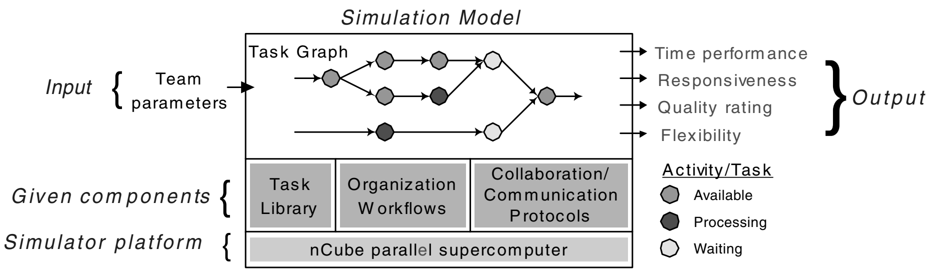
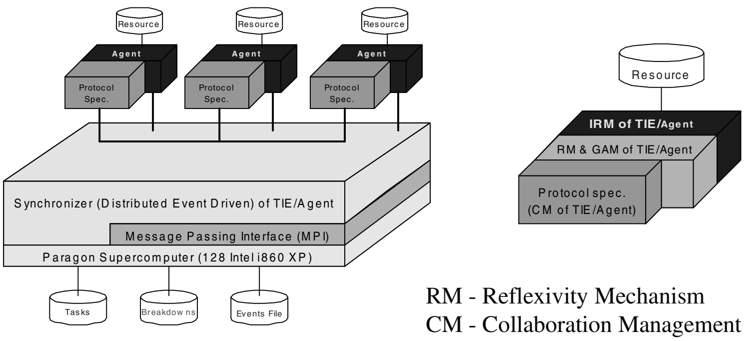


Figure 3 Integration of Distributed Designers with TIE/Design.

process of distributed, often remote organizations is the coordination cost. The coordination equipment and operating costs limit the benefit attainable from collaboration. In certain cases, this cost can render the interaction among distributed organizations nonprofitable. Previous research investigated a distributed manufacturing case, operating under a job-shop model with two distributed collaborating centers, one for sales and one for production. A new model incorporating the communication cost of coordination has been developed (Ceroni et al. 1999) yields the net reward of the total system, determining the profitability of the coordination. Two alternative coordination modes are examined: (1) distributed coordination by the two centers and (2) centralized coordination by a third party. The results indicate that distributed and centralized coordination modes are comparable up to a certain limit; over this limit, distributed coordination is always preferred.

7.1. Coordination Cost in Collaboration

In a modern CIM environment, collaboration among distributed organizations has gained importance as companies try to cope with distributed customers, operations, and suppliers (Papastavrou and Nof 1992; Wei and Zhongjun 1992). The distributed environment constrains companies from attaining operational efficiency (Nof 1994). Furthermore, coordination becomes critical as operations face real-time requirements (Kelling et al. 1995). The role of coordination is demonstrated by analyzing the coordination problem of sales and production centers under a job-shop operation (Matsui 1982, 1988). Optimality of the centers' cooperative operation and suboptimality of their noncooperative operation have been demonstrated for known demand, neglecting the coordination cost (Matsui et al. 1996). We introduce the coordination cost when the demand rate is unknown and present one model of the coordination with communication cost. The communication cost is modeled by a message-passing protocol with fixed data exchange, with cost depending on the number of negotiation iterations for reaching the system's optimal operating conditions. The model developed here is based on the research in Matsui et al. (1996) and the research developed on the integration of parallel distributed production systems by the Production Robotics and Integration Software for Manufacturing Group (PRISM) at Purdue University (Ceroni 1996; Ceroni and Nof 1999).



RM - Reflexivity Mechanism
CM - Collaboration Management
IRM - Internal Resource Management
GAM - Goal Adjustment Mechanism

Figure 4 Viability Analysis of Distributed Agent-Based Enterprises with TIE/Agent.

