Allocation of Engineering Resources to Global Sites Based on Coordination Cost and Project Structure

By

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Submitted to the Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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ABSTRACT

Because of the increasingly globalized world we live in, companies today are very interested in going overseas to develop and utilize global engineering resources. By doing so, they hope to take advantage of new global product development (GPD) enablers and motivators such as the internet, new collaborative information technology tools, access to new markets, and the increasing availability of low-cost engineering talent. While globalization has significantly decreased barriers so that more companies are hurrying to move engineering activities to its global sites, it is no secret that GPD teams pose significant coordination challenges. Cost savings from lower labor rates abroad can easily be eaten up by the increased coordination costs required to manage overseas interactions between local and global activities.

This paper introduces a model that maps a project's coordination structure to help managers decide which activities should be allocated to a global site and which ones should be kept at home. It introduces a new multi-site coordination matrix based on the Design Structure Matrix and an optimization model that chooses where to locate activities to minimize project coordination costs. A key principle the model relies on is the modularization of activities at each site for efficient organization design. This method was employed to design a GPD plan for the Advanced Manufacturing Engineering department at Honeywell Aerospace.

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I had the great fortune of working with another dynamite duo, my terrific thesis advisors, Dan Whitney and Steve Eppinger. Dan and Steve have written many papers about product development, outsourcing, globalization, coordination, and other topics very relevant to this project. They have been a tremendous resource throughout the internship and the writing of this thesis.

There are many more people at Honeywell and at MIT I would like to thank: Sumit Mehrotra, John Garone, Brian Berry, Jeevan Mulgund, Todd Cooper, Tim Henning, Len Benkosky, Phyllis Rathbone, Jeff Pointer, Randy White, Al Sanders, Mary Domo, Gene Bruner, Rob Pierce, Rhonda Fenske, Miriam Park, Kim Murdoch, Billy Lo, Anshuman Tripathy, and Don Rosenfield.

Finally, I would like to thank my family and friends. Thank you for supporting and challenging me during this chapter of my life.

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Biographical Note

Sabrina Chang was born in Santa Clara, California. She attended Stanford University, where she majored in Product Design, a joint program with the School of Mechanical Engineering and the School of Art and Design, and also received a Master's degree in Mechanical Engineering. The program provided many opportunities to work on interdisciplinary product development teams, which included projects with Mattel, Target, the Palo Alto VA Hospital, and DePuy Orthopaedics. She was also a research assistant at the Hansen Experimental Physics Lab, where she worked on a project called Satellite Test of the Equivalence Principle, and spent a summer doing an internship at General Electric's Corporate Research and Development facility (now GE Global Research) in Schenectady, NY. After graduating from Stanford, she worked at Northrop Grumman Space Technology (the old TRW) in the System Dynamics Design department. There, worked on some cutting edge satellite projects, including the JPL Space Interferometry Mission, experiments with active control structures, and the proposal phase for a segmented mirror ground demonstrator.

Sabrina has been playing the piano since she was 5, and kept up her lifelong hobby by taking private lessons through the music departments at Stanford and MIT. She hopes to continue this and other creative and artistic pursuits after she graduates. Her first job after LFM will be to work at Honeywell Advanced Manufacturing Engineering in a global planning role.

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Table of Contents

Table of Figures

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Table of Tables

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1. PART I: Introduction and Background

1.1. Introduction

The content of this paper was developed during a 6-month internship at the Advanced Manufacturing Engineering (AME) group in Honeywell Aerospace. Companies like Honeywell are increasingly sending design and engineering activities overseas. For AME, this is a new way of operating that brings many unfamiliar challenges. The goal of the internship was to design a strategy that could help AME globalize in a way that made sense.

This paper presents a method for structuring global product development (GPD) that is primarily driven by coordination requirements. GPD is rapidly becoming a dominant way to organize product development teams. Part I discusses the globalization landscape that is motivating and enabling GPD, challenges associated with doing it, and research on successful GPD practices. Part II introduces a method for using coordination structure to make global product development decisions. PART III describes the application of this method at Honeywell Advanced Manufacturing Engineering. Part IV concludes the paper with final thoughts and recommendations for future research.

1.2. Globalization

Globalization is a term that has only become commonplace within the last twenty years. It is often used synonymously with contemporary political, economic, and cultural trends such as economic liberalization, Westernization, the Internet Revolution, and global integration. More formally, globalization is the fundamental change in the significance of space and time that society has undergone because of technological advances (Scheuerman).

The concept that technological advances are globalizing the world is not a new one. In a speech about global economic integration, Federal Reserve Chairman Ben Bernanke quoted a historian’s observation that “a citizen of the empire traveling from Britain to the Euphrates in the mid-century CE would have found in virtually every town along the journey foods, goods, landscapes, buildings, institutions, laws, entertainment, and sacred elements not dissimilar to those in his own community" (Hitchner 398). This was possible because the Roman Empire had unified its vas territory with a common language, currency, legal system, and transportation network. In *The Communist Manifesto* Marx describes a similar phenomenon in this famous passage:

> The need of a constantly expanding market for its products chases the bourgeoisie over the whole surface of the globe. It must nestle everywhere, settle everywhere, establish connections everywhere. The bourgeoisie has through its exploitation of the world market given a cosmopolitan character to production and consumption in every country…It compels all nations, on pain of extinction, to adopt the bourgeois model of production; it compels them to introduce what it calls civilization into their midst, i.e., to become bourgeois themselves. In one word, it creates a world after its own image. (Marx 476)

After Alexander Graham Bell invented the telephone, commentators remarked that the ability to communicate instantaneously had caused distances to no longer be relevant. German philosopher Martin Heidegger referred to this phenomenon as the "abolition of distance" and added, "All distances in time and space are shrinking. Man now reaches overnight…places which formerly took weeks and months of travel" (Heidegger 165).

Today, rapid technological advances are again changing the concept of global time and distance, causing companies to re-evaluate how they should organize to take advantage of these changes.

1.3. Global Product Development (GPD)

Global product development (GPD) is the execution of product development activities across multiple global sites, often across different cultures and regions.

Put very simply, there are two ways companies can globalize: outsourcing and off-shoring. The difference between the two is whether the company retains ownership of the "globalized" activities. In outsourcing, a company keeps those activities that are core to its business in-house and contracts out non-core activities to other companies. In off-shoring, a company moves activities to a captive off-shore facility, which allows it to maintain ownership of these activities while doing them abroad. Typically, the companies do this to take advantage of lower labor rates at the off-shore facility. In this case, a company's process for deciding which activities to move to the off-shore facility is not necessarily the same as its decision of what is core or non-core to the business.

In general, outsourcing is the dominant strategy companies use to globalize manufacturing activities, while off-shoring is the dominant strategy for GPD.

1.3.1. Motivation

Why are so many companies rushing to develop GPD capabilities? While the first reason that comes to mind is low cost, there are many other compelling reasons why companies are very interested in GPD.

The framework we will use for this discussion is a simplified GPD value chain shown in Figure 1.

Figure 1: GPD Value Chain

From the company's perspective, suppliers of GPD are workers who provide or support the creation of the intellectual content that goes into designing and developing products. These suppliers are most likely engineers and scientists, and they are supported by other human resources such as lab technicians, administrative staff, project controllers, and project managers. We will refer to these workers generically as engineering resources.

On the other side, the company needs to consider its existing customers and the customers it hopes to serve as it expands into global markets. The relevant buyers to consider are the end customers that buy the company's products. This should not be confused with the "customers" within the company that receive outsourced or off-shored product development services, which are accounted for in the company box.

Following the three boxes in this simple framework, there are three ways to think about where to locate GPD activities: where the company is, where the buyers are, and where the suppliers are. The first option is the traditional model of locating all engineering resources within the company where it does most of its product engineering. The next two models, locating GPD where the buyers are and where the suppliers are, are discussed in further detail in the next paragraphs.

There is a strong case for many companies to locate product development resources where their customers are in order to design products that better suit the local market. In this model, core R&D and product architecture activities may be centralized, but more specific engineering customization takes place at local engineering sites close to customers. For example, Honeywell's Automation and Control Solutions (ACS) business has regional sales and engineering offices all over the world that design and deliver customized building control products and services for its local customers. To sell in this business, Honeywell needs local sales and engineering presence to understand and serve the needs of its customers.

Another strategy is to set up GPD based on where the suppliers are. For example, a luxury goods apparel company may choose to build a design center in Italy in order to take advantage of its supply of highly skilled, fashion forward designers. Similarly, a company might set up GPD resources in Germany for precision machine engineering, Russia if it needs a ready supply of nuclear scientists, and Taiwan for expertise in electronics manufacturing engineering.

Finally, related to setting up GPD based on the supply of talent is the motivation for looking for low cost talent. This is a particularly relevant question if the resources required are widely available and can be easily supplied from many different locations. For example, software development skills are becoming more and more prevalent all over the world, including in low-cost countries such as India. Software code can be transported almost instantaneously and for free anywhere in the world. Thus, many companies have begun their GPD efforts by outsourcing or off-shoring software development activities to places that can provide them with the lowest cost.

1.3.2. Enablers

Why is this all happening now? In *The World Is Flat*, Thomas Friedman describes a “triple convergence” of factors that have come together recently to “flatten” the world. These are new players, a new playing field, and new processes for collaboration (Friedman).

Due to the collapse of communism and the emergence of India and China, the number of people who are part of the “global economic world” has expanded from 2.5 billion people in 1985 to six billion people in the year 2000 (Friedman 213). Using the terminology introduced in the previous section of this paper, this translates into a very large new pool of potential low-cost GPD suppliers. It gets better. Governments in many of these regions have built state-of-the-art institutes of higher education and have offered many incentives for multi-national companies to create knowledge-based jobs on their turf. In some industries, these new players have also become new buyers for the products they produce.

In this global world, new and old players are finding themselves on a new digitized playing field, the second globalization enabler according to Friedman. Today, it is hard to imagine how one could do any engineering work without being in front of a computer. Virtually all design drawings are created using computer-aided drafting (CAD) tools today. When two engineers need to discuss a design, they are no longer required to sit side by side at a drafting table, but can instead open up electronic files to view the drawings on separate computers or laptops. Digital tools have become the standardized platform for design, analysis, and many forms of communication.

The last globalization convergence factor is, in Friedman's words, a "global, Web-enabled platform for multiple forms of collaboration…[that] operates without regard to geography, distance, time, and, in the near future, even language" (205). Anything that is created by the new digital tools available in the new playing field can be transferred almost instantaneously across the world via the internet. These new tools for collaboration include web-based video conferencing, teleconferencing, cell phones and BlackBerrys, VOIP, virtual team rooms, instant messaging, and of course, e-mail. All of these new processes of collaboration shrink the world, bridging physical distance with technology.

1.3.3. Challenges

Global product development certainly comes with its costs and challenges. The most obvious of them have to do with coordination across geographic and cultural distances. Poorly coordinated teams can have serious effects on quality, cost, and schedule. Amplify this by spreading team members around the world and in several different time zones, and it is easy to see how poorly designed GPD can be disastrous.

Much literature has been written about the benefits of co-locating product development teams. In conventional product development teams, co-located team members benefit from frequent informal face-to-face interaction. Often, organizations use co-location in order to encourage key interactions during the product development process. For example, locating product designers close to manufacturing engineers facilitates the design for manufacturability feedback loop. Co-location of experts creates clusters of knowledge that often lead to innovation. In an article countering Friedman's flat-world proclamation, Richard Florida declares that "The World Is Spiky" and points out why there is the high concentration of innovation (measured by the number of patents and the number of engineers and scientists) in only a few cities in the world:

> Creative people cluster not simply because they like to be around another or they prefer cosmopolitan centers with lots of amenities, though both these things count. They and their companies also cluster because of the powerful productivity advantages, economies of scale, and knowledge spillovers such density brings. (48)

When GPD teams are formed, some of these high quality interactions can still be preserved within the local team and the global team, but other coordinations will need to take place across local and global sites. Many times, these coordinations will be hampered by time zone differences, cultural differences, language barriers, and bad phone or internet connections. Even in the new “flat” world, these frictions are very real, and inefficiencies due to “coordination drag” stack up very quickly.

Unsurprisingly, coordination drag is highest during the startup phase of GPD adoption. Processes and process handoffs need to be very clearly defined between the global team and the local team. When they are not, it takes time to discover the bugs and iron them out. Companies that globalize product development activities are often worried about the risk of losing intellectual property and of losing control of their core capabilities. Thus, most companies choose to maintain ownership of overseas product development activities by establishing captive off-shore facilities. These facilities have high fixed costs, steep learning curves, and consequently, long periods before companies see a return on investment. Most companies find that a scale of 300 or more employees is necessary before it makes sense to set up a captive off-shore facility (PTC 4).

Companies have many reasons to be concerned about adopting GPD beyond these coordination challenges, and these concerns need to be taken into account when the company decides which activities it can move overseas. The best way to deal with the concern of losing intellectual property is to account for IP risk in the company’s strategic assessment of what activities it needs to keep in house. The same holds for meeting restrictions on defense-related work and work that the company considers core to its business. With some strategic design, it is possible to disaggregate activities and off-shore some components of defense work while keeping sensitive components on-shore.

1.4. Research

This section introduces research materials that have guided the development of the model presented in Part II of this thesis. These are case studies on GPD using the Design Structure Matrix and a paper on successful GPD practices.

1.4.1. Case Studies

The case study for Honeywell described in Part III of this paper was included as one of five GPD case studies prepared by Anshuman Tripathy and Steven Eppinger. These case studies use a tool called the Design Structure Matrix to analyze each company's GPD structure. Two of these case studies are described here to illustrate the difference between organizing GPD by processes and by product.

Danaher Motion started its GPD efforts by outsourcing CAD drafting and detailing processes to a supplier in India. It then set up a Global Development Center with a different outsourcing supplier in India, where it continues to outsource more processes. Each Danaher company is assigned a group of dedicated engineers at the Global Development Center. In addition, each company can draw upon a pool of engineers shared by all the Danaher companies. Danaher's next steps are to continue outsourcing more complex processes and to achieve better process utilization on its GPD resources.

Pitney Bowes based its outsourcing on the modular architecture of its MEGA Midjet mail processing system. This product automatically feeds in envelopes, seals and weighs them, and prints the postage. This product has three subsystems: the user interface module where the user punches in specifications, the input module which feeds in envelopes into the machine, and the finishing module which prints the stamps. The user interface module was mostly developed in-house, the input module was outsourced to Brother in China, and the printing parts of the finishing module was outsourced to Canon in Japan.

1.4.2. Research on Successful GPD Practices

Steve Eppinger and Anil Chitkara studied GPD for companies in the manufacturing sector by conducting interviews with 30 executives and surveying over 1000 product development executives and professionals from large manufacturing companies. In their article in the Sloan Management Review, they reported the following ten key success factors for successful GPD deployment (29-30).

1. **Management Priority** - Commitment from management to make the necessary organization, process, and cultural changes to make GPD work.
2. **Process Modularity** - Ability to separate activities into modular work packages for global distribution
3. **Product Modularity** - Ability to break products down into subsystems for global distribution
4. **Core Competence** - Good understanding of what the company's core competencies are, so that they do not get outsourced.
5. **Intellectual Property** - Defining processes and products in a modular way to protect IP
6. **Data Quality** - Ability to update and share data with teams in multiple locations
7. **Infrastructure -** Unified infrastructure, systems, technologies, and processes that are shared between all locations
8. **Governance and Project Management** - Ability to coordinate and monitor program, including detailed project planning
9. **Collaborative Culture** - Building and sustaining trust, ensuring teams have consistent processes and standards
10. **Organization Change Management** - Plan and train for new roles, behaviors, and skills

The Danaher Motion and Pitney Bowes case studies described in the previous section illustrate two of these success factors, process modularity and product modularity. While Eppinger and Chitkara recommend modularity in the design of GPD activities, their paper does not offer any method for how to do this. This thesis works to provide such a method.

In the same Sloan Management Review paper, Eppinger and Chitkara observed that GPD strategy is typically best deployed in stages. This allows companies to gradually move development responsibility to new locations. Figure 2 is a diagram from their paper illustrating three basic scenarios of staged GPD deployment. In Process Outsourcing, companies start by outsourcing simple tasks, then move onto more integrated tasks. Similarly, in Component Outsourcing, companies start with simple components and then move onto outsourcing integrated components and complete modules. Finally with a Captive Design Center, companies start with either simple tasks or components, with the goal of growing the center to be able to develop new global products. Companies may choose for various reasons not to advance past a certain stage in any of these three models.

