Human Resource Management in Project Portfolios: Architecting an Allocation Process

by

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SUBMITTED TO THE DEPARTMENT OF SYSTEM DESIGN AND MANAGEMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF

MASTER OF SCIENCE IN ENGINEERING AND MANAGEMENT
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2017

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Submitted to the Department of System Design and Management
on May 2017 in Partial Fulfilment of the
Requirements for the Degree of Master of Science in
Engineering and Management

ABSTRACT

A review of project portfolio management (PPM) literature has shown that human resources allocation is rarely revisited beyond the initial planning cycle, and that it is often treated as a static problem. Therefore, this thesis sought to understand modern PPM practices further and to underscore variables that correlate with proficient portfolio planning, management, and execution. A survey of current practices has yielded several unexpected results. For example, the extent of employee involvement in resource allocation decisions, via active participation in the PMO, is positively correlated with highly effective PPM practices. Organizations experience schedule delays on the order of 10-20%, even though they classify their PPM practices as highly effective. Furthermore, 54% of survey participants indicated their firms do not evaluate nor model resource uncertainties, risks or interdependencies, of which 85% conceded these variables should be addressed. Given the survey results and given that PPM methods were borne of Markowitz's Modern Portfolio Theory, this thesis sought to frame the human resource allocation problem as a sociotechnical system instead. As such, nine critical system design decisions were identified and combined to yield distinct process architectures. Next, these architectures were scored and evaluated against performance metrics levied by the system stakeholders. An architectural tradespace of 11,664 feasible human-resource allocation systems was generated; of which 42 architectures are non-dominated. The systematic analysis in this thesis revealed that 100% of the architectures on the Pareto Front are analogous to a transparent, market-like resource allocation system as opposed to an anonymous, centralized system. Furthermore, 83% of these architectures appointed the employee as the sole decision-maker of its allocation to tasks. Roughly 70% of these architectures required agents to frequently updated task start and end times, hence reducing uncertainty and risk in planning. Future work shall re-assess the architecture scores and stakeholder requirements prior to application on a pilot portfolio.

Thesis Supervisor: Bryan R. Moser
Lead Instructor and Lecturer, System Design and Management

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Acknowledgments

The past two years of my life have been extraordinary; as such the below acknowledgments are well deserved and long overdue.

I thank God for His endless love, grace, blessing and compassion. I am confident that today I am exactly where I should be. I cannot say that God's path that brought me here was the easiest, or the most straightforward, yet I would not have it any other way. Ever since I first came across SDM's website, He has given me peace and stood by me at all times. I am overjoyed because everything He has given me has surpassed my wildest dreams.

I would like to thank the SDM faculty and staff. More specifically: Joan Rubin, Pat Hale, David Erickson, Professor Olivier de Weck, Dr. Bryan Moser, Dr. Bruce Cameron and (future Dr.) John Helferich. I appreciate your vote of confidence when you admitted me the SDM program, and when you selected me to be a teaching assistant for the SDM core class. I have learned many lessons from each one of you; be it educational, professional or the more valuable life lessons.

Dr. Bryan Moser, my thesis advisor, deserves a special thank you! Despite his busy schedule and global commitments, he somehow set aside some time to talk about my thesis. Our meetings were incredibly thought provoking and insightful. At the beginning of the thesis process, Bryan warned that he would push me to explore topics beyond my experience or background before I converge on a research question. Even though I resisted a bit, I am glad he did that. I am very fortunate to have had the chance to work with an advisor who is both well rooted academically and, more importantly, an advisor who has considerable practical industry experience.

I would also like to mention some of my SDM classmates and friends for their much-needed help and support during the past few months: Ahmed Altayyar, JD Caddell, Chacha Durazo, Lenni Kimawati, Gene Scrivner, Edwin Suarez, Christian West, and Ashley Whitney.

And finally, I would like to thank all my family and friends who have continuously encouraged me during this demanding Masters journey. More specifically, though, I would like to mention the following people. This thesis is dedicated to you!

- Mama & Baba: No amount of words will ever be sufficient to thank you for all your sacrifices, compromises and love. Most importantly, you taught us to cleave to God at all times. You left Egypt, your family, your friends and your careers behind, and you risked being unemployed in Canada so that we may have an opportunity to have a better life and education. Everything that I do is dedicated to you, simply because I would not be where I am today without you. Mama, you are the personification of love and sacrifice. It does not matter if you are sick or having a bad day, we could always count on you to

be there for us; whether it is with a hug, uplifting words and if all else fails, some food! Baba, this MIT experience started with you. You encouraged me to apply to the program when I felt I was not good enough. You said I would not lose anything, and you were absolutely right. In fact, this experience has truly been life-changing.

- Monica: The apple does not fall far from the tree – you are slowly turning into a miniature version of Mama. Loving, caring, funny and you are always able to make time for us when we need you. You do not know this, but during these past two years whenever I was feeling overwhelmed or stressed; you would consistently say or do something that immediately lifted me up. Thank you!
- Abraam: The groomsmen gift you got me "hit the nail on the head." Those words are always hard for me to hear, but I needed to hear them then and I need to hear them every day. I thank you for that constant reminder!
- Fadi: Even though I am your older brother and supposed to be your role model, I feel that I have learned more from you than you have learned from me. Your insane work ethic, thirst for knowledge and pursuit of perfection are contagious. I earnestly tried to emulate these qualities through my Master's journey.
- Nagi & Bassem: You two are the older brothers I never had. You continuously challenge me to improve myself and to step outside my comfort zone. Nagi, the many hours we spent talking about project and organization management inefficiencies and shortcomings are invaluable. Bassem, our 2012 trip to SE Asia with your HBS friends and my subsequent trip to visit you in Boston put me on the road that brought me to MIT. So for that, I am eternally grateful.

"Our deepest fear is not that we are inadequate. Our deepest fear is that we are powerful beyond measure. It is our light, not our darkness, that most frightens us. Your playing small does not serve the world. There is nothing enlightened about shrinking so that other people won't feel insecure around you. We are all meant to shine as children do. It's not just in some of us; it is in everyone. And as we let our own lights shine, we unconsciously give other people permission to do the same. As we are liberated from our own fear, our presence automatically liberates others."

Marianne Williamson. Author and Lecturer

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List of Abbreviations

CAD	Computer Aided Design
ConOps	Concept of Operations
DMM	Domain Mapping Matrix
DSM	Design Structure Matrix
EPC	Engineering, Procurement and Construction
GRACE	GRid Architecture for Computational Economy
H-RAS	Human Resource Allocation System
INCOSE	International Council On Systems Engineering
MBSE	Model Based Systems Engineering
MIT	Massachusetts Institute of Technology
MPT	Modern Portfolio Theory
NASA	National Aeronautics and Aerospace Administration
NPD	New Product Development
OPD	Object Process Diagram
OPM	Object Process Methodology
P_i	Provider i, where i = {1, 2, 3, ... N}
PD	Project Design
PI	Project Interdependencies
PM	Project/Program Manager
PMI	Project Management Institute
PMO	Project/Program Management Office
PP	Project Portfolio
PPM	Project Portfolio Management
R_i	Requester i, where i = {1, 2, 3, ... N}
RCMPS	Resource Constrained Multi Project Scheduling
RMS	Resource Management System
$\mathbf{T_{ei}}$	Task i end time, where i = {1, 2, 3, ...N}
$\mathbf{T_{si}}$	Task i start time, where i = {1, 2, 3, ... N}
TTD	Total Time to Delivery
RUF	Resource Utilization Factor
SDM	System Design & Management
SLA	Service Level Agreement
VPM	Visual Project Map

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1. Introduction

1.1. Motivation

In his practical book titled "Islands of Profit in a Sea of Red Ink," Byrnes dedicates a chapter to present proven techniques to instigate change and effectively navigate the change management cycle. More specifically, he discusses the impending disaster method (Byrnes 2010). It entails describing the impending disaster if a proposed change were not implemented immediately. Byrnes is a supply chain expert and recalls a typical encounter with a client. He proposed altering the organizational processes to allow the supply chain team to become an integral part of the sales process. Why? Supply chain professionals are better equipped and motivated to build longer lasting relationships with customers than sales teams are. These professionals accomplish this goal by focusing on customer service and by considering supply chain integration issues. The impending disaster, in this case, was letting the client's competitors build close working relationships with its customers; and subsequently losing their business. The client was eventually persuaded, and the change was implemented. As a result, the client experienced 30%+ increase in revenue. As attractive as that figure seems, the real success is that a deeper relationship with customers, offered the client a competitive edge that would not be eroded by price wars or economic downturns. In similar fashion, we attempt to describe the impending disaster if companies and executive teams continue to behave erratically and reactively in portfolio management and human resource allocation situations.

(Lyneis and Ford 2007) have developed a system dynamics model to help executive clients visualize how reactive managerial actions, in the face of scope changes and rework, can quickly spiral out of control.