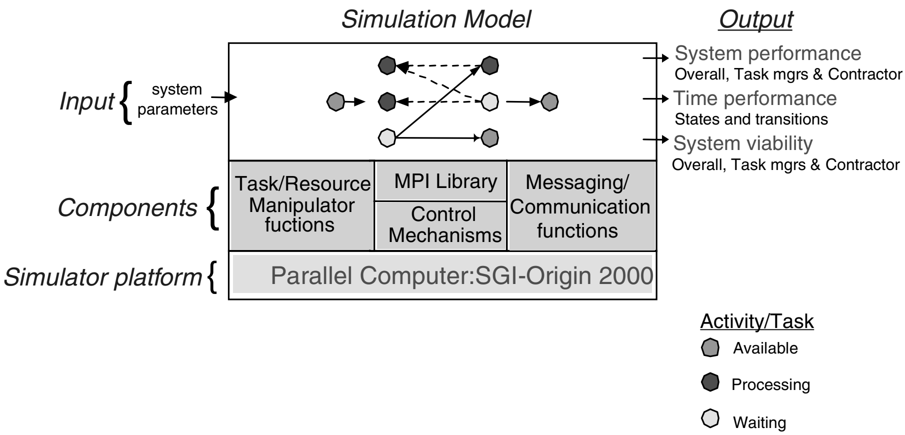


Figure 5 Modeling and Evaluation of Task Administration Protocols with TIE/Protocol.

7.1.1. Job-Shop Model

The job-shop model consists of two distributed centers (Figure 6). Job orders arrive at the sales center and are selected by their marginal profit (Matsui 1985). The production center processes the job orders, minimizing its operating cost (Tijms 1977).

7.1.2. Coordination Cost

Two basic coordination configurations are analyzed: (1) a distributed coordination model in which an optimization module at either of the two centers coordinates the optimization process (Figure 7) and (2) a centralized coordination model where a module apart from both centers optimizes all operational parameters (Figure 8).

The distributed model requires the centers to exchange data in parallel with the optimization module. The centralized model provides an independent optimization module.

Coordination cost is determined by evaluating (1) the communication overhead per data transmission and (2) the transmission frequency over the optimization period. This method follows the concepts for integration of parallel servers developed in Ceroni and Nof (1999). Communication overhead is evaluated based on the message-passing protocol for transmitting data from a sender to one or more receptors (Lin and Prassana 1995). The parameters of this model are exchange rate of messages from/to the communication channel (t_d), transmission startup time (t_s), data packing/unpacking time from/to the channel (t_l), and number of senders/receptors (p).

7.1.3. Results

The coordination of distributed sales and production centers is modeled for investigating the benefits of different coordination modes. Results show that the coordination cost and the number of negotiation iterations should be considered in the decision on how to operate the system. The numerical results indicate:

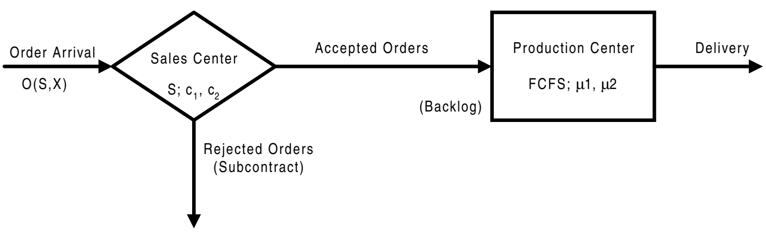


Figure 6 Distributed Job-shop Production System.

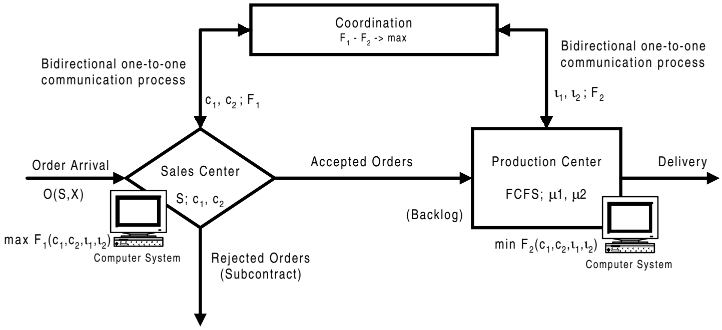


Figure 7 Distributed Configuration for the Coordination Model.

