A Lightweight Method for Improving Coordination in Distributed, High-Variability Product Companies

by

Brian S. Hendrickson

B.E. Electromechanical Systems
Thayer School of Engineering at Dartmouth College, 2007
B.A. Engineering Sciences
Dartmouth College, 2006

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of
Master of Business Administration
and
Master of Science in Mechanical Engineering
in conjunction with the Leaders for Global Operations Program
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2012

Signature of Author _
Department of Mechanical Engineering, MIT Sloan School of Management
May 11, 2012

Certified by__________
Don Rosenfield
Director, LGO Program and Senior Lecturer, MIT Sloan School of Management
Thesis Supervisor

Certified by ___
Josef Oehmen
Research Scientist, Department of Mechanical Engineering, Engineering Systems Division
Thesis Supervisor

Certified by____
Warren Seering
Weber-Shaughness Professor of Mechanical Engineering and Engineering Systems
Thesis Reader

Accepted by__________
David Hardt
Chair, Mechanical Engineering Department Education Committee
Department of Mechanical Engineering

Accepted by__________
Maura M. Herson
Director, MBA Program
MIT Sloan School of Management

A Lightweight Method for Improving Coordination in Distributed, High-Variability Product Companies

by

Brian S. Hendrickson

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering on May 11, 2012, in partial fulfillment of the requirements for the degrees of Master of Business Administration and Master of Science in Mechanical Engineering in conjunction with the Leaders for Global Operations Program

Abstract

Product companies face new challenges as they continue to expand their international footprints. Whereas globalization initially sought savings by outsourcing production to low-cost regions, emerging markets now present new sales opportunities with unique customer demands. Companies increasingly must be sensitive to local expectations at the same time that products are becoming more technology rich and with shorter life cycles. Improved coordination that enables greater speed, flexibility, and multi-market effectiveness is particularly important as companies shift engineering and commercial responsibilities to formerly production-only centers.

This study develops and demonstrates an approach to one domain of coordination—the flow of material and related information between globally distributed sites—based on lessons from engineer-to-order (ETO) operating models. By examining contemporary trends in ETO and identifying several generalizable tensions, this study outlines key parameters that distinguish dynamic coordination needs from those embedded in conventional process improvement frameworks.

The five-step approach developed in this paper takes a dynamic systems perspective on organizational interfaces and seeks to build feedback mechanisms at multiple levels. It targets the knowledge-transfer, business planning, and execution levels of material management while also addressing the behavioral and practical components of implementation. In doing so, the approach recognizes that uneven process maturity and uncertain external demands must be accommodated. It argues that traditional approaches to coordination have had limited success, because they are slow to adapt and encourage circumvention. Whereas these past methods have exchanged reduced process "waste" for greatly increased rigidity and process housekeeping, the proposed method seeks reinforcing loops that align stakeholders without exhaustive process definition or significant maintenance.

A detailed case study at a global ETO business group illustrates the method and its initial results in an environment of limited patience for formal process development. The resulting portfolio of change initiatives, which includes inter-site service level commitments, local forecast sharing, service parts forecasting, and reverse logistics, demonstrates an integrative approach to business site interfaces that attempts to tie local short-term performance with global long-term success.

Thesis Supervisor: Don Rosenfield
Title: Director, Leaders for Global Operations Program and Senior Lecturer, MIT Sloan School of Management

Thesis Supervisor: Josef Oehmen
Title: Research Scientist, Department of Mechanical Engineering, Engineering Systems Division

Thesis Reader: Warren Seering
Title: Weber-Shaughness Professor of Mechanical Engineering and Engineering Systems

This page intentionally left blank.

Acknowledgements

I would like to thank, foremost, my friends and family for their support over the last two years. My participation in the MIT Leaders for Global Operations program has been a tremendous opportunity but also a significant commitment for not only myself but also those people who have stayed connected to me despite my disappearance into work for hours, days and, occasionally, weeks at a time. I very much appreciated your reminders to break free from my studies and your patience when I had to return to my cave.

Thank you to all three of my academic advisors, Don Rosenfield, Josef Oehmen, and Warren Seering. Your thoughtful input was uncanny in its ability to recognize and appreciate issues, and your guidance encouraged me to explore new avenues of thought.

Thank you, as well, to my colleagues at ABB Switzerland, particularly Harald Hepp, Alicia Piazzesi, Dennis Laubbacher, and Gil Fischer. You were very generous with your time, both in supporting this project and in introducing me to your country. Thank you.

Finally, thank you to the LGO program and to all of my colleagues at MIT for exposing me to such a range of perspectives. It has been a pleasure to work with all of you.

This page intentionally left blank.

Table of Contents

Table of Figures

Chapter 1: Introduction

This chapter introduces this thesis. It presents the underlying motivations, the project goals, and the structure of the ensuing theory development and discussion.

1.1 Project Motivation

As manufacturers respond to demand for more complex products and increasingly global reach, they are confronted with the task of coordinating ever more distributed organizations [1,2]. The distribution can be virtual, as in the case of teams assuming responsibility over portions of a product, or it can be physical, as in the case of local engineering and production sites working in concert with a headquarter location. In either scenario, an organization has concentrations of expertise that must be cultivated to bring products to market faster and with higher value. These concentrations reside in the knowledge and skills of each local team and, ideally, generate competitive advantage by adapting to new information and circumstances. At the same time, the overall company must manage operational complexity and system performance by fostering best practices. These best practices are most effective when they can be captured and implemented wherever appropriate throughout the organization. Thus arises the need to balance standardization with capacity for local innovation [3].

Engineer-to-order (ETO) companies in many ways epitomize this challenge of contemporary business. Their products are highly-engineered, designed to customer requirements, and have lead times that resist efforts to compress delivery schedules. Furthermore, for reasons ranging from customer sensitivity to local regulations, ETO organizations often need a physical presence close to market [4]. An ETO firm therefore must replicate at least some of its capabilities at different physical locations in order to serve each of its markets. Local sites that do not have full capabilities must coordinate with other business sites in order to provide complete service.

Interface processes that channel information and material between business sites therefore become critical. Over the shorter term, they allow fulfillment of customer orders. Over the longer term, they should support increased local capability that is tailored to better utilize customer proximity. Efficient global coordination suggests standardized and predictable interfaces, while local innovation suggests flexible and unscripted interfaces. The challenge then becomes how to create and refine coordination points that accomplish both operational efficiency and high flexibility.

1.2 Thesis Goal

The goal of this thesis is to develop and demonstrate an approach to supply chain interfaces that balances system efficiency with local flexibility. The method is particularly suited for distributed organizations that must build or disseminate capability across organizational boundaries and in the face of uncertainty. Recognizing that organizations are most agile when their people can apply their creativity readily and in concert [5], the approach attempts to minimize necessary investment in extensive documentation and other activities needed to support process definition and adaptation.

1.3 Thesis Organization

Chapter Two of this thesis summarizes the current theory relevant to coordination improvement in high-variability businesses. It first presents the engineer-to-order business model as an extreme case of the need for operational flexibility. It discusses key features of engineer-to-order, and it reviews the literature on the implications for supply chain coordination. The section then reviews several models for process development and highlights gaps that this thesis intends to address.

Chapter Three introduces a novel approach to developing interfaces in distributed organizations. The chapter situates the method within engineer-to-order, supply chain management, and coordination theory and provides concrete steps to implementation.

Chapter Four presents a detailed case study of the interfaces development approach within a multi-national capital goods company. The chapter focuses on coordination related to material management across business sites and discusses practical issues of stakeholder engagement and communicating complex ideas. Areas of process change discussed in the case study include:

1. Tiered, multi-national service delivery
2. Internal and external service reporting
3. Upstream and downstream lead time management, including intra-company service level commitments and intermittent demand forecasting

The chapter includes discussion of the challenges implementing these initiatives, initial results, and implications for future efforts. The application case study demonstrates the effectiveness of the proposed method in systematizing coordination in an organization that faces high uncertainty and variability.

Chapter Five concludes the thesis with a summary of research and recommendations for further work.

Chapter 2: Literature Review

This chapter provides a foundation for the proposed process improvement method by examining related work to date. It explores how engineer-to-order businesses exemplify operational complexity and needed flexibility. It reviews existing studies of how ETO firms coordinate their activities, and it summarizes organizational challenges to process improvement. The chapter then examines the applicability of existing process improvement models, identifying gaps that the proposed new method seeks to address.

2.1 The Engineer-to-Order (ETO) Model

Although most research has focused on "conventional" make-to-stock businesses [6-8], engineer-to-order businesses exemplify many of the operational challenges that are becoming relevant for traditionally non-ETO firms. High-product mix, high-technology content and significant lead-time pressures are just some of the issues in ETO that parallel those of mainstream companies operating over larger global footprints. Better understanding of the drivers of ETO uncertainty and of companies' responses to that uncertainty provides a foundation for how inter-site coordination might be approached.

One challenge, however, is that "engineer-to-order" defies consensus definition. Gosling et al. (2009) note that perhaps the only universal aspect of ETO companies is that they have an order decoupling point (ODP) in the design phase. The ODP, also known as the order penetration point (OPP) or push-pull boundary, may seemingly be an esoteric point, but it has consequences at much higher levels of the organization. Technically, it marks the point in the order fulfillment process when a given product becomes tied to a specific order. Upstream of the ODP, activities can be forecast-driven or pre-planned for aggregate demand. Inventory can be held in anticipation of specific orders. Downstream of the ODP, activities shape generic material into specific customer orders. For ETO companies, an early decoupling point means that products are designed to customer requirements and little if anything can be pre-staged.

The exact extent to which each order is started from scratch, however, varies, and that has led researchers to attempt to classify the range with different schemes [9-11]. These ETO taxonomies begin to suggest key operational levers. Olhager (2003), for example, uses the typical spectrum of Engineer-to-Order (ETO), Make-to-Order (MTO), Assemble-to-Order (ATO), and Make-to-Stock (MTS), which can be correlated with the position of the ODP, as illustrated in Figure 1.

Under this scheme, conventional, MTS manufacturers have an expectation of their future sales, and they build up inventories of finished goods to supply the market. Demand for those goods may change over the course of a year or from year to year, but an MTS company has direct or indirect signals from the market that allow it to forecast demand and plan production accordingly.

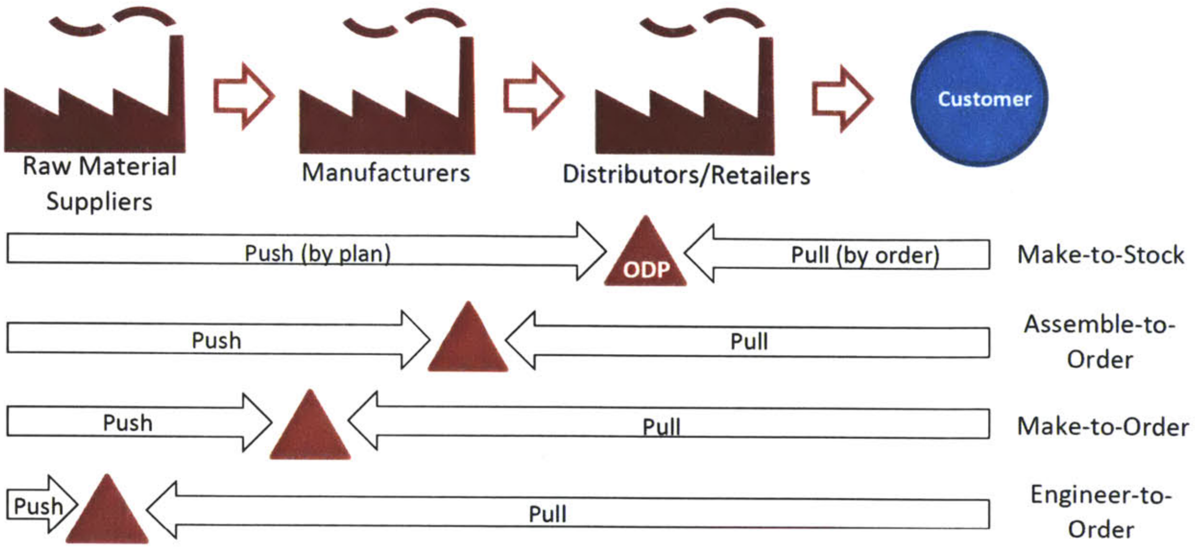


Figure 1: Classification of Fulfillment Strategy by Order Decoupling Point (ODP)

Assemble-to-Order companies have a similar model, except that they stock components, which they then assemble into a finished product once they receive a specific order. Dell and its famed "mass customization" direct model of the early and mid-2000s exemplifies ATO on the large scale. Recognizing that stocking every possible computer configuration would be cost-prohibitive, Dell pioneered capabilities to efficiently manage component inventories and then quickly assemble those components upon receipt of a customer order (see, e.g. [12,13]).

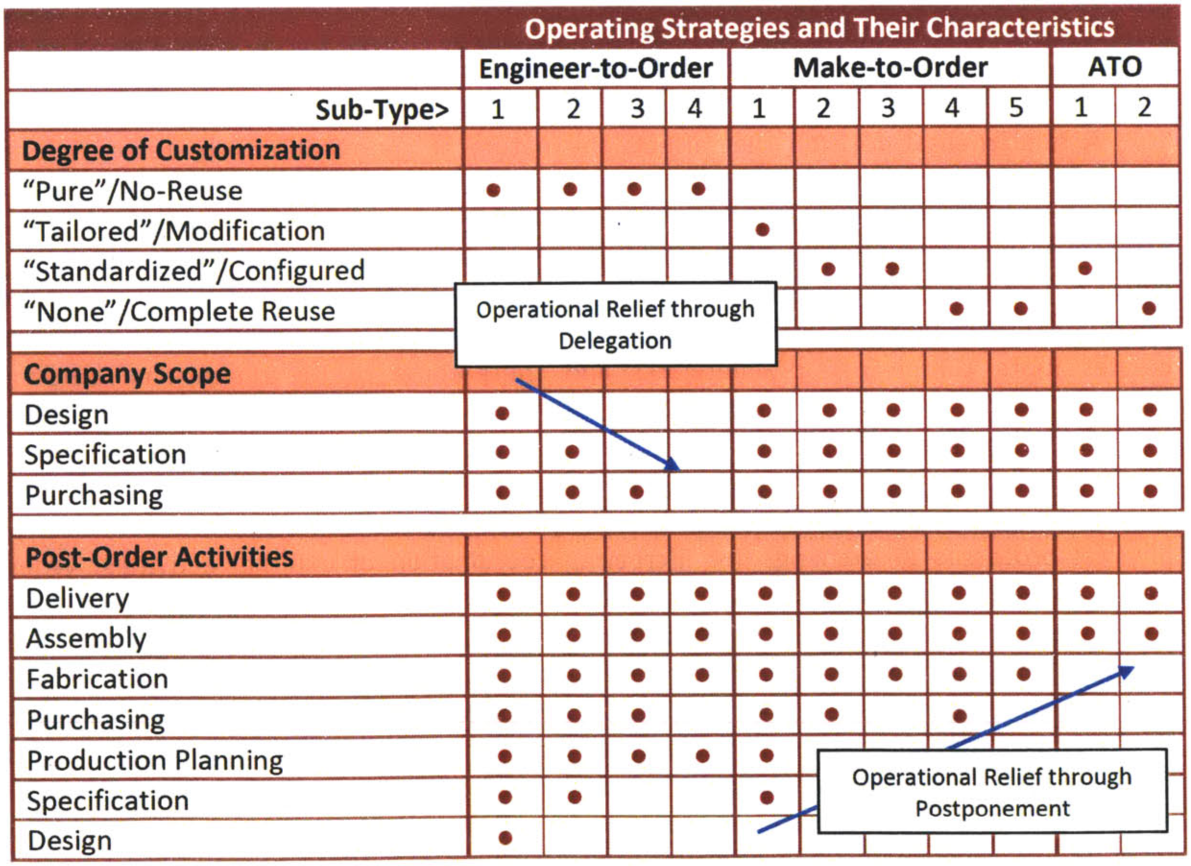
By contrast, Engineer-to-Order and Make-to-Order companies have diverse products with demand that cannot be effectively foreseen, even at the subsystem level. Many ETO and MTO companies generate new business by responding to requests for tender from customers. The companies must generate competitive bids by assessing functional needs and specifications, working with potential suppliers to estimate pricing and timing, and executing a conceptual design. Increasingly, bidding firms also must provide concepts for product operation and long-term servicing [14,15]—a trend that mirrors developments in the "mainstream" business world [16,17]. Bids therefore require significant upfront effort and still do not guarantee a new order. If an order is awarded, detailed designs, sourcing agreements, and production plans must be finalized, generally in an iterative fashion over the course of product development. The significant uncertainty of winning orders, of final designs, and of project timelines limits the possibility of inventory to at most low-level materials.

Amaro et al. (1999), however, build upon Lampel and Mintzberg (1996) to argue that ODP is an oversimplification of the ways companies organize to meet demand. They note that while ODP is typically associated with an inventory buffer, that inventory is a strategic decision, not a forgone conclusion. A configurable product, for example, could be assembled from components held in inventory or from material ordered as needed. Positing that ODP is insufficient as a classification scheme, Amaro et al. instead propose three dimensions more closely tied to operational boundaries.

The first dimension is the extent of design reuse. For a given order, a design may be taken off-the-self, configured from building blocks, tweaked from past designs, or designed from scratch. Design reusability constrains but does not completely determine which fulfillment activities the company executes after receiving a given order. This second dimension reflects to what degree processes can be pre-executed to a plan, such as a regular production cycle or an inventory safety level. Dell, for example, may be able to route its production flow according to algorithms, but it can assemble a custom computer only after it has received an order. A firm must choose how many tasks it postpones within the limits imposed by product customization.

A third dimension is the scope of company responsibility. Whereas the ability to recycle work is constrained by the nature of the products and their applications, a company makes a strategic decision as to how much of that work it assumes. For example, a company may be forced to produce a turbine blade from scratch, but it can choose whether it expects customers to provide functional requirements, detailed specifications, or even complete designs. By limiting its scope of responsibility, a company also has fewer possible post-order activities, thereby reducing pressure on its delivery speed.

The possible combinations of the three Amaro dimensions are summarized in Figure 2 and form what might be called a *configuration space*. Companies may simultaneously occupy several categories with different business lines, but the spectrum suggests some broad strategic levers for managing operational complexity and capability demands.



	Operating Strategies and Their Characteristics										
	Engineer-to-Order				**Make-to-Order**					**ATO**	
Sub-Type>	1	2	3	4	1	2	3	4	5	1	2
Degree of Customization											
"Pure"/No-Reuse	●	●	●	●							
"Tailored"/Modification					●						
"Standardized"/Configured						●	●			●	
"None"/Complete Reuse								●	●		●
Company Scope											
Design	●				●	●	●	●	●	●	●
Specification	●	●			●	●	●	●	●	●	●
Purchasing	●	●	●		●	●	●	●	●	●	●
Post-Order Activities											
Delivery	●	●	●	●	●	●	●	●	●	●	●
Assembly	●	●	●	●	●	●	●	●	●	●	●
Fabrication	●	●	●	●	●	●	●	●	●		
Purchasing	●	●	●		●	●		●			
Production Planning	●	●	●	●	●						
Specification	●	●			●						
Design	●										

Operational Relief through Delegation

Operational Relief through Postponement

Figure 2: A Strategy-Sensitive Classification of the ETO Spectrum

Make-to-order and ATO companies benefit from stable designs and vertical integration, and they can offset the complexity of broad responsibility by executing most of the work in anticipation of actual demand. One might expect the product coordination burden to be largely internal and amenable to routines. Conversely, ETO companies can offset the complexity of significant engineering effort by reducing their scope of responsibility. However, the delegation of responsibilities requires significant internal and external coordination. For each order, designs need iteration, materials must be sourced, and customer requirements may change. In the case of multi-site firms, distributed order execution requires managing these issues across organizational boundaries, and thus, organizational interfaces become paramount.