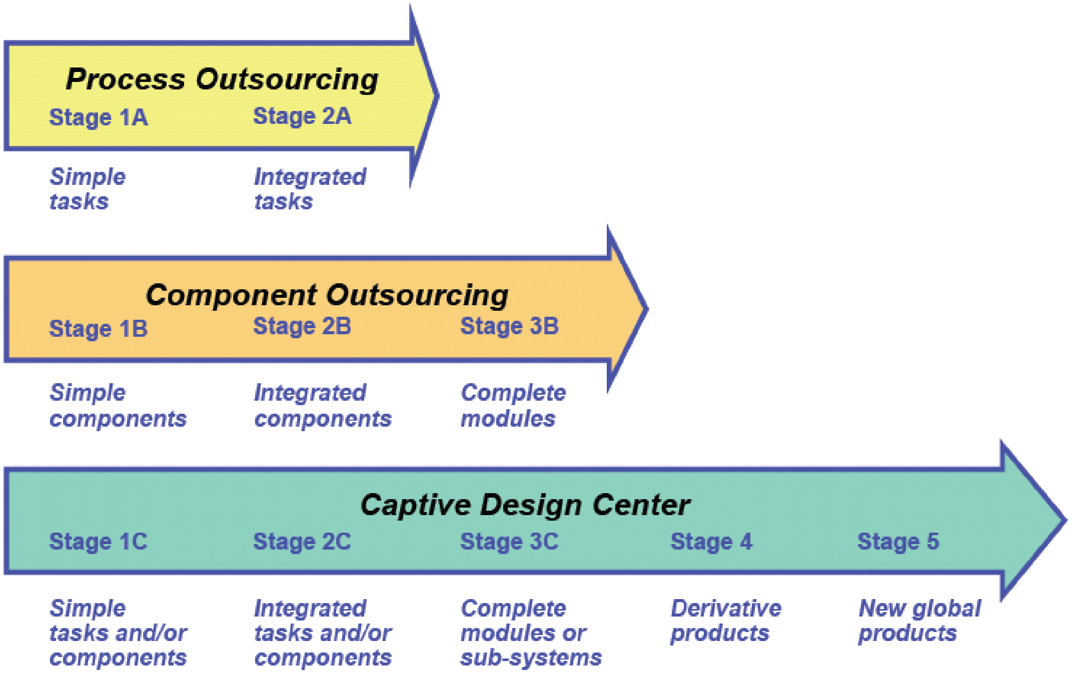

Figure 2: Global Product Development Evolution Stages (Eppinger & Chitkara 28)

1.5. Summary

This chapter introduced globalization concepts and outlined some reasons why engineering companies today are particularly interested in doing global product development. This was followed with a discussion of the challenges associated with GPD and research on GPD best practices.

Part II describes a model to aid in the strategic design of GPD teams. This model helps companies design modularity into their GPD activities based on coordination cost and project structure. Part II contains the theory and the formulation of this model. Application is left for Part III of this paper.

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2. PART II: Methodology

This chapter describes a method for deciding which activities should be included in a global product development effort. This method seeks to minimize coordination costs through process modularity or product modularity, two of the strategic design GPD success factors described in Section 1.4.2.

The primary parameter used to compare the relative attractiveness of one GPD structure over another is coordination drag, and a "coordination cost" is calculated for that purpose. An arrangement that includes a large amount of inter-site coordination is assumed to be less attractive and contain more coordination drag than an arrangement that captures most of its important coordination interactions within each site. Modular assignment of activities for GPD helps us design simpler inter-site coordinations.

This chapter begins with an introduction to the Design Structure Matrix (DSM), the tool used by Tripathy and Eppinger in the GPD case studies described in Section 1.4.1. Then, we introduce a variant of the DSM called the Co-location DSM, which maps coordination costs between DSM elements. The Co-location DSM is used in a decision model that helps the user decide which processes to keep at a local site and which processes to globalize.

2.1. Introduction to the DSM

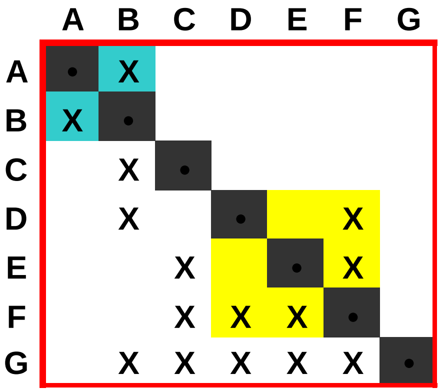
The Design Structure Matrix (DSM) is a visualization tool for project management and system analysis. It is sometimes called the Design System Matrix or the Dependency Structure Matrix. The DSM was first proposed by Steward and adapted by Eppinger, Whitney, Smith, and Gebala for organizing tasks in product development.

The DSM is a two-dimensional square matrix that maps the interaction of each element to every other element in the system. To create a DSM, we first decompose a system into a set of discrete elements. Each non-diagonal cell in the DSM represents an interaction between two different elements in the system. Each interaction can be represented by a symbol such as an X, or by a numerical score assigned based on strength of interaction. Each blank or zero non-diagonal cell indicates there is no known interaction between the two elements that correspond to that cell.

There are three basic ways to decompose a DSM into elements:

- Processes
- Products
- People

The DSM in Figure 3 is an example of the most common use of the DSM, which is to map out task dependencies for managing product development projects. Most product development projects contain many tasks that have cyclic dependencies that cannot be captured in a traditional Gantt chart, which assumes a linear sequence of tasks. The task dependency DSM allows us to map out these cyclic dependencies.



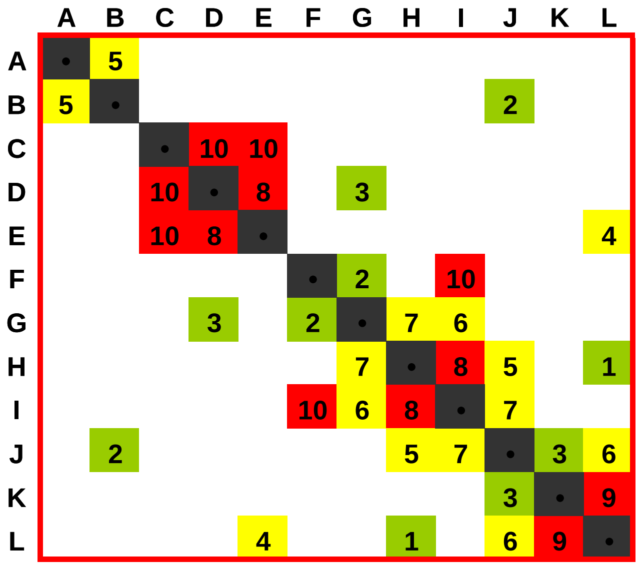
	A	B	C	D	E	F	G
A	•	X					
B	X	•					
C		X	•				
D		X		•		X	
E			X		•	X	
F			X	X	X	•	
G		X	X	X	X	X	•

Figure 3: Task Dependency DSM

In Figure 3, DSM elements A-G represent project tasks, which are listed along the rows and columns of the matrix. Along the matrix diagonal, each task maps to itself. Off the diagonal, each X describes a dependency between a pair of tasks with rows as inputs and columns as outputs. For any given task, each row in the DSM has an X in cells corresponding to tasks that are inputs. Each column has an X where the task needs to give outputs. For example, reading from left to right, in Row F, Task F needs inputs from task C, D, and E and gives outputs to Task D and Task E. Tasks D, E, and F have a cyclical dependence because no task can be completed independently without inputs from other tasks in this group.

2.2. The Co-location DSM

The Co-location DSM is a new adaptation of the DSM designed to answer the question of how to best organize tasks for product development where activities are dispersed across multiple sites. The product development project is decomposed into a discrete set of activities that can be moved independently. The numeric scores in the matrix are assigned by asking the question, “How important is it for these two activities to be co-located?” This is different than the task dependency question, “Which other tasks are inputs and outputs of this task?” While one task might be highly dependent on another task to be completed before it can be performed, there might be very little need or advantage gained by co-locating those two tasks.



	A	B	C	D	E	F	G	H	I	J	K	L
A	•	5										
B	5	•								2		
C			•	10	10							
D			10	•	8		3					
E			10	8	•							4
F						•	2		10			
G				3		2	•	7	6			
H							7	•	8	5		1
I						10	6	8	•	7		
J		2						5	7	•	3	6
K										3	•	9
L					4			1		6	9	•

Figure 4: Sample Co-location Design Structure Matrix

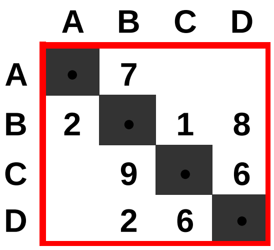
Figure 4 shows an example of a Co-location DSM. The diagonal cells are blank because it simply indicates the obvious need for each task to be co-located with itself. In this matrix, the “need to co-locate” is scored on a scale of 1-10, with 10 being high need to co-locate the corresponding two activities where the score resides.

The elements in the Co-location DSM are referred to as activities, and these activities can be decomposed as processes, products, or a combination of the two. For example, Danaher from the GPD case studies in Section 1.4.1 would decompose its GPD problem into activities such as “Create CAD models.” On the other hand, Pitney-Bowes might decompose its GPD problem into more product-specific activities such as “Design printer” or “Design input module.”

2.2.1. Discussion on Symmetry

In order to understand what the numbers mean in the Co-location DSM, it is first necessary to understand why the Co-location DSM is a symmetric matrix. This was a key decision that had to be made when defining this matrix.

If the Co-location DSM were asymmetric, it could capture asymmetric needs to co-locate. For example, Task A may benefit more from being co-located with Task B than Task B benefits from being close to Task A. In this case, there could be a higher score for A’s need to be co-located with B, than B’s need to be co-located with A, as shown in a hypothetical asymmetric Co-location DSM on Figure 5. Thus, each pair of activities would receive two scores if co-location asymmetry is captured. These scores can be the same if there is equal need for these two activities to be co-located, as is the case for Tasks C and D in Figure 5.

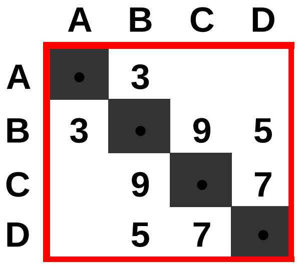


	A	B	C	D
A	•	7		
B	2	•	1	8
C		9	•	6
D		2	6	•

Figure 5: Hypothetical Asymmetric Co-location DSM

The problem with allowing for asymmetry is that as an overall representation of the need to co-locate each activity with every other activity, it is unclear which activity pairs are most important. For example, is the (7,2) score between A and B more important than the (6,6) score between C and D? Is a (6,6) score worth more than the (1,9) score between B and C?

The answer is, it depends on circumstances that are not captured in the scores in Figure 5. Perhaps in the case of the (1,9) score, even though one of the scores is a 1, the overall need for C to be located with B is still so compelling that the overall score for the pair should still be a 9. On the other hand, the (8,2) score between B and D can be simply averaged to a score of 5 for the pair. Perhaps since C and D have a reciprocal need to co-locate, we can bump this pair up to a score of 7. Scores for A and B have a weighted average in favor of the lower interaction, which we assign a total score of 3 for the pair. Figure 6 shows a revised symmetric version of this Co-location DSM.



	A	B	C	D
A	•	3		
B	3	•	9	5
C		9	•	7
D		5	7	•

Figure 6: Symmetric Co-location DSM

In this DSM, it is clear which interactions have the highest need to be co-located. Each pair of activities now has a single score that can be easily compared to the scores for every other pair of activities in the matrix.

A symmetric representation recognizes it is more important to rate total co-location importance than to individually track asymmetric needs to co-locate. Put a different way, if Task A needs to be co-located with Task B, Task B needs to be co-located with Task A.

2.2.2. Explanation of Scores

Building a symmetric Co-location DSM requires making management judgment calls along several dimensions. We can think of the need to co-locate in terms of the three grouping categories defined by Nadler and Tushman in *Competing By Design: The power of organizational architecture*. These grouping categories are pooled interdependence, sequential interdependence, and reciprocal interdependence. In pooled interdependence, activities are relatively independent but share some scarce resources. Activities with only pooled interdependence are given scores from 1-3. Sequential interdependence is the dependence tracked in the task dependency DSM, which logs information dependence (inputs and outputs) between activities. Activities with sequential interdependence typically have scores ranging from 4-7, depending on how important co-location is for proper information to be transfer. Finally, pairs of activities with reciprocal interdependence receive the highest scores from 8-10. In activities with reciprocal interdependence, the people performing these activities must work very closely together to jointly create a common product or service. Many times, activity pairs can be characterized by multiple types of interdependence. In general, this bumps up scores because there are multiple reasons for these activities to be co-located. Boundaries between scores for these three types of interdependence are just guidelines; it certainly is possible for a pair of activities with pooled interdependence to receive a co-location score of 10 because the resource they share is so expensive and scarce.

There is an implicit assumption about the Co-location DSM that we make from here on. While the Co-location DSM maps the "need to co-locate," for every pair of activities, it is assumed that if there is a high need to co-locate, there is a higher coordination cost associated with the two tasks than if there is a low score between each pair. This may seem unfair at first because not all activities are equally important, lengthy, or need to be performed with the same frequency. It is important to think of these "costs" still as scores on a point-based system, not as dollar costs. The future research section of this paper describes some attempts that were made to translate these scores into real costs. If there is a high need to co-locate two activities and the people who own them do not communicate with each other, these coordination costs will manifest themselves in other ways such as need for rework or poor product quality. No scoring scheme can account for all of the nuances in these different activities, nor is a perfect scheme desirable. For our purposes, these coordination costs work very well for comparing the attractiveness between different arrangements of activities. This is similar to the interpretation of "coordination costs" used in the DSM team co-location clustering algorithm developed by Carlos Fernandez in an MIT SM thesis (Fernandez).

2.3. Multi-Site Coordination Matrix

The Co-location DSM was built assuming all activities are performed at the same site, but that some activities can be moved independently to other sites. The coordination costs in the Co-location DSM can now be extended to map coordination costs for all combinations of activities assigned to each possible site. Since tasks are no longer necessarily co-located, high "need to co-locate" scores lead to high coordination costs. Each element in a multi-site coordination matrix refers to a DSM activity performed at a specific site.

Figure 7 shows a conceptual diagram of a coordination matrix for two sites, Site 1 and Site 2. There are four different sections to this new matrix:

- C1: Site 1 with Site 1
- C2: Site 1 with Site 2
- C3: Site 2 with Site 1
- C4: Site 2 with Site 2

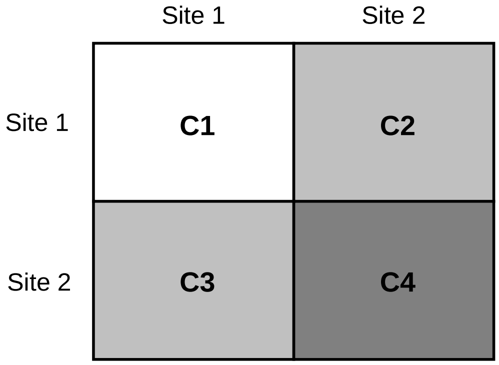


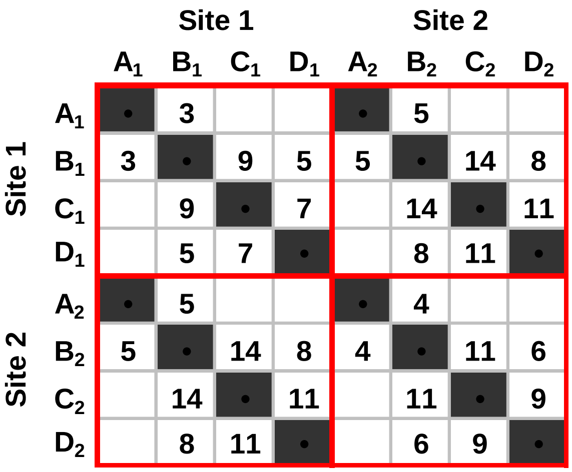
Figure 7: Two-Site Coordination Matrix Concept Map

We assume all activities are currently being performed at Site 1, and Site 2 is where we are considering moving some activities. The Co-location DSM is used to fill in the coordination numbers in quadrant C1. Since the original Co-location DSM numbers were assigned without taking direction of coordinations into account, the new two-site coordination matrix cannot capture the direction of information flow between sites. Thus, C2 = C3 and the two-site matrix will be also symmetric. Since these are cross-site coordinations, these numbers are related to the numbers in the Co-location DSM, but need to be penalized for the coordination drag that is involved in having to work across sites. Rather than building these matrices from scratch, penalty factors can be applied to the original DSM to get C2, C3, and C4. This penalty factor can be an additive factor, a multiplicative factor greater than 1, or any formula the user believes to be true of the other coordinations compared to C1. After populating the full two-site coordination matrix using formulas, individual coordination values can be edited based on known information about the coordinations in the other quadrants.