1. Same break-even point for the distributed and centralized modes at 400 iterations and $\lambda = 2$ jobs per time unit.
2. The lowest break-even point for the centralized mode at 90 iterations and $\lambda = 5$ jobs per time unit.
3. Consistently better profitability for the centralized mode. This effect is explained by lower communication requirements and competitive hardware investment in the centralized mode.
4. The distributed mode with consistently better profitability than the centralized mode at a higher hardware cost. This shows that distributed coordination should be preferred at a hardware cost less than half of that required by the centralized coordination mode.

From this analysis, the limiting factor in selecting the coordination mode is given by the hardware cost, with the distributed and centralized modes becoming comparable for a lower hardware investment in the centralized case. Coordination of distributed parties interacting for attaining a common goal is also demonstrated to be significant by Ceroni and Nof (1999) with the inclusion of parallel servers in the system. This model of collaborative manufacturing is discussed next.

7.2. Collaboration in Distributed Manufacturing

Manaco S.A. is a Bolivian subsidiary of Bata International, an Italian-based shoemaker company with subsidiaries in most South American countries as well as Canada and Spain. The company has several plants in Bolivia, and for this illustration the plants located in the cities of La Paz and Cochabamba (about 250 miles apart) are considered. The design process at Manaco is performed by developing prototypes of products for testing in the local market. The prototypes are developed at the La Paz plant and then the production is released to the Cochabamba plant. This case study analyzes the integration of the prototype production and the production-planning operations being performed at distributed locations by applying the distributed parallel integration evaluation model (Ceroni 1999).

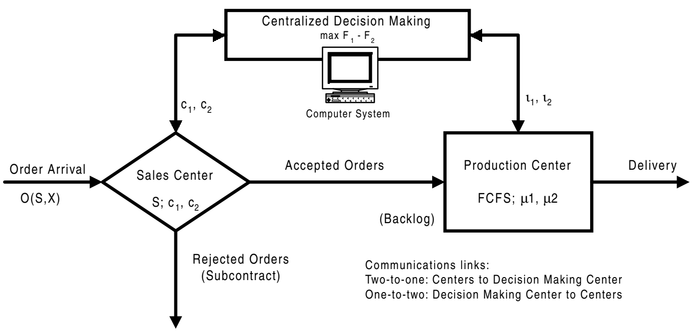


Figure 8 Centralized Configuration for the Coordination Model.

TABLE 3 Description of Tasks in the Distributed Manufacturing Case

Operation: Production Planning (La Paz plant)		Operation: Prototype Production (Cochabamba plant)	
Task	Description	Task	Description
1A	Market research	1B	CAD drawing
2A	Cutting planning	2B	Cutting
3A	Purchasing planning	3B	Sewing
4A	Capacity planning	4B	Assembly
5A	Assembly planning		
6A	Generation of production plan		

The production-planning operation (operation A) consists of six tasks, with some of them being executed in parallel. The prototype development operation (operation B) consists of four tasks, all of them sequential. Table 3 and Figure 9 show the description and organization of the tasks in each operation.

Means and standard deviations for the task duration are assumed. The time units of these values are work days (8 hours).

To contrast the situations with and without integration, two alternative solutions were developed. The first solution considers the sequential processing of the operations: the prototype was developed at La Paz and then the results were sent to Cochabamba for performance of the production planning. Parallelism is included at each operation for reducing the individual execution cycles. The second solution considers the integration and inclusion of parallelism in both operations simultaneously.