2.2 Three Tensions in Supply Chain Management

Embedded within the many possible ETO configurations are several operational trade-offs. These tensions are broad strategic issues that drive what capabilities are needed, how they are disseminated, and the terms under which inter-site coordination might deliver them. Although particularly acute in ETO firms, the operational balances arguably apply also to more traditional manufacturers facing changing and uncertain environments.

2.2.1 Vertical Integration versus Responsibility Delegation

A fundamental decision that affects the nature of coordination requirements is how broadly a company draws its operational boundary. As ETO companies expand their reach, they face pressures from new competitors and new local market expectations. Demands for reduced costs, faster development and, often, local content, have led many ETO companies to delegate activities outside of their immediate organizations [14]. This outsourcing provides some operational relief by narrowing a company's internal scope of responsibility. However, it also creates more complex supply networks and shifts some of the operational burden to coordination of those networks. Hicks et al. (2001) outline some of the broad implications of this tradeoff by identifying four "ideal" types of ETO companies. As summarized in Figure 3, these four types range from fully-integrated manufacturer to specialist project coordinator. Moving from one end of the spectrum to the other represents a shedding of responsibility for physical processes in exchange for increasing coordination of external activities. Whereas Amaro et al. include manufacturing capability in all categories of ETO, Hicks et al. consider companies that have no in-house production capability. These companies are purely management service providers that compete on their ability to coordinate projects.

But while Hicks et al. include "logistics" in the core competencies of these organizations, they provide little additional detail. They note that increased outsourcing of physical activities creates greater reliance on the quality and timeliness of suppliers. The ETO firm assumes coordination responsibility but is dependent on outside organizations to execute, which can result in less adversarial supplier relationships. However, as with Amaro et al., Hicks et al. do not examine the underlying coordination processes, their mechanisms, or their success factors.

	ETO Type I	ETO Type II	ETO Type IIIa	ETO Type IIIb
Definition	Vertically Integrated	Design and Assembly	Design and Contract	Project Management
Core Competencies	Design, manufacturing, assembly, management	Design, assembly, project management	Design, project management, logistics	Project management, technical expertise, logistics
Vertical Integration	High	Moderate	Low	Very Low
Supplier Relationships	Adversarial	Partnership	Partnership	Contractual
Environment	Stable	Uncertain	Dynamic	Dynamic

Figure 3: ETO Scope of Responsibility and High-Level Characteristics

The details of effective coordination with partners are especially important given the opportunities for it to not work well. An important characteristic of ETO products is that their components span mass-produced commodities to specialized materials requiring batched or job-shop production. Because ETO companies have limited abilities to batch project orders, they typically purchase even commodities in relatively small numbers. Orders by an ETO firm to both internal and external suppliers therefore typically represent a small share of a supplier's overall demand, weakening the ETO firm's negotiating position. McGovern and others (1999) have noted that this power structure is the opposite of what appears in traditional SCM studies and typically produces less integrated supplier relationships than those generally espoused in the literature [18]. Indeed, supplier relationships are often characterized by mistrust [4].

ETO companies face a second challenge at the other end of the material spectrum, with specialized, technology-rich items. Designs for certain components and their manufacturing processes may represent important enabling technologies for a firm. The company may therefore prefer to retain close ownership of those components to protect intellectual property and capture the value margins. Direct responsibility for the components also allows the firm to build technological expertise, although with the added expense of supporting associated in-house production or test infrastructure.

Alternatively, the ETO firm may outsource that component. A supplier then can utilize its own capabilities, possibly leverage economies of scale, and perhaps introduce new innovations based on its own experience [58]. However, with outsourcing comes the risk of atrophying expertise within the ETO firm [19]. Unless the company can successfully utilize the expertise of its partners through tight coordination, it risks losing the technical capability that may be necessary for it to contend in the market. Moreover, misjudgment of what is valuable as core intellectual property eventually may elevate suppliers into competitors at the same time that it hollows out an incumbent firm.

These short-term and long-term aspects of partner relations are amplified when a company builds out new sites, highlighting the importance of coordination that operates at multiple levels. At the level of execution, an ETO company's limited leeway with both suppliers and customers means that its internal operations must be as cohesive as possible. For example, sourcing material from shared suppliers may require aggregated procurement across sites, or the company risks disorganized vendor communications and further erosion of purchasing power. At higher strategy and planning levels, a satellite business location that holds only partial technology or production responsibility may not have the knowledge needed to react effectively to any technical issues affecting product development or supply issues pacing production. A headquarter site, likewise, may seek to retain the value of intellectual property but is nonetheless dependent on the quality of technical or commercial information returned to it from local sites as headquarters attempts to steer that intellectual property. In all, a distributed ETO firm requires significant cross-site coordination at the same time that product complexity and business uncertainty resist stable integration [2]. Figure 4 summarizes some of the key implications of the vertical integration issue for organizational coordination.

Implications of Vertical Integration on Coordination
• ETO firms have limited leverage with external suppliers, placing greater burden on internal coordination to maximize utilization of supplier terms
• Delegating responsibilities away from a central organization is a common ETO strategy, but it creates interdependencies that must be orchestrated through coordination
• Coordination must operate on multiple levels—including strategy, planning, and execution— while also preserving a sustainable distribution of value generation among participating organizations

Figure 4: Implications of Vertical Integration on Coordination

2.2.2 Process Standardization versus Differentiation

A second major consideration for ETO coordination is the appropriate level of process standardization given upstream and downstream uncertainty. Here, too, ETO and high-volume companies are converging, as ETO organizations seek opportunities for efficient process replication [20] while traditional companies seek added flexibility and customization [21]. The conventional approach to process standardization has been to standardize what is stable and leave flexible what is unstable. Indeed, some researchers have advocated the same high-level filter for ETO processes (eg Veldman et al. (2007)).

However, the issue of standardization is less obvious at finer levels of detail and given the centrality of innovation to ETO competitiveness. From a practical standpoint, the high variation in project demands and execution trajectories makes defining candidates for standardization difficult. The processes used in a given project appear uniquely suited to the circumstances of that project. Moreover, the level of standardization implies a balance of local versus global decision-making. On the one hand, local decision-making affords rapid reaction to specific circumstances, using the judgment of people close to the matter. This capacity for variation allows experimentation and possible discovery of better methods or new product opportunities. Such innovation is critical to ongoing competitiveness. On the other hand, local decisions may not capture the experience of other people in the organization and may have unintended consequences that ripple through the organization. In ETO programs, where stakeholders are tightly coupled but perhaps temporally or spatially distant, unintended consequences are particularly easy to overlook [22-24].

Unfortunately, the literature provides little guidance as to how a low-volume, high-mix manufacturer might balance process standardization. Rupani (2011), in a detailed examination of linkages between process deviations and product development outcomes, argues that the effects of standardization depend on the process level at which the standardization operates. For example, standardizing the format of deliverables provides a baseline foundation for subsequent discussions of project performance among stakeholders. That effect is different from the introduction of a standard tool, which may impact defect generation or the speed of onboarding new team members. Rupani notes that, at least within the domain of product development, standardization yields a net benefit, even given project variability. He hypothesizes that the gain arises because standards incorporate institutional knowledge while balancing local stakeholder needs.

That standardization provides a net benefit beyond product development is less clear, but it does serve as a reminder that interaction processes have multiple components. The overall balance of local versus global decision-making—and therefore the compromise between stability and flexibility—depends on which aspects of coordination are formalized.

Implications of Process Standardization on Coordination

- When developing coordination processes, companies must balance local decision-making with global standards
- Conventional guidance to standardize "stable" processes is not necessarily practical in ETO operations where variation is inherent and innovation is critical
- Standardization can operate on different process aspects, including expectations, sequences, and outputs. These layers form a second dimension to coordination in tandem with the levels of strategy, planning, and execution

Figure 5: Implications of Process Standardization on Coordination

2.2.3 Project Execution versus Capability Growth

If there is one common behavioral characteristic of ETO firms noted in the literature, it is that they tend to be very project oriented, which has several important implications for developing improved coordination [14,25]. First, ETO firms hire skilled workers and organize them in anticipation of uncertain project demands. Changes in customer requirements, technology readiness, supply availability and production quality are just some of the drivers of uncertainty that project teams may experience. With each project presenting a unique combination of surprises, stakeholders may become accustomed to uncertainty without discerning what may be avoidable from what may be intrinsic. If stakeholders take all uncertainty to be *de facto*, they have little reason to believe that they can improve performance through increased internal capability.

The long lead times for ETO components, coupled with frequent unplanned developments, also creates significant deadline pressure. The result is an inclination to "just get things done" over investing in measures with greater long-run value [26]. This bias is reinforced by the conspicuousness of successful crisis resolution compared to, for example, preventative actions or work documentation [27]. Given finite time, people are more likely to work on immediate issues that are easily recognized and measured by their peers and supervisors. The short-term versus long-term tension thus suggests that adoption of process improvement may be especially difficult in ETO organizations, with possible gains to the extent that deadline pressure and uncertainty can be ameliorated.

All of these drivers of myopia are despite the fact that important ETO decision-making must integrate information beyond the details of a specific project. A common risk for an ETO company is committing to a project that is a poor fit with its capabilities and strategic priorities [28]. Effective upfront decision-making is particularly important, because three-quarters or more of a project's eventual costs can be locked up in the early stages of project bidding and initial design [23,25,29]. Similarly, ETO firms must assess new product introductions in light of support needs for existing products and with attention to obsolescence planning. Treated in isolation, new product decisions can quickly add portfolio complexity and erode customer loyalty by leaving them without long-term support [30].

Integrative decision-making, supported by ongoing knowledge management, forms a potential bridge from short-term project success to long-term capability grown. Each additional project affords the opportunity to cull new knowledge for future work. However, true expansion of expertise requires disseminating the knowledge, retaining it for future use, and then applying it successfully to new challenges [31]. That ability to capture new knowledge and to bring it to bear on decisions requires coordination mechanisms that deliver not only information to the appropriate people but also the context that imbues information with greater meaning.

Implications of Short-Term versus Long-Term on Coordination

- The customized nature of their products makes ETO firms very project-oriented, obscuring recurring issues and opportunities for improved efficiency
- Under-investment in long-term improvements is likely because delays and uncertainty foster short-term reactions to surprises
- Coordination that builds knowledge amongst stakeholders can form a bridge from short-term project performance to long-term organization improvement

Figure 6: Implications of Long-term versus Short-Term on Coordination

2.2.4 The Case for Continuous Rebalancing

The three tensions faced by ETO companies influence both strategic and tactical types of coordination, but decisions must be re-evaluated continuously. By their nature, ETO firms create value by fulfilling special customer needs, case by case. Detailed understanding of both explicit and implicit customer expectations is critical, as is the technical know-how required to produce a custom-fit solution. However, the performance evaluation metrics—such as technical performance, delivery timeliness, upfront costs, and operating costs—that may be order winners in one region or for one customer, may simply be order qualifiers in another instance [14,32]. The myriad approaches, priorities, and possible divisions of work mean that a firm's needed capabilities will likely vary not only compared to those of its competitors but also by market and over time.

What emerges, then, is the need to adapt to circumstances at the project and overall network scales [33]. Local capability levels develop, certain projects attain special strategic significance, and technologies that were once leading edge no longer retain exceptional value. As each of these shifts occurs, so too must a company's balance of integration, standardization, and capability development adjust. Coordination across organization boundaries will always be required, but where it is formalized and how it is anchored must also adapt to reflect a company's strategic and tactical needs.

2.3 **The Role of Information Technology (IT)**

Many ETO companies have responded to the need for tight coordination by implementing information systems such as material resource planning (MRP) and enterprise resource planning (ERP) software. The IT systems provide a repository for the significant amounts of data tied to complex ETO products. The systems can enable computer-driven planning and scheduling, both of which are key contributors to delivery timeliness [20]. They also provide channels for data exchange that can link geographically-dispersed sites both internal and external to an ETO organization [34].

However, research has indicated that a mismatch often exists between company needs and software capability [7] and that the gains from ERP-type implementations are often more modest than expected [35]. A key issue is that typical ERP systems have been developed over the years for make-to-stock operating models. The systems propagate changes triggered by concrete purchase orders, definite material requests, and predictable inventory requirements. Fundamental data can be entered once and need updating only occasionally. Users of ERP systems in the ETO environment, however, use the software for provisional planning [36]. Precise material requirements may not be known until well into a project, and long-lead items may even need to be ordered before a purchase order is received from a customer [24]. Subsequent developments in the project, driven by either internal or external changes, may require alterations to commercial or technical data in the planning system. Still other data may be absent because of the high frequency of using material for the first time.

The challenges of keeping an ERP system flexible and current extend to other forms of IT-backed coordination. While computerized information-sharing channels potentially offer lower transaction costs and increased traceability, their promise is offset by practical issues of implementation. Such systems tend to require a significant commitment to defining functional specifications upfront and then rely on specialists to develop the actual software. In larger organizations, these specialists are often constrained shared resources, delaying initial implementation and subsequent refinements. Moreover, effective software connections between organizations may require reconciliation of local information systems. That unification may be limited by costs, discrepancies in local functional needs, managerial and budgetary ambiguity, or legal restrictions.

Technology-based coordination mechanisms for ETO thus have the potential to help alleviate a significant information management burden, but the issue of keeping such systems current with the dynamic needs of ETO organizations remains unresolved. Therefore IT may be considered a component of ETO coordination, but it is far from a panacea.

2.4 Tacit Coordination

Although the ETO literature offers only limited treatment of supply chain coordination, the field of coordination theory offers more insights. In examining coordination mechanisms, Srikanth et al. (2011) define two conventional approaches as *modularization* and *ongoing communication*. Under modularization, an organization manages coordination by grouping interdependent activities as much as possible and then defining set interfaces between groups. An interface serves to limit the need for communication by prescribing a handoff, and the expectations for that handoff are all that counterparties need to share. Of course, such interfaces generally will not capture all interdependencies and, in a situation with as much coupling as an ETO operation, significant opportunity costs could arise. Content that does not fit the interface could be lost or require circumvention of the interface. Modularization also requires significant upfront investment in defining a static system, which may be perceived as an encumbrance and distraction, particularly in a dynamic ETO organization [37,38].

Ongoing communication represents a more flexible variant of coordination. By capturing information as needed, it can accommodate uncertain or shifting transaction needs. Whereas modularization seeks distilled common knowledge, ongoing communication continuously updates common knowledge. It achieves that flexibility at the expense of significant back-and-forth, increased need for rework, and reduced potential for best practices propagation [39].

In their empirical study of geographically dispersed organizations, Srikanth et al. (2011) identify a promising third coordination means, which they call *tacit coordination mechanisms*. Tacit mechanisms establish baseline common knowledge and then build upon it through increased transparency. Efforts such as shared trainings, job rotations, and work progress updates provide individuals with greater context and thereby allow them to leverage common knowledge that may be only indirectly related to a given issue. A key requirement is that people share common ground that adapts and *that they know that they share common ground* [1]. They thereby can act towards a shared purpose and with confidence that their motives are understood by colleagues and counterparts [27,40]. Tacit mechanisms are thus predicated on people's ability to collaborate freely and productively when given sufficient contextual information. In ETO organizations accustomed to free-thinking, such tacit mechanisms offer a promising approach to coordination across organization boundaries if they can be operationalized.

2.5 Gaps in ETO Literature

The literature on engineer-to-order provides an important foundation for how companies might respond to uncertain customer demands and lead-time pressure. It also begins to suggest that some process uncertainty can be tamed through selective process control, while other exogenous uncertainty demands ongoing organizational adaptation. However, the literature has several major gaps relevant to the particular challenge of improving coordination between sites. These gaps are summarized in Figure 7.

Summary of Gaps in ETO Literature

1. Studies on ETO have been largely taxonomic, focusing on the general sources of intrinsic uncertainty that differentiate ETO from more conventional make-to stock operating models; Examinations of responses to that uncertainty have been limited (see Section 2.1)
2. Those studies that do examine ETO coordination do so at high levels, concentrating more on the broad characteristics of relationships and less on the underlying mechanisms and success factors (see Section 2.2.1)
3. Studies mention a trend towards ETO organizations developing multiple sites, but the literature does not provide any theory or empirical data on how those distributed organizations allocate activities or coordinate internally or with external partners (see Section 2.2.1)
4. Knowledge management, supported by information technology, is cited as a source of ETO competitive advantage, but the literature provides no operational details on maintaining freshness or dealing with organizational boundaries (see Section 2.3)

Figure 7: Gaps in Engineer-to-Order Literature Relevant to Coordination

2.6 Process Improvement in ETO

The second major building block for improving coordination is the management of process change. Over the years, change management literature has exploded [41], however most all of it has been developed in the context of make-to-stock businesses or other types of organizations with similar levels of predictability. Nonetheless, some of the generic models provide a starting point for how changes to coordination processes may be introduced in high-variability organizations.

Nearly all process improvement frameworks recognize three main stages of organizational change—an assessment of current state conditions, an argument for why the current state is insufficient, and a plan to reach a desired future state. An early form of this process was championed by W. Edwards Deming as the "Plan-Do-Check-Act" cycle [57]. Under PCDA, an organization plans a path towards a target state, executes that plan, analyzes the new situation for any deviations from expected, and then implements any needed corrective actions. By iterating the method, an organization can refine a process towards an end goal. Other frameworks, such as Six Sigma's "Design-Measure-Analyze-Improve-Control" (DMAIC) and "Define-Measure-Analyze-Design-Verify" (DMADV), use similar approaches based on the principles of the scientific method [42] and concepts from Lean manufacturing [43].

All of the methods above are predicated on the idea of eliminating waste by stabilizing processes and reducing variation. This goal is somewhat at odds with the ETO operating model, which inherently requires variable processes to accommodate uncertain customer demands. However, some variability in ETO organizations is avoidable [18,44], reinforcing the idea that selective anchoring of process points can introduce added efficiency while retaining robustness to variation where uncertainty must be tolerated.

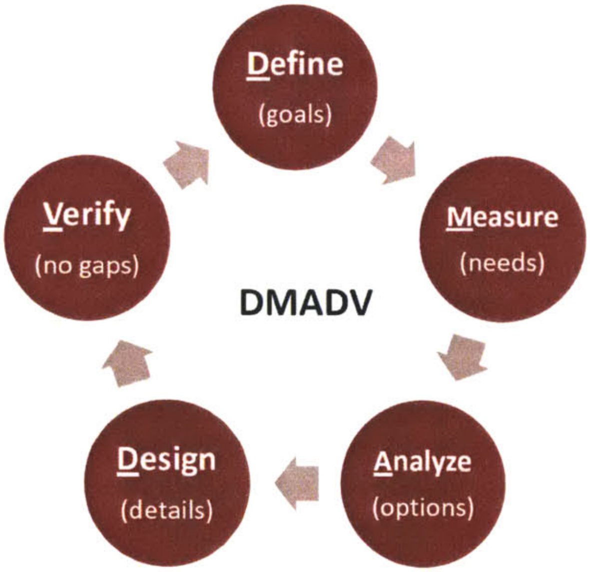


Figure 8: Define-Measure-Analyze-Design-Verify (DMADV) Approach to Process Development

The Lean-based improvement frameworks also presume that all people need to initiate change is better understanding of the system and quantitative measures of deviations [45]. In work that has since become canon, Kotter (1996) argued that motivating change is more complicated. He recognized that organizations often fail to gather momentum behind their efforts because of complacency with the status quo that has multiple behavioral drivers. Insufficiently visible crisis, low or overly narrow performance expectations, and habituation to frequent calls for change all impede commitment to improvement efforts. By extension, engineer-to-order businesses face an additional habituation risk in the constant uncertainty of their projects. Exposed to unforeseen changes that often lag distant causes, people in ETO firms may feel less capable of overcoming what appears to be well out of their control.