2.3.1. Example

As an example, we can build a two-site coordination DSM using the simple 4-process symmetric matrix from Figure 6. The task labels A_1, B_1, C_1, and D_1 represent tasks done at the original site, Site 1. A_2, B_2, C_2, and D_2 represent the same tasks done at Site 2. This matrix now maps co-location scores for each possible pair of coordinations, given that tasks A, B, C, and D can be assigned to either Site 1 or at Site 2.

The resulting 8 x 8 matrix is comprised of 3 versions of the original Co-location DSM. The top left quadrant of this matrix is simply the Co-location DSM from Figure 6. Two multiplicative penalty factors were applied to the Co-location DSM to fill in the other quadrants. This matrix assumes that Site 1-Site 2 coordinations take 50% more time than Site 1-Site 1 coordinations, and that Site 2-Site 2 coordinations take 25% more time than Site 1-Site 1 coordinations.

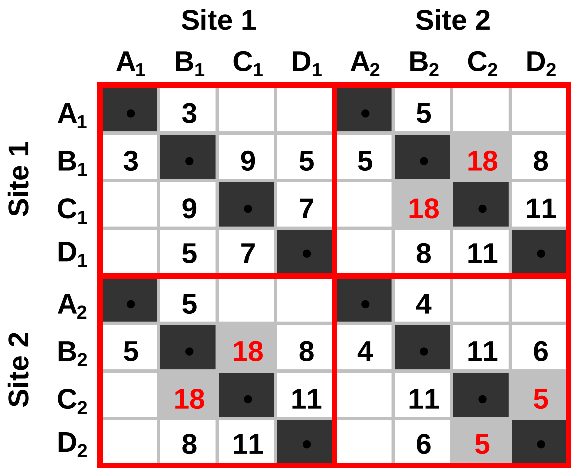


		Site 1				Site 2			
		A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2
Site 1	A_1	•	3			•	5		
	B_1	3	•	9	5	5	•	14	8
	C_1		9	•	7		14	•	11
	D_1		5	7	•		8	11	•
Site 2	A_2	•	5			•	4		
	B_2	5	•	14	8	4	•	11	6
	C_2		14	•	11		11	•	9
	D_2		8	11	•		6	9	•

Figure 8: Initial Two Site Coordination Matrix for 4 Tasks

Now that this matrix is fully populated, we can go back and manually edit cells where we have more information. For example, maybe the 50% coordination penalty does not do justice to how difficult it would be to coordinate tasks B and C if they were in two different locations. We might bump those coordination scores up from 14 to 18. Also, suppose we find that the global site is actually better at handling the coordination between tasks C and D within its site than local can is because of engineering efficiencies at the global site. Here, we decided to discount the corresponding score from a 9 to a 5.

The new coordination matrix is shown below in Figure 9. Values modified from Figure 8 to Figure 9 are shown in shaded boxes.



		Site 1				Site 2			
		A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2
Site 1	A_1	•	3			•	5		
	B_1	3	•	9	5	5	•	18	8
	C_1		9	•	7		18	•	11
	D_1		5	7	•		8	11	•
Site 2	A_2	•	5			•	4		
	B_2	5	•	18	8	4	•	11	6
	C_2		18	•	11		11	•	5
	D_2		8	11	•		6	5	•

Figure 9: Final Two Site Coordination Matrix

2.4. Decision Model

This section describes the decision model for assigning tasks to two different sites. The formulation can easily be extended for solving this problem with more than two sites. The objective of this model is to minimize a total coordination score that represents a total coordination cost for the system. Total coordination cost depends on a calculation that takes into account where each activity is assigned. Coordination costs are expected to rise when there are more high-cost cross-site coordinations.

2.4.1. Formulation

There are n tasks in the Co-location DSM. The original Co-location DSM is an n x n matrix, and a two-site coordination matrix will be $2n$ x $2n$.

For simplicity, we will refer to the two-site coordination matrix separately as four matrices, C1, C2, C3, and C4, as defined in Figure 7.

The decision variables are binary variables that indicate whether each activity is assigned to Site 1 or Site 2. These are tracked in X, a 2 x n matrix of binary decision variables with the first index referring to the site number (Site 1 or Site 2) and the second index being the task number.

The following formula expresses the total cost *T* to minimize in this optimization problem.

$$T = \sum_i \sum_j X_{1,i} X_{1,j} C1_{i,j} + \sum_i \sum_j X_{1,i} X_{2,j} C2_{i,j} + \sum_i \sum_j X_{2,i} X_{1,j} C3_{i,j} + \sum_i \sum_j X_{2,i} X_{2,j} C4_{i,j}$$

Decision variables assign each activity to exactly one site based on two constraints. Constraint #1 is the constraint that each activity must be done at exactly one site. Constraint #2 introduces a constraint variable Y that either forces the total number of activities at Site 1 to be less than or equal to a certain number Y_1 or forces the number of activities at Site 2 to be greater than or equal to another number Y_2.

Constraint #1: For every activity *i*, $X_{1,i} + X_{2,i} = 1$

Constraint #2: $\sum_n X_1 \leq Y_1$ or $\sum_n X_2 \geq Y_2$

It is highly likely for this analysis that certain activities will need to be constrained to one site or the other for practical or strategic reasons. These site limitations can either be added in as additional constraints, or more elegantly, the corresponding decision variables can be taken hard-coded into the model to avoid unnecessary calculations.

2.4.2. Coordination Structure Diagram

The coordination structure diagram helps us map the relative portability of each of the DSM elements. To create this diagram, we run the optimization model multiple times while either increasing Y_2, the number of tasks that must be done at Site 2, or decreasing Y_1, the maximum number of tasks that Site 1 can handle. Since the two-site coordination matrix is set up so that any coordinations involving Site 2 cost more than coordinations that are only between Site 1 tasks, total coordination costs will go up as more tasks are forced to move to Site 2.

By solving for every constraint for every integer between 0 and N, we can map out all these solutions to get a sense of which elements are easy to move and which are hard to move. Highly portable items will be placed at the other site earlier, when the model only has to choose a few items to move. Highly unportable elements will hang onto the original site until very late when they are finally forced to switch over.

2.4.3. Solved Example

The example we will solve is the 4 task, two-site coordination situation we left off with in Figure 9. In this simple scenario, there are only 16 ways to place these 4 tasks at the 2 sites. We can calculate the coordination costs of each of these arrangements simply by plugging each arrangement into the total cost equation. Because of the penalty factors applied on coordinations outside of the local site, all arrangements where any tasks are moved to Site 2 "cost" more in coordination than the arrangement where all tasks are kept at Site 1. Figure 10 illustrates the 16 ways to place tasks at Site 2. For each case, the white squares with 0's under each corresponding task column mean the task is assigned to Site 1, black squares with 1's refer to tasks that have been moved to Site 2. These combinations are grouped by how many tasks are moved to Site 2. The total coordination cost *T* is displayed in the gray box to the left of each scenario.

Move 0 Tasks

	A	B	C	D
48	0	0	0	0

Move 1 Task

	A	B	C	D
60	0	0	0	1
73	0	0	1	0
74	0	1	0	0
51	1	0	0	0

Move 2 Tasks

	A	B	C	D
67	0	0	1	1
79	0	1	0	1
68	0	1	1	0
63	1	0	0	1
76	1	0	1	0
73	1	1	0	0

Move 3 Tasks

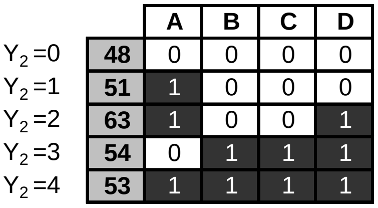
	A	B	C	D
54	0	1	1	1
70	1	0	1	1
77	1	1	0	1
66	1	1	1	0

Move 4 Tasks

	A	B	C	D
53	1	1	1	1

Figure 10: Definitions and Costs for All 16 Scenarios in Example

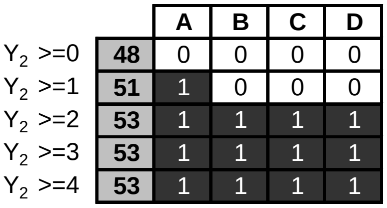
The coordination cost of not moving anything to Site 2 is 48. If we want to move exactly one task out of the four, Task A would be the best task to move. The worst task to move would be Task C. If exactly half of the tasks need to move, A and D would be the cost least in additional coordination. Finally, if we needed to move 3 of the 4 tasks, it would cost least to move Tasks B, C, and D together and to leave A at Site 1. The total coordination cost of moving all 4 tasks is lower than the cost of moving only two or three tasks. The scenario with the highest cost is moving only Tasks B and D to Site 2. This scenario should be avoided if possible. If the plan is to eventually move all four tasks to Site 2 in two equal phases, it would be best to move tasks A and D, then move tasks B and C, avoiding any of the high-cost scenarios where B and C are separated.



		A	B	C	D
$Y_2 = 0$	**48**	0	0	0	0
$Y_2 = 1$	**51**	1	0	0	0
$Y_2 = 2$	**63**	1	0	0	1
$Y_2 = 3$	**54**	0	1	1	1
$Y_2 = 4$	**53**	1	1	1	1

Figure 11: Lowest cost solutions for moving exactly 1, 2, 3, and 4 tasks

The coordination structure diagram maps the best possible set of tasks to move given each constraint. Basically, we log the cost minimizing solution for each constraint. Since the number of tasks that should be moved to Site 2 is a greater than or equal to constraint, the model will choose to move all 4 tasks when $Y_2 = 2$ and $Y_2 = 3$ as well. The coordination structure diagram for the example model is shown in Figure 12.



		A	B	C	D
$Y_2 >= 0$	**48**	0	0	0	0
$Y_2 >= 1$	**51**	1	0	0	0
$Y_2 >= 2$	**53**	1	1	1	1
$Y_2 >= 3$	**53**	1	1	1	1
$Y_2 >= 4$	**53**	1	1	1	1

Figure 12: Coordination Structure Diagram for Example Model

2.5. Summary

This chapter introduced a method for allocating product development activities to multiple sites based on coordination cost and project structure. First, the product development project is decomposed into activities. Then, a DSM is built mapping each activity's need to co-locate with every other activity in the system. These scores become our "coordination costs," with high scores corresponding to high costs. A matrix of the coordination costs for all the possible interactions between the sites can then be built starting from this DSM. A simple two-site optimization model was formulated that picks tasks to move to a new site while minimizing total coordination costs given a constraint on how many activities must be moved to the new site. The coordination structure diagram shows the activities that get moved under each solved constraint condition.

The next chapter of this paper uses this method to design a GPD plan for AME, a group at Honeywell that is choosing activities to allocate to a new global site for the first time.

3. PART III: Application to Honeywell Advanced Manufacturing Engineering

This chapter describes the application of the activity allocation method described in Part II at Honeywell in the Advanced Manufacturing Engineering (AME) group, where this method was developed. The author was at Honeywell Aerospace in Phoenix, Arizona from June to December, 2006.

The problem statement identified for the internship was to look for a more systematic way for AME to decide which of its activities to globalize and where to do these activities. Because of the globalization mandate set forth by Honeywell CEO Dave Cote, AME was limited in the headcount it could add at its current U.S. sites. This was particularly challenging for AME because this organization was still growing and trying to sort out its own processes. Some activities for AME were already being supported from the Honeywell Technology Solutions Lab in Bangalore, and AME wanted to make sure that additional global activities could be designed and managed judiciously.

3.1. Sponsor Company Background

Honeywell International Inc. is a $31 billion diversified technology and manufacturing company headquartered in Morris Township, New Jersey. Its roots can be traced back to 1886 with the founding of the Butz Thermo-Electric Regulator Company, which eventually became the Minneapolis Heat Regulator Company, the first company to patent an electric motor. The company’s 1927 merger with Honeywell Heating Specialty Company was the first of many mergers, acquisitions and joint ventures that involved companies including included Brown Instrument Co. (controls and pyrometer), Doelcam Corp (gyroscopes), Sperry Aerospace (avionics), Pioneer, Lycoming, Garret, Grimes, and Allied Signal (aerospace, specialty materials, automotive).

Honeywell has four major business units: Aerospace, Automation and Control Solutions, Specialty Materials, and Transportation Systems.

3.1.1. Honeywell Aerospace

Honeywell Aerospace, an $11 billion division of Honeywell, is a leading industry supplier of avionics and electronics, consumable hardware, engine controls, environmental controls, landing systems, power systems, and propulsion engines for commercial and military aircraft and space systems. Honeywell Aerospace employs about 40,000 people worldwide and is headquartered in Phoenix, Arizona.

Honeywell's customers include Boeing, Airbus, Bombardier, Cessna, Hughes, Learjet, Lockheed Martin, Northrop Grumman, Raytheon, United Technology, the U.S. Department of Defense, the U.S. Department of Energy, NASA, and leading airlines and airport authorities.

Honeywell Aerospace has about 70 sites worldwide, with about 60% of these sites in the continental United States. There are six sites in the Phoenix area. Other sites are close to Honeywell's key customers such as Boeing and Airbus. Aerospace sites in the United States are organized by product or by customer. Since many of these sites were brought into Honeywell through acquisitions, they have historically operated independently. As such, Honeywell often reorganizes to better align products and functions at these sites with its strategic objectives.

Figure 13 shows the organizational structure of Honeywell Aerospace and the organizational structure of the Integrated Supply Chain (ISC) group, which is where AME resides.

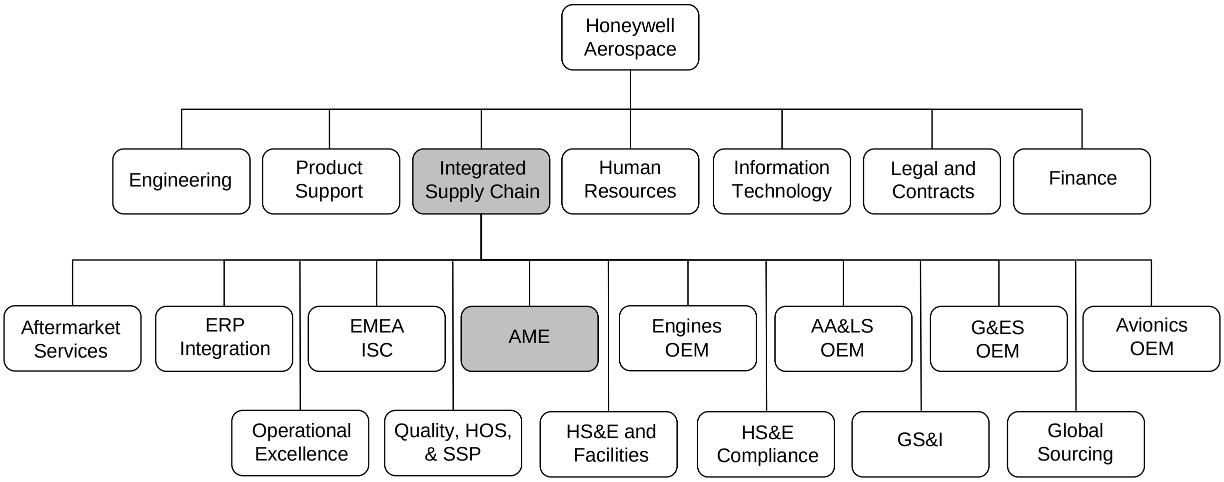


Figure 13: Honeywell Aerospace Organizational Structure

3.1.2. Advanced Manufacturing Engineering (AME)

The Advanced Manufacturing Engineering (AME) group was created in July, 2005 during a major reorganization of Honeywell Aerospace. Honeywell had recently lost some key bids because its costs were not competitive. This was a wake up call for Honeywell, a company that was more accustomed to competing on technology than on cost.