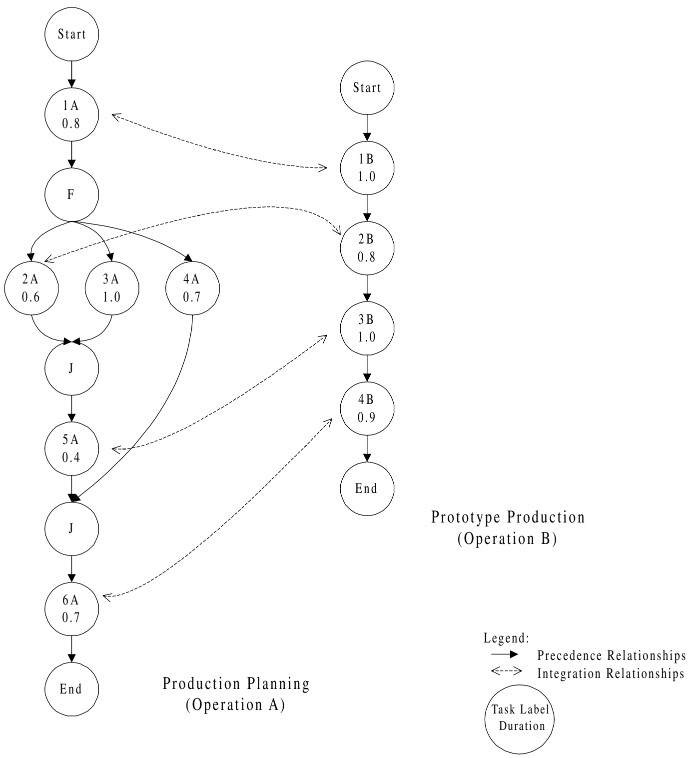


Figure 9 Tasks and Their Precedence Relationship in the Distributed Manufacturing Case.

Assumptions were made for generating an integration model for applying the parallelism optimization.

7.2.1. Integrated Optimization

The integration process in both operations is simplified by assuming relationships between tasks pertaining to different operations. A relationship denotes an association of the tasks based on the similarities observed in the utilization of information, resources, personnel, or the pursuing of similar objectives. Integration then is performed by considering the following relationships:

1A–1B
2A–2B
5A–3B
6A–4B

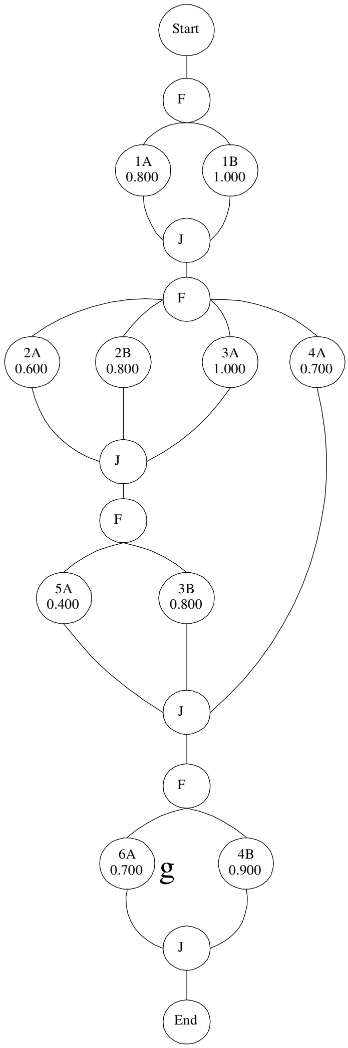


Figure 10 Integrated Model of the Distributed Manufacturing Tasks.

TABLE 4 Simulation Results for Operation A

Task	λ_I Average Communication Delay	$\sigma_{\lambda I}$ Standard Deviation	π Average Duration
1A	0.0008104	0.000129777	0.801865
2A	0.0004519	0.000154528	0.595181
4A	0.0003821	2.87767E-05	0.977848
3A	0.0003552	1.83533E-05	0.734888
5A	0.0277421	0.013688588	0.399918
6A	0.0561208	0.022934333	0.698058

The task relationships allow the construction of an integrated model of the operations. This integrated model preserves the execution order of the tasks as per their local model (Figure 9). Figure 10 shows the integrated model for operations A and B.

Once the integrated schema was generated, the parallelism analysis was performed. In order to evaluate the parallelism in the system, the time of communication and congestion delays needed to be estimated. The estimation of these delays was performed using the software TIE 1.4 (Khanna and Nof 1994; Huang and Nof 1998). TIE 1.4 allows the simulation of a network of distributed tasks with an Intel Paragon Supercomputer, up to a maximum of 132 parallel processors. TIE 1.4 uses a message-passing mechanism for communicating data among the computer nodes simulating the tasks. The data transmission can take place either synchronously or asynchronously. In synchronic data transmission the activity of the sending processor is stalled while waiting for confirmation from the receiver processor. In asynchronic data transmission, the sending processor does not wait for confirmation from receiving nodes and continue with their activity.