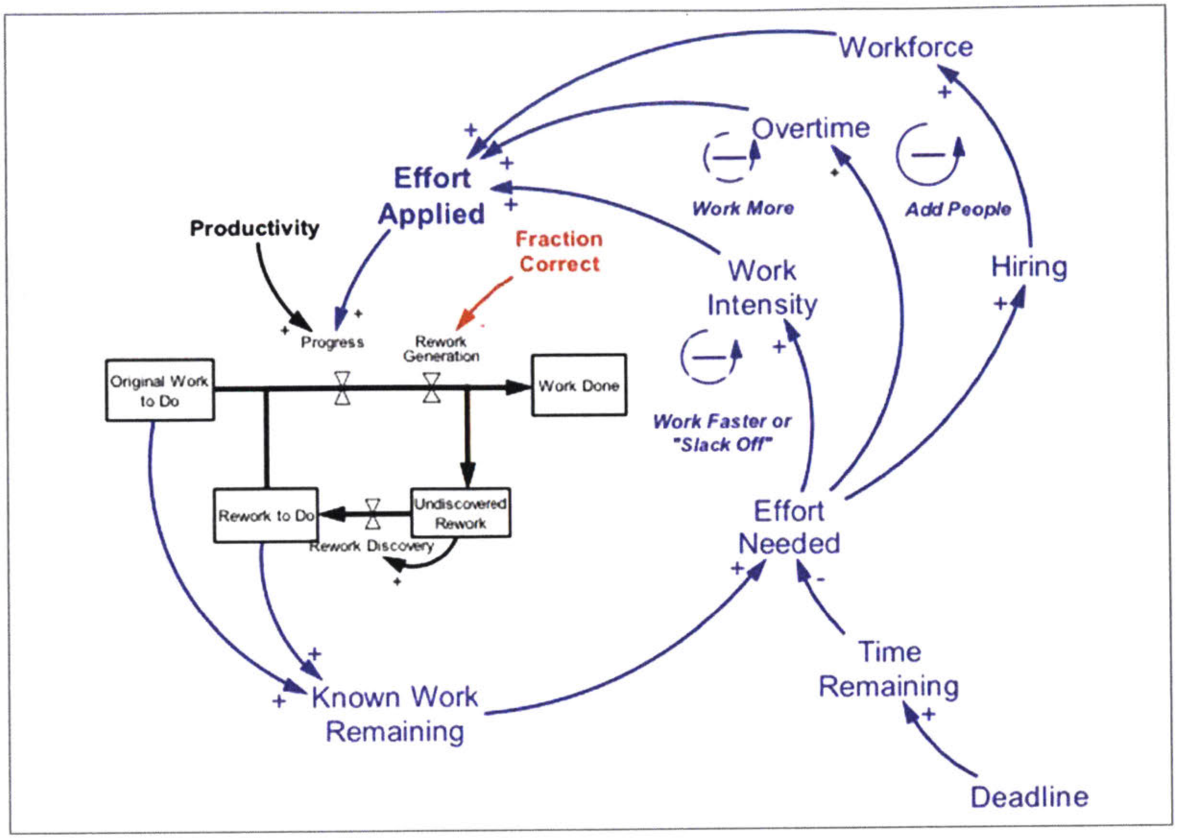

Figure 1-1 | Managerial Actions. Reproduced from (Lyneis and Ford 2007)

The figure shown above depicts the basic structure of the model. The three blue loops in this model can be thought of as alternative managerial actions. As the effort needed increases, management can either increase the work intensity (i.e. work faster or more efficiently), encourage employees to work overtime, or increase the size of the workforce by hiring new employees. These options are typical, and we have seen them used in practice time and time again. These are balancing loops, such that they seek a goal as opposed to reinforcing loops that exhibit exponential growth or decay (Sterman 2000). For example, as effort needed increases, a decision is made to hire more people, the size of the workforce increases, the effort applied increases, then progress speeds up, work done increases, which eventually decreases the amount of known work remaining and that decreases hiring. Executives, however, fail to foresee the adverse effects of these decisions. We have reproduced the model to show the effects of increased overtime and hiring in Figure

1-2 below. Continuing with the hiring loop, we follow the red arrows to evaluate the reinforcing nature of the actions' negative effects.

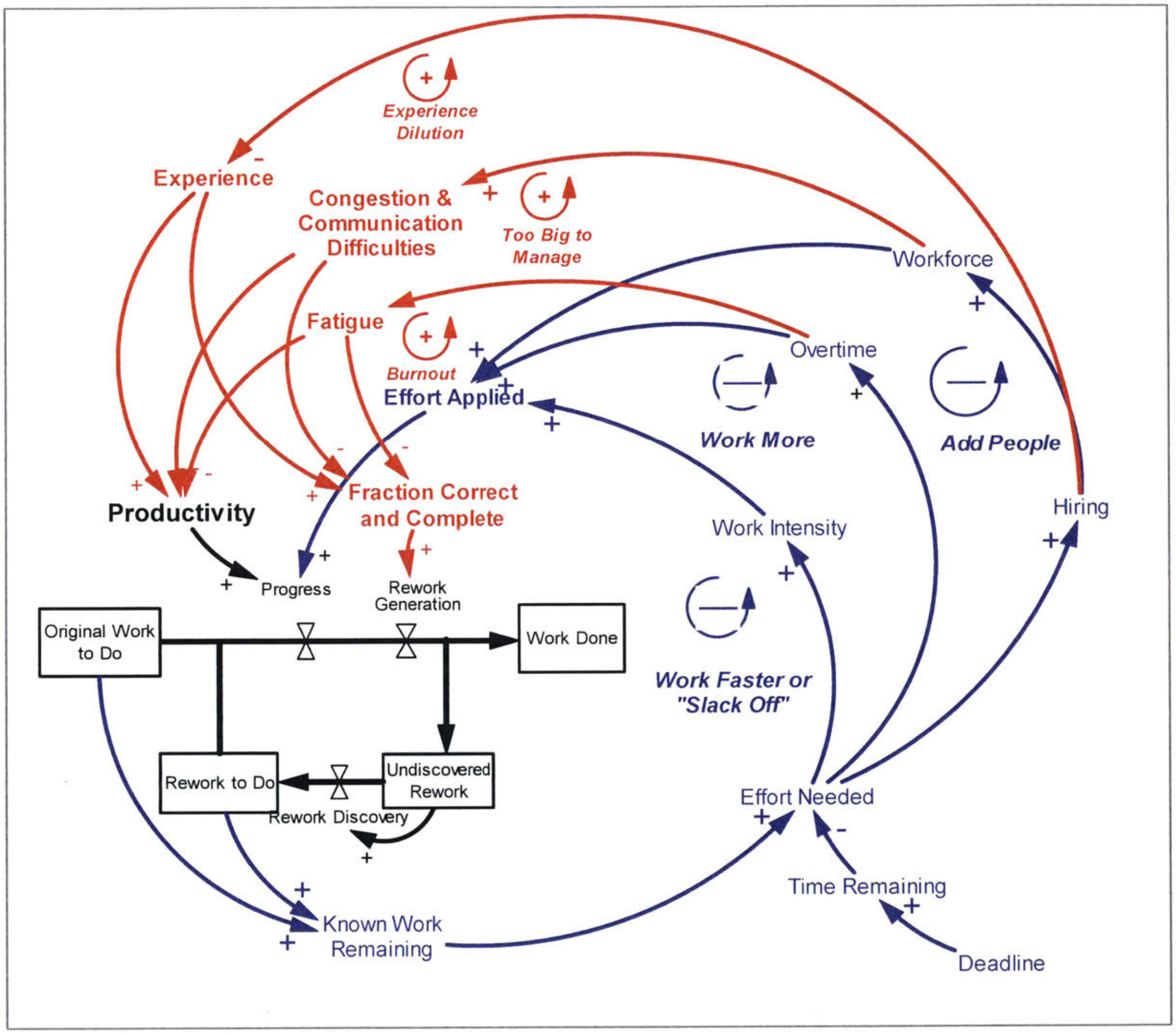

Figure 1-2 | Negative Effects of Overtime and Hiring. Reproduced from (Lyneis and Ford 2007)

As hiring increases, the company's experience diminishes (due to lengthy onboarding processes and ramp-up times for new employees), which lowers productivity and the fraction of correct and complete tasks subsequently reducing productivity and increasing rework generation, respectively. The amount of work done is reduced, which eventually increases the volume of known work remaining, and effort needed leading to more hiring or overtime. At this point, the company is trapped in a vicious cycle and finds itself in an endless fire-fighting mode. Another managerial solution not explicitly depicted is the action of laying-off employees when known remaining work decreases.