In light of the impediments to change, Kotter advocated creating a heightened sense of crisis—the proverbial "burning platform"—by creating tangible evidence of distress. Methods include revealing dramatic internal evidence, finding impartial external evidence, creating unobtainable stretch goals, and eliminating perks that convey success. Organizations then must build a coalition of change champions that have resources within the company and are committed to utilizing them. This coalition helps stakeholder develop a vision for change, which is distributed throughout the organization with the intention of embedding it in daily thought-processes. The change leaders also seek to eliminate bureaucratic obstacles, such as procedures and evaluation metrics, that might impede stakeholder action. Finally, the organization seeks to achieve visible successes early in the effort to bolster resolve for further efforts and to institutionalize the change vision over time.

Steps to Organizational Transformation

1	Create Urgency
2	Mobilize Champions
3	Create Vision
4	Disseminate Vision
5	Remove Obstacles to Change
6	Secure Quick Wins
7	Sustain Urgency
8	Institutionalize Vision

Figure 9: Kotter Framework for Implementing Organizational Change

The fundamental activities of assessing baseline conditions, building a vision for change, and tracking progress have led to a number of models for organizations to reference. For example, self-assessment models provide managers a sense of how process areas are performing and where opportunities may lie, and they can form the foundation for improvement plans. Still other assessments take the broader perspective of the organization as a whole and their performance relative to demands of their environments [41].

For example, Van Aken et al. (2001) propose a three-part assessment of ETO organizations that examines system-level performance, leadership quality, and team work effectiveness. The framework employs qualitative interviews for some portions and detailed questionnaires for others. Questionnaire responses are scored on either 6-point or 10-point scales, depending on the nature of the questions and based on judging criteria from the Malcolm Baldrige National Quality Award [46].

Other assessments focus on process areas in far more detail. Knoblinger (2011), for instance, develops a comprehensive set of questions that target an organization's product development (PD) best practices and its ability to adapt those practices to a changing environment. In total, the questionnaire includes 45 metrics for PD best practices, 22 metrics for agility, and 24 metrics for project results, on the premise that an assessment facilitator could oversee tailoring of the tool to the scale and circumstances of its application within a given organization. This clearly represents a significant investment in setting up what is just the fourth of nine steps in the proposed improvement process.

The Capability Maturity Model (CMM), upon which the Knoblinger assessment is partially based, highlights further challenges to systematically introducing process changes generally and in ETO environments in particular. The CMM was originally developed to support process improvement in software development, but it has since been advocated for adoption across business types [47].

Central to the CMM system is the concept of assessing the capability level of organizations on a maturity scale of 1-5. Processes of maturity 1 are ad hoc and reactive, whereas the target level of 5 represents processes that are quantitatively optimized. Each of a company's processes fall into one of 22 process areas with reference goals for both individual processes and for process areas. The supporting manual requires over 480 pages to detail the various areas, general goals, specific goals, practices and subpractices associated with introducing new products under CMM [47]. Distilling relevant material from the model is a significant task, especially given the limited patience for "non-core" work in ETO organizations. Additional effort is needed to augment areas relevant to ETO, such as logistics and information systems, that are underdeveloped in CMM given its software development heritage [48]. These underdeveloped areas pertain directly to the issue of inter-site coordination.

The CMM model is also highly hierarchical in structure, employing a reductionism that has important consequences for application in ETO. By relying on extensive process documentation, CMM implementation not only consumes significant resources, but it does so fixating process expectations in libraries of standardized process forms. Given the high level of variability in ETO organizations, at least some of which is inescapable, and given their focus on project specifics, regimented process documents risk stagnation and effective irrelevance. The CMM framework also aspires for highly flexible organizations but expects point goals and deterministic process controls, which forms something of a contradiction. The mismatch may be one reason why approximately 70% of attempted improvement efforts using CMM fail [49].

2.7 Gaps in Process Improvement Literature

Overall, the substantial literature on process change has focused on traditional high-volume, low-mix organizations. As a consequence, it provides limited guidance for improving coordination in light of uncertain demands. Figure 10 summarize some of the key gaps in the reviewed literature that the proposed coordination improve framework seeks to address.

Summary of Gaps in Process Change Literature

1. Much of the "plan-do-check-act" problem solving that underpins conventional continuous improvement methods are predicated on point goals and do not readily accommodate the "fuzzy" objectives often encountered in ETO (see Section 2.2.4
2. Capability assessments treat ETO largely as a product development activity and assess coordination only by the general level of trust or involvement of suppliers
3. Assessment frameworks and their associated process improvement models rely on significant process documentation that is both time-intensive and potentially static
4. Process change models intended for high-variability environments do not incorporate the organizational behavior issues that may be especially pronounced given the high variability (see Section 2.2.3)

Figure 10: Gaps in Process Change Literature Relevant to Coordination

2.8 Chapter Summary

This chapter reviewed existing literature related to supply chain coordination and capability development in engineer-to-order businesses. Although the ETO literature is rather sparse, the following major themes from it should inform a coordination improvement methodology:

1. Engineer-to-order companies face exogenous sources of uncertainty, which distinguishes them from high-volume, low-mix companies, but not all of the variability that they experience is inescapable

2. Faced with process complexity, a primary operational lever for ETO companies is delegation of activities. However, with narrowing responsibility comes increased dependence on coordination with other organizations.

3. Engineer-to-order companies can standardize their processes at multiple levels, including methods, outputs, and tools, which affects the balance of local versus global decision-making in the firm.

4. Having project-based operations biases ETO firms towards the short-term, but decision-making that integrates knowledge across projects is critical to long-term competitiveness.

5. Existing process development models have stability expectations at odds with ETO agility needs, are predicated on integrated information systems unrealistic in ETO supply chains, and provide little actionable detail about improving coordination mechanisms throughout the project cycle.

Chapter 3: A Method for Improving Interface Processes

This chapter outlines a novel approach to improving inter-site coordination in environments where uncertainty and variation prevent deterministic process controls. By segmenting coordination into several layers, the framework uses dynamic feedback loops to align stakeholders with an economy of process constraints. The method is intended to balance efficiency with organizational adaptability and has five major steps—Understand, Visualize, Disseminate, Prioritize, Improve—or UVDPI.

3.1 Guiding Principles

The need for operational flexibility in ETO companies creates unique or at least amplified challenges to process improvement. Whereas process improvement typically is predicated on stable processes, the unpredictable circumstances of ETO often lead to inconsistency and improvisation. Even the target capabilities that processes must deliver may change rapidly [8,14,25]. At the same time, the customer is exposed to nearly all of the project lead time, exacerbating the pressure for process velocity. Moreover, ETO firms often assume significant financial risk because they have limited opportunity to pre-plan and aggregate demand. They therefore have to act faster and with fewer mistakes.

The high stakes and high uncertainty require a high level of nimbleness, which forms a double-edged sword. On the one hand, the expectation of creative problem-solving may breed a culture of high autonomy that may resist attempts to standardize processes. On the other hand, the resourcefulness of people within the organization has the potential to drive continued improvement given sufficient impetus and direction. This duality suggests a latent opportunity to better utilize the capability of agents in an ETO organization by providing a lightweight framework and vision for change. Based on a review of the literature and experience in high-variability organizations, that change framework should:

1. Improve an organization's ability to deliver value to its customers

2. Recognize that complex business operations cannot be captured in a set of process rules; Contingencies are numerous, and necessary capabilities change. Therefore so must the coordination processes delivering them

3. Capitalize on the ability of people to adapt quickly by providing them the contextual information that they need to assess and close gaps

4. Introduce constraints economically and where they encourage common ground between counterparties more than they inhibit needed local innovation

5. Harness positive feedback loops that drive global business performance from local process success

6. Promote sustained implementation by limiting the scarce resources needed to plan and execute process change

The process improvement method described in this thesis attempts to incorporate the above principles by emphasizing the potential efficiency of informed agents working within a dynamic system. The approach distinguishes areas that need stability through formal interface definition from those that need a stronger foundation through greater common ground. In doing so, it provides a path for ongoing improvement that has low investment burden, is sensitive to the dynamic needs of a distributed ETO company, and encourages adoption by preserving creative decision-making. The key distinguishing aspects of the proposed method compared to existing approaches appear in Figure 11.

	Existing Improvement Methods	Proposed Improvement Method
Premise	*Eliminate all variation*	*Eliminate variation where possible; accommodate where necessary*
Market Outlook	*Predictable*	*Uncertain*
Capability Needs	*Stable*	*Dynamic*
Process Performance	*Deterministic*	*Multi-faceted and subject to stakeholder behavior*
Process Upkeep	*Significant documentation and IT-dependence*	*Minimal*

Figure 11: Differences between Proposed and Conventional Improvement Methods

3.2 Change Leadership

Process change is only as effective as the leadership overseeing the transformation. As noted by Kotter (1996) and others, managers of change must overcome stakeholder resistance and manage many moving pieces. Change leadership in an ETO environment is potentially even more difficult, because processes have many variants, they tightly couple many stakeholders, and people are highly focused on solving immediately pressing problems.

Coordination improvement efforts must therefore be facilitated by a person that is capable of operating above the fray of project particulars and that can recruit influential people in each of the affected functional areas and business sites. The project facilitator should seek to engage local project champions and assist them in building conviction around a shared vision for change. The facilitator should be sensitive to the communication and discussion norms of the organization and work within those norms to identify patterns across projects and to synthesize meaning from them. The facilitator should seek to maximize the productivity of stakeholder participation so as to limit the burden placed on the organization.

3.3 Project Initiation

Senior management should introduce the facilitator to a group of relevant managers during a project kick-off meeting. That meeting should provide a forum to discuss motivations for improving coordination and enable the facilitator to begin judging the sense of urgency felt by stakeholders. The kick-off meeting is an opportunity to discuss strategic priorities for the organization as whole and for coordination between organization sites in particular. Consensus is not necessary so much as generation of key elements in the eyes of functional or program leads. Stakeholders should agree on a scope for the project, recognizing that it may need to be updated as the investigation of issues progresses. The meeting should also include discussion of specific goals for the improvement project and conclude with an approximate timeline for the project, with major milestones and points of stakeholder engagement delineated.

3.4 Overview of the UVDPI Model

The proposed coordination framework consists of five main steps aimed at improving material flows between organizational sites. The overall trajectory of the steps follows the familiar path of moving from stages of assessment to brainstorming to detailed analysis and action. What differ are its focal points at each of the steps, its emphasis on visualization, and its conception of how coordination processes can operate in dynamic ways. The following steps are intended to guide a facilitator after a project kick-off meeting with stakeholder representatives.

3.5 Step I: Understand

Understanding of the organization's inner operations is fundamental to later assessment and utilization of performance opportunities. Working with individual stakeholders and with groups of stakeholders, the change facilitator must begin to piece together the processes of functional groups and their relations to adjacent groups. A holistic perspective on material flow is critical, and the facilitator should seek understanding of functional areas upstream and downstream of actual material transfers. Potentially relevant groups are listed in Figure 12.

Potential Stakeholder Groups	
1	Engineering
2	Program/Project Management
3	Order Handling
4	Production Planning
5	Supply Chain Management
6	Quality
7	Service
8	Accounting Controls
9	Shipping/Receiving/Logistics

Figure 12: Potential Stakeholder Groups Related to Material Flows

Using semi-structured interviews, the facilitator should probe both the tactical activities and the thought processes related to material movement and material use. Discussions should involve organizational groups on either side of exchanges, which, if left unchecked, could lead to overwhelmingly broad scope. Therefore the facilitator must thoughtfully direct conversations towards issues related to material management and particularly issues tied to flows into and out of organizational groups. Recommended points of concern are included in the checklist of Figure 13.

Checklist for Interview Discussion Areas

☐ Local functional objectives related to materials

☐ Perceived drivers of success

☐ Process references

☐ Process Tools

☐ Expected inputs and outputs

☐ Perceived sources of uncertainty

☐ The role of timing

☐ The evolution of processes and explanations of change

☐ Primary motivators

☐ Perceived activities and rationales of counterparties

Figure 13: Checklist for Initial Discussions with Stakeholders

The purpose of initial discussions is not only to educate the facilitator but also to initiate stakeholder introspection. Therefore, probing assumptions is key. What on first pass may be portrayed as typical may actually have pertained to specific circumstances or reflect what the stakeholder wished had happened. Similarly, a stakeholder may misattribute an occurrence based on partial information or hearsay. Triangulation using multiple stakeholders on either side of an exchange is helpful in identifying discrepancies. These discrepancies and other awareness gaps are especially important, as they indicate opportunities for improved common ground that may benefit coordination.

3.6 **Step 2: Visualize**

The complexity and variation of ETO processes makes framing conversations difficult. Accounts may vary from stakeholder to stakeholder or even with the same stakeholder. Visualization forms a powerful tool for anchoring conversations. It establishes common terms, creates tangible boundaries, and begins the process of establishing a common vision of current and future organizational states.

As the facilitator accumulates conversations with stakeholders, he or she can begin to identify repeating activities, recurring process issues, recurring sources of uncertainty or change, key aspirations, and disparate perceptions of situations. Each of these elements can be captured in diagrams, offering concrete points of reference for conversation. Because the overall intention is to build better situational awareness that is tied to strategic goals, visualizations should provide several levels of granularity, starting with a system-wide view of how coordination relates to desired capabilities. Senior managers are more likely to be able to contribute to such global visioning than lower level managers and operators.

Subsequent diagrams then can provide greater detail at the process and handoff levels. The intention is to capture sufficient detail to be relevant for specific conversations while always providing a connection to the big picture. Figure 14 illustrates the recommended system of visualizations, and Figure 15 provides guidelines for creating those visualizations.

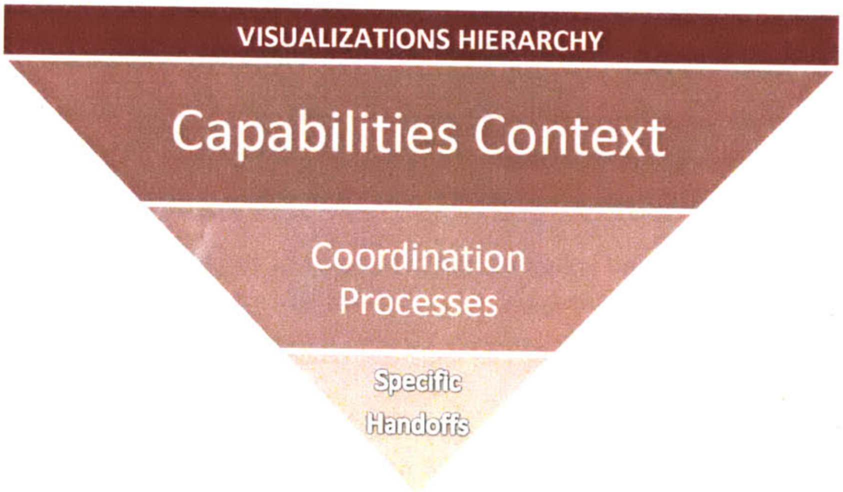


Figure 14: Visualizing Ties between Coordination and Global Context

OVERALL CONTEXT DIAGRAMMING

1. Diagram how any strategic capabilities that depend on material flow might evolve with time
2. Situate processes that involve material exchanges within the trajectory of desired capabilities
3. Indicate drivers of long-term change and sources of short-term variation

COORDINATION PROCESS DIAGRAMMING

1. Select a process that involves material flows or material information exchanges between organizations
2. Define horizontal "swim lanes" that correspond to major functional or organization entities and group them by business site
3. Plot the major activities as a flow diagram from left to right
4. Label handoffs between lanes with the transfer medium employed and any associated process references or tools
5. Annotate the diagram with green/yellow/red boxes that denote specific points of key process control success, weakness, or recurring failure, respectively.

Figure 15: Guidelines for Creating Visualizations of Material Coordination

Creation of visualizations should be an iterative process borne mostly by the facilitator but with follow-up conversations with appropriate stakeholders to gather feedback. These follow-up discussions should both refine the diagrams and explore any surprises or updated insights from stakeholders upon seeing the diagrams. The visualizations need only be as detailed as necessary to capture process points raised by stakeholders. Where possible, the facilitator should seek to use any existing lexicon or design language from the organization to ease stakeholder interpretation.

The result of the Understand step should be a single schematic representation of the path of organizational capabilities related to material transfer and one or more flow diagrams of "core" activities that involve relevant coordination. These flow diagrams should capture process sequences, task responsibility, handoff details, and opportunities for process issues. Pertinent types of issues worth noting are listed in Figure 16.

	Potential Process Issues Worth Noting
☐	Shortcutting of prescribed sequences
☐	Handoff processes that vary by project, stakeholder, or instance
☐	Mistimed exchanges
☐	Opportunities for information corruption
☐	Missing handoff acknowledgement or feedback
☐	Stakeholder over-burden due to rework
☐	Stakeholder involvement outside of intended role
☐	Missing task or handoff ownership
☐	Key decision-making without all stakeholders or needed information
☐	Rolling changes to key decisions after important freeze points
☐	Incomplete communication of changes to affected parties
☐	Opportunities for conflicting information that resides in more than one location

Figure 16: Potential Coordination Issues Worth Noting

Potential coordination issues that arise during discussions should be compiled in master list and can be coded by issue type or impacted process area. Visualizations thus become a tangible framing device for ongoing conversations, while the issues master list forms a distillation of process concerns to help guide the facilitator.

3.7 **Step 3: Disseminate**

Once global and process visualizations have undergone some refinement, at least by stakeholders in one business site, they can be shared with adjacent stakeholders and counterparties on the other side of transactions. This dissemination is an important element of building a shared vision predicated on a common vocabulary. Such a vision must be sensitive to the local concerns of specific stakeholders but also should work towards a collective understanding of major patterns that emerge across project instances.

As with initial Understand discussions, the facilitator should elicit feedback from coordination counterparties and incorporate any new process concerns into the master list. This list should be comprehensive, but careful filtering of extraordinary issues and conflating variants of the same issue can prevent the list from becoming overwhelmingly long.

The master list then can be used as a stakeholder survey. This survey should ask process stakeholders to score candidate issues on both issue significance (ranging from very urgent to does not exist) and solvability (ranging from very easy to beyond control). If a seemingly major issue has multiple hypothesized contributors, all forms can be included in the survey to begin differentiating causes. However, the facilitator should be mindful of keeping the survey reasonably short. It is intended to be a first screening of issues and should require only nominal time from participants.

Distribution of the survey to enough stakeholders and to the right people improves the validity of the survey results. Exactly who and how many people are appropriate will vary by instance, but an assessment of the scope of the improvement project may help determine the proper breadth of survey distribution. Adding samples includes more perspectives that form the organization's collective awareness, and the facilitator may consider soliciting survey responses from beyond those stakeholders that were involved in its creation. A distribution matrix may be helpful in ensuring adequate coverage of organizational groups on either side of site boundaries. A matrix also helps quantify population size and response rate, which are required to evaluate statistical significance.[1] Figure 17 provides an example distribution matrix format.

	Function 1			Function 2			Function...
Site A	Person 1	Person 2	Person 3	Person 10	Person 11	Person 12	Person 19
Site B	Person 4	Person 5	Person 6	Person 13	Person 14	Person 15	Person 20
Site C	Person 7	Person 8	Person 9	Person 16	Person 17	Person 18	Person 21

Figure 17: Example Survey Distribution Matrix

---

[1] For a desired accuracy, needed sample size can be estimated as $\frac{t^2 * \frac{(scoring\ range)^2}{36}}{(desired\ margin\ of\ error)^2}$ where t is the t-statistic for a given confidence (typically 0.975) and population size [56].

3.8 Step 4: Prioritize

Distribution of the survey and collection of responses mark an important shift in the improvement process. The Understand and Visualize steps are largely fact-finding activities, whereas the Disseminate and Prioritize steps initiate more narrowed examination of potential target issues. Step 4 of the improvement process, Prioritize, has two main portions in this spirit. The first is the processing and utilization of stakeholder data generated by the survey. The second part is detailed examination of a subset of issues from the survey to identify high priority issues for remediation.