The simulation with TIE 1.4 is modeled based on two types of programs: a controller node and a task node. The controller assigns each of the programs to the available computer nodes and starts the execution of the first task in the execution sequence. The implementation in TIE 1.4 will require as many computer nodes as there are tasks in the operation plus the controller node. For example, operation A has 6 tasks, requiring a partition of 7 nodes for its execution on the parallel computer.

7.2.2. Simulation Results

Three models were simulated: operation A, operation B, and integrated operation. A total of 10 simulation runs were performed for each model, registering in each case the production (Π), interaction (T), and total (Φ) times, and the degree of parallelism (Ψ), which is a concurrency measurement for the system. The results obtained for each case are presented in Tables 4 to 6. The simulation of the individual operations allows us to generate an estimate of the delay times due to communication and congestion, both required to optimize the operations locally.

The results obtained from the simulation of the integrated operation were utilized for determining the parallelism of the tasks. The parallelism optimization assumes the tasks' duration and communication times as per those generated by the TIE 1.4 simulation (Table 5) and congestion time as $0.02e^{0.05*\Psi}$. The results obtained are presented in Table 7 and Figures 11 and 12.

The solution generated includes the number of parallel servers for the tasks shown in Figure 12.

7.2.3. Local Optimization

For generating the local optimal configurations of the tasks, the PIEM model was applied to both cases with the congestion delays computed according to the expression $0.02e^{0.05*\Psi}$. The results obtained for each operation are presented in Figures 13 and 14.

TABLE 5 Simulation Results for Operation B

Task	λ_I Average Communication Delay	$\sigma_{\lambda I}$ Standard Deviation	π Average Duration
1B	0.000779	0.000073	0.971070
2B	0.000442	0.000013	0.793036
3B	0.000450	0.000013	0.790688
4B	0.000433	0.000017	0.877372

TABLE 6 Simulation Results for the Integrated Operation

Task	λ_I Average Communication Delay	$\sigma_{\lambda I}$ Standard Deviation	π Average Duration
1A	0.000523	0.033373	0.777950
1B	0.000428	0.030206	0.726785
2A	0.000423	0.040112	0.725435
2B	0.000409	0.023629	0.726027
3A	0.000382	0.053346	0.737365
3B	0.000411	0.036727	0.720308
4A	0.000348	0.079189	0.689378
4B	0.000422	0.024282	0.725532
5A	0.040830	0.037069	0.714532
6A	0.102065	0.015836	0.748419

7.2.4. Case Remarks

The numerical results obtained from the local and integrated scenarios are presented in Table 8.

The results in Table 8 show a slight difference in the total production time, which seems to contradict the hypothesis that the integrated scenario will benefit from a reduction of the cycle time. However, it must be noted that the number of subtasks required by the local scenario for achieving a comparable total production time is double that required by the integrated scenario. This situation is the result of no constraint being imposed on the maximum number of subtasks for each task in each scenario (infinite division of tasks). In particular for operation B, the number of subtasks in which each task is divided is nine, which can be considered excessive given the total number of four tasks in the operation.

For evaluating the comparative performance of the integrated and local scenarios, the local scenario for each operation was chosen according to the final number of subtasks in the integrated

TABLE 7 PIEM Model Result for the Integrated Operation

Iteration #	Task Modified	Ψ	Π	T	Φ
0	–	4	3.7000	0.2006	3.9006
1	1B	4	3.5000	0.2010	3.7010
2	3A	5	3.3000	0.2169	3.5169
3	4B	5	3.1000	0.2173	3.3173
4	1A	5	2.8000	0.2178	3.0178
5	2B	6	2.2000	0.2380	2.4380
6	6A	6	1.9500	0.3401	2.2901
7	2A	7	1.8500	0.3660	2.2160
8	1B	7	1.7500	0.3664	2.1164
9	3A	8	1.6500	0.3995	2.0495
10	4B	8	1.5500	0.3999	1.9499
11	1A	8	1.4833	0.4004	1.8838
12	2B	9	1.4167	0.4428	1.8595
13	5A	9	1.38333	0.4837	1.8670
14	4A	10	1.28333	0.5379	1.8212
15	6A	10	1.23333	0.6400	1.8733
16	1B	10	1.16667	0.6404	1.8071
17	3A	11	1.13333	0.7100	1.8433
18	2A	12	1.10000	0.7993	1.8993
19	4B	12	1.03333	0.7997	1.8330
20	1A	12	1.01667	0.8002	1.8169
21	2B	13	0.93333	0.9147	1.8480
22	6A	13	0.92500	1.0168	1.9418
23	1B	13	0.87500	1.0172	1.8922
24	3A	14	0.82500	1.1641	1.9891
25	4B	14	0.78000	1.1645	1.9445