The above models are constructed for a single project. We are concerned these results would become more pronounced and more difficult to control at the portfolio level. Imagine a portfolio comprised of a handful of projects, each facing the same issues simultaneously. Now, imagine these projects are competing for the same scarce human resources. As a result, the company proceeds to hire more employees to meet its schedule commitments. Past a certain threshold, as effort-needed decreases, work intensity will inevitably decrease as well. At this point, the company is paying employees who are not productive. One can begin to realize the gravity of this problem as well as its effects on the company's workforce. Said workforce is continuously fluctuating between certain maxima and minima. Furthermore, we have learned that Wall Street Investment Banks track companies' workforce levels (Rothman 2007). Any significant changes or persistent trends are perceived as negative signals in the eyes of quantitative analysts. A continuous increase in workforce, when revenues are flat, symbolizes that management is not efficiently allocating its capital. On the other hand, sudden drops in workforce levels may be early indicators of financial trouble. Therefore, managerial actions have an impact on a company's stock price, which in turn has an indirect impact on its future ability to raise capital.

The urgent question, then, is how could companies more effectively manage their human resources?

1.2. Problem Statement and Research Questions

(Engwall and Jerbrant 2003) have indicated that project portfolio management (PPM) literature addresses the human resource allocation problem a priori portfolio composition and scheduling. Meanwhile, very few studies treat this problem dynamically to mimic how management teams approach this problem in action. As seen in Figure 1-2, as rework and scope changes materialize, tasks and projects in the portfolio begin to fall behind schedule, and the predetermined human resource allocation plans become obsolete. As such, we are seeking to develop a process of allocating human resources, to facilitate and to streamline planning and execution activities given resource scarcity and interdependence.

With that in mind, we make use of the nomenclature scheme defined by (Crawley, Cameron, and Selva 2016) to present our system problem statement.

> ***To*** *effectively and dynamically plan portfolios of projects*
> ***By*** *architecting a human resource allocation system*
> ***Using*** *reservation and brokering techniques*

Figure 1-3 | System Problem Statement

To solve the problem at hand, we have identified two questions to be answered by this thesis.

> RQ1. What is the current state of project portfolio management practices today?
> RQ2. What are the key process design decisions for a human resource allocation system?

Figure 1-4 | Thesis Research Questions

The thesis is structured as follows. Chapter 2 summarizes a literature review of several domains of interest; namely Project Portfolio Management (PPM), grid brokering and agency theory. Chapter 3 lays out our system thinking principles, which have guided the work presented in this thesis. Chapter 4 presents the results of the PPM survey and discusses several noteworthy observations. Chapter 5 presents the human resource allocation system (H-RAS) requirements. Chapter 6 lays out the key process design decisions, explores the architectural space and discusses the intricacies of a sample architecture of a human resource allocation system. Finally, Chapter 7 recaps the thesis' findings and suggests future work.

2. Literature Review

2.1. Project Portfolio Management

This thesis was spurred by a keen interest in project portfolio management (PPM), particularly human resource interdependencies. PPM was borne of Harry Markowitz' Modern Portfolio Theory (MPT) paper (Markowitz 1952). PPM techniques are rooted in finance and Markowitz's risk management process. PPM literature and knowledge base have experienced exponential growth in the 21st century. PPM related journal articles have increased from only four in 2000 to 35 in 2004 (Sarbazhosseini 2017).

We sought first to explore how professional organizations and academics define PPM. The Project Management Institute (PMI) describes project portfolio management as identifying, prioritizing, managing and controlling project or programs ("PMI | Glossary of Project Management Terms" 2016). Other authors have offered additional, more specialized descriptions of PPM. For example, it has been described as a process conducted on a regular basis to identify, analyze and quantify project value; as well as identifying which projects shall be undertaken, reprioritized or altogether cancelled or halted (Levin and Rad 2008). Furthermore, Levin and Rad stipulate that the output of PPM is a prioritized list of projects. While their definition does not completely diverge from PMI's, Levin and Rad seem to fixate on the evaluation and analysis aspects of PPM. Per Figure 2-1, Pajares and Lopez's definition of PPM is in line with PMI's. However, they observe that there is a departure from PMI's classic definition of PPM saying that, "PPM has been more concerned with strategy than with operational issues." They argue that there is a gap between project portfolio literature that solely focuses on strategy, project selection and portfolio balancing, and multi-project planning literature centered on scheduling and resource allocation. Likewise, some have indicated that the role of project portfolio management is to connect corporate strategy to the organization's programs and projects (Arifin et al. 2016).

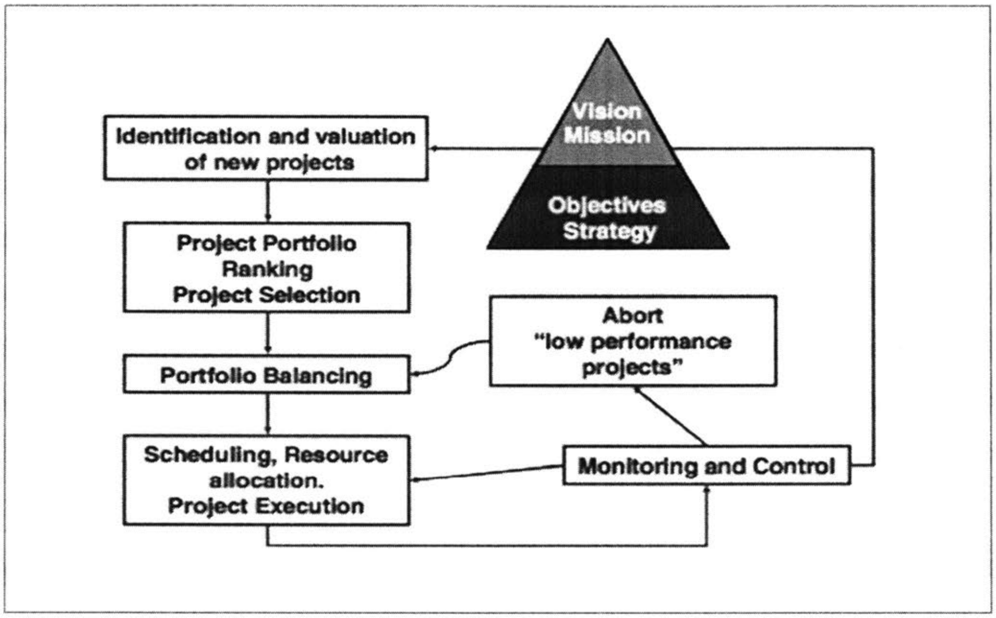

Figure 2-1 | "PPM as a dynamic process" Reproduced from (Pajares and López 2014)

Similarly, (Teller and Kock 2013) assert that PPM objectives are well established in literature, and they are the maximization of portfolio value, the balance of the portfolio and the project alignment to strategic goals.

PMI offers a superficial definition for dependencies or logical relationships such as start-to-finish, finish-to-start, start-to-start and finish-to-finish. The two latter types of dependencies insinuate concurrent relationships. Interestingly though, PMI does not offer an explicit definition of concurrency ("PMI | Glossary of Project Management Terms" 2016). It has been suggested that dependencies should not be thought of as output-input relationships, but rather as a demand for interaction (Bryan Moser, Grossmann, and Starke 2015) (Chucholowski et al. 2016). These authors hypothesize that dependency stems from sharing resources, time constraints and project outcomes. (Arifin et al. 2016) note that PPM researchers have often treated each project in a portfolio as an independent entity. Yet, they found that starting in 2010, many researchers have begun to appreciate the importance of project interdependencies (PI). (Verma and Sinha 2002) have codified PI into three general categories: resource interdependencies, technology interdependencies and market interdependencies. Resource interdependencies are due to sharing scarce resources among projects, otherwise known as inverse interdependencies as first described by (Thompson 1967). Technology interdependencies result from employing common technologies among projects. And, market interdependencies occur when a current product's market knowledge is leveraged for development of a new product for a different market segment. Resource and technology interdependencies are what (Thompson 1967) classified as sequential dependencies. Additionally, (C. P. Killen et al. 2009) have enumerated five types of PI from various sources: resource interactions, benefit interactions, technical dependence, outcome dependence and learning dependence.

Organizations tend to manage and execute several projects concurrently to provide flexibility, efficiency and to serve as a risk hedging technique (Chucholowski et al. 2016; Teller and Kock 2013). In fact, some research shows that 90% of projects (by value) are executed in a multi-project environment (Danilovic and Sandkull 2005). As the complexity of project and portfolio networks increases, PPM practitioners and researchers have embarked on a journey to package existing methodologies and solutions to tackle the challenges of PPM. For example, researchers in Sweden have employed a design structure matrix (DSM) to model complexity and internal dependencies for healthcare IT projects, and have also employed a domain mapping matrix (DMM) to model dependencies between a project and its organization (Grönevall and Danilovic 2014). Others have also employed DSM and DMM techniques to the product development domain (Danilovic and Sandkull 2005), and have stated, "...uncertainty is the normal state we have to face." They have also stated that complexity breeds uncertainty, while complexity is determined by the interdependencies between people, technology and functionality; as can be seen in Figure 2-2.