An LFM who interned at Honeywell in 2005 described the situation that led to the Aerospace reorganization and the creation of the AME as follows: “The competitive landscape for Honeywell Aerospace is maturing with an increased level of price sensitivity. While still not a commodity market, operational efficiency is becoming increasingly important. Additionally, trends toward globalization drive new operational optimization challenges.” (Robinson 9)

AME was created in order to improve upstream and downstream coordination between Engineering and Integrated Supply Chain (ISC). The designers of the AME organization recognize that most product cost decisions are made during the design process. These decisions were historically made only by Engineering and then thrown over the wall to ISC to be made as cheaply as possible. ISC can make better investments and plans for delivering new products if it is more aware of what products are coming down the pipeline. At the same time, ISC has information about product manufacturability, quality, and cost that needs to be communicated upstream to help Engineering design cost-competitive products.

The following are the key goals of the AME organization:

- Drive cost and performance of new products (New Product Development)
- Drive down cost of existing products (Value Engineering)
- Develop and implement manufacturing technology

The core AME team is based at the Engines site in Phoenix, Arizona. Most AME directors are based in the Phoenix area. AME New Product Development (NPD), Value Engineering (VE), and Product Line Manager (PLM) employees are each assigned to work on one or more Aerospace products, and they are based at the various product sites all over the U.S. There are about 130 employees in AME.

AME underwent a department reorganization in December, 2006. This reorganization turned AME into a matrix organization for greater emphasis on products, and greater fluidity of engineering functions to support new product development and value engineering product needs.

3.1.3. Product Development

Honeywell follows a product development process called IPDS, Integrated Product Development System. Each associated phase has a checklist of tasks that the program needs to perform before advancing to the next phase. These phases are shown in Figure 14.

Figure 14: Honeywell Integrated Product Development System Phases

3.2. Applicability of Methodology

This section describes why the method in Part II of this paper makes sense for the AME globalization problem.

3.2.1. Process Focus

There are many reasons why process decomposition works particularly well for the AME globalization problem. As an organization, AME does not own products or programs, it owns a set of processes across all aerospace programs. Thus, it makes more sense for AME to globalize processes, rather than to globalize its support on products. Because of these existing conditions, the application at Honeywell is focused on achieving modularization of processes, rather than modularization of products.

3.2.2. Globalization and Centralization

In the case of AME, processes that are globalized to one site also become centralized, since most processes for all products are being performed at local product sites. This means there are two sources of potential benefit from globalization: centralization of processes and globalization of processes.

Working globally is relatively new to AME. As GPD research suggests, globalizing simple processes may be the easiest way to start global product development efforts. These processes can later be turned into products or modules.

One key advantage of globalizing processes is that those activities that are centralized at the global site can develop into centers of excellence for those processes. These process experts would be able to learn and disseminate best practices across Aerospace product lines. Process centralization means that not everyone needs to be the expert at every AME process. AME engineers at every site could then summon expertise from a centralized pool of resources when they needed help.

3.3. DSM Preparation

There were two steps to building a useful DSM for AME. The first was to put together a suitable list of processes to map in the DSM. Once this was done, then the DSM could be populated and sorted accordingly. This section describes how the AME DSM was built.

3.3.1. Process Identification

The first step to building the DSM was to come up with a list of AME processes. The following are some key AME processes as defined on Honeywell's IPDS checklists:

Phases 1-2	Establish preliminary cost targets
Phase 3	Total project cost estimate Plan for DfX analysis Production cost estimates
Phase 4	BOM life cycle screen for obsolescence Design for manufacturability Design for assembly Design for robustness and immunity to variation Design for testability (product and test equipment) Design for cost Design for reparability and maintainability Design for reliability Yield Prediction
Phase 5-7	Value Engineering (Cost Takeout Opportunities) Component Risk/Obsolescence Analysis Plan

Table 1: AME Processes from IPDS Checklist

3.3.2. Process Redefinition

What we learned when we started to map coordinations in the DSM with our first process list was that processes defined too broadly needed to be co-located with almost every other process in the DSM. It was difficult to nail down real co-location needs of catch-all processes such as *Design for Manufacturability*.

Many of the core AME processes are the Design for X (DfX) processes listed under IPDS Phase 4. Design for X is a generic term for design for fill-in-the-blank desirable results downstream such as manufacturability, ease of assembly, reliability, cost, and export compliance. The problem with these DfX processes is that they sound like activities that need to be done by the design engineer. There seems to be little room for someone else to do DfX alongside the design engineer, let alone ask this person to do it remotely from an overseas site.

Interviews with AME staff helped us better understand the actual tasks they undertake as keepers of these DfX processes. This helped us capture the tasks more precisely in the process list. In an activity like *Design for Manufacturability,* AME product managers drive awareness for DfM and run analysis tools to check for yield and cost, but do not carry out the actual design. AME managers are there to drive change in behavior if the design team is not properly accounting for DfM as the design evolves.

In order to build a meaningful DSM, processes in the list had to be defined in a way that was clear and specific enough for us to map out its need to be co-located with other processes. For example, DfM can be broken down into a set of many more specific processes that AME can control such as *Run Circuit Card Assembly Analysis Tool for Yield Prediction*, *Machining versus Casting Manufacturing Analysis*, and *Design for Manufacturability Idea Generation*. While it would be difficult to imagine putting all AME DfM activities overseas (this would off-shore almost all AME activities in one shot), it is easier to imagine providing some DfM analysis and support activities overseas. Now, processes that were once inseparable from local product engineering stand a chance at being good candidates for globalization.

Table 2 shows the breakdown of DfX processes into more specific tasks. Tasks in italics are common to multiple DfX processes. This gives further motivation to define tasks at this level to observe underlying interactions.

Design for Manufacturability (DfM)	DfM idea generation Manufacturing process cost analysis Circuit card assembly (CCA) complexity analysis Composite complexity analysis Mechanical part complexity analysis Product complexity analysis Machining vs casting manufacturing analysis Alternate material analysis Quality/yield analysis and prediction *Part count reduction identification* *Should-cost modeling*
Design for Assembly (DfA)	Assembly human factors/ part interference accessibility analysis Fastener/connector/harness analysis *Quality/yield analysis and prediction* Part count reduction identification
Design for Cost (DfC)	BOM analysis life cycle screen for obsolescence Identify component replacement opportunities *Should-cost modeling* *Quality/yield analysis and prediction*
Design for Reliability (DfR)	Analysis of robust and immunity to variation/reliability *Quality/yield analysis and prediction*
Design for Test (DfT)	Analysis of design to test requirements
Design for Environment	Check BOM for environmental impact
Design for Export Compliance	Check BOM for export compliance

Table 2: AME Assigned Processes and Corresponding Decomposed Tasks

In addition to these official AME processes, there are many more IPDS activities that AME participates in but does not own. For example, while AME does not have the responsibility of maintaining and tracking a project's Failure Modes and Effects Analysis (FMEA), DfX analysis results from AME are key inputs to FMEA, and the preliminary FMEA results tell AME on where it needs to focus its DfX efforts. AME's coordinations with non-AME activities need to be in the DSM, even if AME does not have the authority to move them.

Table 3 lists all processes included in the DSM. Each process is labeled with the name of the group that is primarily in charge of the process, and well as an initial guess on whether this process can be moved to a global site. This process list is divided into four shaded sections. The first three sections list all the tasks that were assigned "No" in portability, and they are divided into Marketing and Program Management (M&PM), Engineering, and Integrated

Supply Chain (ISC) non-AME tasks. Some of the ISC non-AME tasks are specifically called out as being Sourcing activities. The last section has all the tasks owned by AME and all tasks owned by other groups with a portability designation of “Yes” or “Maybe.” The portable tasks are renumbered from 1-53 and the non-portable tasks are grouped into sections A, B, and C on the left column of Table 3.

ID	Portability	Owner	Process
A	No	M&PM	Capture customer requirements
	No	M&PM	Set target cost
	No	M&PM	Demand Forecast and Planning
B	No	Engineering	Design Guideline Creation
	No	Engineering	Develop product architecture
	No	Engineering	Quality plan
	No	Engineering	Design product
	No	Engineering	Consolidate/Capture Bill of Materials
	No	Engineering	Capture/Consolidate Design Drawings
	No	Engineering	Develop test plan & define test requirements
	No	Engineering	FMEA of design
	No	Engineering	Process selection
C	No	ISC	Develop ISC strategy for program
	No	ISC	Identify Core vs. Non-Core
	No	ISC	Design value chain
	No	ISC	Plant Selection
	No	ISC	Internal capacity analysis
	No	ISC	Develop site-specific manufacturing plans
	No	Sourcing	Develop material plan
	No	Sourcing	Supplier selection
	No	ISC	Make parts
	No	ISC	Assemble Product
	No	ISC	Test product
	No	ISC	Work Instruction Tracking
	No	ISC	Tooling & Capital Readiness Tracking
	No	ISC	Work Breakdown Structure for ISC
1	Yes	AME	Job order Creation and Tracking (Budget management)
2	Yes	AME	Budget Analysis and Tracking
3	Yes	AME	Savings Tracking
4	Yes	AME	Savings Validation
5	Maybe	ISC	Capital Request Tracking
6	Maybe	Sourcing	Quote Acquisition
7	Maybe	Sourcing	Quote Tracking
8	Yes	AME	BOM cost analysis
9	Yes	AME	BOM alternate part cost analysis
10	Maybe	AME	Should-Cost Modeling
11	Yes	AME	Identify component replacement opportunities
12	Yes	AME	BOM analysis life cycle screen for obsolescence
13	Yes	AME	Check BOM for export compliance
14	Yes	AME	Check BOM for environmental impact

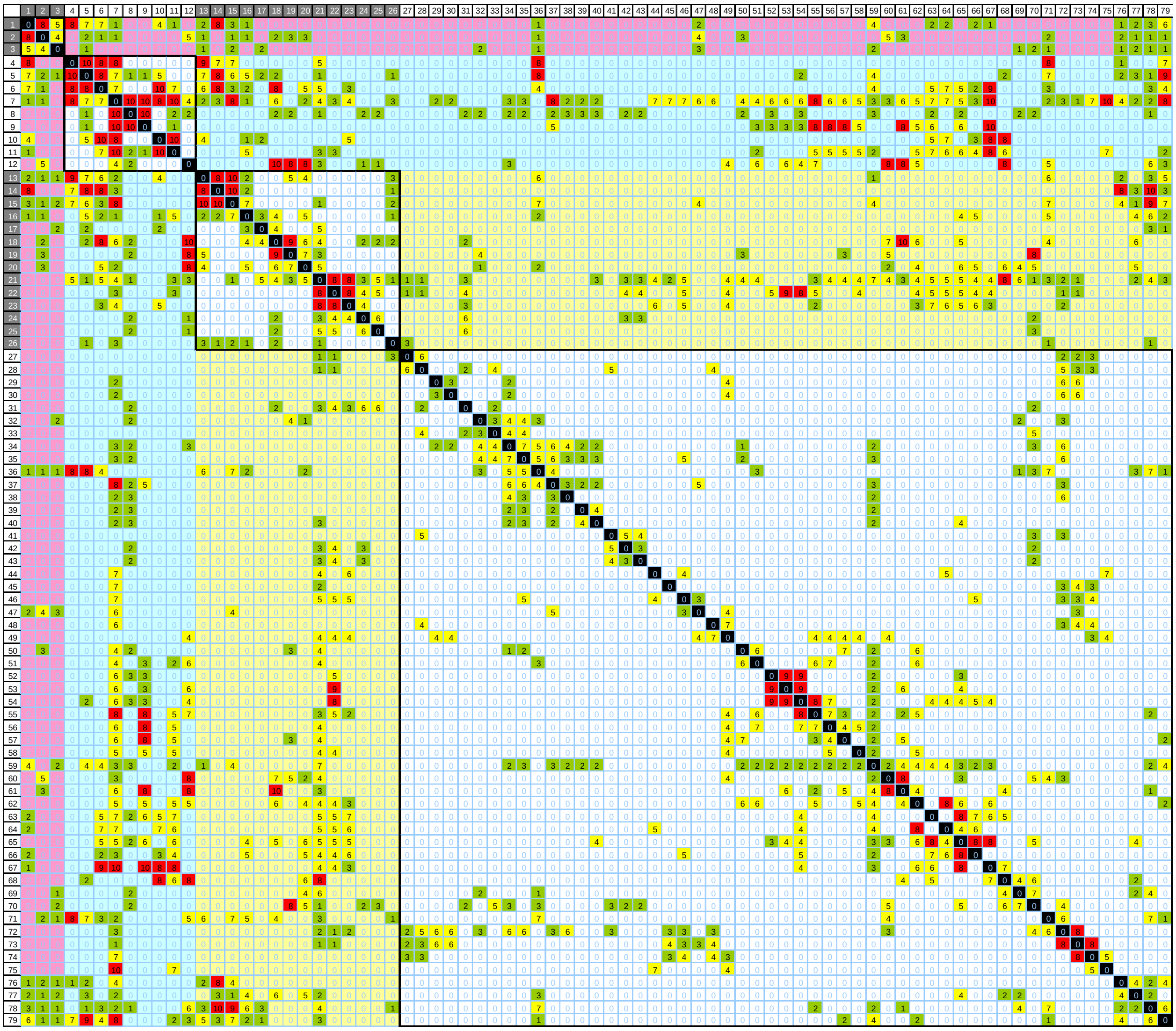
15	Maybe	Sourcing	PO Tracking
16	Maybe	Sourcing	Material (Hardware) Delivery Tracking (internal)
17	Maybe	Sourcing	Material (Hardware) Delivery Tracking (external)
18	Yes	AME	Product test revisions
19	Yes	AME	Transition opportunity identification on phase 6 products
20	Yes	AME	Identify Redesigns in IPDS Phase 6
21	Yes	AME	Idea financial analysis (ROI & NPV)
22	Yes	AME	MOR Reporting tools and support
23	Yes	AME	AME tool support and improvements
24	Yes	AME	Alternate material analysis (non-electrical components)
25	Yes	AME	Machining vs casting manufacturing analysis (DfM)
26	Yes	AME	Part count reduction identification (Mechanical DfA)
27	Yes	AME	Assembly human factors/part interference accessibility analysis (DfA)
28	Yes	AME	Fastener/connector/harness analysis (DfA)
29	Yes	AME	Product complexity analysis (Mechanical DfM/DfA)
30	Yes	AME	Mechanical part complexity analysis (DfM)
31	Yes	AME	Composite complexity analysis (DfM)
32	Yes	AME	CCA Complexity Analysis (DfM)
33	Yes	AME	Design for X idea generation
34	Maybe	AME	Manufacturing Process cost analysis (Bill of Processes)
35	Maybe	Engineering	Mfg Process Identification (available options)
36	Yes	AME	Quality/Yield Analysis & Prediction (DfM)
37	Yes	AME	Analysis of robustness and immunity to variation/reliability
38	Yes	AME	Analysis of design to test requirements (testability)
39	Yes	AME	Producability feedback from suppliers
40	Yes	AME	Collect R&O reparability and maintainability feedback from previous products
41	Maybe	ISC	Capture Cpk for key processes
42	Maybe	Sourcing	Determine supplier process capability
43	Maybe	Sourcing	Supplier capacity analysis
44	Maybe	Sourcing	PO Placement
45	Maybe	AME	Develop product cost roadmap
46	Maybe	AME	Monitor product cost
47	Yes	AME	Monitor program cost
48	Yes	AME	Process Management
49	Yes	AME	Design assurance documentation for electronic hardware
50	Yes	AME	Competitive Analysis for ISC (us vs. competitors)
51	Maybe	Sourcing	Identify Potential Suppliers
52	Maybe	Sourcing	Make/Buy analysis
53	No	AME	Re-use, Modularity, etc.

Table 3: Full Process List

3.3.3. DSM Population

The co-location scores in the DSM were assigned based on the importance of these process interactions are without regard to where these processes are currently performed. The numbers in the DSM are based on interviews with people who carried out the tasks and interviews with AME management. Some effort was made to capture process co-location requirements inherent to the processes themselves, even though these judgments were sometimes hard for interviewees to divorce from the status quo.