The overarching intention for processing survey responses is to start identifying important issues with seemingly obtainable solutions. These high-urgency, high-solvability issues are potential "low-hanging fruit" that may offer quick successes to build momentum behind the coordination improvement method. One way to begin isolating these opportunities is to graph mean survey responses on a scatter plot with ordinates of solvability and importance and then look for clustering. Figure 18 illustrates how this might look.

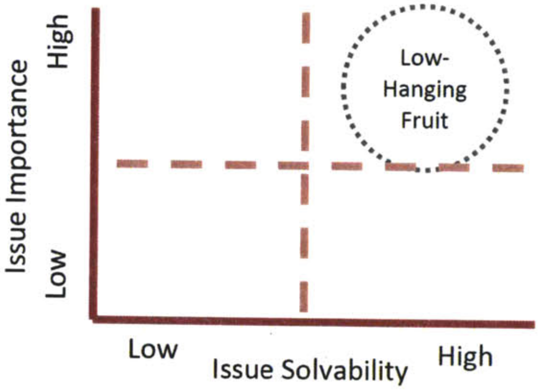


Figure 18: Identifying Candidate Issues from Survey Reponses

The precise cut-off between the quadrants shown in Figure 18 will vary depending on the distribution of survey responses and on the quality of survey participation. Strong clustering may allow obvious segregation of target issues from those that stakeholders consider either unimportant or too hard to address. If clustering is modest, an examination of response confidence intervals may help distinguish more important, more amenable issues from the rest. Confidence intervals should be calculated based on issue-level variance in responses and on the number of responses gathered for each issue relative to the stakeholder population in question. At the aggregate level, population size may be based on the overall number of managers or other "expert" stakeholders in the in-scope organizational areas. For inferences about responses at the business site or functional group levels, the population size must be scaled down accordingly.

Stratified population groups are important, because cross-sectional patterns in the survey results may provide learning opportunities. For example, different mean responses across business sites may suggest discrepancies in the perceptions at those sites, which could motivate discussions about why. Subsequent dialogue about differing priorities may uncover inconsistent assumptions across the overall organization. Similarly, high response variances within business sites or functional areas may indicate internal perception gaps that are inhibiting cross-coordination.

By breaking out survey data at the functional and site level, the facilitator therefore can provide tailored assessments that frame local perceptions against global reference averages. The survey thus becomes a tool not only for identifying major coordination issues but also for building more common ground generally, which itself may improve tacit coordination. Quick feedback also rewards stakeholders for their participation, reinforcing their engagement in the process.

The second major portion of the Prioritize step is to select a subset of the issues from the low-hanging fruit analysis to act on. Here, the underlying concept is that process issues do not occur in isolation and instead are part of a larger system of coordination. This system consists of a number of activities that work in concert to determine the performance of an overall coordination mechanism. The quality of one activity may impact the quality of a downstream activity, which impacts the quality of the next activity, etcetera. Some activities may affect coordination performance over the short-term and some may have longer-term effects.

One approach to final issue selection is to start with the fundamental material-related objectives of each business site (or functional group within each business site) and to work backwards, enumerating the activities that drive achievement of those objectives for each group. The facilitator need not include every activity in each organizational group, but instead can focus on three main types of activities tied to material management: Information gathering, planning, actual material movement.

Each organizational group engages in some or all of these activities, and the success of the activities depends on both upstream activities within the same group *and contributions from coordinating groups*. These contributions are the information handoffs and physical material flows documented in the process diagrams during the Visualize step. By re-diagramming the sequence of activities in the current step, the facilitator can begin visualizing how both the quality of activity execution and of handoffs can ripple through the system and impact the fundamental objectives of the counterparties.

Figure 19 illustrates how one might diagram this interconnectedness using a causal loop diagram for two organization sites. A causal loop diagram consists of interconnected nodes linked by arrows. Arrows with positive signs indicate that an increase in one node leads to an increase in the node connected by the arrow. Similarly, a decrease in an upstream node causes a decrease in the node connected downstream.

Importantly, the diagram in Figure 19 treats the quality of content, quality of transmission, and confidence in a process as separate contributors to process success. Considered another way, the availability of information, the utilization of it in processes, and the adherence of stakeholders to those processes are distinct drivers of process success. They therefore appear as separate nodes for each activity.

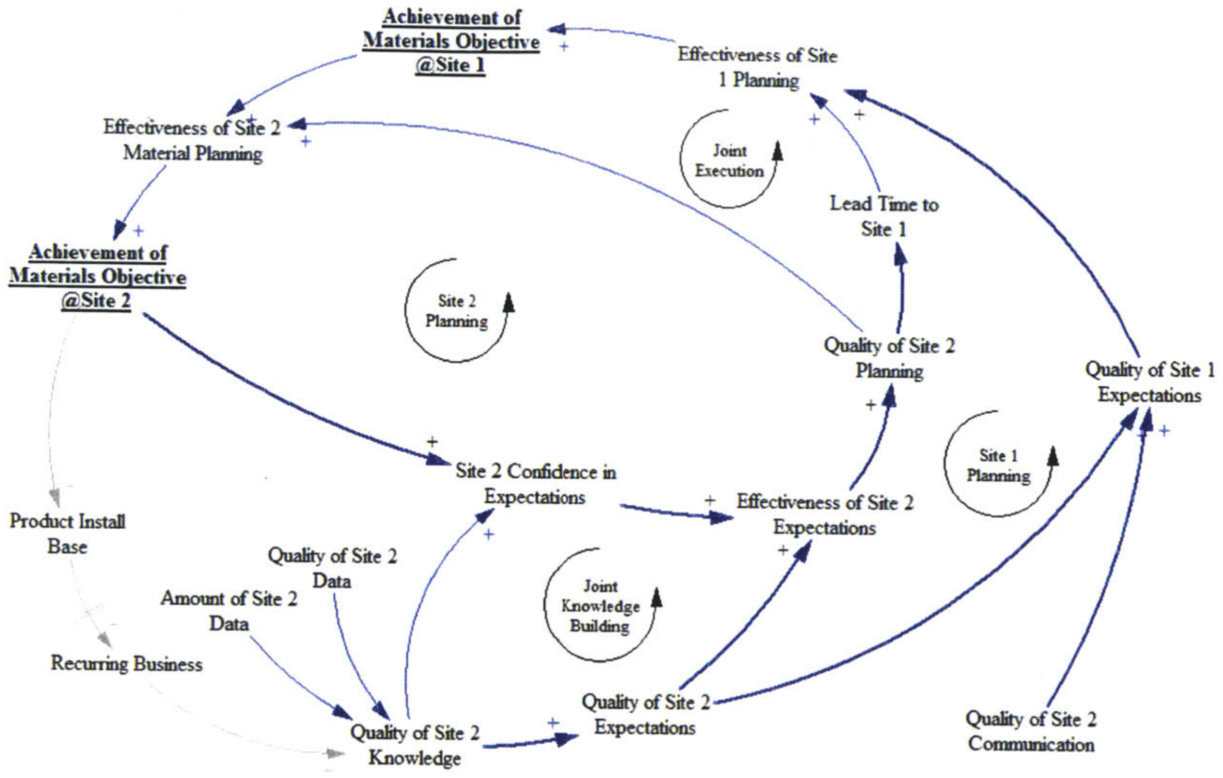


Figure 19: Generic Inter-Site Coordination Causal Model

A causal diagram is sufficiently detailed if the high-priority issues identified by stakeholders can be mapped to the diagram. When overlaid on the diagram, some issues will appear in series along the same chain of activities and others will appear in more isolation. Issues in series may indicate that addressing one of them will yield only local benefit, because an issue that remains downstream may continue to inhibit performance. Issues that appear alone may indicate a performance bottleneck that if addressed would allow the existing successes of other activities to "flow through" and improve realization of the group's bottom-line objective. The facilitator must evaluate the merits of selecting isolated issues or pursuing one or more coupled issues. Likewise, it should be recognized that activities related to information gathering may impact organizational capability on a longer time frame, whereas execution activities impact project performance and in the near-term.

The facilitator, if not yet comfortable with causal loop diagramming, may want to undergo the exercise alone before working through it again with designated project champions. The group then can select its target issues based in its priorities for "quick wins", long-term capability development, mutually reinforcing improvements, etc.

3.9 **Step 5: Improve**

Once the target issues are selected, the facilitator can begin working with relevant process stakeholders to complete a root cause analysis. This analysis can use the process diagrams created during the Visualize step to frame conversations while considering the three dimensions of process listed in Figure 20. For each of these process layers stakeholders can ask what is in place, how is it working, and why.

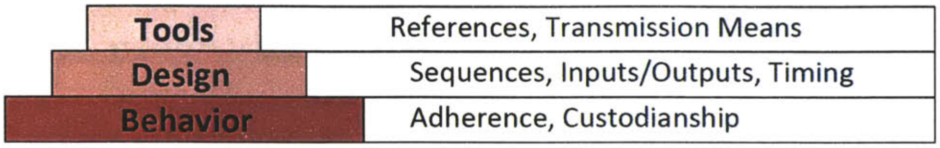


Figure 20: Components of Process

One challenge in the ETO environment is determining what more could be done given the many apparent sources of uncertainty that might impede process performance. Stakeholders should be honest about what flexibility is genuinely needed versus what has been left in place because a process is too out of control. It may be helpful to consider under what conditions a coordination process could be fully standardized and then to question which of those conditions cannot be achieved and why. If standardization is prevented by external uncertainty—unforeseeable changes in customer demands or stipulations from suppliers, for example—then a process that is allowed "to float" within prescribed bounds may be all that is achievable.

The lowest level of coordination capability would be a process in which the timing, content, format, and possibly transmission means of exchanges are improvised on a case-by-case basis in reaction to present circumstances. Such a process would be labor-intensive, prone to errors, and difficult to scale. With increasing capability, more stability can be introduced in the form of partial standardization, and the process becomes better able to foresee and adjust to upcoming coordination needs.

The highest level of process maturity is not necessarily a fully standardized, quantitatively optimized process. Such a state is certainly possible, even under ETO circumstances. However, it may not be realistic given exogenous sources of uncertainty. What instead should always be possible is a process in which participants understand their counterparty's thought processes and have full confidence in it. The timing, content, and format of exchanges are agreed upon and adhered to. And, importantly, the stakeholders have a consistent system for updating their coordination mechanism as needed. Ideally, enough common ground and good faith should exist on each side that a new participant could enter the process and be readily coached.

The levels of coordination maturity delineated in Figure 21 may help guide process improvement planning by illustrating how some variability might be selectively avoided.

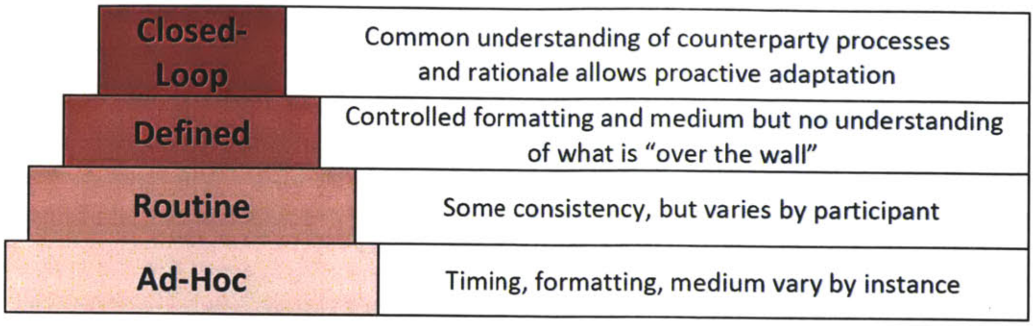


Figure 21: Coordination Maturity Levels given Uncertainty

Countermeasures to process issues can be designed in light of the root cause analysis and assessed process maturity. Proposals for less mature processes can emphasize solutions that build common expectations and confidence in the process. Actions might include standardizing the content, timing, or format of information transfers. Given potentially limited understanding of variation sources, establishing a communication medium that can easily adapt as needs change may be helpful.

For more mature processes, higher levels of automation may be possible given greater understanding of process needs and participant concerns. Information exchanges may be able to pull directly from database systems or rely on algorithmic triggers. Because variability is still possible, plans can be formalized for anticipating needed changes to the coordination mechanism and for updating it.

As stakeholders begin coalescing their vision for change, they can adapt the causal loop diagram of Figure 19 into a picture that distills how the proposed coordination mechanisms relate to the larger objectives of the organization or company. These mechanisms are the activities in the causal loop diagram that connect sites to form feedback loops, and they can be grouped by the operational level at which they act, as illustrated in Figure 22.

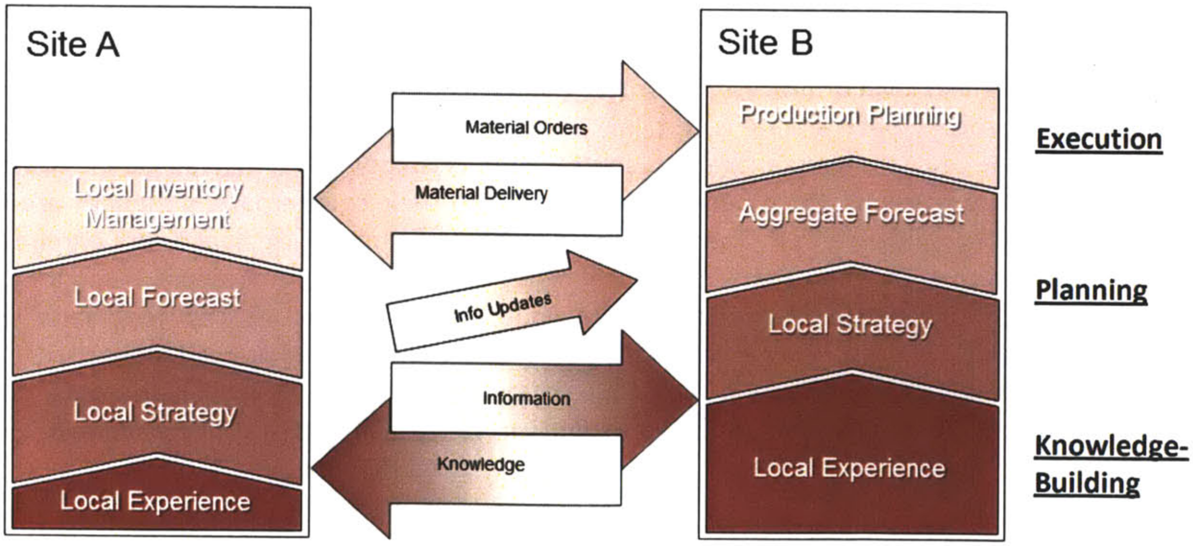


Figure 22: Operating Levels of Coordination

With a completed vision for change, stakeholders can define process change objectives, assign responsible overseers, and design mechanisms for tracking and reviewing progress towards objectives.

3.10 Chapter Summary

Chapter 3 introduced the process improvement model developed in this thesis. Major aspects of the model that differentiate it from other frameworks include:

1. Establishing a common vocabulary and sense of boundaries is critical for process improvement in high-variability environments; Incorporating diagrams into stakeholder discussions can help establish visions for current and future process states

2. Disseminating stakeholder impressions of processes to counterparties and adjacent groups can help identify recurring issues and build common ground

3. High potential process issues can be recognized by soliciting stakeholder feedback and pairing it with a causal loop analysis that examines the performance dependencies of related activities

4. Coordination improvements can be planned that selectively address process tools, designs, and/or underlying participant behaviors

5. Change leaders can target both short-term and long-term performance gains by seeking coordination mechanisms that create positive feedback loops at the execution, planning, and knowledge-building operating levels

Chapter 4: Case Study—ABB Traction Converters (TRA)

The process improvement method presented in this thesis was developed over the course of a six-month project concerned with "improving logistics interfaces" within a Swiss business unit of ABB Group. As a rapidly-evolving ETO organization, the host business group provides a real-world example of a high-variability organization responding to the pressures of an expanding global footprint. Issues of standardization, vertical integration, and process focus are all present and provide a test bed for the proposed improvement method. The practical experience of implementing the process also provides general insights that might guide improvement efforts at other organizations.

4.1 ABB Background

ABB is among the world's largest power equipment manufacturers. Formed in 1988 by a merger of Brown Boveri Company in Switzerland and ASEA of Sweden, ABB serves numerous sectors, ranging from ultra-high voltage power transmission to electric propulsion and process automation. Power grids, mining operations, ocean ships, factories, wind generators, and hotels all utilize ABB products. The company currently employs about 135,000 people in 100 countries around the world.

Central to ABB's business strategy is a focus on technology leadership through significant investments in research and development. Each of five divisions—Power Products, Power Systems, Discrete Automation, Process Automation, and Low Voltage Products— share related technologies but generally operate independent development centers. These centers conduct basic research for global product groups that then adapt the technologies to new or updated products. As customer interest in a new application expands, the company may create a new business unit within the global product group to develop that market segment.

One consequence of the company's broad technology portfolio is a wide variety of product types. Low Voltage products, for example, tend to be high volume commodity items such as switches, circuit breakers, and interconnects. Products from the Power Products division tend to be larger, but configurable capital equipment. Examples include surge arrestors and switchgear. Offerings from the Power Systems and Process Automation divisions emphasize system integration and ongoing service delivery. They often utilize components supplied internally from other ABB business units. The Discrete Automation division, however, has a mix of commodity electrical components and substantial, engineer-to-order capital equipment. Products range from programmable controllers and motor drivers to robotics, high-power interconnects and electric vehicle charging stations.

The diverse mix of businesses within ABB and the sheer size of the organization present challenges to process standardization. ABB corporate disseminates broad guidelines across most all business areas, but ultimately each unit within a global product group adapts processes to its own business needs. Functional groups that support several co-located business units therefore may have to interface with different approaches to the same activity. Moreover, small business units may share production facilities with larger, more mature business units, adding heterogeneity to how physical material is handled. A natural tension in material management thus arises from the need to balance local business needs with standardization and increased efficiency.

4.2 **Railroad Industry Background**

One of the sectors served by ABB is the railroad industry. For this study, the relevant end customers are generally railroad operators, which are either private enterprises or, in many countries, at least partially government-owned. These operators produce tenders for new locomotives or rolling stock that are bid on by a consortium of system integrators and subsystem producers. Companies like ABB will form alliances with partners and internally negotiate scopes of supply intended to maximize the strategic position of the overall bid. Thus companies that compete head-to-head for one project may collaborate on another depending on how their product offerings align with project specifications.

Some of the major products up for tender are electric railroad vehicles, either in the form of locomotives or powered passenger carriages. The vehicles utilize onboard power electronics that convert the electric energy supplied the railroad system into the forms needed onboard to power the train and operate secondary systems. The power electronic systems ("traction converters") are carefully engineered for the specific operating circumstances of a particular application. Both electrical aspects—such as operating voltages, frequencies, and software systems—and mechanical aspects—such as weight, shape, and cooling—must be tailored for each customer order. Typical power converters are large cabinets that, not including accompanying motors and hardware, weigh 500-2,500kg. Figure 23 is an example of one power converter.

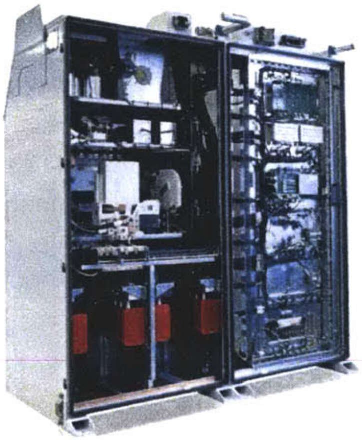


Figure 23: Example Railroad Traction Converter

Bids for these traction systems are judged by customers along multiple dimensions, with the weighting of each factor depending on the customer or region. Basic order qualifiers may include technical performance such as power output, energy efficiency, system weight, and communication with a train's central control system. Other aspects that may be order qualifiers or winners include noise, durability, upfront cost, service coverage, or simply confidence in the technical rigor behind a system's design. Each customer may have different priorities, and a traction supplier must understand where to focus its efforts and expenditures.