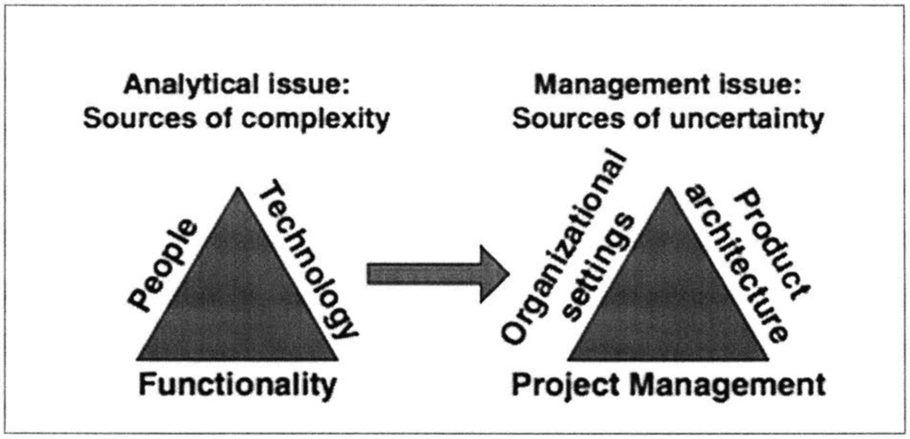

Figure 2-2 | Source of Complexity and Uncertainty. Reproduced from (Danilovic and Sandkull 2005)

While others have combined several quantitative and qualitative metrics to optimize the mixture of projects in a portfolio; such as level of dependence of project X on project Y and normalized dependency (Dickinson, Thornton, and Graves 2001). This process was implemented at Boeing, where practitioners have summarized that mapping tools (DSM or DMM) are not capable of prioritizing projects. They witnessed that the cost of the optimized portfolio was roughly 15% lower than the baseline. With that being said, they did concede that the complexity of optimizing even a limited number of projects with few constraints and objectives is overwhelming. To our knowledge, this example presented the first instance where interdependencies were used to prioritize and to include or exclude projects in a portfolio. (Chucholowski et al. 2016) have derived 8 dependency characteristics and 21 measures to quantify them. Table 2-1 below reflects the top three characteristics that were determined reliably using the proposed measures. (Catherine P. Killen 2013) has written that there is a need for better tools to understand and manage project interdependencies. Consequently, she has concluded that the type of tool used may influence the quality of management's decision-making processes. Specifically, visual project maps (VPM) are highly correlated with better outcomes. Additionally, she discussed a limitation of design structure matrices (DSM), in that they do not logically illustrate multi-step dependencies. For example, project B is dependent on project A, and project C is dependent on project A. Therefore, there is an implicit dependency between projects A and C. This dependency is not easily identified in a DSM. Her findings are summarized in Figure 2-3 below.

Characteristic	Measures
Feedback mechanism The way feedback is passed between dependent activities.	**F1** Frequency of scheduled information exchanges **F2** Frequency of scheduled budget reviews **F3** Number of times data is needed
Impact The extent to which not fulfilling the dependence in the desired manner affects the dependent activities.	**I1** Fraction of activity dependent on input **I2** Rework caused by faulty input **I3** Excess capacity **I4** Specification connectedness
Satisfaction criteria The criteria necessary to fulfill the dependence.	**C1** Understanding of what is necessary to fulfill the dependence **C2** Consensus on what is necessary to fulfill the dependence

Table 2-1 | Dependence Characteristics. Partially Reproduced From (Chucholowski et al. 2016)

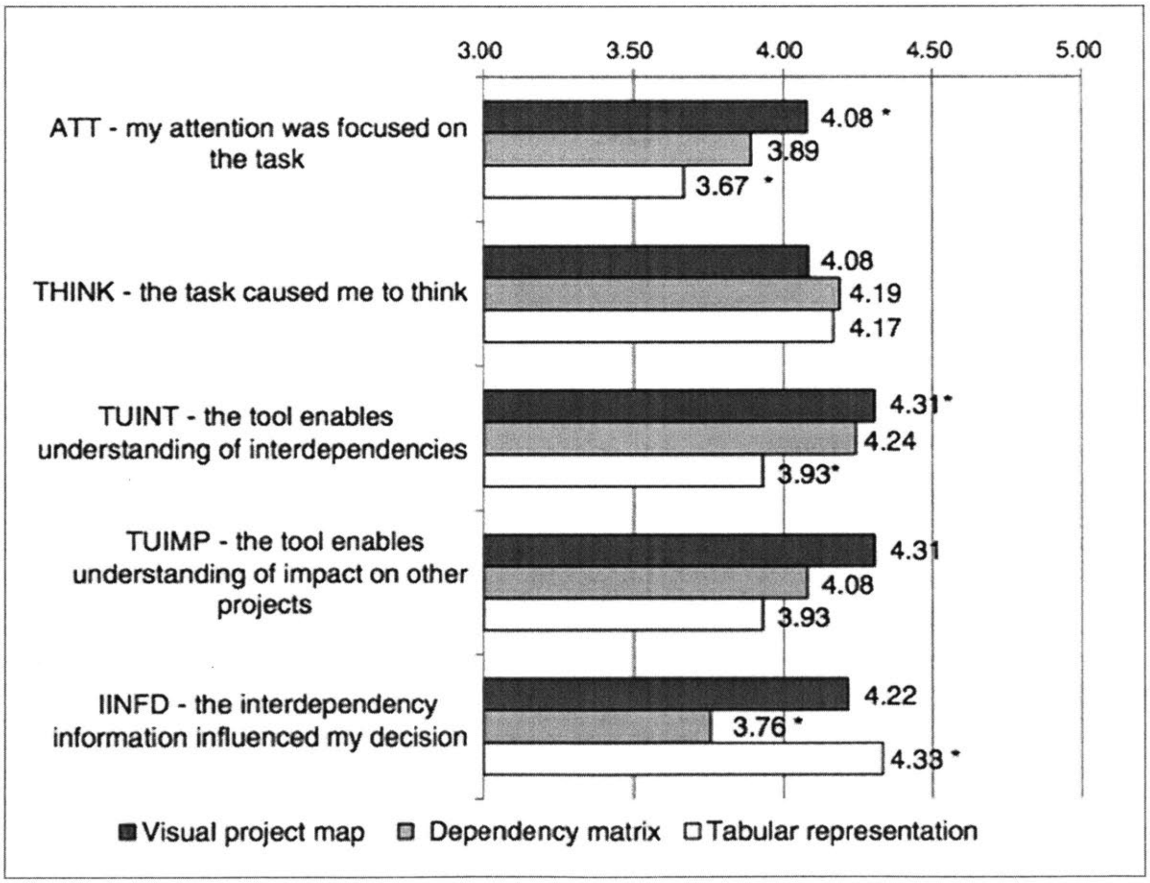

Figure 2-3 | Comparison of Three Dependence Modeling Tools. Reproduced From (Catherine P. Killen 2013)

2.2. Modeling Human Resource Dependencies

Some researchers have attempted to solve dependency conflicts using a plethora of optimization algorithms. For example, a combination of entropy weight and particle swarm optimization algorithms are used to address the problem of resource allocation and levelling at a Chinese port authority (Ye et al. 2014). However, the authors had made a critical assumption that the port authority had access to an unlimited resource pool. This assumption may be acceptable in some environments, but it would be an absurd assumption in a corporate environment. On the one hand, (Laslo 2010) employs a search algorithm to determine the optimum hiring and releasing schedules of expert (i.e., expensive), scarce resources; given the competition of different projects over these resources. On the other hand, (Browning and Yassine 2016) take on the more holistic perspective of a portfolio manager and employ priority rules to solve the resource constrained multi-project scheduling (RCMPS) problem. This approach poses a new challenge: disputes between project managers and the portfolio manager. The optimal direction for the portfolio may be at odds with some of its constituent projects. The authors have used several combinations of priority rules, but have found that the ideal choice depends on project and portfolio characteristics. More importantly, they have concluded that a manager will experience poor results most of the time; if she uses the same priority rule indiscriminately. (Gonçalves, Mendes, and Resende 2008) extend genetic algorithms to solve the RCMPS problem. The authors have assumed that the number of resources and task durations are deterministic. Although one could argue that the number of resources is static (i.e., deterministic) over the life of a portfolio, deterministic task duration is a grossly simplifying assumption. Experience tells us that durations are highly dependent on factors such as resource attributes (e.g., ramp-up time) and task scope.