Table 4 shows the full DSM we put together for this analysis. This DSM has been grouped into four groups outlined by the four boxes along the matrix diagonal. The large box on the bottom right corner is the matrix of tasks that will be considered “portable” for this analysis. This box includes all AME tasks and all tasks that were rated a “Maybe” or a “Yes” in Portability in Table 3. The first three grouped boxes are tasks that are “unportable,” meaning they will not be considered for moving to a global site in this analysis. Reading from the top right corner, they correspond to tasks owned by Marketing & Program Management, Engineering, and ISC that will be constrained to stay at the local site for this analysis.



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2	8	0	4	0	2	1	1	0	0	0	0	5	1	0	1	1	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	3	0	0	0	0	0	0	0	0	0	5	3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	1	1	1
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43	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
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45	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	3	0	0	0	0	0
46	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	3	3	4	0	0	0	0	0
47	2	4	3	0	0	0	6	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	3	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
48	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	4	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	4	4	4	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	7	0	0	0	0	0	0	4	4	4	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0
50	0	3	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	7	0	2	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	4	0	3	0	2	6	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	6	7	0	0	2	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	0	0	0	0	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	6	0	3	0	0	6	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	9	0	0	0	0	2	0	6	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	2	0	6	3	3	0	0	4	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	0	8	7	0	0	2	0	0	0	4	4	4	5	4	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	8	0	8	0	5	7	0	0	0	0	0	0	0	0	3	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	6	0	0	8	0	7	3	0	2	0	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
56	0	0	0	0	0	0	6	0	8	0	5	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	7	0	0	7	7	0	4	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	6	0	8	0	5	0	0	0	0	0	0	0	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	7	0	0	0	0	3	4	0	0	2	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
58	0	0	0	0	0	0	5	0	5	0	5	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	5	0	0	2	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	4	0	2	0	4	4	3	3	0	0	2	0	1	0	4	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	3	2	2	2	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	0	2	4	4	4	4	3	2	3	0	0	0	0	0	0	0	0	0	0	2	4
60	0	5	0	0	0	0	3	0	0	0	0	8	0	0	0	0	0	7	5	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	0	8	0	0	0	3	0	0	0	0	5	4	3	0	0	0	0	0	0	0
61	0	3	0	0	0	0	6	0	8	0	0	8	0	0	0	0	0	10	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	2	0	5	0	4	8	0	4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	1	0
62	0	0	0	0	0	0	5	0	5	0	5	5	0	0	0	0	0	6	0	4	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	0	0	0	5	0	0	5	4	0	4	0	0	8	6	0	6	0	0	0	0	0	0	0	0	0	0	0	2
63	2	0	0	0	0	5	7	2	6	5	7	0	0	0	0	0	0	0	0	0	5	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	4	0	0	0	0	0	8	7	6	5	0	0	0	0	0	0	0	0	0	0	0
64	2	0	0	0	0	7	7	0	0	7	6	0	0	0	0	0	0	0	0	0	5	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	4	0	0	0	0	4	0	0	8	0	0	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	5	5	2	6	0	6	0	0	0	0	4	0	5	0	6	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	3	4	4	0	0	0	0	3	3	0	6	8	4	0	8	8	0	0	5	0	0	0	0	0	0	4	0	0
66	2	0	0	0	0	2	3	0	0	3	4	0	0	0	0	5	0	0	0	5	4	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	5	0	0	0	0	2	0	0	0	7	6	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1	0	0	0	0	9	10	0	10	8	8	0	0	0	0	0	0	0	0	0	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	6	6	0	8	0	0	7	0	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	2	0	0	0	0	8	6	8	0	0	0	0	0	0	0	6	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	5	0	0	0	7	0	4	6	0	0	0	0	0	0	2	0	0
69	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	7	0	0	0	0	0	0	2	4	0
70	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	8	5	1	0	0	2	3	0	0	0	0	0	2	0	5	3	0	3	0	0	0	0	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	5	0	0	6	7	0	0	4	0	0	0	0	0	0	0
71	0	2	1	8	7	3	2	0	0	0	0	5	6	0	7	5	0	4	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	7	1
72	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	0	0	0	2	5	6	6	0	3	0	6	6	0	3	6	0	0	3	0	0	0	3	3	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	4	6	0	8	0	0	0	0	0	0
73	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2	3	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	0	0	0	0	0
74	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	5	0	0	0	0
75	0	0	0	0	0	0	10	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
76	1	2	1	1	2	0	4	0	0	0	0	0	2	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	4
77	2	1	2	0	3	0	2	0	0	0	0	0	0	3	1	4	0	6	0	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	2	2	0	0	0	0	0	0	4	0	2	0
78	3	1	1	0	1	3	2	1	0	0	0	6	3	10	9	6	3	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	1	0	0	0	0	0	0	0	4	0	7	0	0	0	0	2	2	0	6
79	6	1	1	7	9	4	8	0	0	0	2	3	5	3	7	2	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	6	0

Table 4: Full DSM

3.4. Model Setup

This section describes the setup of the model for solving the Honeywell co-location problem. This is a two-site model that decides between keeping a task at its current local site and moving it to a global site based on the coordination structure of all processes in the DSM. We begin by describing site definitions and assumptions in the model.

3.4.1. Site Definitions

Each portable task can be assigned to one of two sites, the local site where it currently resides, or to a new global site where tasks will be centralized. There are three types of coordination between any pair of tasks that result from these parameters:

- **Local-Local Coordination:** Both tasks are done in the local site
- **Local-Global Coordination:** One task is done at the local site, the other task is done at the global site.
- **Global-Global Coordination:** Both tasks are done at the global site.

The global site was used as a placeholder for a to-be-determined site where AME would assign the bulk of its off-shored activities. This way, the coordination structure of AME's activities determines a set of activities that are good candidates for globalization, which helps us select an appropriate site to place these activities, not the other way around.

3.4.2. Assumptions

Before this point, some key assumptions have already been made in this model. A set of tasks in the DSM have been assumed to be unportable, and cannot be moved to the global site. The DSM itself was built based on many assumptions of how important it is for pairs of tasks to be co-located.

The next set of assumptions we make have to do with coordination penalties for the three types of coordination described in the previous section. The DSM was created assuming Local-Local coordinations. Local-Global coordinations are the most costly because of the overseas transactions that will have to take place. For these coordinations, we apply a multiplicative penalty factor of 1.5 to all DSM entries, meaning cross-site coordinations will take about 50% longer than local-only coordinations. Similarly, a penalty factor of 1.25 is applied for all Global-Global coordinations, meaning coordinations taking place at the global site will take 25% longer than local-only coordinations. AME will be operating globally at this scale for the first time, coordinations that take place exclusively at the global site may be less efficient simply because this will be a new site. Also, these coordinations may need to be facilitated or monitored remotely through a third party at a local site, making this a Global-Local-Global coordination rather than a true Global-Global coordination.

3.5. Solution and Results

This application involved solving the decision model twice for the set of tasks that can be moved to the global site. This first model reveals a coordination structure diagram that helps us group together tasks of like portability and high co-location affinity together to form job descriptions of several activities. The second model solves for which task groups should be moved to the global site. By moving groups of tasks rather than individual tasks, the final solution simulates hiring people abroad to support AME program managers. The local AME resources retain responsibility for the non-globalized “jobs.”

The models for both stages were implemented in Excel and solved using the Frontline Solver 7.0 add-in. The model assumptions described in Section 3.4.2 were used in both stages.

3.5.1. Stage 1: Task Based Solution

In this first solution, the model allows all portable tasks to be assigned independently to either the local or the global site. The goal is to see which tasks move together and to form job descriptions out of tasks of similar portability. Of the 79 tasks mapped in the DSM, 53 tasks are portable, meaning they are free to be assigned to either the local or the global site. The other 26 tasks are constrained to stay at the local site, but still play an important role in the solution because high coordination costs between portable and non-portable tasks make it very costly to globalize the portable tasks.

Since the model formulation is based on sums of all coordination values in the DSM, we can collapse several tasks together by summing together the coordination values within those groups. For ease of use, the 26 tasks that are constrained to stay at the local site have been collapsed into 3 cells, A, B, and C, corresponding to the M&PM, Engineering, and ISC constrained tasks, respectively. The summed values inside the A, B, and C diagonal do not change with different solutions, so they are set to 0 for this analysis.

The resulting 2-site coordination matrix has 109 rows and columns, 3 for the task groups constrained to the local site, and 53 for local tasks, 53 for global tasks. There are 106 (2 sites possible for each of 53 portable tasks) binary decision variables to set for the portable tasks. Figure 15 shows the resulting coordination matrix.

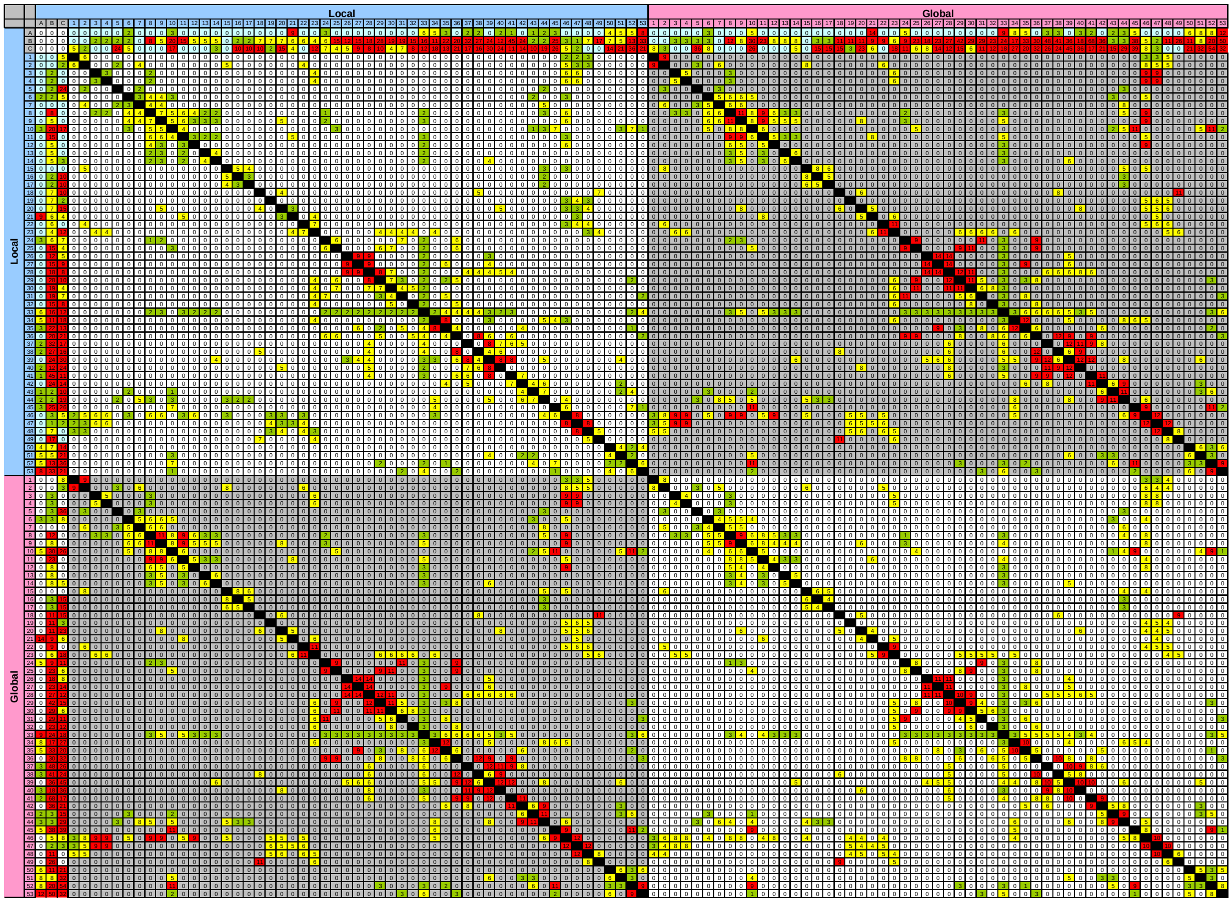
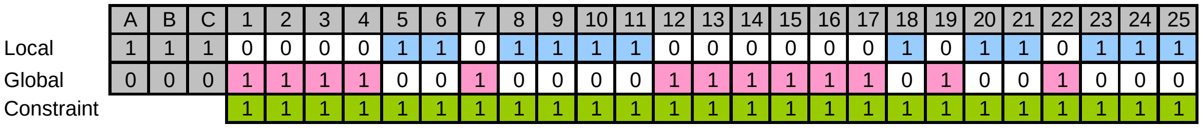


Figure 15: Stage 1 Coordination Matrix

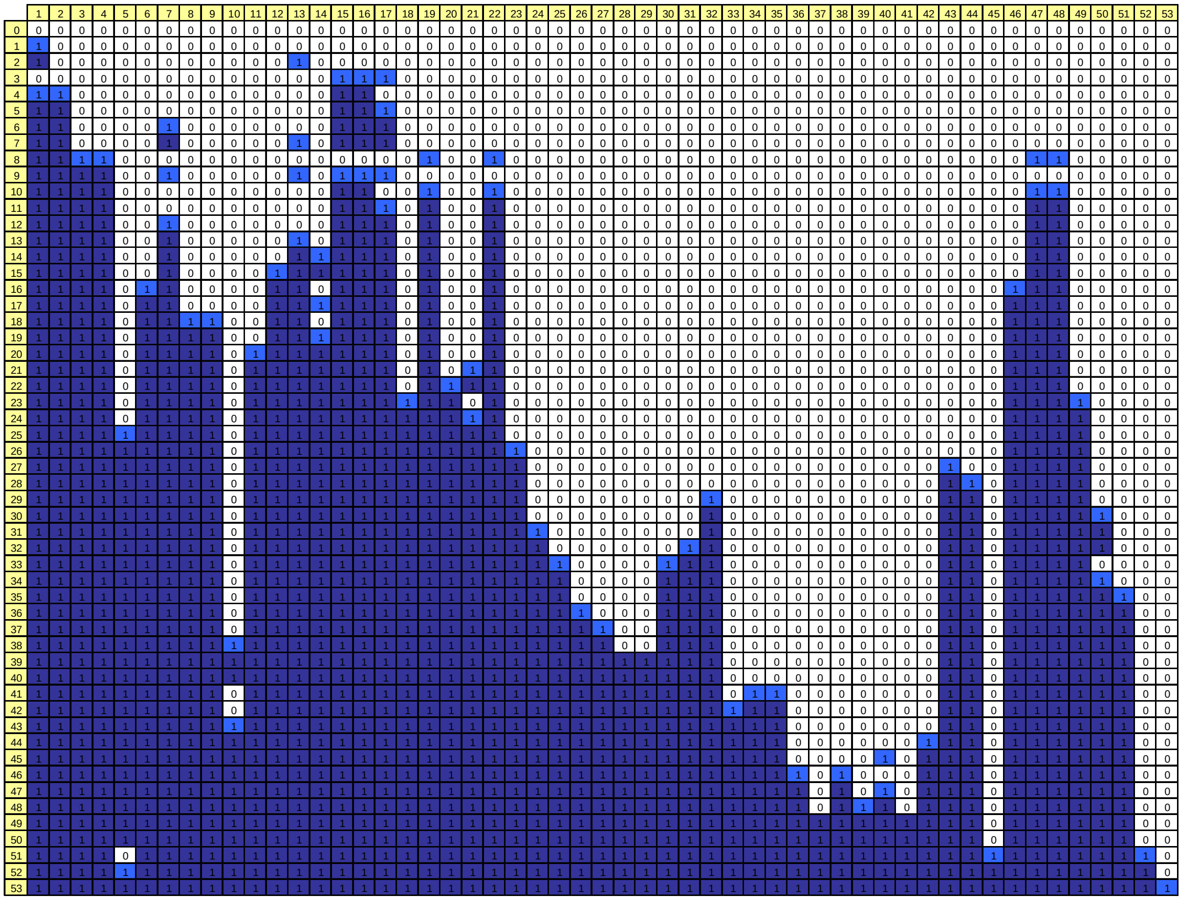
Figure 16 is a snapshot of the spreadsheet representation of the binary decision variables for the first 25 portable tasks. The decision variables choose which pairs of coordinations to read off of the coordination matrix. The first row has 1’s where the model has chosen to put each task at the local site. Tasks chosen for the global site have 1's in the second row. The third row shows the constraint that rows 1 and 2 must sum to 1 for each task. These decision variables happen to be showing a solution where the constraint was to move 15 or more tasks to the global site.