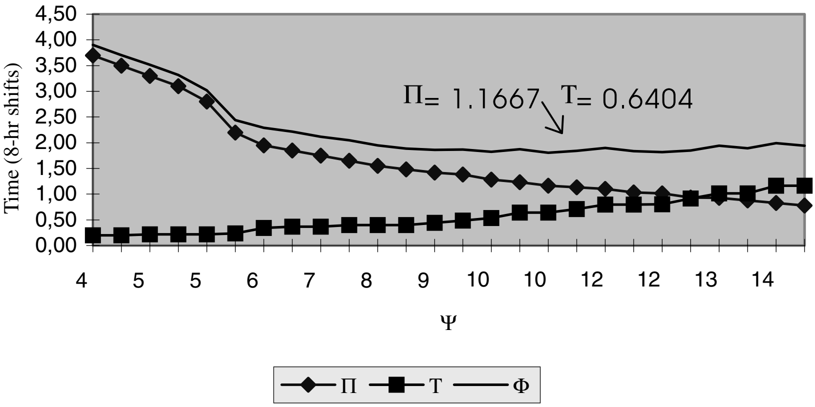


Figure 11 Changes in the Total Production Time per Unit (Π) and Congestion Time (T) for Different Values of the Degree of Parallelism (Ψ) at the Integrated Operation.

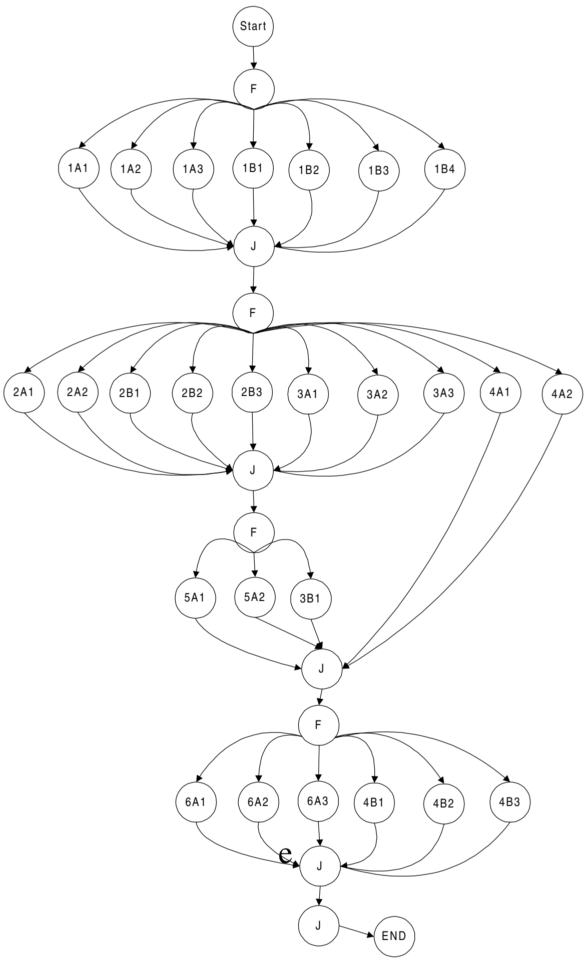


Figure 12 Configuration of Parallel Tasks for the Integrated Operation.