Project portfolio management practices share many methodologies and techniques with financial portfolio management, as outlined by Harry Markowitz. Most academic and professional users define PPM as the act of analyzing, evaluating, prioritizing and balancing of project portfolios. A few rare sources, however, assign operational matters, such as resource management, to project portfolio management. As firms undertake more and more concurrent projects that share scarce resources, the importance of understanding and modeling resource dependencies has reached unprecedented levels of interest in academic and corporate circles. Many methods have been outlined and implemented; however, the underlying assumption is that project interdependencies (PI) are static in nature. To treat dynamic interdependencies, one needs to balance and to compute the optimal portfolio frequently. Practically speaking, this requires incessant data collection and tremendous computing power, especially as projects and portfolios grow in size and complexity. As such, we turned our attention to grid resource brokering processes.

2.3. Grid Resource Brokering

Grid computing is similar to an electric grid. The users (i.e., electrical appliances) obtain electricity from the grid through wall outlets. An electrical grid is comprised of many components. For example, there is a generating element, a transforming element, a switching element, a transmitting element and so on. The user, however, may not know or care about the source of the electricity. Similarly, a computational grid is comprised of processors, storage, memory, data, applications, computers, networks and so on. The users in this domain are client applications (Brown et al. 2005). Consider an example where a student launches a word processor on her computer. As the word processor is launched, the application pings a grid broker to reserve processing power, memory, and storage. The application may not have a preference which processor fulfills its request or where the document will be physically stored on the hard drive; as long as the operation is completed promptly. Therefore, the responsibility of a grid resource broker is to identify and characterize available resources dynamically and to select and allocate the most appropriate resource to fulfill a specific user's request (Elmroth and Tordsson 2004). Extrapolating this domain-specific knowledge to the subject of this thesis, the grid is the assembly of the human resources whereas the user is the project or portfolio manager. (Krauter, Buyya, and Maheswaran 2002) offer a comprehensive overview and taxonomy of grid resource management systems. They propose the following relevant definitions. A resource is a reusable entity such as a machine or a network. A resource provider is an agent that controls the resource such as a resource broker. A resource requester is a machine that is requesting a resource. A resource management system (RMS) is a service that manages a pool of resources. They begin at the highest level of abstraction, which is the grid system. They explain that the grid's design objectives and applications dictate the architecture of the resource management system. For example, a distributed supercomputing grid executes an application in parallel on multiple machines to reduce completion time. In this case, the grid is employing a distributed RMS since the task is shared among several resources. The authors allude to the challenge of predicting resource requesters' requirements; however, they do not offer solutions to mitigate usage overruns. The authors argue that a single, fixed scheduling policy is not desirable in large grid resource management systems. The resources in the grid may belong to secure networks or may have different performance characteristics and operational functions. Therefore, an extensible schedule policy is made available. However, these types of schedule policies are only available for a handful of resource brokers serving special applications.

(Elmroth and Tordsson 2004) assert that a reservation capability is essential for enabling efficient allocation of resources in highly utilized grids. Furthermore, grid brokering becomes all the more complex because a resource's relative performance may vary depending on the specifics of the request (the same is also true for human resources, but more on this topic in Chapter 6). They present three types of grid brokers; namely centralized, distributed and hierarchical brokers. A centralized broker handles reservation requests from all grid users. As such, this class of brokers is, in theory, more adept since it can best optimize resource allocation because it handles all incoming requests. However, it may become an informational bottleneck. Additionally, if the system were to experience any failures, there are no redundant brokers. On the other hand, distributed brokers can field requests from one user or a specific group of users. This architecture scales well and provides broker redundancy. The authors postulate that the ideal architecture is the hierarchical broker wherein a central broker manages requests from multiple distributed brokers.

Grid resource brokering systems are essentially algorithms, however. (Elmroth and Tordsson 2008) present one possible solution where the objective function is the total time to delivery (TTD). Once a request is received from a user, the broker shall contact one or more servers to obtain a list of available resources. Individual resources are then contacted to obtain their specifications such as hardware and software characteristics, current load, among others. Resources that are not suitable based on the job requirements and their specifications are filtered out. TTD is estimated for each resource. Once the shortest time to delivery has been established, the job is submitted to the corresponding resource. If the submission fails for any reason, the resource with the next shortest TTD is contacted and so on, until the job is accepted. Figure 2-4 is the illustration of the latter algorithm.

Furthermore, (Buyya, Abramson, and Giddy 2000) address a key issue in grid resource management. Most scheduling and brokering algorithms are system centric, in that they optimize resource selection with the system's performance in mind. They, however, ignore the user or requester's requirements, chiefly cost constraints. Cost is of particular importance as applications and jobs become larger in size or consume several resources on the grid. However, one must first understand one of the grid's primary uses. Resources on grid systems can be packaged to offer supercomputing services to grand challenge problems such as weather modeling or nuclear simulations (Krauter, Buyya, and Maheswaran 2002). These problems require access to several supercomputers as well as access to scientific instruments and devices. The authors propose a resource management system that is augmented by an economic analysis. Grid users can specify cost and TTD constraints; therefore the proposed system provides them with a means to trade-off cost and performance.

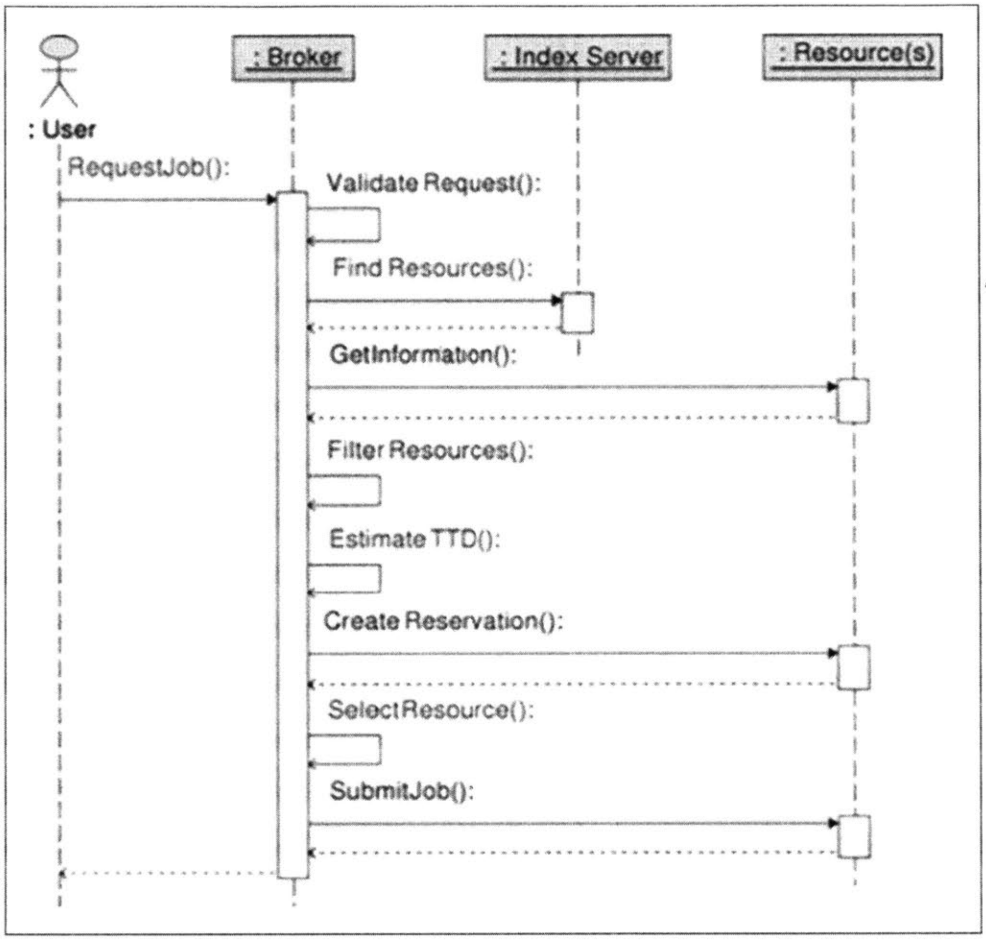

Figure 2-4 | Grid Resource Brokering Algorithm. Reproduced From (Elmroth and Tordsson 2008)

It is important to note that there exist resource-brokering systems, such as Nimrod/G, that support deadline, and cost driven scheduling. Yet, these systems employ a static cost structure (Buyya, Abramson, and Giddy, n.d.). The latter term signifies that a resource's cost is constant regardless of its current load or popularity. Consequently, the authors have created a new type of grid middleware, which serves to couple grid users and resource brokers. The new product is called GRid Architecture for Computational Economy (GRACE), and it is depicted in Figure 2-5 below.