	A	B	C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Local	1	1	1	0	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	1	0	1	1	0	1	1	1
Global	0	0	0	1	1	1	1	0	0	1	0	0	0	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0
Constraint				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 16: Stage 1 Decision Variables for Tasks 1-25

This model was solved for all 53 possible constraint conditions Y_2, the minimum number of tasks that needed to be moved to the global site. The resulting coordination structure diagram is shown below in Figure 17. The columns are labeled with the ID numbers for each of the 53 portable tasks. The rows show the solutions for increasing constraint conditions Y_2, starting with no globalization requirement, and ending with all 53 tasks at the global site. Tasks that were assigned by the model to the global site under each constraint condition are indicated by 1's with shaded squares in their respective columns. The light shaded squares simply highlight the tasks that were chosen for globalization but were not moved in the solution immediately above it. This helps to show what changed from one solution to the next.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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Figure 17: Stage 1 Coordination Structure Diagram

Reading down the columns of the coordination structure diagram, we can characterize each task as an early mover, late mover, or a flip-flopper. Late movers are the easiest to identify. Task 53 (Re-use, Modularity, etc.) does not move until the bitter end, when the model forces all 53 tasks to move to the global site. Likewise, Tasks 37 (Analysis of robustness and immunity to variation/reliability), 41 (Capture Cpk for key processes), 45 (Develop product cost roadmap), and 52 (Make/Buy analysis) move very late in the game and never flip back and forth. These are tasks that are very costly to globalize because they have such strong coordination requirements with unportable tasks. In contrast, early movers are the most portable tasks in the DSM. Interestingly, many early movers are also flip-floppers because they are some of the most flexible tasks. For example, the first two tasks to move are Task 1 and Task 13, but both of these tasks flip back to the local site when 3 tasks need to be moved to the global site. The flip-flopping behavior yields some very interesting insights on what tasks like to naturally group together. For example, Tasks 15 (PO Tracking), 16 (Material Delivery Tracking – internal), and 17 (Material Delivery Tracking – external) have high co-location affinity, causing them to flip back and forth together. Similarly Tasks 47 (Monitor program cost) and 48 (Process Management) move to the global site at a constraint of 8 tasks, jump back together at 9, and stay at the global site for constraints of 10 or more tasks. These tasks are moderately-early movers that like to stick together.

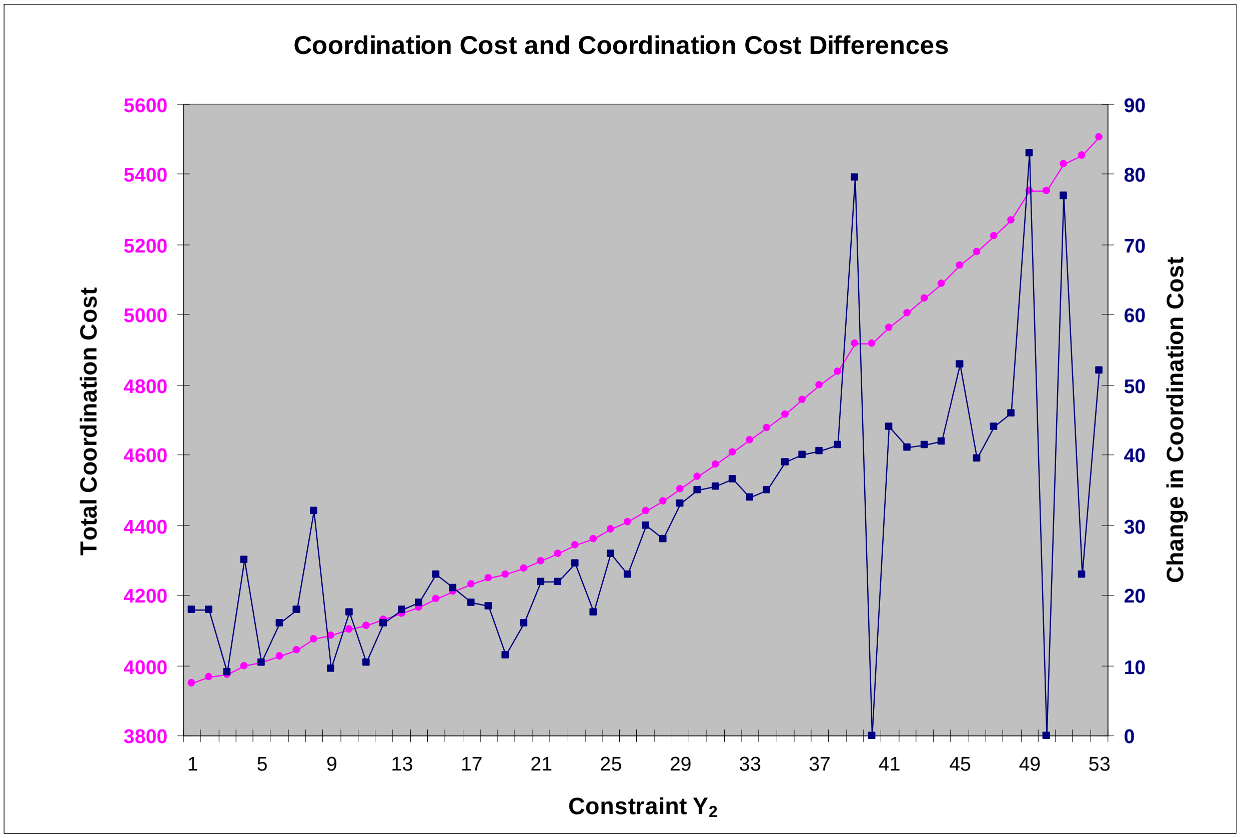

Figure 18: Coordination Costs for Stage 1 Solutions

Figure 18 shows what is happening to coordination cost as the constraint Y_2 forces more and more tasks to move to the global site. This chart has two vertical axes. The axis on the left corresponds to the curved ascending line which graphs total coordination costs. The axis on the right corresponds to the jagged line which graphs the difference in coordination cost for each solution and the solution requiring one less globalized task. There are two kinks in the total coordination cost plot at constraints 39 and 49. These are solutions where it is less costly to off-shore one more task than what is required by the constraint Y_2. The graph for change in coordination costs is characterized by some small steps followed by large peaks. Breaks before the large peaks are good points to think twice before requiring more tasks to move to the global site. Likewise, some increases in Y_2 can be achieved with very small gains in coordination cost. For example, the added coordination cost between off-shoring 8 tasks and 9 tasks is relatively low, whereas the additional coordination cost between $Y_2 = 38$ and $Y_2 = 39$ is very large.

3.5.2. Task Groups

Using the coordination structure diagram and some management judgment, we can start grouping tasks together into job descriptions. Task groups should ideally contain tasks of like portability and tasks that have co-location affinity as revealed from the Stage 1 model results. If a job description contains an early mover and two very late movers, for example, the task that is an early mover will get stuck not being moved to the global site until very late in the game. That being said, it is still reasonable to group tasks together of dissimilar portability for other strategic reasons. Some common sense also needs to be used to make sure task groups match up with reasonable sets of skills that can be found in one person. For example, CCA analysis is separated from other complexity analysis tasks because it requires electrical engineering expertise, while the others require material science or mechanical engineering expertise. We were okay with grouping CCA analysis by itself because the task was significant enough for us to write a job description for it on its own.

Figure 19 shows the coordination structure diagram once again in conjunction with the 25 task groups that were determined using the Stage 1 analysis results. Yellow boxes highlight the tasks included in each group. Each group contains 1-3 tasks. Table 5 lists the task groups by name.

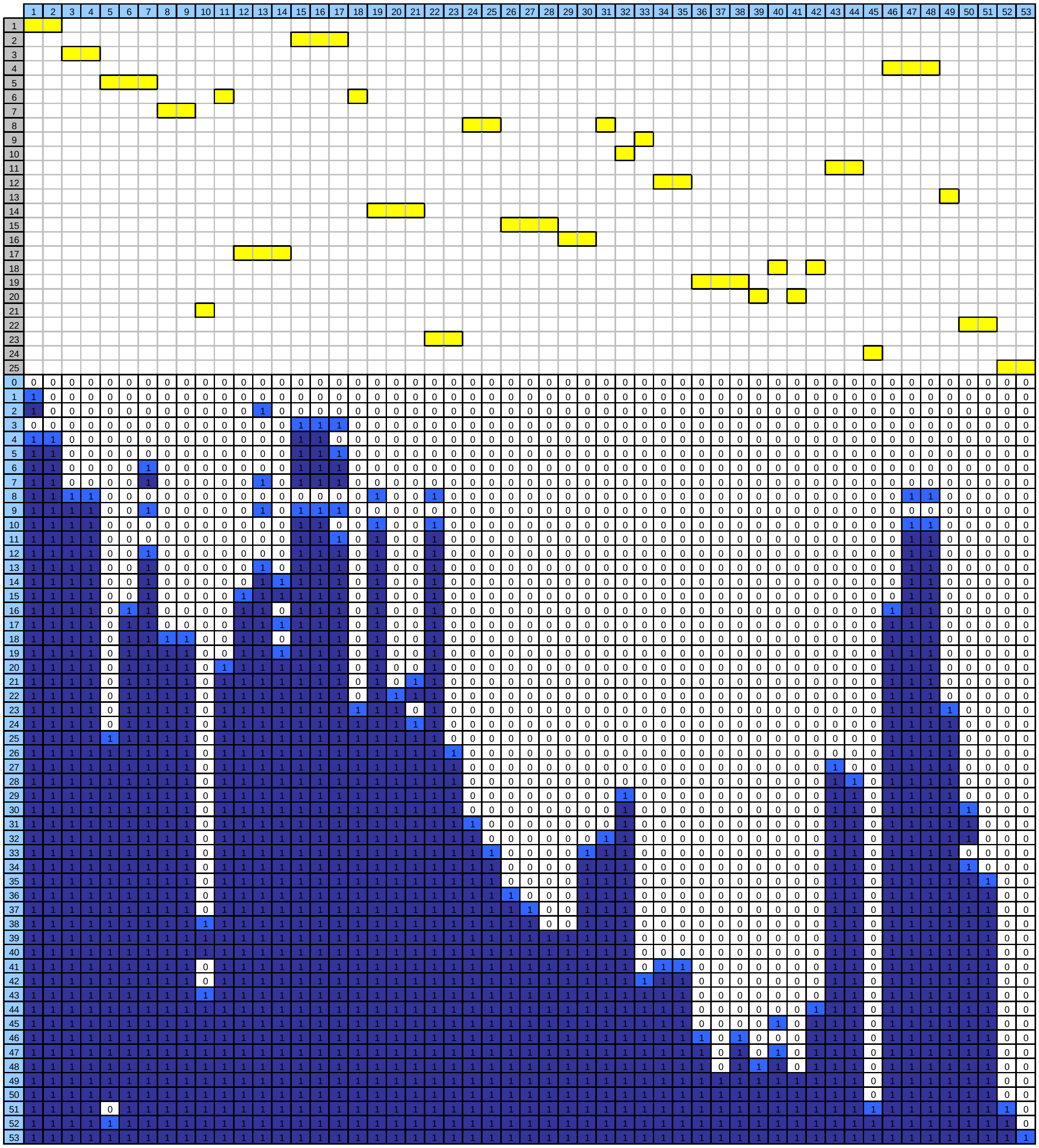

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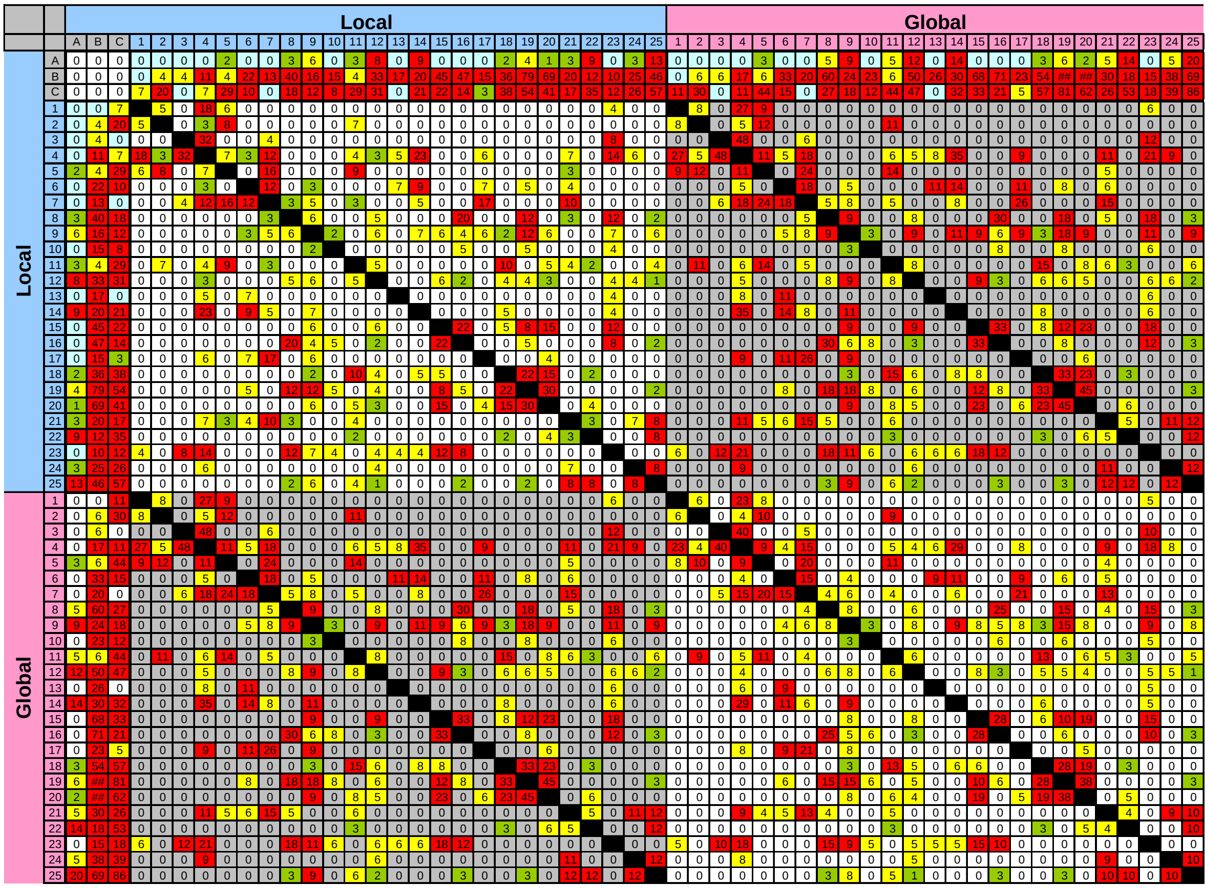
Figure 19: Coordination Structure Diagram with Task Groups

1	JO Creation and Tracking (Budget management) Budget Analysis and Tracking
2	PO Tracking Material (Hardware) Delivery Tracking (internal) Material (Hardware) Delivery Tracking (external)
3	Savings Tracking Savings Validation
4	Monitor product cost Monitor program cost Process Management
5	Capital Request Tracking Quote Acquisition Quote Tracking
6	Identify component replacement opportunities Product test revisions
7	BOM cost analysis BOM alternate part cost analysis
8	Alternate material analysis (non-electrical components) Machining vs casting manufacturing analysis (DfM) Composite complexity analysis (DfM)
9	Design for X idea generation
10	CCA Complexity Analysis (DfM)
11	Supplier capacity analysis PO Placement
12	Manufacturing Process cost analysis (Bill of Processes) Mfg Process Identification (available options)
13	Design assurance documentation for electronic hardware
14	Transition opportunity identification on phase 6 products Identify Redesigns in IPDS Phase 6 Idea financial analysis (ROI & NPV)
15	Part count reduction identification (Mechanical DfA) Assembly human factors/part interference accessibility analysis (DfA) Fastener/connector/harness analysis (DfA)
16	Product complexity analysis (Mechanical DfM/DfA) Mechanical part complexity analysis (DfM)
17	BOM analysis life cycle screen for obsolescence Check BOM for export compliance Check BOM for environmental impact
18	Collect R&O reparability and maintainability feedback from previous products Determine supplier process capability
19	Quality/Yield Analysis & Prediction (DfM) Analysis of robustness and immunity to variation/reliability Analysis of design to test requirements (testability)
20	Producability feedback from suppliers Capture Cpk for key processes
21	Should-Cost Modeling
22	Competitive Analysis for ISC (us vs. competitors) Identify Potential Suppliers
23	MOR Reporting tools and support AME tool support and improvements
24	Develop product cost roadmap
25	Make/Buy analysis Re-use, Modularity, etc.