4.3 ABB Traction Global Product Group

4.3.1 Business Position

Up until 2008, ABB served the traction converter market from its Power Electronics business group. Its traction converters were adapted from the group's stationary industrial drives, modified for the more dynamic operating cycles and harsh environments encountered in railroads. Diverging technical needs and an interest in increased market sensitivity led ABB to form a dedicated traction converter product group, known as ABB Traction Converters (TRA), in 2008.

Today, TRA operates as an independent sister organization to Power Electronics and MV Drives and produces a comprehensive portfolio of propulsion and auxiliary power converters for rail applications. When acting as a primary supplier, TRA recruits other ABB units to offer complete traction packages to train manufacturers. These packages may include circuit breakers, transformers, generators and motors to the converters manufactured by TRA, and additional parts from external suppliers also may be bundled. Even though TRA may be directly supplying only a subset of the traction system, as producer of the "heart" of the system, it assumes responsibility for coordinating the technical and commercial aspects of the other bundled components, acting as liaison to the customer on behalf of ABB.

In other projects, TRA provides just traction converters. Many of the unbundled converters are used to upgrade existing systems that employ less efficient or difficult to maintain components. Besides technology obsolescence, traction converters have a useful lifetime of 10-15 years compared to the 30-40 year lifespan of the train itself. Therefore, retrofits are a significant source of business.

Finally, TRA in some cases may sell just key modules within a converter, several of which ABB is considered a technology leader. Other companies in the railroad traction space, including OEMs, incorporate these ABB components into their own designs and will turn to TRA for future servicing. Figure 24 illustrates the high-level organization of TRA and resulting flow of material internally and to customers.

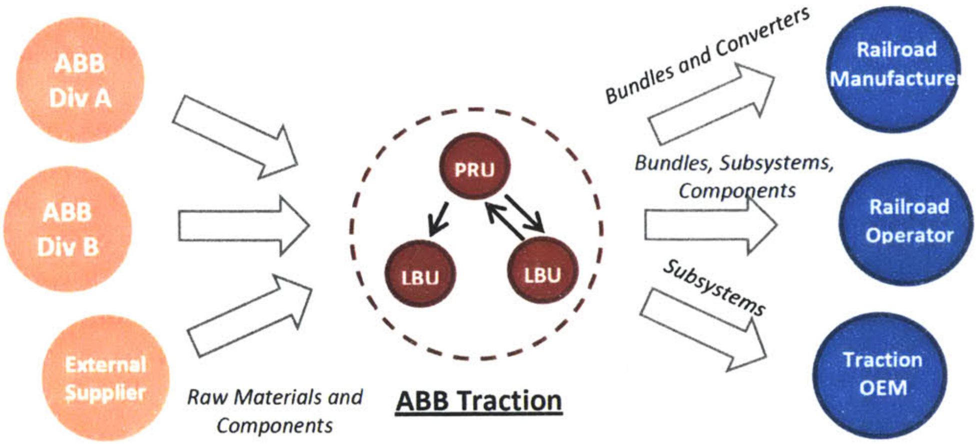


Figure 24: ABB Traction Converters (TRA) Market Position

4.3.2 Business Strategy

In many ways, the recent evolution of TRA parallels the trajectory of other capital goods manufacturers examined by Hicks, McGovern, and others. As the business group looks to expand its sales volumes by entering new regions, it is establishing local business units to better understand local market needs and to meet expectations for local content. At the same time, the headquarters office is hedging the complexity of its operations by attempting to delegate responsibilities away from the center. This distribution of effort is tempered by the recognition that core technologies represent significant value worth fostering. Therefore, as the product responsible unit (PRU) looks to shift activities to local business units (LBUs), some engineering and production activities are expected to remain at global headquarters.

The distributing of tasks across sites is occurring in tandem with nascent efforts to reduce product complexity. As the business group has gained more product experience, it has been able to repackage some critical electronic parts to improve reliability and ease installation. However, the number of fundamental modules has grown substantially as applications have proliferated. Rationalizing the portfolio is complicated by the number of technology generations in the field and the need to provide long term service. Hundreds of components, including some semiconductors, copper bus bars, and other high-value materials continue to be customized on a regular basis.

4.3.3 Global Network

Much of the effort to standardize project work has stemmed from an interest in improving efficiency and quality within TRA but also in easing the ramp-up of new business sites in India, China, and elsewhere. Over the last two years, the organization has seeded new local business units (LBUs) with the intention that they gradually assume project engineering and commercial responsibility. The original Swiss office, as the product responsible unit (PRU), is expecting to oversee the overall product portfolio while providing some critical sub-modules to the LBUs.

To date, the LBUs have varying levels of engineering, production and commercial capability, and the Swiss PRU retains much of the project ownership that it intends to eventually delegate. The result is a complex mesh of ongoing projects, each with different levels of localization depending on the LBU involved and the demands of a particular contract. The resulting information exchanges between the PRU and the LBUs have been very complicated and far from optimized. Making improvements in how TRA coordinates material flows within its group was the primary motivation of the project forming this case study.

4.3.4 History with Process Improvement

Priority within the product group has been on sales growth and only recently has it begun efforts at formal process improvement. The most notable exception is adoption of a gated, waterfall-type product development model that has been used in the overarching global Business Unit for many years. This model incorporates initial bidding, project specifying, detailed engineering, production, and commissioning. For some other internal key processes, discussions among stakeholder groups are ongoing. For example, the transition of ownership from the project management team to the service and customer support team, as intended after gate five of the product development model, is still under development as product installed base grows. One consequence is an overlap in involvement of project managers originally charged with steering the project from sales contract to formal delivery and the service group responsible for warranty claims and after-market service contracts.

A division-wide operational excellence group does exist, but its involvement in TRA to date has been limited. All projects in collaboration with the group have focused on production process refinement. Business processes, in particular as shared with the new LBUs, with a few exceptions have been undocumented and left to stakeholders to execute on a case-by-case basis, as needed.

4.4 **Project Introduction**

The underlying project motivating this study had an original scope focused on classic logistics issues—that is, physical material movement between the TRA headquarter location and the new local business units abroad. However, the scope was quickly broadened to take a more holistic perspective that considered the interconnected decision-making and communication activities that affected material transport. At the time, it was unclear precisely which portions of the product lifecycle would be included.

The process of defining a vision for TRA-wide capability development, identifying core interfaces, and then implementing a portfolio of changes provided an opportunity to validate the UVDPI method. The case study also details concrete measures for coordinating in the midst of uncertainty, which thus far have been absent from the literature. The ideas generated could apply more broadly to organizations wrestling with the tension between process efficiency and flexibility.

4.5 Understand

As an outsider to the organization, the facilitator-author first set about meeting one-on-one with managers of functional groups within the headquarter PRU. Project goals had only been loosely defined by the sponsoring global manager, as had been the underlying motivations. When asked what about inter-site coordination had been inadequate, each manager reported a different burning issue, each tied to a specific project. An LBU had requested unrealistically expedited processing, wrong information had been sent from an LBU, the wrong material had been ordered, insufficient capacity had been reserved for a long lead-time item and now it was too late, critical material was stuck in customs, a local supplier had fallen through at the last moment, and local production was inexplicably not hitting targets were just a few of the issues mentioned.

When asked whether any of these issues were recurring ones, managers often had trouble recalling if similar problems had happened before, during prototype pilots, or during ongoing production runs. Each project seemingly had a different level of localization, clouding the circumstances of any issues in the memories of the stakeholders that had fought through them. What emerged was a general sense that coordination between the sites had not been as smooth as people had expected or hoped but that inevitable surprises did not leave much room for more control. If anything, people at new local sites just did not have the needed expertise, and it would be some time before they got it. Some PRU managers suggested that localization would never be complete, while others communicated that it could be going faster.

Indeed, interviews with various stakeholders at the PRU revealed a common impression that it was too soon to try formalizing any processes, because they were in such flux. Not only were processes undocumented, but most stakeholders had limited understanding of the processes of adjacent functions within the PRU. In many cases, functional managers had no understanding of the activities of their counterparty's at the LBUs. Some managers had tacitly decided that any new process proposals, if they had them, should not yet be shared with potential stakeholders either internally or at LBUs for fear of distracting from time-sensitive project work.

4.6 Visualize

High operational variability within the PRU impeded comparisons across stakeholder discussions and obscured any possibility of generalizable changes that could compete with the imminence of project demands. Therefore, visualization of the overall concept of localization within TRA and of its impact on *general* coordination needs within the global group was critical to gaining a sense of direction.

The facilitator-author worked with the global project sponsor to begin structuring a high-level view of the group's localization efforts that included the desired LBU responsibilities for materials for the present time and at progressive stages into the future. They then identified recurring major processes involving material movement. The facilitator checked these processes against those noted in stakeholder discussions to produce the diagram of Figure 25.

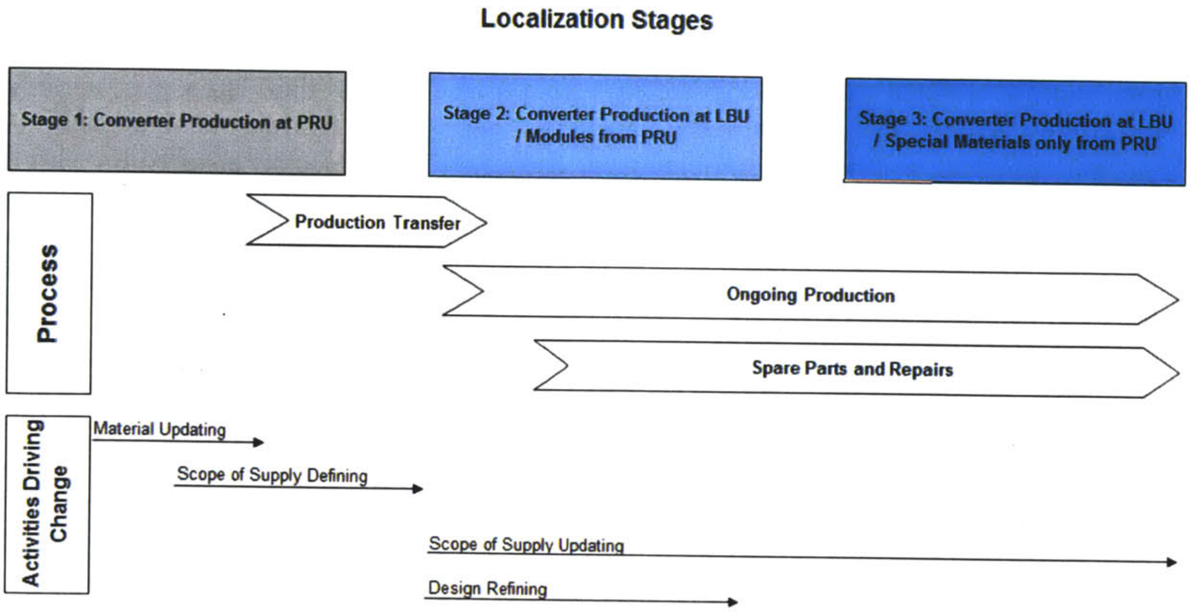


Figure 25: Stages of Localization in TRA

Once the overall picture of localization and the boundaries of the problem were agreed upon with the global manager, the facilitator returned to PRU managers to discuss the major coordination processes in detail. The contextual diagram helped focus discussions on the types of projects that fell into one of the three stages in Figure 25, and stakeholders could begin working with the facilitator to map out their involvement in the major processes. After each discussion, the facilitator would fold new information about sequences, expectations, standards, and perceived issues into a swim-lane diagram of that process. Follow-up with the relevant stakeholders, using the diagram as a focal point, then allowed refinement of process maps.

Where processes differed between one set of LBUs and another, separate maps were constructed to allow side-by-side comparison. Figure 26 provides an example of one process map, drawn in a style similar to the format of the stage-gate system recently developed in the PRU. Horizontal lanes represent functional groups at either the PRU or LBU, and vertical lines indicate handoffs of material-related information or physical information. Color-coded boxes represent process points of important coordination success or concern.

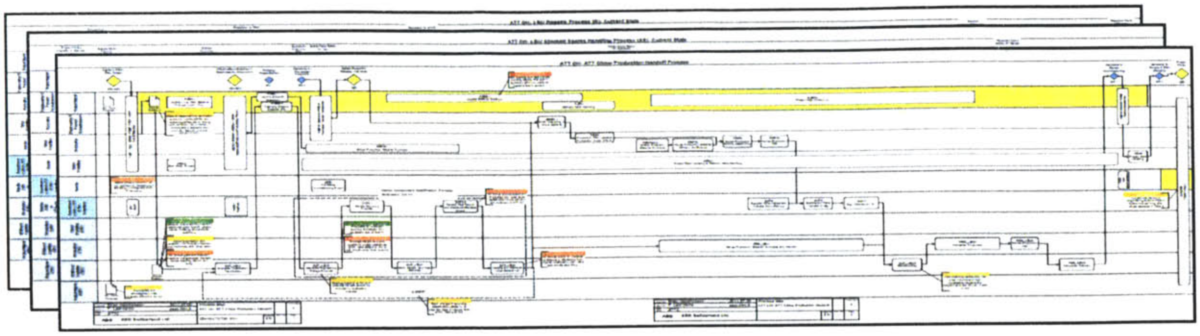


Figure 26: Example Coordination Process Map

Given the diffuse sense of urgency amongst stakeholders and the dominant concern for execution of immediate tasks, the facilitator also attempted to identify major performance assumptions of each stakeholder group and to use available data to make gaps in actual performance conspicuous.

For example, PRU order handlers reported that they worked hard to offer the LBUs the committed delivery dates that they requested—an effort above and beyond what should be necessary. Historical order processing data, however, illustrated that LBUs had received commitments matching their desired delivery only a portion of the time. Order handlers suggested that last-minute ordering prevented them from satisfying all expectations, but actual data indicated little correlation between order lead time and commitment to desired delivery dates. Figure 27 illustrates these gaps in headquarter perception of their performance (left) and of LBU behavior (right).

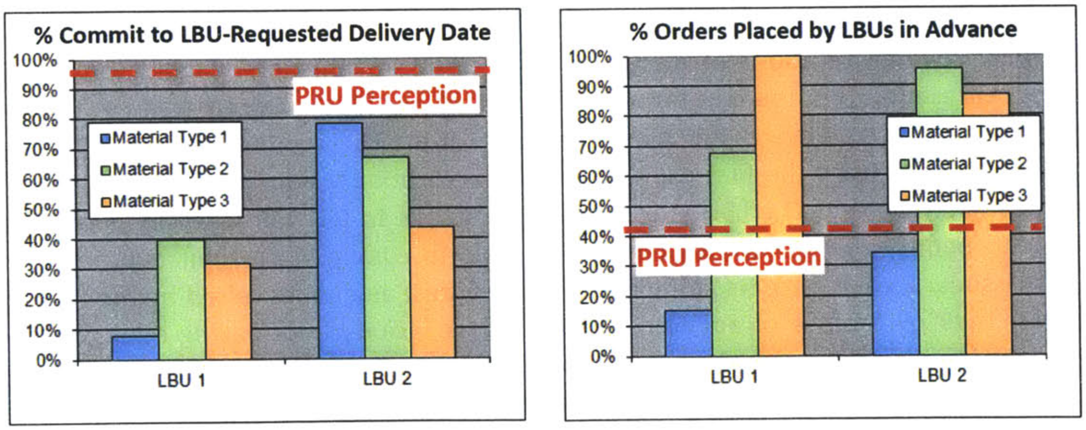


Figure 27: Gaps in Perceived versus Actual PRU Delivery Commitment

Similarly, PRU project managers and service managers reported that excessive effort was required but that PRU delivered orders almost always within the time frames informally agreed upon for material sent to the LBUs. However, as illustrated in Figure 28, that situation was not reflected in historical order fulfillment data. Especially for shipments to one of the LBUs, orders were frequently late and had a high probability of being six months late or more.

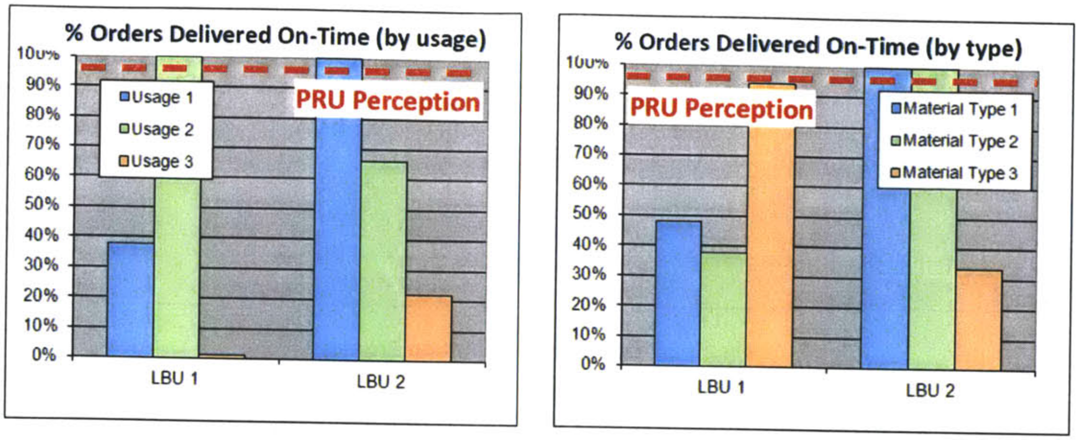


Figure 28: Gaps in Perceived and Actual PRU Delivery Performance

By discussing possible causes of these gaps with the associated stakeholders, the facilitator was able to begin identifying operating assumptions held by stakeholders. Most of these assumptions were related to last minute changes from outside the business unit. For example, a customer changed order quantities or a supplier had a shortage. When other LBUs were involved, PRU managers explained that people there "just don't understand what we are dealing with", "they don't know how to plan ahead", or "the LBUs run so lean they have no margin of safety and expect that we will save them."

4.7 Disseminate

After several iterations of discussions with PRU stakeholders yielded some stability in process representations, the facilitator-author approached PRU counterparties at the LBUs with the process diagrams. Several functional managers at the LBUs communicated to the facilitator that the diagrams were the first explanations of localization vision and internal PRU processes that they had received. The LBU stakeholders were able to fill in process areas that had been unclear to people at the PRU, and they were able to comment on their own impressions of process issues. Local managers generally did not contest any issues raised by the PRU, but they did offer their own sense of additional issues. These included not having enough information for the PRU to plan local operations effectively, sending information or material to the PRU and never hearing anything back, and feeling pressure to grow their local business but not having much visibility into coordination issues such as transfer pricing and repairs at PRU.

Where possible, the facilitator mapped these issues to specific points in the process diagrams and added the issues to the master list of concerns. This list was adapted into a survey asking stakeholders to rate process issues on two scales: Importance on a 1-5 scale from "Very Urgent" to "Does Not Exist" and Solvability on a 1-5 scale from "Very Easy" to "Nearly Impossible/Beyond Control".

Managers from the PRU and LBUs were then convened to review the vision for localization and discuss a concept for coordination that combined process tools and design with increased mutual understanding and trust. The facilitator provided a timeline for the project and introduced the issue survey as a key next step to moving from general discontent with coordination to closing actual performance gaps. Stakeholders were requested to complete the survey, which was designed to take less than one hour, within two weeks.

4.8 **Prioritize**

After one reminder one week after survey release, 89% of surveyed stakeholders had responded, rating on average 92% of the candidate issues. Distribution included all managers in functional groups at the PRU and LBUs that touched material or material information flows between business sites. The facilitator then computed response averages for both important and solvability scores and plotted them as shown in Figure 29. Results were coded by whether they related to production of service activities and if particular issues were highest-priority issues for one or more sites.