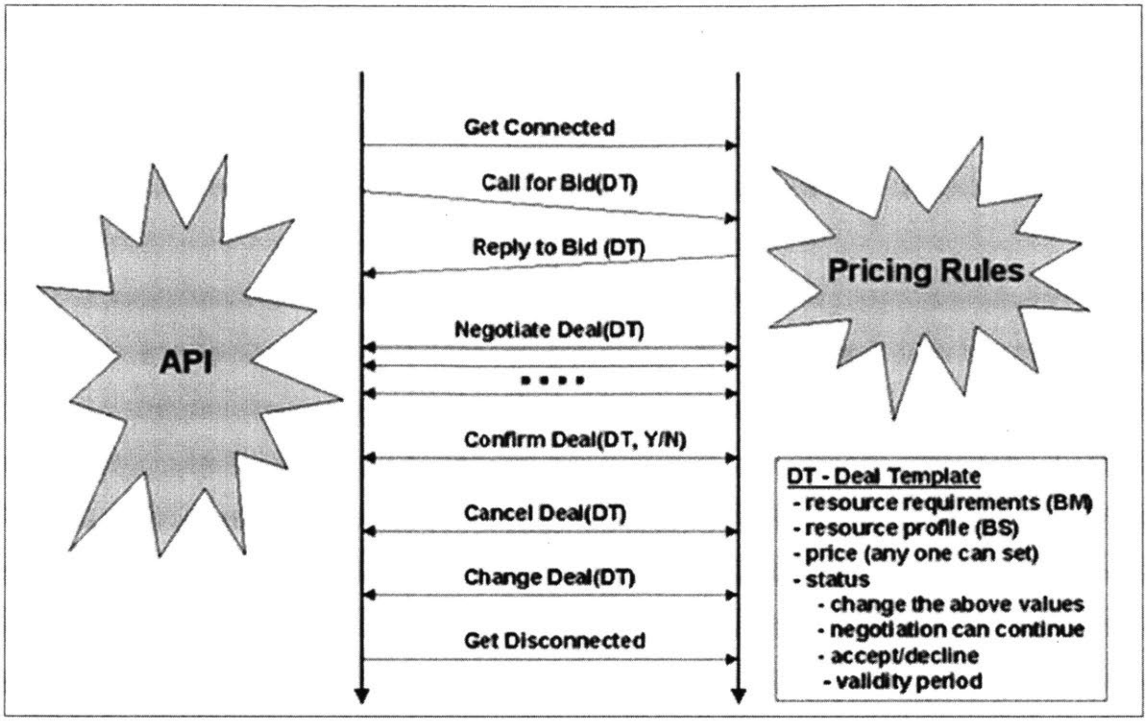

Figure 2-5 | Illustration of GRACE. Reproduced from (Buyya, Abramson, and Giddy, n.d.)

Each party in the trade runs a unique algorithm to maximize its benefit. As such, the resource owner wants to maximize its profits, while the user attempts to minimize TTD and costs. Therefore, GRACE is synonymous to a stock market where buyers post bid prices in responses to sellers' ask prices.

The literature review on grid resource brokering presented here is not intended to be exhaustive. We aimed to introduce this domain and several of its constructs. It is our opinion that the concept of grid systems, resource reservations, and deadline-cost tradeoffs can be abstracted and applied to human resource management in project portfolios. Grid systems came about as the Internet proliferated, and resources could be connected and packaged to realize superior performance characteristics at competitive prices. Similarly, we believe that as organizations strive to spur innovation by pursuing numerous concurrent projects while maintaining a lean, productive workforce; they will continue to seek new methods and tools to effectively manage said workforce.

2.4. Agency Theory

Even though agency theory has been defined in numerous ways, the underlying concept is constant. For example, Michael Jensen defines agency theory saying, "because people are, in the end, self-interested they will have conflicts of interest over at least some issues any time they attempt to engage in cooperative endeavours." (Jensen 1994) Kathleen Eisenhardt offered a broader definition writing, "agency theory is directed at the ubiquitous agency relationship, in which one party (the principal) delegates work to another (the agent), who performs that work." (Eisenhardt 1989) However, she restates Jensen's characterization of conflicts and appends to it by saying, "Agency theory is concerned with resolving two problems that can occur in agency relationships. The first is the agency problem that arises when (a) the desires or goals of the principal and agent conflict and (b) it is difficult or expensive for the principal to verify what the agent is doing (...) The second is the problem of risk sharing that arises when the principal and agent have different attitudes towards risk." Others have summarized the issue in laymen's terms saying, "the agent does not work entirely on the principal's behalf." (Mahaney and Lederer 2003)

The agency problem occurs at all levels of an organization; for example, employee and manager, or board of directors and shareholders. The agency is governed by a contract. Consequently, a central focus of agency theory is the selection of the most optimal contract given the agent's and the principal's divergent needs and characteristics (Eisenhardt 1989). Researchers have observed that contract type directly influences a project's outcome. That is, if an agent is rewarded for the quality of the results of her work, the more successful the project will be (Mahaney and Lederer 2003). Naturally, "success" has different definitions for different people. In the context of agency theory, success is driven by the principal's requirements. So, in the context of PPM, success would be defined by a manager as completing projects on time and budget while meeting the intended scope requirements. (Jensen 1994) stipulates that contracts, among other organizational artifacts, must be transformed to reduce conflicts and to increase the benefits to both the agent and the principal.

Agency theory research outlines two types of contracts, outcome-based and behaviour-based. Outcome-based, in this context, refers to the success of the task undertaken by the agent on behalf of the principal. (Eisenhardt 1989) puts forth several propositions that may be thought of as guidelines for contract creation. Firstly, if a contract is outcome-based, the agent is more likely to behave in the interests of the principal, which is synonymous to performance-based bonuses typically seen in sales organizations. Word of caution: outcome-based contracts must be linked to the appropriate accounting or organizational metric, to avoid internal conflicts of interest (Byrnes 2010). For example, a sales team should not be compensated based on revenues but based on profit margin. Revenue-based compensation drives sales teams to close as many deals as possible, regardless of strategic alignment with the organization's objectives or the resulting profit margin. This behaviour would be at odds with finance and accounting teams, for example.

Secondly, if the principal has access to information to verify the agent's behaviour, the agent is more likely to behave in the interests of the principal. For instance, behaviour contracts are created between children (i.e., agent) and parents (i.e., principal), wherein children are rewarded for good behaviour such as eating their vegetables. The third proposition supports the second as it states that information systems are positively related to behaviour-based contracts and negatively related to outcome-based contracts. In other words, behaviour-based contracts should be used where an information gathering and reporting system exists. The fourth proposition indicates that outcome uncertainty is positively related to behaviour-based contracts and negatively related to outcome-based contracts. We recall the actions of some Wall Street investment bankers during the years leading up to the 2007-08 Financial Crisis when they knowingly sold risky, uncertain financial instruments because they are compensated on commission. The United States

Congress would not be otherwise occupied with lengthy hearings if Wall Street bankers' bonuses were decided based on behaviour rather than outcomes.

The next two propositions focus on risk aversion. The risk aversion of the agent is positively related to behaviour-based contracts and negatively related to outcome-based contracts. The opposite is true for principals. The risk aversion of the principal is negatively related to behaviour-based contracts and positively related to outcome-based contracts. The latter dichotomy is the first complication in contract creation. Therefore, agents should seek principals with a similar risk appetite. Next, the goal conflict between agent and principal is negatively related to behaviour-based contracts and positively related to outcome-based contracts, which is the crux of the agency problem. Since the agent may not behave or act in the principal's best interests, the solution is to create outcome-based contracts.

The following proposition is related to task programmability, and that is the degree to which appropriate agent behaviour can be specified in advance. For example, a Starbucks barista's job is more programmed than that of an early employee in a technology start-up. Therefore, task programmability is positively related to behaviour-based contracts and negatively related to outcome-based contracts. This proposition is similar to the previous outcome uncertainty statement. That explains why the start-up employee will be compensated with stock options rather than a yearly salary. In conjunction with the latter proposition, outcome measurability is negatively related to behaviour-based contracts and positively related to outcome-based contracts. Outcome measurability simply points to ease of measurement. In other words, if the principal cannot measure the outcome of the agent's work, a behaviour-based contract is more suitable. Finally, the length of the agency relationship is positively related to behaviour-based contracts and negatively related to outcome-based contracts.

A contract may be decomposed into one or several workflow processes. (Medina-Mora et al. 1992) have introduced the notion of ActionWorkflow™ loops. The authors argue these loops are the atomic components that describe the interaction between a performer and a customer (Figure 2-6). Furthermore, an organization's workflow processes may be comprised of intertwined action loops.