Table 5: List of Task Groups

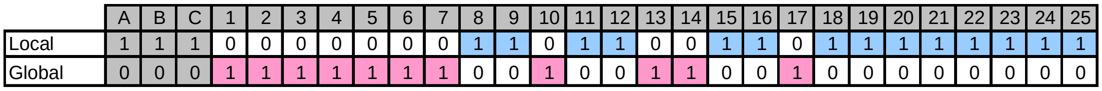
3.5.3. Stage 2: Job Based Solution

The second stage of the solution is assign jobs to globalize using the task groupings defined in Table 5. To get the new coordination matrix, we resort the original matrix so that tasks are grouped by clusters, and sum the scores of all coordinations within cluster groups, the same way we had collapsed tasks A, B, and C earlier. Again, the summed scores within the diagonal of each group can be eliminated because these scores do not change with different model solutions. Thus total coordination scores will be lower than the starting score for the Stage 1 solution, but this does not matter because we are only interested in the lowest-cost task arrangements given each constraint Y_2. Figure 20 shows the full Stage 2 coordination matrix. This time, numbers from 1-25 represent task groups, not individual tasks. A, B, and C represent the same collapsed sets of tasks as before. The 50 decision variables for this problem are shown in Figure 21.



		Local																												Global																								
		A	B	C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	A	0	0	0	0	0	0	0	2	0	0	3	6	0	3	8	0	9	0	0	0	2	4	1	3	9	0	3	13	0	0	0	0	3	0	0	5	9	0	5	12	0	14	0	0	0	3	6	2	5	14	0	5	20
	B	0	0	0	0	4	4	11	4	22	13	40	16	15	4	33	17	20	45	47	15	36	79	69	20	12	10	25	46	0	6	6	17	6	33	20	60	24	23	6	50	26	30	68	71	23	54	##	##	30	18	15	38	69
	C	0	0	0	7	20	0	7	29	10	0	18	12	8	29	31	0	21	22	14	3	38	54	41	17	35	12	26	57	11	30	0	11	44	15	0	27	18	12	44	47	0	32	33	21	5	57	81	62	26	53	18	39	86
Local	1	0	0	7	■	5	0	18	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	■	8	0	27	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
	2	0	4	20	5	■	0	3	8	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	■	0	5	12	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	4	0	0	0	■	32	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	■	48	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0
	4	0	11	7	18	3	32	■	7	3	12	0	0	0	4	3	5	23	0	0	6	0	0	0	7	0	14	6	0	27	5	48	■	11	5	18	0	0	0	6	5	8	35	0	0	9	0	0	0	11	0	21	9	0
	5	2	4	29	6	8	0	7	■	0	16	0	0	0	9	0	0	0	0	0	0	0	0	0	3	0	0	0	0	9	12	0	11	■	0	24	0	0	0	14	0	0	0	0	0	0	0	0	0	5	0	0	0	0
	6	0	22	10	0	0	0	3	0	■	12	0	3	0	0	0	7	9	0	0	7	0	5	0	4	0	0	0	0	0	0	0	5	0	■	18	0	5	0	0	0	11	14	0	0	11	0	8	0	6	0	0	0	0
	7	0	13	0	0	0	4	12	16	12	■	3	5	0	3	0	0	5	0	0	17	0	0	0	10	0	0	0	0	0	0	6	18	24	18	■	5	8	0	5	0	0	8	0	0	26	0	0	0	15	0	0	0	0
	8	3	40	18	0	0	0	0	0	0	3	■	6	0	0	5	0	0	0	20	0	0	12	0	3	0	12	0	2	0	0	0	0	0	0	5	■	9	0	0	8	0	0	0	30	0	0	18	0	5	0	18	0	3
	9	6	16	12	0	0	0	0	0	3	5	6	■	2	0	6	0	7	6	4	6	2	12	6	0	0	7	0	6	0	0	0	0	0	5	8	9	■	3	0	9	0	11	9	6	9	3	18	9	0	0	11	0	9
	10	0	15	8	0	0	0	0	0	0	0	0	2	■	0	0	0	0	0	5	0	0	5	0	0	0	4	0	0	0	0	0	0	0	0	0	0	3	■	0	0	0	0	0	8	0	0	8	0	0	0	6	0	0
	11	3	4	29	0	7	0	4	9	0	3	0	0	0	■	5	0	0	0	0	0	10	0	5	4	2	0	0	4	0	11	0	6	14	0	5	0	0	0	■	8	0	0	0	0	0	15	0	8	6	3	0	0	6
	12	8	33	31	0	0	0	3	0	0	0	5	6	0	5	■	0	0	6	2	0	4	4	3	0	0	4	4	1	0	0	0	5	0	0	0	8	9	0	8	■	0	0	9	3	0	6	6	5	0	0	6	6	2
	13	0	17	0	0	0	0	5	0	7	0	0	0	0	0	0	■	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	8	0	11	0	0	0	0	0	0	■	0	0	0	0	0	0	0	0	0	6	0	0
	14	9	20	21	0	0	0	23	0	9	5	0	7	0	0	0	0	■	0	0	0	5	0	0	0	0	4	0	0	0	0	0	35	0	14	8	0	11	0	0	0	0	■	0	0	0	8	0	0	0	0	6	0	0
	15	0	45	22	0	0	0	0	0	0	0	0	6	0	0	6	0	0	■	22	0	5	8	15	0	0	12	0	0	0	0	0	0	0	0	0	0	9	0	0	9	0	0	■	33	0	8	12	23	0	0	18	0	0
	16	0	47	14	0	0	0	0	0	0	0	20	4	5	0	2	0	0	22	■	0	0	5	0	0	0	8	0	2	0	0	0	0	0	0	0	30	6	8	0	3	0	0	33	■	0	0	8	0	0	0	12	0	3
	17	0	15	3	0	0	0	6	0	7	17	0	6	0	0	0	0	0	0	0	■	0	0	4	0	0	0	0	0	0	0	0	9	0	11	26	0	9	0	0	0	0	0	0	0	■	0	0	6	0	0	0	0	0
	18	2	36	38	0	0	0	0	0	0	0	0	2	0	10	4	0	5	5	0	0	■	22	15	0	2	0	0	0	0	0	0	0	0	0	0	0	3	0	15	6	0	8	8	0	0	■	33	23	0	3	0	0	0
	19	4	79	54	0	0	0	0	0	5	0	12	12	5	0	4	0	0	8	5	0	22	■	30	0	0	0	0	2	0	0	0	0	0	8	0	18	18	8	0	6	0	0	12	8	0	33	■	45	0	0	0	0	3
	20	1	69	41	0	0	0	0	0	0	0	0	6	0	5	3	0	0	15	0	4	15	30	■	0	4	0	0	0	0	0	0	0	0	0	0	0	9	0	8	5	0	0	23	0	6	23	45	■	0	6	0	0	0
	21	3	20	17	0	0	0	7	3	4	10	3	0	0	4	0	0	0	0	0	0	0	0	0	■	3	0	7	8	0	0	0	11	5	6	15	5	0	0	6	0	0	0	0	0	0	0	0	0	■	5	0	11	12
	22	9	12	35	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	4	3	■	0	0	8	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	6	5	■	0	0	12
	23	0	10	12	4	0	8	14	0	0	0	12	7	4	0	4	4	4	12	8	0	0	0	0	0	0	■	0	0	6	0	12	21	0	0	0	18	11	6	0	6	6	6	18	12	0	0	0	0	0	0	■	0	0
	24	3	25	26	0	0	0	6	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	7	0	0	■	8	0	0	0	9	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	11	0	0	■	12
	25	13	46	57	0	0	0	0	0	0	0	2	6	0	4	1	0	0	0	2	0	0	2	0	8	8	0	8	■	0	0	0	0	0	0	0	3	9	0	6	2	0	0	0	3	0	0	3	0	12	12	0	12	■
Global	1	0	0	11	■	8	0	27	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	■	6	0	23	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
	2	0	6	30	8	■	0	5	12	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	■	0	4	10	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	6	0	0	0	■	48	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	■	40	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
	4	0	17	11	27	5	48	■	11	5	18	0	0	0	6	5	8	35	0	0	9	0	0	0	11	0	21	9	0	23	4	40	■	9	4	15	0	0	0	5	4	6	29	0	0	8	0	0	0	9	0	18	8	0
	5	3	6	44	9	12	0	11	■	0	24	0	0	0	14	0	0	0	0	0	0	0	0	0	5	0	0	0	0	8	10	0	9	■	0	20	0	0	0	11	0	0	0	0	0	0	0	0	0	4	0	0	0	0
	6	0	33	15	0	0	0	5	0	■	18	0	5	0	0	0	11	14	0	0	11	0	8	0	6	0	0	0	0	0	0	0	4	0	■	15	0	4	0	0	0	9	11	0	0	9	0	6	0	5	0	0	0	0
	7	0	20	0	0	0	6	18	24	18	■	5	8	0	5	0	0	8	0	0	26	0	0	0	15	0	0	0	0	0	0	5	15	20	15	■	4	6	0	4	0	0	6	0	0	21	0	0	0	13	0	0	0	0
	8	5	60	27	0	0	0	0	0	0	5	■	9	0	0	8	0	0	0	30	0	0	18	0	5	0	18	0	3	0	0	0	0	0	0	4	■	8	0	0	6	0	0	0	25	0	0	15	0	4	0	15	0	3
	9	9	24	18	0	0	0	0	0	5	8	9	■	3	0	9	0	11	9	6	9	3	18	9	0	0	11	0	9	0	0	0	0	0	4	6	8	■	3	0	8	0	9	8	5	8	3	15	8	0	0	9	0	8
	10	0	23	12	0	0	0	0	0	0	0	0	3	■	0	0	0	0	0	8	0	0	8	0	0	0	6	0	0	0	0	0	0	0	0	0	0	3	■	0	0	0	0	0	6	0	0	6	0	0	0	5	0	0
	11	5	6	44	0	11	0	6	14	0	5	0	0	0	■	8	0	0	0	0	0	15	0	8	6	3	0	0	6	0	9	0	5	11	0	4	0	0	0	■	6	0	0	0	0	0	13	0	6	5	3	0	0	5
	12	12	50	47	0	0	0	5	0	0	0	8	9	0	8	■	0	0	9	3	0	6	6	5	0	0	6	6	2	0	0	0	4	0	0	0	6	8	0	6	■	0	0	8	3	0	5	5	4	0	0	5	5	1
	13	0	26	0	0	0	0	8	0	11	0	0	0	0	0	0	■	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	6	0	9	0	0	0	0	0	0	■	0	0	0	0	0	0	0	0	0	5	0	0
	14	14	30	32	0	0	0	35	0	14	8	0	11	0	0	0	0	■	0	0	0	8	0	0	0	0	6	0	0	0	0	0	29	0	11	6	0	9	0	0	0	0	■	0	0	0	6	0	0	0	0	5	0	0
	15	0	68	33	0	0	0	0	0	0	0	0	9	0	0	9	0	0	■	33	0	8	12	23	0	0	18	0	0	0	0	0	0	0	0	0	0	8	0	0	8	0	0	■	28	0	6	10	19	0	0	15	0	0
	16	0	71	21	0	0	0	0	0	0	0	30	6	8	0	3	0	0	33	■	0	0	8	0	0	0	12	0	3	0	0	0	0	0	0	0	25	5	6	0	3	0	0	28	■	0	0	6	0	0	0	10	0	3
	17	0	23	5	0	0	0	9	0	11	26	0	9	0	0	0	0	0	0	0	■	0	0	6	0	0	0	0	0	0	0	0	8	0	9	21	0	8	0	0	0	0	0	0	0	■	0	0	5	0	0	0	0	0
	18	3	54	57	0	0	0	0	0	0	0	0	3	0	15	6	0	8	8	0	0	■	33	23	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	13	5	0	6	6	0	0	■	28	19	0	3	0	0	0
	19	6	##	81	0	0	0	0	0	8	0	18	18	8	0	6	0	0	12	8	0	33	■	45	0	0	0	0	3	0	0	0	0	0	6	0	15	15	6	0	5	0	0	10	6	0	28	■	38	0	0	0	0	3
	20	2	##	62	0	0	0	0	0	0	0	0	9	0	8	5	0	0	23	0	6	23	45	■	0	6	0	0	0	0	0	0	0	0	0	0	0	8	0	6	4	0	0	19	0	5	19	38	■	0	5	0	0	0
	21	5	30	26	0	0	0	11	5	6	15	5	0	0	6	0	0	0	0	0	0	0	0	0	■	5	0	11	12	0	0	0	9	4	5	13	4	0	0	5	0	0	0	0	0	0	0	0	0	■	4	0	9	10
	22	14	18	53	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	6	5	■	0	0	12	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	5	4	■	0	0	10
	23	0	15	18	6	0	12	21	0	0	0	18	11	6	0	6	6	6	18	12	0	0	0	0	0	0	■	0	0	5	0	10	18	0	0	0	15	9	5	0	5	5	5	15	10	0	0	0	0	0	0	■	0	0
	24	5	38	39	0	0	0	9	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	11	0	0	■	12	0	0	0	8	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	9	0	0	■	10
	25	20	69	86	0	0	0	0	0	0	0	3	9	0	6	2	0	0	0	3	0	0	3	0	12	12	0	12	■	0	0	0	0	0	0	0	3	8	0	5	1	0	0	0	3	0	0	3	0	10	10	0	10	■

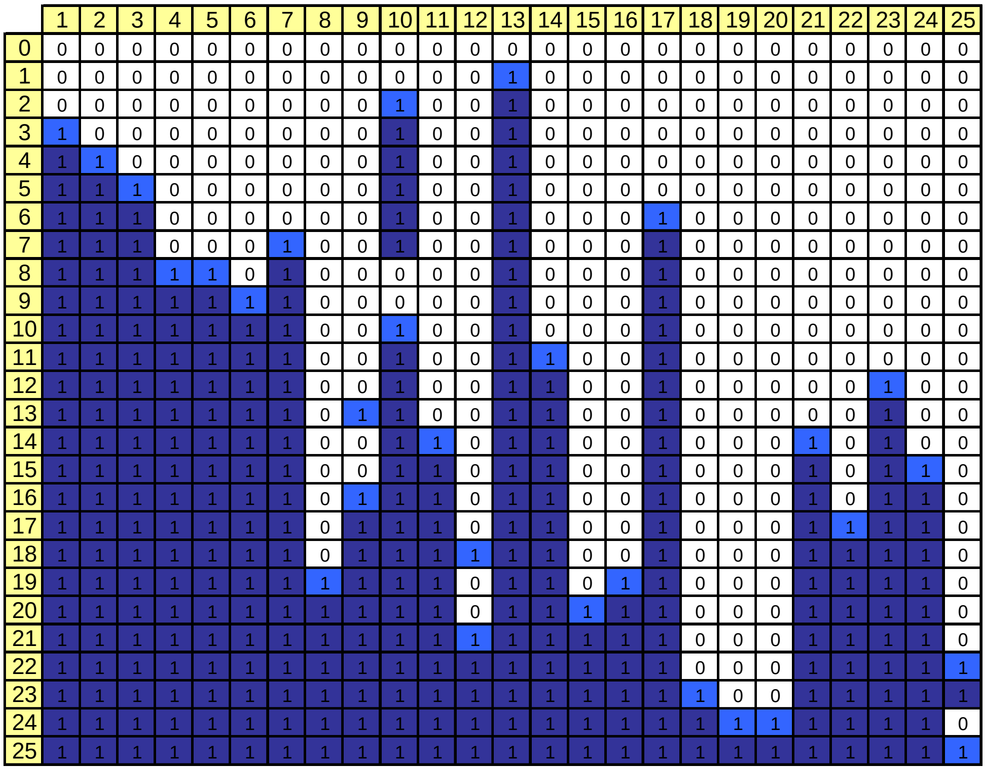
Figure 20: Stage 2 Coordination Matrix



	A	B	C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Local	1	1	1	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1
Global	0	0	0	1	1	1	1	1	1	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0