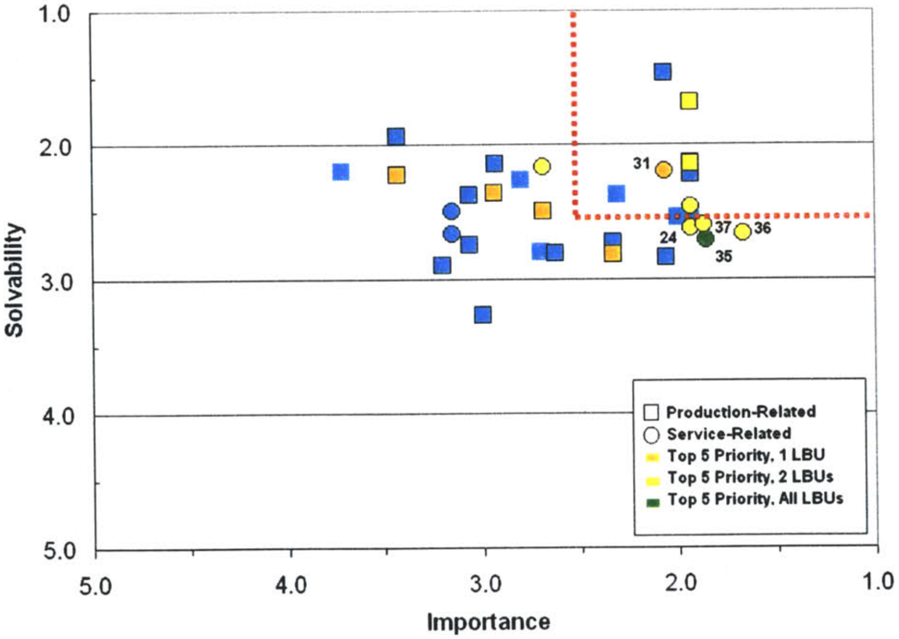


Figure 29: TRA Stakeholder Scores for Coordination Issues

In general, sites overlapped in their highest-priority issues with eight issues. Service-related issues also showed strong clustering near the region of "low-hanging fruit", which was demarcated by looking for break points in mean scores given confidence intervals.

Responses within and across sites indicated differing levels of consensus, which the facilitator communicated to stakeholder groups through tailored results briefs. These briefs provided comparisons of responses across the functions within a site and relative to the other sites. An example illustration is included in Figure 30.

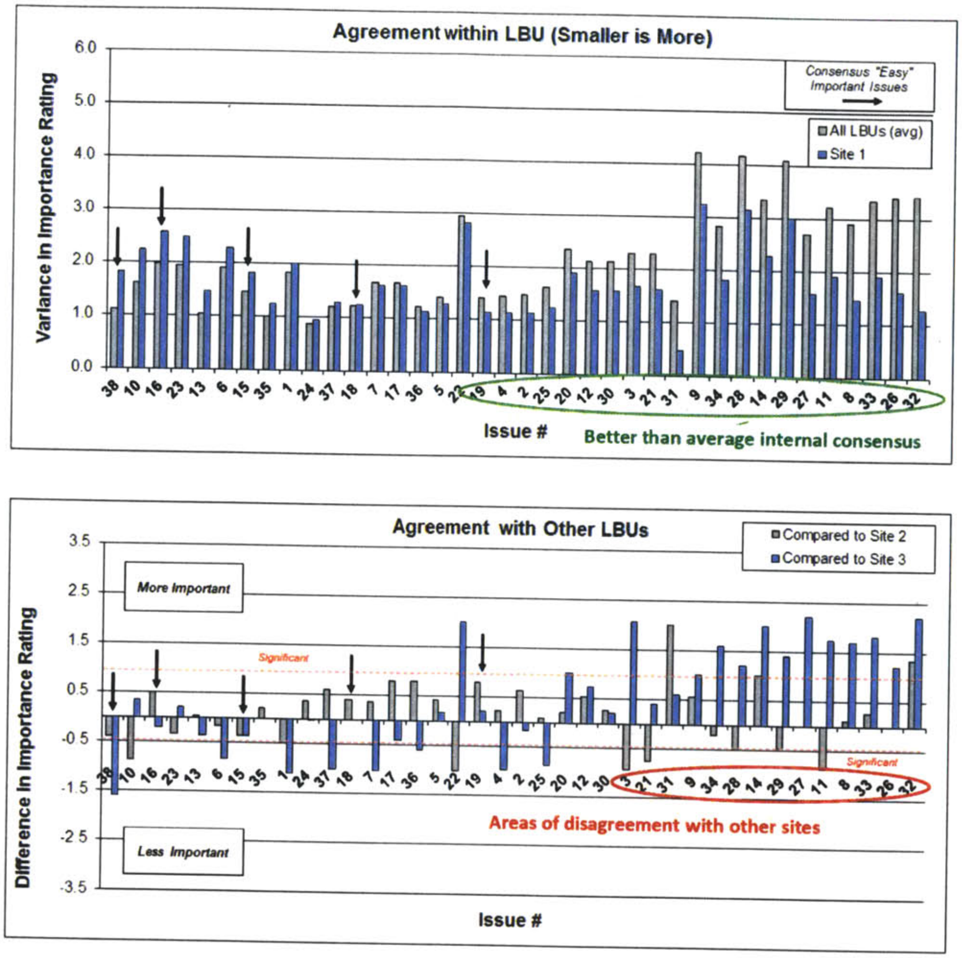


Figure 30: Example Cross-Sectional Survey Results

The high-priority issues identified as having high consensus importance and solvability, were then mapped to a causal loop diagram of material coordination between PRU and an exemplar LBU. This diagramming began with the assertion that the fundamental materials-related objective of the PRU was to ship the correct material to the LBU when it was needed. The bottom-line objective of the LBU was to install this material when customers demanded it. These objectives pertained to both production material and service-related material, although the associated activities differed depending on the use case. The key execution, planning, and information-gathering activities driving the quality of delivery and installation timing were then traced back. Figure 31 depicts the final representation for service-related causal chains, with target service issues mapped to their point of occurrence.

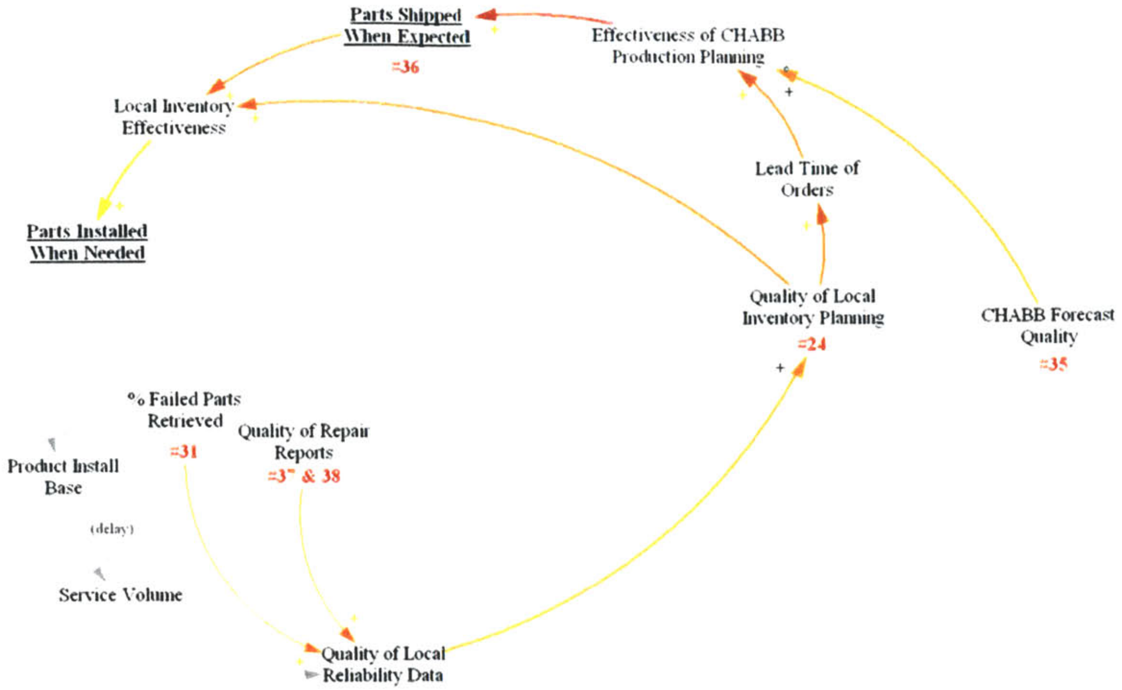


Figure 31: Current State Causal Loop Diagram for TRA Service

Visualization of the current state revealed that key activities at each site could benefit from inputs from the counterparty site, and the necessary links were either weak or non-existent based on a review of process diagrams and stakeholder comments. The concept of closed feedback loops that can operate at the long-term knowledge-building, medium-term planning, and short-term execution levels guided a general vision for a future state of coordination, as depicted in Figure 32. In this future state, added local activities and exchanges enable quality performances at each site to mutually reinforce, improving the overall group's ability to build install base and generate long-term business.

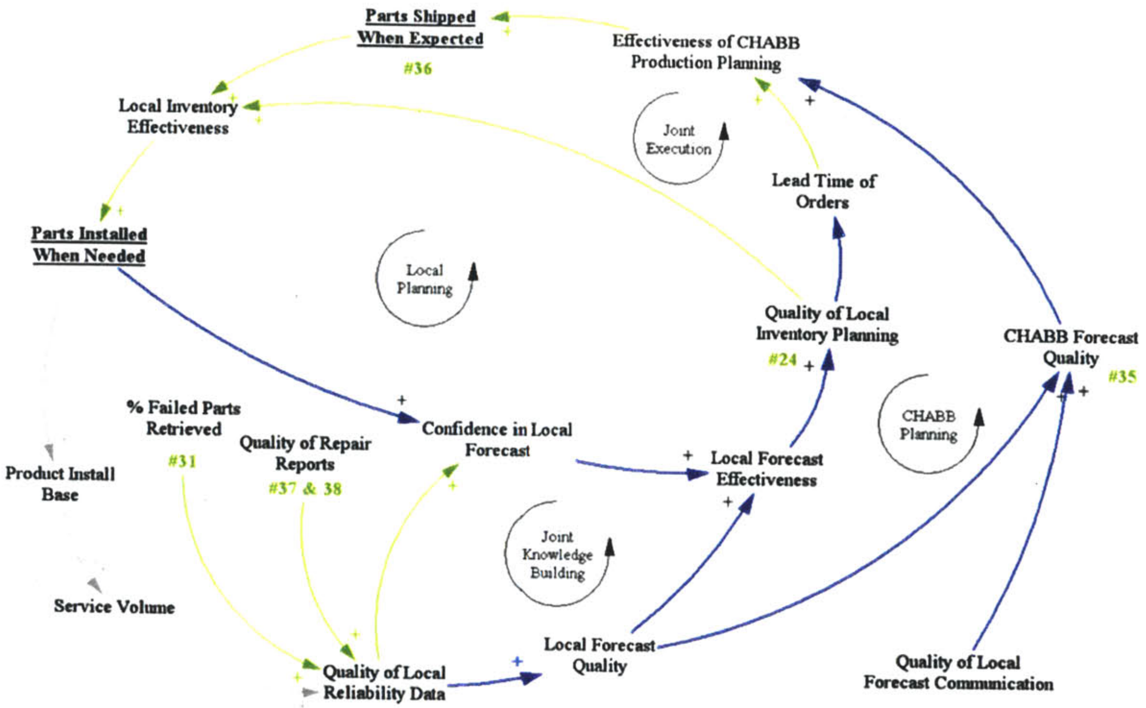


Figure 32: Future State Concept for TRA Service Coordination

4.9 Improve

Follow-on discussions with stakeholder groups examined how the gaps in Figure 30 relative to Figure 31 could be improved. For areas deemed immature by stakeholders, change proposals focused on introducing more consistency that was still flexible but allowed counterparties to gain more experience working together. Formalizing agreed upon responsibility, timing, or exchange formats had the intention of reducing *avoidable* variability and therefore improving the visibility of stakeholders into the actions of their counterparties. Over time, stakeholders could better their understanding of each other's thought processes, and they could more productively align their efforts.

Change proposals for those areas deemed more mature by stakeholders focused on increasing efficiency by standardizing more aspects of interfaces. Greater existing mutual understanding and confidence was hypothesized to allow narrower process definitions and more formalized mechanisms for monitoring and synchronizing coordination performance.

Change plans were further focused on service-related issues, given the high preponderance of service issues noted by stakeholders and by the PRU service group's ongoing efforts to build systems for growth. Moreover, the production facilities at PRU were soon moving, prompting a consensus that attention to production-related issues wait for completion of the move.

The facilitator worked with relevant PRU heads to draft proposals for the target service coordination areas, resulting in a distilled vision for exchanges between sites, as depicted in Figure 33.

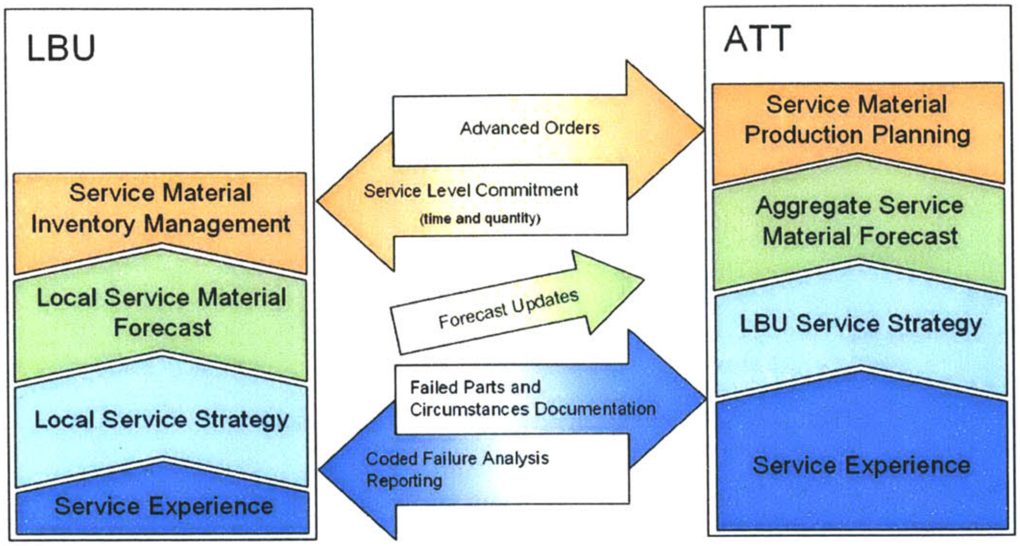
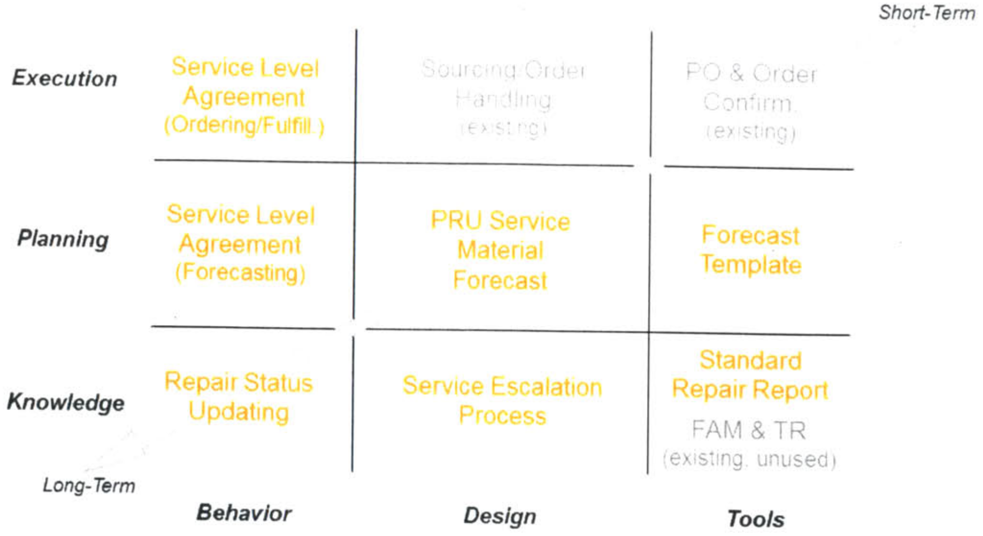


Figure 33: TRA Service Future State Vision

This new vision stipulated three levels of exchanges, with modified planning activities at both the PRU and the LBUs. These exchanges, color-coded in Figure 33 to match the business areas within which they occur, also operate on different time scales. At the short-term, tactical level, reciprocal commitments to order in advance and deliver with known limits add stability to material flow transactions. Over the medium term, forecast sharing improves the planning efforts that support future material flows. And over the long term, information and knowledge transfers build capability across sites to inform and enable future business strategies.

The time dimension of the proposed interfaces is complimented by the layers of process elements—tools, design, and behavior—discussed in Chapter 3. These elements, along with the different time horizons, form two axes in a coordination process space, as illustrated in Figure 34. Existing coordination mechanisms within TRA were focused on short-term order execution, commensurate with the organization's growth priorities. Systems for cross-project material planning and knowledge management, when viewed in the matrix of Figure 34, were noticeably absent.

By contrast, the proposed initiatives "back fill" coordination mechanisms in light of expanding product mix and installed base. These mechanisms build on each other to introduce process definition, define exchange formats within those processes, and build stakeholder confidence in the underlying process intentions. In doing so, the proposed coordination system seeks to add efficiency to transactions, enabling more scale, while also supporting longer-term performance through greater alignment of stakeholder effort.



Short-Term

	Behavior	Design	Tools
Execution	Service Level Agreement (Ordering/Fulfill.)	Sourcing/Order Handling (existing)	PO & Order Confirm. (existing)
Planning	Service Level Agreement (Forecasting)	PRU Service Material Forecast	Forecast Template
Knowledge	Repair Status Updating	Service Escalation Process	Standard Repair Report FAM & TR (existing, unused)

Long-Term

Figure 34: Coverage of Proposed Initiatives

These changes were folded into two main proposals for joint execution between sites, and one proposal internal to the PRU for capitalizing on the new exchanges. Improved local forecasting was left to the LBUs to determine, with support from the PRU as requested.

4.10 Reverse Logistics Proposal Details

Two major issues reported by stakeholders were that materials sent to the PRU for repair were very late to return and that results of failure analysis never filtered back to the LBUs. The LBUs did not feel they could efficiently manage local safety inventory, so they did not carry any, and late replacements were causing local production delays. This issue was compounded by the absence of information feeding back from the PRU, which inhibited the LBUs' ability to grow their understanding of material reliability and improve their material planning.

A review of the processes in place revealed that while the service group at the PRU had systems in place for conventional customers, no systems had been established for interacting with the LBUs. Instead, emails and phone calls were used to coordinate repair material as needed, and the PRU service group had no plans for providing diagnostic reports beyond one regular phone call with one LBU for a specific high-issue project.

The facilitator therefore worked with PRU service managers to draft a proposed process for tiered sharing of service responsibility with the LBUs. This escalation process tailored the existing service levels offered by the PRU to external customers and added an additional tier marking a transfer of service responsibility from the LBU to the PRU. A process diagram, shown in Figure 35, was drafted to define what information the PRU would need from the LBU at each stage of escalation to allow central tracking at the PRU. It also stipulated how the PRU and LBU would agree on which material to quarantine, and how the PRU would provide diagnostic information back to the LBUs.