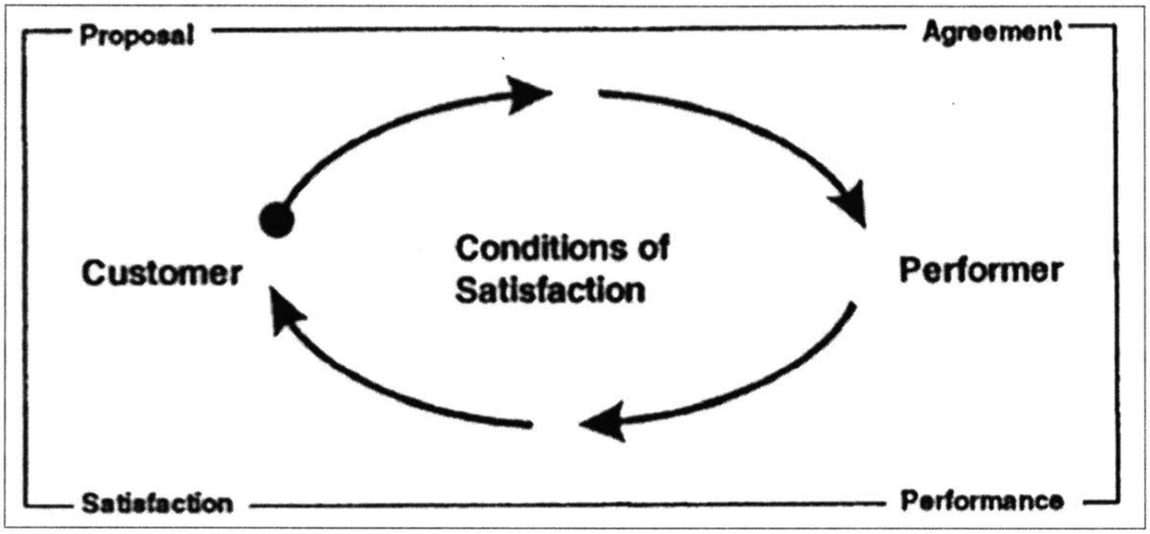

Figure 2-6 | Worflow Loop. Reproduced from (Medina-Mora et al. 1992)

We note the importance of the conditions of satisfaction to which the performer must complete the agreed-upon action, which is directly related to outcome measurability in contracts (Eisenhardt 1989). At the surface, GRACE (Buyya, Abramson, and Giddy, n.d.) and ActionWorkflow™ are both services that manage a process. Although GRACE manages software processes and ActionWorkflow™ manages business processes, their anatomy is essentially identical. Both approaches mediate between two parties; a resource broker and a resource provider and a customer and a performer, respectively. The customer or the performer can initiate ActionWorkflow™'s proposal stage. The proposal includes the required satisfaction conditions. That is different from any grid brokering system where the resource provider does not actively seek tasks. The next stage entails an agreement between both parties, where the conditions of satisfaction are established. Since ActionWorkflow™ is applied to business processes, which are human interactions; some of the terms of the agreement are not explicitly stated. The creators realize both parties may sometimes have a shared background and standard practices. This stage implies the existence of negotiations, although the creators of ActionWorkflow™ did not explicitly state that. Once the performer has completed the action, the customer declares the action's outcomes to be per the satisfaction conditions, and the loop is closed. It is important to appreciate that the works by (Eisenhardt 1989) and (Medina-Mora et al. 1992) are complementary rather than different. ActionWorkflow™ can either help practitioners quantify the terms of new contracts or diagnose existing contracts to determine gaps in information flows and definition of satisfactory results.

In his 1994 rebuttal of Michael Brennan's "Incentives, Rationality, and Society," Michael Jensen summarizes his professional and educational experiences as they pertain to agency theory, particularly incentives (Jensen 1994). He states that incentives exist in all situations when humans have real choices to make. In fact, he describes incentives as tradeoffs between "good" and "bad" choices. Moreover, Jensen argues that the real dilemma facing organizations is not whether to implement incentives (they exist regardless), but rather which incentives should be encouraged and which ones should be discouraged. He, then, concludes that for managers to make the best possible choices (i.e., ensuring a certain behaviour is displayed), organizations must ensure managers are given incentives to encourage them to make the best choices. Jensen adds that monetary incentives are not the best solution. He indirectly references Eisenhardt's outcome measurability as an impediment to monetary incentives. Finally, he adds that even though agents are self-interested and may not act in the principal's best interest; they always have incentives to reduce conflicts of interests because they are directly affected by these conflicts.

Akin to our discussion about grid resource brokering, the literature review about agency theory is not intended to be exhaustive either. Eisenhardt's propositions are seemingly contradictory sometimes, however it is crucial to realize that contract selection is not a binary problem. In fact, it is a scale, on which an organization shall attempt to place itself to maximize its benefit and its agents' benefits while minimizing conflicts. In other words, contract type selection is a complex trade-off exercise. Once the resource brokering system is abstracted and entirely applied to human beings, we expect agency problems to become more pronounced.

3. System Thinking Principles

We strongly feel that organizations and human beings should live by personal codes and principles. An organization creates a vision, codifies its values and communicates its strategy. Similarly, a project manager prioritizes the components of the Iron Triangle. These implicit or explicit forms of knowledge can subsequently guide decisions and actions. As such, we have listed below six principles that we will rely on in our endeavour to architect the Human Resource Allocation System (H-RAS).

3.1. Principle of Simplicity

Steve Jobs was quoted saying, "Simple can be harder than complex: You have to work hard to get your thinking clean to make it simple. But it is worth it in the end because once you get there, you can move mountains." Psychologist George Miller introduced the notion of a magical number, which is 7±2 (Miller 1956). This number represents human beings' capacity to process information. This figure also provides an easy-to-remember rule of thumb that could be applied in domains other than social sciences. Therefore, the principle in discussion instructs us to limit complexity and strive for simplicity. In the context of this thesis, controlling complexity can take on many forms. Organizations should not assign responsibilities to system and integration engineers to minimize labour costs, for example. Instead, organizations should logically decompose the project in question, then assign independent system engineers to each fragment. In turn, it is not recommended that these system engineers should be gathering and coordinating information from hundreds of individuals. Instead, organizational charts should be purposefully designed such that there exists a gradual reduction in the number of people as one moves up the chart. We should note that we do not advocate that Miller's magical number be followed blindly. On the contrary, we believe that engineers and managers should err on the side of caution and limit complexity by actively managing the number of components in a product, the number of members in a team, among others.

3.2. *Principle of Uncertainty*

Statistician George Box famously said, "All models are wrong, but some are useful." We believe the useful models Box is referring to may share a common feature. They include a representation of risk and uncertainty. One could easily argue that risk and uncertainty can never be entirely eliminated, as such this principle instructs us to embrace them and avoid using deterministic values in models. We understand that risk and uncertainty can be difficult to quantify; however, it is a critical conversation to be had between customers and performers. The satisfactory conditions previously discussed, may very well include a notion of risk (Medina-Mora et al. 1992). For example, if Customer A approaches Provider B to remodel her kitchen; the project's finish date depends on many variables such as the availability of the marble countertops. Therefore, Provider B would let Customer A know that the project will be completed within X to Y weeks. Naturally, discussions about risk and uncertainty will inevitably lead to discussions about mitigation plans. These would most likely affect the original plan and create new plans altogether. If Customer A wishes to host a holiday party in X weeks, she may elect to buy locally sourced marble or use another material with a shorter lead-time. If these options are more expensive than the originally quoted marble countertops, Customer B is effectively paying a premium to increase the probability of finishing the project within X weeks.

3.3. *Principle of Learning*

We have quoted Ron Haigh, project manager at Toyota Motor Corporation, saying, "Don't be too lean." Haigh was explaining that Toyota purposefully plans for its production lines to produce less than their full capacity. Why? To enable workers to evaluate the company's operating procedures, and recommend improvements to its processes. Otherwise, workers will be consumed by their tasks to meet production targets. As such, we have adopted this wisdom into a principle that instructs us to allow for a system (project or process) to learn and improve over time. The concepts of learning, buffers, and design margin are not the subject of this thesis; however, we offer examples to illustrate the utility of the principle. Project-based organizations, such as EPC companies, seek to maximize their employees' billable hours and offer little training time. In other words, these companies attempt to maintain their employees' utilization factors as close to 1.0 as possible. Academic researchers have proven the importance of training to combat skill obsolescence (Bhattacharya and Wright 2005), and its use as a performance incentive (Mahaney and Lederer 2003). Project-based organizations' most valued asset is the workforce, which also offers a competitive and financial edge. As these organizations merge or acquire one another, the price of the deal may include several large variables, one of which is goodwill. It is an accounting term, and it describes the value of intangible assets, one of which is the company's workforce. Furthermore, Google allows its employees to spend up to 20% of their time working on personal projects they believe would benefit the business (D'Onfro 2015). In fact, Google's Gmail started as a 20% project.

3.4. Principle of Alternatives

A tradespace is a two-dimensional plot used to compare architectures with two mutually exclusive metrics. Tradespaces are used extensively to evaluate the effect of changes in the system's performance metrics, or any quantifiable variables (Ross and Hastings 2005). As such, this principle instructs us to conceive and develop backup system architectures. This exercise can be viewed as a risk hedging technique or a conversation starter between customer and provider. Recall the kitchen remodelling example previously discussed. Provider B may develop a tradespace of cost and schedule to illustrate different project scenarios.