Figure 21: Stage 2 Decision Variables

The results of the Stage 2 analysis are shown in Figure 22 using the same format that was introduced in Figure 17 for the Stage 1 solution. Figure 23 graphs total coordination costs for each constraint condition as well as the change in coordination cost in the same format as Figure 18.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
5	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
7	1	1	1	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
8	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
9	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
10	1	1	1	1	1	1	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
11	1	1	1	1	1	1	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0
12	1	1	1	1	1	1	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0
13	1	1	1	1	1	1	1	0	1	1	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0
14	1	1	1	1	1	1	1	0	0	1	1	0	1	1	0	0	1	0	0	0	1	0	1	0	0
15	1	1	1	1	1	1	1	0	0	1	1	0	1	1	0	0	1	0	0	0	1	0	1	1	0
16	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	0	1	0	0	0	1	0	1	1	0
17	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	0	1	0	0	0	1	1	1	1	0
18	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	0	0	0	1	1	1	1	0
19	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	0	0	1	1	1	1	0
20	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	1	0
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 22: Stage 2 Coordination Structure Diagram

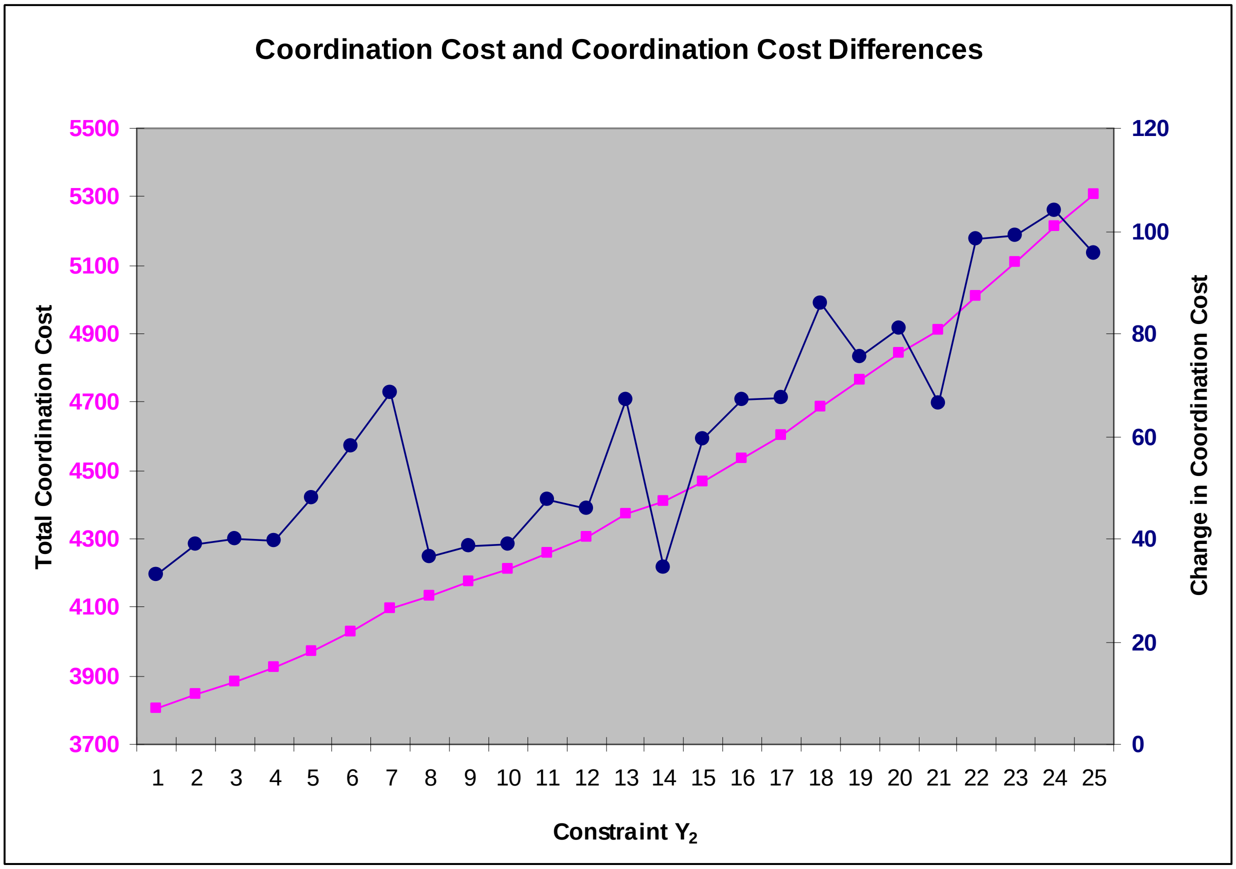


Figure 23: Coordination Costs for Stage 2 Solutions

Examining Figure 22, Groups 10 (circuit card assembly complexity analysis) and 13 (design assurance documentation for electronic hardware) immediately jump out as being good task groups to move early to the global site. The next groups that look good to move are groups 1, 2, and 3, which contain mostly of the budget and material tracking tasks. Groups 1 and 3 belong to AME, but group 2 belongs primarily to Sourcing, so it is something we can recommend for Sourcing to move, but cannot include in our own recommendations. The next groups that look like good globalization candidates are groups 7 and 17, which are the two groups of BOM analysis activities. AME should be very wary of high coordination costs if it wants to move any of the following groups: 18 (R&O feedback, supplier capability), 19 (Design for Quality/Variation/Test Analyses), 20 (Supplier producability and capturing Cpks), and 25 (Make/Buy, Re-use, Modularity).

3.6. Recommendations

This section describes the globalization recommendations that were made to Honeywell AME as a result of this internship. Phase 1 recommendations came from building the DSM, grouping tasks, and selecting jobs to place at the global site. For Phase 2, some predictions are made on what activities AME should take abroad next. This section describes how the model should be updated to reflect new information learned during Phase 1. Finally, this section includes a discussion of how these recommendations fit in with the ten GPD success factors described in Section 1.4.2.

3.6.1. Phase 1

The decision model helped us identify good tasks and groups of tasks to move early if AME were to perform activities at a global site. Table 6 lists the ten most portable task groups in the order they were identified by the model.

13	Design assurance documentation for electronic hardware
10	Circuit Card Assembly Complexity Analysis (DfM)
1	JO Creation and Tracking (Budget management) Budget Analysis and Tracking
2	PO Tracking Material (Hardware) Delivery Tracking (internal) Material (Hardware) Delivery Tracking (external)
3	Savings Tracking Savings Validation
17	BOM analysis life cycle screen for obsolescence Check BOM for export compliance Check BOM for environmental impact
7	BOM cost analysis BOM alternate part cost analysis
4	Monitor product cost Monitor program cost Process Management
5	Capital Request Tracking Quote Acquisition Quote Tracking
6	Identify component replacement opportunities Product test revisions

Table 6: Ten most portable task groups

The answers given by the model only account for the inputs we gave it, and it is important to remember that the computer program only knows how to find solutions that minimize coordination costs given the by the DSM built by the user. Other factors such as site capabilities, customer considerations, and IP concerns need to be considered in addition to coordination cost when making GPD decisions.

The recommendation made to AME during the internship was to globalize in stages and to start by hiring people at a new global site to perform some of the groups of tasks in Table 6.

The task groups we chose to globalize were groups 10, 1, 3, 17, and 7 because these are groups of AME-owned tasks. Group 13, Documentation of electronic hardware design changes, was tabled for the first phase, but AME managers leading Value Engineering activities are very interested in getting global support for this task for the following phase. Group 10, Circuit Card Assembly Complexity Analysis, is a particularly good fit at the global site because the site chosen has strong capabilities in electronics manufacturing engineering. Other related electrical DfM tasks (such as Group 13) will added to this role as it matures.

The total coordination cost of off-shoring groups 1, 3, 7, 10, and 17 is 4026, which is 200 points (about 7%) more costly than the total coordination cost of off-shoring nothing. This recommendation adds about 27% more in total coordination cost than the optimal solution the model found for off-shoring 5 or more groups of tasks. This is a good check to do to make sure the final recommendation does not drastically increase the coordination cost from the solutions the model recommends.

Job descriptions were written for groups of tasks identified through this analysis. Since then, AME has signed on more than 15 new people to work at a new global site identified for AME. The site was chosen for many reasons, one of which was its fit for the activities we identified for global support.

3.6.2. Phase 2

For the next phase, lessons learned from the first phase of implementation should be captured in the DSM and both stages of analysis should be run again to update recommendations on what to globalize next. Looking at the Stage 2 coordination structure diagram in Figure 22, the model currently recommends moving some of the product cost management and value engineering tasks next to the global site. We predict that when we run the model again with Phase 1 jobs constrained to the global site, some of the DfX analysis tasks will be good candidates for globalization as well, and AME would be particularly interested in moving activities related to electronics manufacturing because of the expertise available at this global site. In addition, the activities that should be added to the global site in the next phase may depend on AME's ability to convince Sourcing to move some of the task groups identified in the previous section. AME should work with Sourcing to hire people to do Groups 2 and 5 (Quote and material tracking activities) at the global site. If this is not possible, the model can easily be run again constraining these Sourcing tasks to stay at the local site. Some aspects of Group 3 (Savings Tracking and Savings Validation), can be supported through the Budget management and tracking tasks in Group 1, but other aspects are very core to the AME product manager's integrative duties and should not be globalized.

3.6.3. Integration with GPD Success Factors

Back in Section 1.4.2 of this paper, we listed 10 key GPD success factors described by Eppinger and Chitkara (29-30). These ten key success factors can be categorized as Strategic Design, Cultural, or Political factors following the MIT Sloan School of Management "Three Lenses view of Organizational Processes" (Carroll). Factors listed under multiple lenses are written in italics.

Strategic Design	**Cultural**	**Political**
Process Modularity (2) Product Modularity (3) *Core Competence (4)* Intellectual Property (5) Data Quality (6) *Infrastructure (7)* *Governance and Proj Mgmt (8)* *Org Change Mgmt (10)*	Collaborative Culture (9) *Core Competence (4)* *Infrastructure (7)* *Org Change Mgmt (10)*	Management Priority (1) *Core Competence (4)* *Infrastructure (7)* *Governance and Proj Mgmt (8)* *Org Change Mgmt (10)*

Table 7: Strategic Design, Cultural, and Political GPD Success Factors

Most of these success factors fall under Strategic Design, but have significant overlap with Cultural and Political factors. The globalization arrangement recommended through this internship primarily achieves Process Modularity for AME through Strategic Design, but all other factors have to be considered for successful implementation of these recommendations.

Many of the Strategic Design success factors were considered when building the process list for the AME DSM. Processes were decomposed or redefined to break portable components of these activities away from less portable components based on Core Competence and Intellectual Property considerations. To support the recommendations for Phase 1 of AME globalization, we also drew up new process flow diagrams, IT requirements, and an organizational structure for the new team.

This project is less of a giver than a taker on the GPD success factors that fall under the Cultural and Political lenses. Certainly, this internship project existed only because Management Priority was given to GPD. As mentioned in Section 3.1.1, Honeywell Aerospace has grown through acquisition and is accustomed to undergoing another key success factor, Organizational Change Management. AME engineers and product managers are already based at product sites all over the U.S., so they have some experience collaborating across different sites. To facilitate the complex web of interactions that must take place for all local AME staff to use the global site as a service center, this new global team needs a gatekeeper to receive and assign work requests and, most importantly, to say no if they cannot do the job. This job was given to the AME engineering manager of this site, and special attention was given when drafting this manager's job description to make this a key person for building and reinforcing a good environment for GPD.

3.7. Summary

This chapter began with background on the Honeywell internship and the sponsor company. After assessing the applicability of the method described in Part II of this paper to the AME globalization problem, we dove into the nuts and bolts of the application. A process list had to be put together for all AME tasks, tasks AME does not own but contributes heavily to, and tasks AME has high coordination with. Defining these processes with the right amount of detail turned out to be critical for this analysis. Then, the optimization model for allocating tasks to the global site was solved in two stages. In the first stage, the placement of all 53 portable tasks was chosen independently by the model. Tasks of similar portability or high co-location affinity were grouped together into job descriptions. The second stage solved the same optimization model for these task groups, so that portable jobs could be placed either at the global site or the local site with all of its corresponding tasks intact. Finally, we described the recommendations made to Honeywell on which activities to globalize and how.

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4. PART IV: Conclusion and Future Research

In the previous chapter, the case study at Honeywell illustrated how a DSM-based method can be used to select activities to globalize based on project coordination structure. While the example given in Part II was very small and very easy to solve by inspection, the Honeywell AME model contained information about coordination costs between all pairs of 79 tasks. The ability to solve this model for minimal cost solutions gives us very valuable new intuition on the coordination structure of the project. This chapter wraps up this paper with some final thoughts and recommendations for future research.

4.1. Conclusions

A method was developed that helps companies to allocate activities to global sites based on coordination costs and project structure. This method was applied to design a globalization strategy for the AME at Honeywell Aerospace during the author's internship there. The recommendations from the internship have resulted in AME's participation in building a new global Honeywell Aerospace site and the hiring people to work at this site on jobs defined through this process.

We began this paper with a discussion on globalization and global product development, and what is motivating and enabling companies to develop these capabilities. The examples in this paper illustrate how modularization of activities assigned to each site can help minimize some of the high coordination costs associated with global product development. Better process and process handoff definitions are required at all levels of the organization to minimize coordination "drag." Before jumping onto the GPD bandwagon, is important to make sure the benefits the company hopes to gain from globalizing outweigh the expected additional coordination costs in time, money, and management attention. These benefits might be quantifiable like lower labor costs, or they might be qualitative and strategic benefits such as cross-pollinating ideas, recruiting global talent, or the developing the ability to serve new customers.

Planning GPD for an organization is a dynamic problem with many changing inputs and moving targets. The site that is low-cost today will be not be low-cost tomorrow, especially if other companies agree that this is an attractive site. Company processes and organizational structures change, as do program and staffing requirements. The world's capabilities today look very different than they did yesterday. A plan that looks too far ahead is likely to become obsolete, but a plan that is too short-sighted may exploit only temporary advantages or cause the company not to make smart long-term investments. For any plan, it is important to build in the management flexibility to adapt plans to new information. This is another reason why it pays to build up GPD resources in phases. Before proceeding to the next phase, physical and mental models should be updated to make sure the next scale-up in GPD still makes sense.

4.2. Future Research

Several other models for allocating GPD activities were explored during the Honeywell internship. Some of these models can be further explored as areas of future research.

An easy extension of this model is to build the coordination matrix for more than two sites. A three-site model built during the internship tat included the local site and two global sites, one at a low cost site and one at a medium cost site. The highest coordination penalty factors were given to coordinations between the low cost site and the medium cost site. This model ended up not being as useful for us as two-site model, which asks a much simpler question of whether or not to globalize each activity to begin with. However, in GPD design problems with many different sites of similar importance, it may be useful to work with a coordination matrix that includes all the sites under consideration, rather than emphasizing just a local site and a global site.

The three-site model was built during an attempt to optimize for total costs in the system including labor costs. To do so, we calculated labor rate savings for moving tasks to the low cost and medium cost sites and tried to weigh these savings benefits with the added coordination costs they generated in penalized overseas coordinations. To compare labor savings with coordination costs, the coordination "costs" in the DSM, which started out as scores from 0-10 on the need for task co-location, needed to be converted into dollar costs. To do this for the AME problem, we had to make task time and coordination time estimates as averages for all programs during the lifetime of each project, and turn these average times into costs. These estimates ended up dominating the optimization problem, unfortunately, the GIGO (garbage in, garbage out) principle held true and we had to abandon this model for AME. A model that optimizes for both the costs and benefits of globalization would certainly be useful, as it would yield an ideal solution of exactly how many and which activities to globalize. One could imagine a situation where this model could be built for a standard project or a set of stable processes where labor and coordination times can be better estimated. The idea that globalization costs and benefits can be optimized also opens up some interesting areas of further research on how one might quantify the costs and benefits of globalization.

Another quantification exercise that could be very interesting for future research is to quantify is the real options value of management flexibility when implementing a staged GPD development process. Some nodes of uncertainty that could be interesting to evaluate are future labor costs, future productivity improvements in task execution and coordination, and market opportunity in the global region if the company is doing GPD there to serve new customers. These real options valuations can really help companies quantify the costs and benefits of strategic GPD investments, given the many uncertainties at play when designing an initial GPD strategy.

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