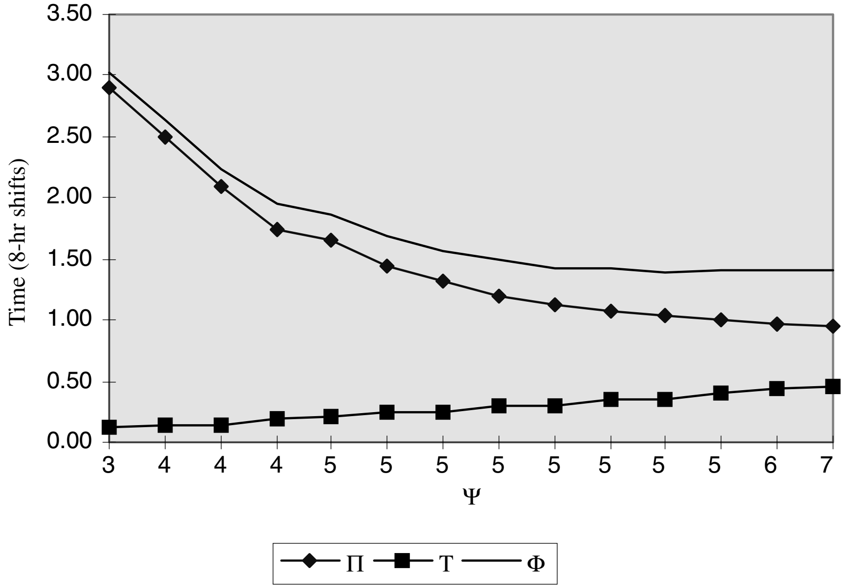


Figure 13 Total Production Time (Π) and Congestion Time (T) for Different Values of the Degree of Parallelism (Ψ) at Operation A.

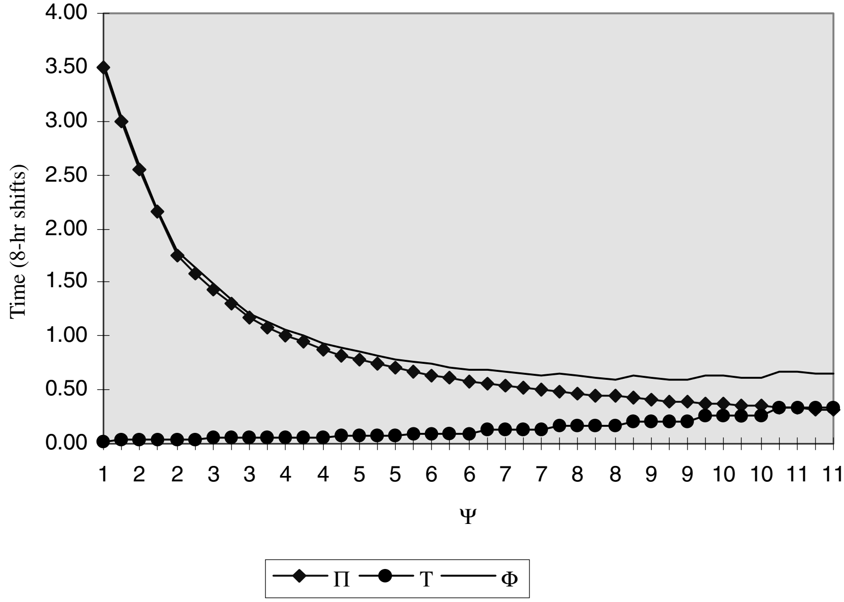


Figure 14 Total Production Time (Π) and Congestion Time (T) for Different Values of the Degree of Parallelism (Ψ) at Operation B.

TABLE 8 Summary of the Results for the Local and Integrated Scenarios

	Φ	Π	T	Number of Subtasks
Local Scenario	1.9846	1.4239	0.5607	52
Operation A	1.3908	1.0350	0.3558	16
Operation B	0.5938	0.3889	0.2049	36
Integrated Scenario	1.8071	1.1666	0.6404	26

scenario. Therefore, the number of subtasks was set at 15 for operation A and 11 for operation B. This makes a total of 26 subtasks in both local operations, which equals the number of subtasks for the integrated scenario. The values for the performance parameters show a total production time (Π + Φ) of 2.7769 shifts, direct-production time (Π) of 2.3750, and interaction time (Φ) of 0.4019 shifts. These values represent an increment of 54% for the total production time, an increment of 104% for the production time, and a decrement of 37% for the interaction time with respect to the integrated solution.