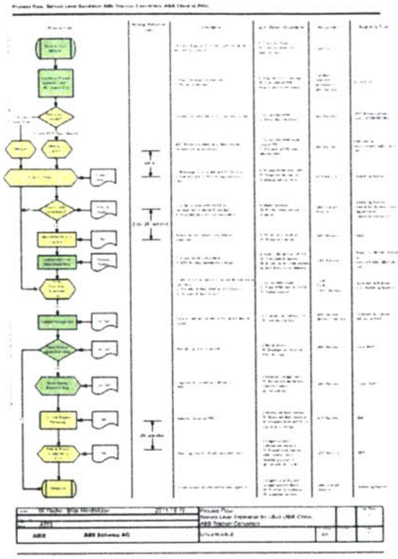


Figure 35: Fully-Defined Tiered Service and Reverse Logistics Plan

Because the process was adapted from a more established system used elsewhere, it was felt that it could be formalized to a greater degree given the understanding and confidence of service managers at the PRU. Thus activity inputs/outputs, decision criteria, response times, and stakeholder responsibilities were fully defined at the process design level. Moreover, the process design stipulated inputs to the PRU service group that were compatible with the tracking tools already in place at the PRU.

To address the issue of slow repairs, existing PRU plans to provide customers with expedited spares were extended to the LBUs. However, committed response times were lengthened to provide incentive for the LBUs to increase their local inventories. The defined expediting option would provide a backstop for the LBUs, but they would be expected to utilize the greater information-sharing and more predictable material transfer terms to improve their own planning capability.

The proposed process thus introduced changes at multiple coordination levels. A process diagram anchored process sequence, expected inputs and outputs at each step, and responsible parties. As a derivative of a system established elsewhere, the process could begin to introduce the execution efficiency realized in the original implementation. However, the system acknowledged that the LBUs were not conventional customers and that the relationship with PRU was more nascent. Therefore the process utilized a template for determining which parts to return to PRU that could be easily changed as process demands evolved. This template formed a tool that was flexible, in keeping with the low process maturity.

Finally, the proposal targeted longer-term expertise and behavioral gains. By establishing channels for two-way knowledge sharing, the reverse logistics proposal encouraged capability development at both sites. The potential effectiveness of new knowledge was encouraged by fostering greater mutual trust through increased common ground. Counterparties at each site could share an understanding of a joint system and would have consistent means for ongoing communication around a shared goal of better serving end-customers.

4.11 Inter-Site Service Level Commitments Proposal Details

As identified in the review of historical order fulfillments, LBUs had a tendency to order with less lead time than agreed upon, and the PRU often delivered material slower than it generally agreed to. Survey results reaffirmed that LBUs stakeholders felt that the PRU could be doing more to manage long lead items, and PRU stakeholders communicated that they did not have the information from LBUs to better forecast long lead demands. In response, the facilitator worked with the lead PRU project manager and with the global manager to devise inter-site service level agreements. The lead project manager was generally responsible for coordinating long-lead material orders based on projects in the pipeline. However, at the time, he did not include projects at the LBUs because he did not have the same outlook information from them that he received from PRU sales.

A proposed solution thus took the shape of an exchange of lead time adherence and regular forecast data from the highest-volume LBU in return for consistent, and shortened, delivery times from the PRU. The facilitator worked with the global manager and lead PRU project manager to create two classes of materials. A first group of high-volume materials were designated for fulfillment from a new dedicated inventory at PRU, up to a quantity expected to meet lead time needs for the LBU. These materials were inputs to the most mature product offered by the LBU—a traction converter intended to be a staple product for that regional market. The second category of materials would be supplied through the PRU's usual channels, and would be subject to longer lead times. These materials supplied products that were undergoing development at the LBU or otherwise had uncertain sales prospects.

As demonstrated by the gap in the pareto chart of Figure 36, the PRU's ability to furnish materials to the LBUs was poorly understood at the time. Managers within the PRU were confident that the group achieved its target delivery speed to LBUs, but its actual service level at that delivery speed was below 40%. Shifting project deadlines due to customer delays or change requests obscured delivery performance that, on the whole, was far worse than most managers at PRU realized.

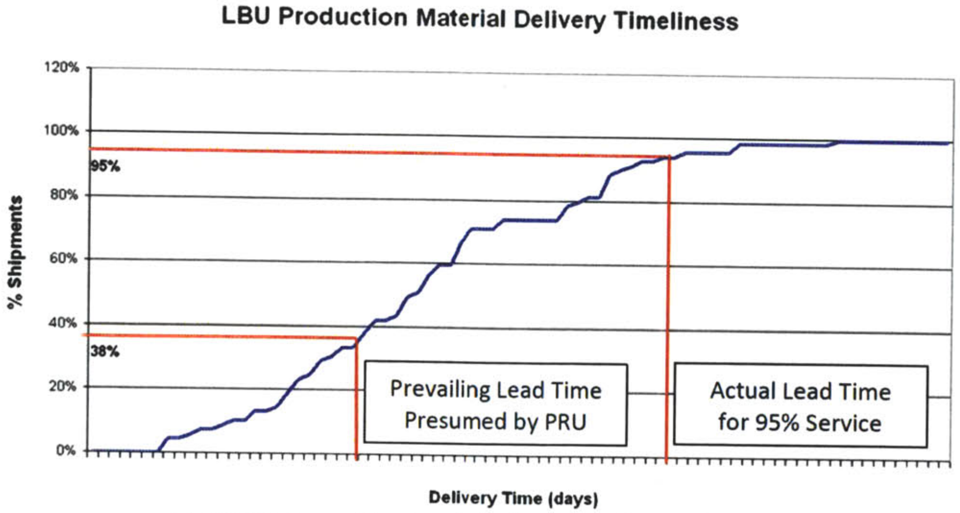


Figure 36: Perception Gap in Delivery Service Level to LBUs

The facilitator therefore conducted a logistic regression analysis to begin placing quantitative limits on realistic PRU delivery capability, based on historical performance. Delivery volumes and timeliness were compiled from an extract of the PRU's SAP system, and material orders were sorted as component, subassembly, or bulk commodity. In the frequent case that a single LBU order generated multiple shipments, each shipment was separately coded by material type. Each of these shipments was then coded with a 1 if it arrived no more than a week after the committed date or a 0 if it was more than one week late. Fitting logit models[2] to each of the material types generated expressions for the likelihood of on-time delivery given order lead time and monthly production demands. The facilitator then could set allowed monthly order volumes based on a target service level and reasonable lead time expectations. These volume limits and lead times were grouped by converter product and formed the first third of an intra-TRA service level agreement document.

The sharing of local demand signals was the second portion of the agreement document, and the facilitator worked with the lead PRU project manager to maximize the ease of forecast transfer. Because the process space was new and would likely need refinement as stakeholders gained more experience with it, the handoff employed an easily-changed Excel-based template. This template was designed to allow copy-and-paste transfer of monthly forecasts from the LBU into the PRU information system, which could not technically be linked directly to the LBU site.

Given the novelty of an intra-TRA service agreement, metrics were added to the service level agreement to support on-going tracking of performance. Volume utilization, lead time adherence, and delivery timeliness were included to allow review of the agreement in six months' time and possible refinement of service targets. These metrics were intentionally bottom-line measures to provide objective discussion anchors and were easily-tabulated to encourage use. The service level agreement document thus included target service levels, data exchange to help achieve those service levels, and metrics to allow ongoing refinement.

Shortened delivery times from the PRU required creation of a new inventory buffer, and that raised possible issues. The PRU service group was in the process of building its own inventory that would carry most of the same parts, but neither the service group nor the project management group was aware of each other's inventory plans. Requesting two forecasts—one for service parts and one for production—for essentially the same material seemed unreasonable and inefficient, especially given the reluctance of LBUs to provide forecast information to date. Moreover, managers within PRU ultimately did not want to care about the end use of LBU material. The increasing number of planned inventories, however, created confusion about how they would be managed and by whom.

The facilitator thus created a system view of demand signal sources, processing methods, and inventory placements to establish a common vision. This diagram, depicted in Figure 37, provided a foundation for discussion of inventory management strategy across PRU groups as they planned more sophisticated service offerings. Much like the context diagrams used in the original Visualize step, the diagram provided a systems perspective removed from specific project struggles. In particular, it framed a discussion between the service manager and the

---

[2] A logit model is a linear model of the log-odds of an occurrence happening and takes the form:
$Pr(Y|x_i, x_2, \dots, x_n) = \frac{e^z}{e^z+1}$ $where\ z = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n$ and x_n are explanatory variables

lead project manager in which project management agreed to take responsibility for all spares and production material requests from the LBUs. Aggregation of LBU material requests under a single group not only simplified internal operating complexity within PRU but also boosted the group's ability to leverage volume purchasing with suppliers.

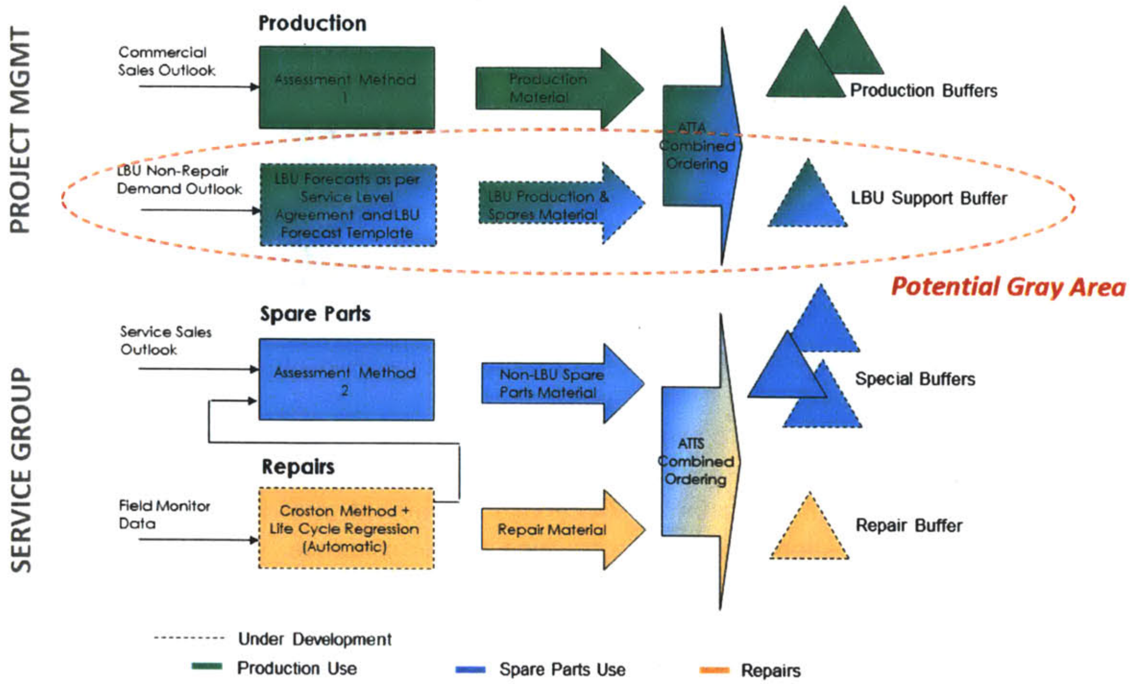


Figure 37: Visualization of Inventory Management System at PRU

Overall, the inter-site service level agreements integrate several levels of process change. For order transactions, which had accumulated significant history between the sites, quantitative bounds were possible to add process stability. These bounds were augmented with a system of performance tracking of lead times, delivery timeliness, and inventory utilization to guide ongoing refinement of service levels as LBU material demands evolved. Given practical limits to IT connectivity, the transmission form for forecasts utilized a universal spreadsheet platform that also could adjust as unforeseen needs developed. By introducing different levels of definition to different parts of the ordering process, service level agreements could address both mechanical coordination issues as well as begin to dispel behavioral prejudices created by opaque processes.

4.12 Material Forecasting Proposal Details

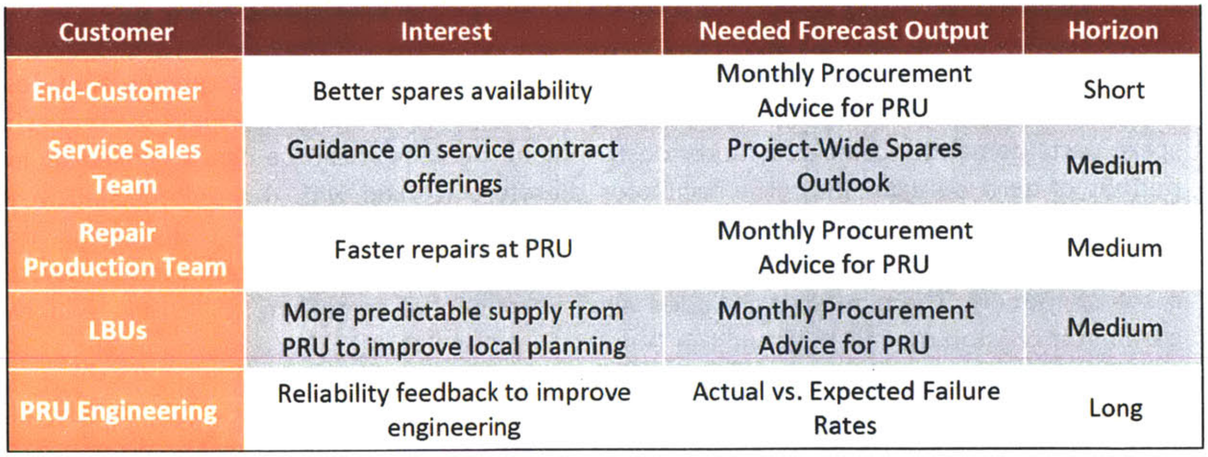
Written commitment to delivery service levels represented a heightened pressure on the PRU to perform, but new demand updates from the LBU also created an opportunity for more effective material management. To date, that material management had been largely manual, and material shortfalls and overruns were becoming increasingly conspicuous as production volume ramped up.

Within ABB Traction the headquarter PRU relied on separate managers in project management and service to produce demand forecasts based on informed opinion. These forecasts triggered separate material requests through the organization's SAP system and were rarely synched within the supply chain group to optimize order size. Each forecast stream also required significant manual intervention as production dates neared, because demand, as generally happens in ETO companies, was "lumpy" and difficult to anticipate [4].

Demand may be difficult to anticipate under ideal ETO conditions, but the coordination in place within TRA made material management even more error-prone. The manager who forecasted production material received no information from the LBUs about their upcoming needs, which created a blind spot in the PRU's lead time management. Similarly, the PRU service group faced the typical intermittency of spare parts demand [50], but added more uncertainty by also not incorporating information from the LBUs. These blind spots had been tolerated by PRU managers, because LBU business still constituted a relatively small share of demand volume. Someday the LBUs would contribute the bulk of production demand, but that reality seemed far off compared to the immediacy of current project challenges. An alternative perspective would suggest that learning to close those gaps sooner would be better than waiting until the consequences of mistakes were much greater.

Thus, the third change initiative proposed more rigorous forecasting of demand to improve management of long lead material. A pilot quantitative system was designed initially for spare parts and repairs, because the PRU service group had recently rolled out a new field data collection system that provided valuable demand information. By collecting real-time updates from the field, the system could automatically update the database of field failures in the service group with minimal reliance on expert judgment. Stakeholders also had identified spares availability and repair speed as critical concerns in their survey responses.

The facilitator therefore worked with a project lead within the service group to begin structuring the use cases for a service forecasting system and testing potential quantitative models to drive it. In meeting with various functional groups within PRU, the project lead identified multiple interests in a forecasting system, each desiring a different output. Figure 38 summarizes the use cases distilled by the facilitator.



Customer	Interest	Needed Forecast Output	Horizon
End-Customer	Better spares availability	Monthly Procurement Advice for PRU	Short
Service Sales Team	Guidance on service contract offerings	Project-Wide Spares Outlook	Medium
Repair Production Team	Faster repairs at PRU	Monthly Procurement Advice for PRU	Medium
LBUs	More predictable supply from PRU to improve local planning	Monthly Procurement Advice for PRU	Medium
PRU Engineering	Reliability feedback to improve engineering	Actual vs. Expected Failure Rates	Long

Figure 38: Potential Use Cases for a Service Material Forecasting System

As reflected in Figure 38, three possible uses for a forecast system emerged. Of these, the failure rate reporting required only straight computation from appropriately filtered field data. A portion of this calculation was already programmed into the service field data system, but it was not shared with the engineering group in a systematic way. The project lead therefore investigated how the generated failure statistics might be presented more effectively to the PRU engineering team.

Similarly, guidance for after-sales service required a one-time computation for each project based on the type and number of products involved. Average failure rates need only be updated periodically and perhaps adjusted for project circumstances that biased failures in one direction or another. A regression analysis supervised by the facilitator indicated that certain regions and customer types had slightly different failure rates, perhaps because of prevailing operating temperatures, ambient humidities, or installation quality. Similarly, some types of materials demonstrated burn-in and/or wear-out effects that justified a segmented lifecycle approach to failure rates, as diagrammed in Figure 39. Using these results, a spreadsheet system was mocked up in which salespeople in the service group could select the products being sold, their quantity, a time horizon, and then several risk factors. The tool would then output recommended spares quantities of critical high-value or long-lead materials to cover the selected time period.

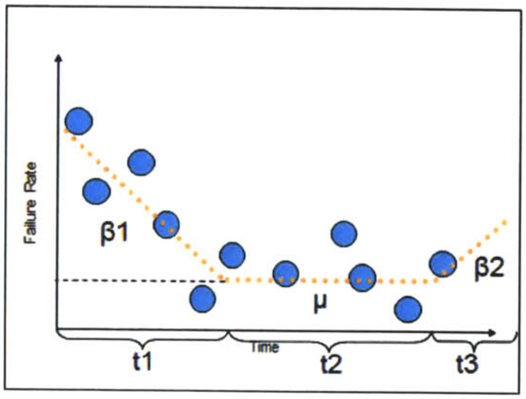


Figure 39: Life-Cycle Modeling for After-Sales Service Planning

Monthly procurement guidance required a more traditional forecast engine that could make repeated statistics-based predictions based on updated demand information. Forecasting spare parts demand, however, is notoriously difficult because it can be characterized by long periods of zero demand [51]. The facilitator therefore worked with the project lead in the service group to repair historical failure data and begin testing alternative statistical methods for forecasting demand. To do this, several years of data were segregated and used to calibrate a set of models. These models included single exponential smoothing [52], one- and two-parameter Croston models [53], and the Teunter-Syntetos-Babai (TSB) model and method [54].

The Croston model treats demand inter-arrival time and demand size as separate Bernoulli events and has become a mainstay for intermittent demand forecasting in ERP systems such as SAP. However, because it updates demand predictions only when positive demand occurs, it simply carries over non-zero forecasted quantities when no demand is observed. Thus, it cannot indicate sudden obsolescence [54], which is a particularly important issue in ETO because of long product lifetimes, high-value components, and frequent technology updates. In response, the TSB method computes demand size and arrival *probability* as separate Bernoulli events and updates the demand size every period. The TSB method therefore can downward correct predictions quickly when demand drops to zero, whereas Cronston models would indicate sustained demand.

Each of these models was calibrated by minimizing root-mean square error (RMSE) over the quarantined data period and then was back-tested against the remaining historical demand data. Figure 40 shows a truncated portion of this data and the resulting forecasts for one material group.