The results obtained from this case study reinforce the hypothesis that exploiting potential benefits is feasible when optimizing the parallelism of integrated distributed operations. Key issues in PIEM are the communication and congestion modeling. The modeling of time required by tasks for data transmission relates to the problem of coordination of cooperating servers. On the other hand, the congestion modeling relates to the delays resulting from the task granularity (number of activities being executed concurrently).

7.3. Variable Production Networks

The trend for companies to focus on core competencies has forced enterprises to collaborate closely with their suppliers as well as with their customers to improve business performance (Lutz et al. 1999). The next step in the supply chain concept is the production or supply networks (Figure 15), which are characterized by intensive communication between the partners. The aim of the system is to allocate among the collaborating partners the excess in production demand that could not be faced by one of them alone. This capability provides the entire network with the necessary flexibility to respond quickly to peaks in demand for the products. A tool developed at the Institute of Production Systems at Hanover University, the FAS/net, employs basic methods of production logistics to provide procedures for the efficient use of capacity redundancies in a production network. The tool satisfies the following requirements derived from the capacity subcontracting process:

- Monitoring of resource availability and order status throughout the network
- Monitoring should be internal and between partners

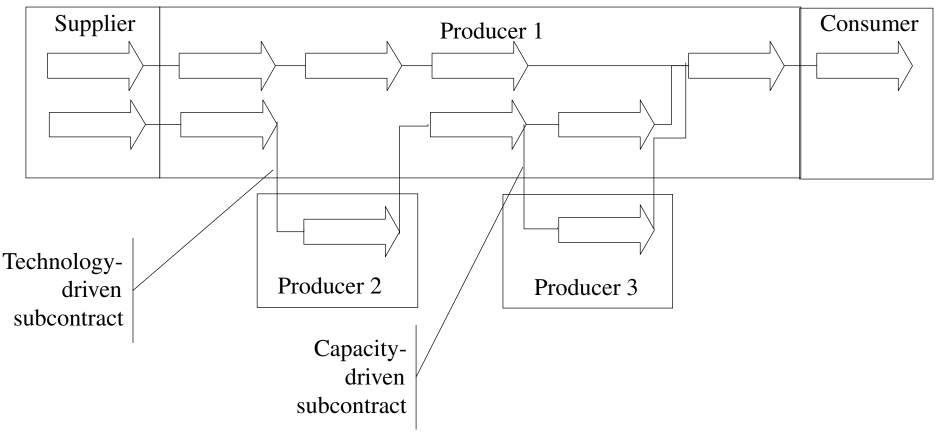


Figure 15 Capacity- and Technology-Driven Subcontracting in Production Networks. (Adapted from Lutz et al. 1999)

- Support of different network partner perspectives (supplier and producer) for data encapsulation
- Detection of the logistics bottlenecks and capacity problems

A key aspect of the system is the identification of orders the partner will not be able to produce. This is accomplished by detecting the bottlenecks through the concept of degree of demand (a comparison of the capacity needed and available in the future, expressed as the ratio between the planned input and the capacity). All the systems with potential to generate bottlenecks are identified by the FAS/net system and ranked by their degree of demand. The subcontracting of the orders can be performed by alternative criteria such as history, production costs, and throughput time.

The system relies on the confidence between partners and the availability of communication channels among them. Carefully planned agreements among the partners concerning the legal aspects, duties, responsibilities, and liability of the exchanged information are the main obstacles to implementing production networks.

8. EMERGING TRENDS AND CONCLUSIONS

The strongest emerging trend that we can observe in the collaborative manufacturing arena is partnership. In the past, the concept of the giant, self-sufficient corporation with presence in several continents prevailed. Emerging now and expected to increase in the years to come are agile enterprises willing to take advantage of and participate in partnerships. The times of winning everything or losing everything are behind us. What matters now is staying in business as competitively as possible. Collaborative efforts move beyond the manufacturing function downstream where significant opportunities exist. Manufacturing is integrating and aligning itself with the rest of the value chain, leaving behind concepts such as product marginal profit that controlled operations for so long. The future will be driven by adaptive channels (Narus and Anderson 1996) for acquiring supplies, producing, delivering, and providing after-sale service. Companies will continue to drive inefficiencies out and become agile systems, forcing companies around them to move in the same direction.

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