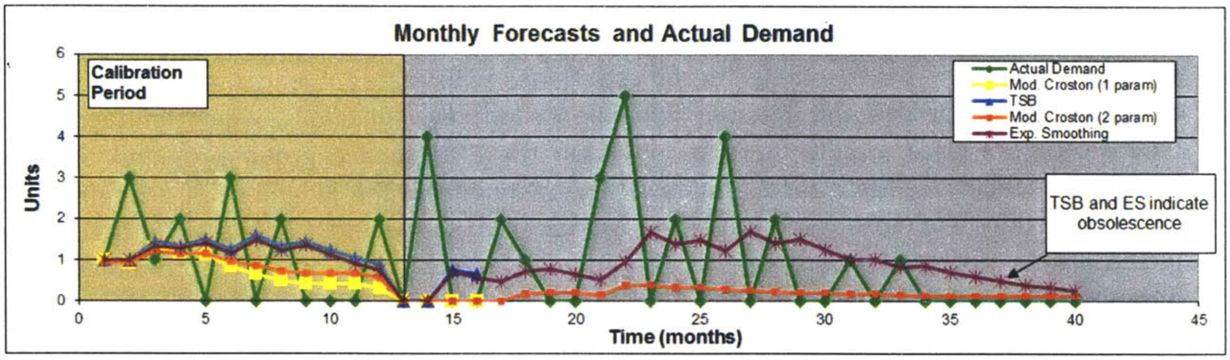
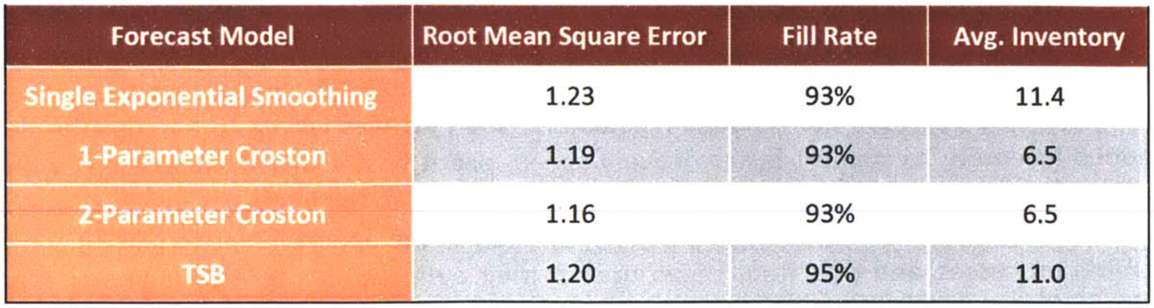


Figure 40: Testing of Forecast Models for Intermittent Material Demand

In each case, inventory levels were computed assuming a periodic review inventory policy targeting a 95% fill rate [55]. Although empirical work suggests the use of a negative binomial distribution to describe lead time demand, a normally-distributed lead time demand was assumed based on the favorable results found by Zou et. al (2011). Replenishment time was assumed to be a fixed 3 months, and demand variance was calculated based on the RMSE of each forecast model over the calibration period. Inventory levels were initialized to the safety stock levels suggested by each model, and backorders were allowed to accumulate at no cost.

As indicated in Figure 41, the Croston models produced significantly lower average inventory but at a slight service level penalty. The TSB model produced the highest type 2 service level but required inventory levels only slightly better than those produced with a traditional exponential smoothing algorithm.



Forecast Model	Root Mean Square Error	Fill Rate	Avg. Inventory
Single Exponential Smoothing	1.23	93%	11.4
1-Parameter Croston	1.19	93%	6.5
2-Parameter Croston	1.16	93%	6.5
TSB	1.20	95%	11.0

Figure 41: Back-tested Forecast Performances at Inventory Level

Given the superior inventory performance of the Croston methods, the project lead set about designing a tool that could pull data from the service group's field data and produce monthly guidance on demand, sortable by region, project, product, or subsystem. Obsolescence recognition remained an issue, and the facilitator suggested building an indicator into the forecasting system that would highlight increases in the maximum number of observed consecutive zero-demand periods. Sharp increases in the count during recent periods could alert a forecast user of a possible structural drop in demand. Conversations with sales and engineering then could triangulate causes and guide sourcing decisions that deviate from the forecast.

Overall, the multi-faceted forecasting proposal sought increased rigor and scalability in a critical area primed for higher process maturity. Expertise internal to PRU had provided some process consistency based on significant experience with material lead times and reliability. However, that expertise also created dependence on key individuals, which limited process bandwidth. The data monitoring system within the PRU service group provided untapped signals that could decouple service material forecasting from the judgment of a single expert. Moreover, the newly-proposed reverse logistics plan connected LBU data to the system, increasing its potential effectiveness. The forecasting tool thus offered potentially better-optimized service material sourcing using less effort than the current approach. With the project management team also expecting LBU forecast information under the new service level agreements, a forecasting tool in the service group could be a pilot for more tightly-coordinated material management across the PRU. At the time of this writing, the PRU service group was in the midst of integrating the forecasting system into its processes.

4.13 Impact at ABB and Implications

After six months of effort improving coordination in ABB Traction using the UVDPI framework, the specific proposals above were in varying states of adoption, but the underlying stance of stakeholders towards inter-site coordination had shifted significantly.

The service level agreements, for example, had been deployed with the highest-volume LBU and were staged for use with other LBUs once they achieved higher volume. The adoption of these agreements seemed to accompany a new outlook at PRU on the LBUs. At the start of the project, managers at the PRU considered shipment delays to the LBUs largely a function of the LBUs' poor planning. Special shipping terms requested by the LBUs were considered reproachable excursions from the expectations of the PRU made by normal customers. But by the end of the six months, managers in the PRU appeared to recognize that the LBUs were partners different from conventional customers. The PRU was willing to assume the cost of added inventory to support faster delivery speed, and it hosted several workshops with LBU managers to share process methods and rationales internal to the PRU.

Managers at the LBUs had responded positively to the opportunities to participate in the UVDPI processes, and they, too, began to shift their outlooks on inter-site relations. Many of the process distillations that had been novel to PRU managers were particularly revelatory for stakeholders at the LBUs. The charge of LBU managers to build new businesses at the frontier of the organization had coupled with the PRU's apparent eagerness to treat the LBUs as conventional customers, which created a certain isolation. This LBU isolation built a vacuum of understanding of PRU processes and rationales, breeding a mistrust of transfer pricing, inventory levels, order handling, and other means by which the PRU might subjugate the fledgling LBUs. After six months of collaboration under the UVDPI framework, however, the largest LBU assumed responsibility for not only a new local inventory but also agreed to hold material on behalf of another LBU. This assumption of cost and risk would never have occurred under the more adversarial relations that marked the beginning of the project.

The challenges of using UVDPI within the case company also suggest lessons for implementation elsewhere. Despite their new openness to inter-site collaboration, some managers clearly remained wary of introducing disturbances to their activities, even if the potential downside risk was arguably quite limited. These managers appeared to conflate the raising of an idea with personal commitment to that idea, creating an ongoing barrier to open dialogue amongst counterparties and therefore process innovation. This resistance to change was compounded at least within the PRU by a tendency for proposals to be submitted for consensus decision and then subjected to long deliberations during which demands from projects would displace any attention on the longer-term plans.

This potential for distraction highlights the importance of "the burning platform", particularly in ETO organizations. The pervasiveness of project concerns and the high autonomy of skilled stakeholders both resist wide-spread adoption of change. Multiple stakeholders must buy in because of the interconnectedness of ETO processes at the same time that the stakeholders have local concerns and limited sway over colleagues outside their domains. Momentum behind change therefore is especially difficult to build.

In the case project, the motivation for the project originated with a single manager and took a defuse form. The facilitator worked to bring signs of poor performance into relief, using both quantitative and qualitative data, but insufficient progress moving stakeholders from a state of issue recognition to one of emotional attachment to improvements limited the speed of proposal adoption. The tools of the UVDPI framework were instrumental to the recognition of opportunities, but the psychological pull of immediate project crises, particularly in an organization with few mechanisms for global strategizing, were formidable. Moreover, all PRU-wide discussions of performance revolved around sales volume and revenue growth and never avoidable costs, delays, or negative customer impacts. Management-led awareness of performance with respect to customer value and operational efficiency, combined with higher-prioritization of cross-project thinking prior to or in the early stages of the improvement project may have increased its effectiveness.

4.14 Chapter Summary

This chapter detailed as case study of UVDPI implementation in the capital goods organization ABB Traction. This organization, like other ETO companies, has recently expanded its global footprint and has encountered challenges coordinating ramp-up of technical and commercial activities at its new satellite locations. By applying the steps of the UVDPI framework, the author was able to work with stakeholders across the sites of ABB Traction to distill a common vision for localization, identify key processes involved in localization, prioritize recurring issues in those processes, and design and begin to implement a portfolio of changes that treats inter-site coordination as a dynamic system. The change initiatives selectively formalize different points of coordination depending on their needs for flexibility, and they encourage common ground among counterparties to build self-reinforcing processes that can adapt with time.

Chapter 5: Conclusions

This final chapter provides a summary discussion of key findings from this research effort and of suggestions for further study based on the existing literature and the results of the case study.

5.1 Key Findings

Much has been written about supply chain coordination and process improvement, and yet the frequent presumption of relatively stable, pseudo-deterministic business operations leaves a sizable gap in the literature. Existing approaches to coordination have emphasized enterprise integration and the utilization of digital connectivity. Schools of thought in process improvement have espoused the elimination of variation and the exhaustive documentation of process parameters.

But as product offerings become increasingly segmented and life cycles ever shorter, these lessons appear less prescriptive. Companies face greater uncertainty and pressure to adapt, risking expensive IT systems that struggle to accommodate new demands. Integration across global sites challenges IT systems to surmount technical incompatibilities, legal considerations, and behavioral externalities. And process improvement methods that exchange elimination of process "waste" with high expectations for process housekeeping appear out of touch with the dynamic needs of organizations, which also have scarce resources.

If ETO organizations are indicative of what companies might face as they add product variation and global reach, conventional approaches to coordination will not work. The tensions among standardization and flexibility, integration and delegation, and short-term and long-term require a holistic perspective on coordination that encourages adaptation. Under the proposed UVDPI framework, interactions between business sites are viewed as having several components and as operating on multiple levels. By selectively constraining certain process components and operating levels, organizations may be able to introduce efficiency and maintain needed flexibility. Moreover, by viewing coordination as linkages in larger chains of activities, organizations can build self-reinforcing loops that connect sites and align local stakeholder performance with global capability development. In all of this, establishing a common vocabulary among stakeholders through diagrams can assist in envisioning organizational direction, the interconnectedness of processes, and the opportunity in process changes.

5.2 Areas for Future Study

This thesis identified deficiencies in the existing SCM and process improvement literature and used a case study to provide a new concept for improving coordination in uncertain operating environments. However, this study is only an initial effort, and much more could be investigated. Some of these opportunities include:

1. Empirical study of coordination mechanisms across many ETO organizations
2. The impact on change adoption speed and longevity given varying size and make-up of the UVDPI facilitation team
3. The limits of tacit knowledge transfer when processes have sparse documentation and are subject to change
4. Detailed empirical mapping of how formalizing different coordination dimensions affects process outcomes, in a manner similar to Rupani (2011)

Works Cited

(1) Srikanth K, Puranam P. "Integrating Distributed Work: Comparing Task Design, Communication, and Tacit Coordination Mechanisms." *Strategic Management Journal* 2011;32:849-875.

(2) Makumbe, P. Globally distributed product development: role of complexity in the what, where and how. Ph.D. thesis, Massachusetts Institute of Technology, Engineering Systems Division; 2008.

(3) Braithwaite, A. "Integrating the global pipeline: Logistics systems architectures." Logistics Information Management 1992;5(3):8-20.

(4) Hicks, C., McGovern, T., Earl, C. "Supply Chain Management: A Strategic Issue in Engineer to Order Manufacturing." International Journal of Production Economics 2000;65:179-190.

(5) Zang, D. "Towards theory building in agile manufacturing strategies-- case studies of an agility taxonomy." International Journal of Production Economics 2011;131:303-312.

(6) Gosling, J, Naim M. "Engineer-to-order supply chain management: A literature review and research agenda." International Journal of Production Economics 2009;122:741-754.

(7) Hendry, L. "Applying world class manufacturing to make-to-order companies: problems and solutions." International Journal of Operations and Production Management 1998;18(11):1080-1100.

(8) Hicks, C., McGovern, T., C. "A Typology of UK Engineer-to-Order Companies." International Journal of Logistics: Research and Applications 2001;4(1):43-56.

(9) Handfield, R. "Distinguishing features of just-in-time systems in the make-to-order/assemble-to-order environment." Decision Sciences 1993;24(3):581-602.

(10) Mintzberg, H. "Generic strategies: toward a comprehensive framework." In: Lamb R, Shrivastava P, editors. Advances in Strategic Management Greenwich, CT: Jai Press Inc.; 1988. p. 1-67.

(11) Marucheck, A., McClelland, M. "Strategic issues in make-to-order manufacturing." Production and Inventory Management 1986;27(2):82-95.

(12) Einhorn, M. Managing Forecast Variability in a Build-to-Order Environment. Master of Business Administration and Master of Science in Mechanical Engineering thesis, Massachusetts Institute of Technology; 2007.

(13) Vainio, T. Intelligent Order Scheduling and Release in a Build to Order Environment. Master of Business Administration and Master of Science in Civil and Environmental Engineering thesis, Massachusetts Institute of Technology; 2004.

(14) Hicks, C., McGovern T. "Product life cycle management in engineer-to-order industries." International Journal of Technology Management 2009;48(2):153-167.

(15) Ivory, C., Alderman, N. "Who is the customer? Maintaining a customer orientation in long-term service-focused projects." International Journal of Technology Management 2009;48(2):140-152.

(16) Subramoniam, R., Huisingh. D., Chinnam, RB. "Remanufacturing for the automotive aftermarket-strategic factors: literature review and future research needs." Journal Clean Production 2009;17(13):1163-1174.

(17) Kinkel, S., Kirner, E., Armbruster, H., Jager, A. "Relevance and innovation of production-related services in manufacturing industry." International Journal of Technology Management 2011;55(3):263-273.

(18) Naylor, J., Naim, M., Berry, D. "Leagility: Integrating the lean and agile manufacturing paradigmsin the total supply chain." International Journal of Production Economics 1999;62:107-118.

(19) Venkatesarn, R. "Strategic sourcing: to make or not to make." Harvard Business Review 1992;December-November:98-107.

(20) Gunasekaran, A., Ngai, E. "Modeling and analysis of build-to-order supply chains." European Journal of Operational Research 2009;195:319-334.

(21) Pine, B., Victor, B., Boynton, A. "Making Mass Customization Work." Havard Business Review 1993(9).

(22) Veldman, J., Alblas, A. "Managing Engineering Change Decisions." 5th GTMC Doctoral Symposium 2007.

(23) Pandit, A., Zhu, Y. "An ontology-based approach to support decision-making for the design of ETO (Engineer-To-Order) products." Automation in Construction 2007;16:759-770.

(24) McGovern, T., Hicks, C., Earl, CF. "A review of supply chain management issues in engineer to order supply." Proceedings of the Seventh International Annual IPSERA Conference on Supply Strategies: Concepts and Practice at the Leading Edge 1998:376-386.

(25) McGovern, T., Hicks, C., Earl, CF. "Modelling Supply Chain Management Processes in Engineer-to-Order Companies", International Journal of Logistics Research and Applications. 1999;2(2):147-159.

(26) Senge, P. The Fifth Discipline: The art and practice of the learning organization. New York, NY: Doubleday; 1990.

(27) Repenning, N., Sterman, J. "Capability Traps and Self-Confirming Attribution Errors in the Dynamics of Process Improvement." Administrative Science Quarterly 2002;47:265-295.

(28) Cooper, RG. Winning at new products: accelerating the process from idea to launch. Cambridge, MA: Perseus Publishing; 2001.

(29) Kumar, S., Wellbrock, J. "Improved new product development through enhanced design architecture for engineer-to-order companies." International Journal of Production Research 2009;47(15):4235-4254.

(30) Ausura, B. "Recapturing 'true' life cycle portfolio management: the path to more successfulproduct development." Visions Magazine 2003;XXVII(2).

(31) Marsh, S., Stock, G. "Building Dynamic Capabilities in New Product Development through Intertemporal Integration." Journal of Product Innovation Management 2003;20:136-148.

(32) Amaro, G., Hendry, L., Kingsman, B. "Competitive advantage, customization, and a new taxonomy for non make-to-stock companies." International Journal of Operations and Production Management 1999;19(4):349-371.

(33) Alderman, N., Thwaites, A, Maffin, D. "Project-level influences on the management and organisation of product development in engineering." International Journal of Innovation Management 2001;5(4):517-542.

(34) Chow, H., Choy, KL., Lee, WB. "Knowledge management approach in build-to-order supply chains." Industrial Management and Data Systems 2007;107(3):882-919.

(35) Little, D., Rollins, R., Peck, M., Porter, JK. "Integrated planning and scheduling in the engineer-to-order sector." International Journal of Computer Integrated Manufacturing 200;13:545-554.

(36) Wortmann, JC. "Comparison of information systems for engineer-to-order and make-to-stock situations." Computers in Industry 1995;26(3):261-271.

(37) Browning, T. On the Alignment of the Purposes and Views of Project Process Models. Journal of Operations Management 2010;28(4):316-332.

(38) Cooper, R. Product Leadership: Pathways to profitable innovation. New York: Basic Books, Perseus Books Group; 2005.

(39) Adler, P., Cole, R. Designed for learning: a tale of two auto plants. Technology, Organizations and Innovation 2000;November:157-177.

(40) Kraut, R., Fussel, S., Brennan, S., Siegel, J. "Understanding Effects of Proximity on Collaboration: Implications for Technologies to Support Remote Collaborative Work". In: Hinds, P., Kiesler, S., editors. Distributed Work Cambridge, MA: MIT Press; 2002. p. 137-162.

(41) Knoblinger, C. PDSAT- A New Product Development Assessment Tool.Ph.D. thesis, Technische Universität München, 2011.

(42) Pyzdek, T., Keller, P. The Six Sigma Handbook. Third Edition ed. New York, NY: McGraw-Hill; 2009.

(43) Krafcik, J. "Triumph of the lean production system." Sloan Management Review 1988;30(1):41-52.

(44) Mason-Jones, R., Naylor, B., Towill, D. "Lean, agile or leagile? Matching your supply chain to the marketplace." International Journal of Production Research 2000;38(17):4061-4070.

(45) Watson, G. Business Systems Engineering. New York: John Wiley and Sons; 1994.

(46) National Institute for Standards and Technology. Malcolm Baldrige National Quality Award Criteria for Performance Excellence. 2000; Available at: <http://www.nist.quality.gov>, 2012.

(47) Software Engineering Institute. CMMI for Development. 2010;CMU/SEI-2010-TR-033.

(48) Veldman, J., Klingenberg, W. "Applicability of the capability maturity model for engineer-to-order firms." International Journal of Technology Management 2009;48:219-239.

(49) Ngwenyama, O., Nielson, P. "Competing Values in Software Process Improvement: An Assumption Analysis of CMM from an Organizational Culture Perspective." IEEE Transactions on Engineering Management 2003;50(1).

(50) Zhou, C., Viswanathan, S." Comparison of a new bootstrapping method with parametric approaches for safety stock determination in service parts inventory systems." International Journal of Production Economics 2011;133:481-485.

(51) Wallstrom, P., Segerstedt, A. "Evaluation of forecasting error measurements and techniques for intermittent demand." International Journal of Production Economics 2010;128:625-636.

(52) Snyder, R. "Forecasting sales of slow and fast moving inventories." European Journal of Operational Research 2002;140:685-699.

(53) Eaves, A. Forecasting for the Ordering and Stockholding of Consumable Spare Parts. Ph.D thesis Lancaster School of Management, 2002.

(54) Teunter R, Syntetos A, Babai M. "Intermittent demand: Linking forecasting to inventory obsolescence." European Journal of Operational Research 2011;214:606-615.

(55) Jensen, P., Bard, J. "Inventory Models." in Operations Research Methods and Models. New York, New York: Wiley; 2002. Chapter 25.

(56) Bartlett, J., Kotrlik, J., Higgins, C. "Organizational Research: Determining Appropriate Sample Size in in Survey Research." Information Technology, Learning, and Performance Journal 2001;19(1):43-50.

(57) Deming, E. W. Out of Crisis. Cambridge, MA: MIT Center for Advanced Engineering Study, 1986.

(58) Beckman, S., Rosenfield, D. Operations Strategy: Competing in the 21st Century. New York, NY: McGraw-Hill; 2008. Chapter 2.