3.5. Principle of Universal Incentives

Former premier of the Soviet Union, Nikita Khrushchev, once said, "Call it what you will, incentives are what get people to work harder." Regardless of the nature of incentives, they alleviate the agency problem and encourage agents to avoid conflicts (Jensen 1994). Furthermore, Byrnes stipulates that organizations should migrate towards non-zero sum incentive structures to foster collaborative, rather than competitive environments (Byrnes 2010). Thus, this principle instructs us to employ non-zero sum incentives where, theoretically, all members could be treated equally. In zero-sum games, the sum of all participating parties' scores must equal zero. A common phrase used in zero-sum scenarios is "your gain is my loss." However, in non-zero-sum games, the sum of all participating parties' scores may be larger or lower than zero. Participants in zero-sum games perceive each other as threats thus creating an intensely competitive, and sometimes hostile, environment. Therefore, what is the expected outcome if incentives and bonuses became a non-zero sum game, which is coupled to an entire team's performance? A highly collaborative environment may be described as one where members seek to do what's best for themselves and their team. We recall the Nash Equilibrium in game theory, wherein players make decisions to maximize their own benefits, as well as other players' benefits (Nash 1950). In the context of this thesis, it may be more prudent for organizations to reward members of a project equally, rather than singling out top performers.

3.6. Principle of Understanding

The final principle is based on the Golden Triangle, whose vertices are people, process, and technology. Practitioners in several domains have argued that the prioritization of the triangle's vertices should be as listed above (Schneier 2013) (Injazz J. Chen and Karen Popovich 2003). They also argue that this prioritization holds true in many use cases such as cyber security, customer relationship management and change management among others. Albert Einstein was quoted saying, "Any fool can know. The point is to understand." This principle instructs us to invest in building relationships and understanding the system's most important stakeholders. We need to build a thorough understanding of these stakeholders' value to the system and vice versa. This process is akin to building allies. We have seen many corporate initiatives falter because stakeholders or system users did not buy into them, which lead to longer than estimated rollout periods and higher change management costs. Next, a process should be tactful and conducive to value delivery. For example, let us consider an example where a project manager is considering a new model-based systems engineering (MBSE) package for her project. However, this package has a steep learning curve, which may be met with resistance from the project team. It is, therefore, the manager's responsibility to first understand her team's needs, strengths and weaknesses; then select initial beta testers before rolling the system out to the entire team. The manager's strategy should also complement the organization's ethos. Some organizations are more accepting of change than others. Additionally, this strategy allows the manager to learn and refine her tactics as the beta users provide feedback.

4. Survey of Current PPM Practices

DISCLAIMER: Some participants did not complete the survey in its entirety.

4.1. Survey Hypotheses

In response to the research questions shown in Figure 1-4 above, we present the following research hypotheses. Any findings that either support or refute the research hypotheses will be **bolded** throughout the thesis.

RH1. Small companies exhibit more proficient PPM practices than their larger counterparts.

RH2. Companies strive to minimize the number of projects within a portfolio and maximize the number of portfolios.

RH3. Equal representation of corporate functions within the PMO yields superior PPM proficiency.

RH4. Companies that have small, centralized PMO exhibit superior PPM proficiency.

RH5. Companies that rebalance their portfolios more frequently exhibit superior PPM proficiency.

4.2. Demographics

The survey was created and distributed using MIT's license to the online software called Qualtrics®. The survey is comprised of three sections: demographics, current practices, and value identification. Participants could respond to a maximum of 44 questions. We shared the survey through various social media outlets such as LinkedIn®, Facebook® and the System Design and Management (SDM) WhatsApp® groups. The list of survey questions and the aggregate raw data is available in Appendix A: Survey Results. A total of 72 individuals responded to the survey. Figure 4-1 depicts the survey participants' current or most recent industries. Note that 22% of survey participants are from the Aerospace and Defense industry, which is notorious for its structured, but sometimes overly rigid, project management practices.

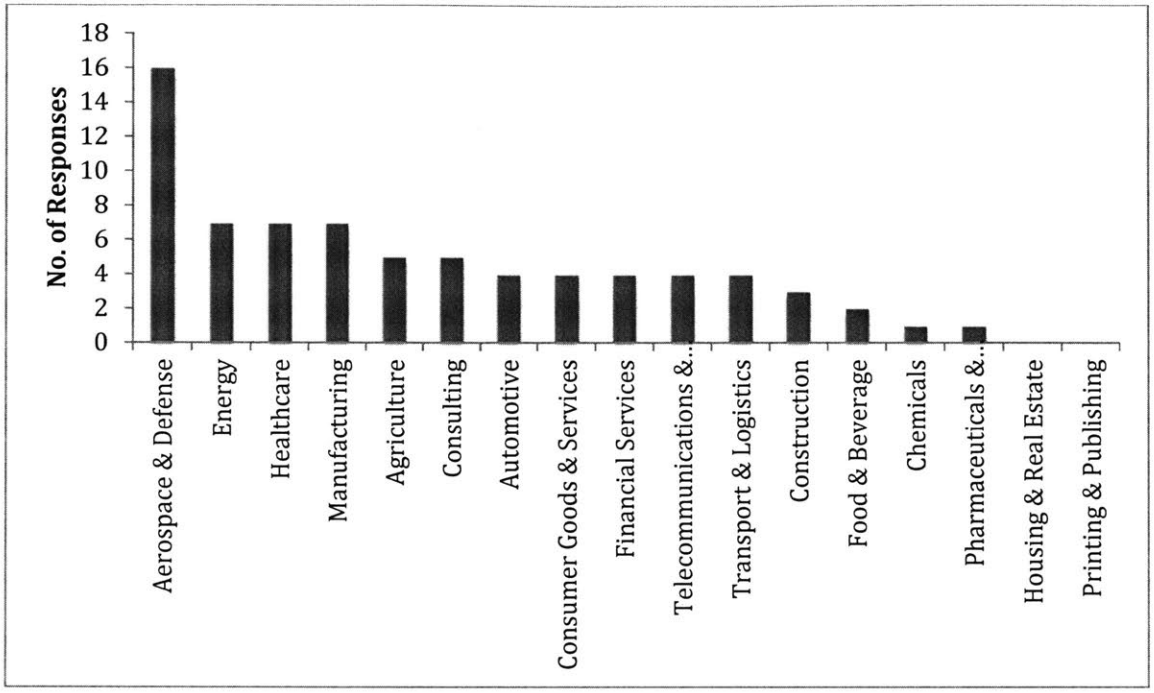

Figure 4-1 | Survey Participants' Industries

Participants were asked to qualitatively rate the proficiency of their companies' Project Portfolio Management (PPM) practices. They were given three choices – nonexistent, mediocre or highly effective. Sixty-two percent of participants selected mediocre, while 33% selected highly effective and 5% indicated that their companies had nonexistent PPM processes.

Next, we compare company size and industry against PPM proficiency (proficiency) as seen in Table 4-1.

Company Size	Nonexistent	Proficiency Mediocre	Highly effective
>10,000 employees		27	12
5,001-10,000 employees	1	5	4
1,001-5,000 employees	1	4	6
501-1,000 employees		2	
201-500 employees		3	
51-200 employees		3	1
10-50 employees		1	1
<10 employees	2		

Industry	Nonexistent	Proficiency Mediocre	Highly effective
Aerospace & Defense	3	7	6
Agriculture		4	1
Automotive		1	3
Chemicals		1	
Construction		2	1
Consulting		2	3
Consumer Goods & Services			4
Energy		4	3
Financial Services		3	1
Food & Beverage		2	
Healthcare		5	2
Manufacturing		7	
Pharmaceuticals & Biotechnology		1	
Telecommunications & Media		4	
Transport & Logistics	1	2	

Table 4-1 | Mapping Company Size and Industry to PPM Proficiency

We are not able to find a clear correlation between company size or industry and proficiency (RH1). Furthermore, proficiency results maintain their distribution irrespective of the variables to which they are compared. However, we were curious if there were any relationship between company size, industry, and proficiency. Therefore, we mapped company size to industry and indicated the average proficiency score; as can be seen in Table 4-2.

Proficiency Score

Proficiency Score	
Highly Effective	3
Mediocre	2
Nonexistent	1

Industry \ Company Size	>10,000 employees	5,001-10,000 employees	1,001-5,000 employees	501-1,000 employees	201-500 employees	51-200 employees	10-50 employees	<10 employees
Consumer Goods & Services	3.000 1	3.000 1	3.000 1				3.000 1	
Consulting	2.667 3		3.000 1		2.000 1			
Construction	2.000 2	3.000 1						
Automotive	3.000 3	2.000 1						
Energy	2.333 3	3.000 1	2.500 2			2.000 1		
Healthcare	3.000 1	2.000 1	3.000 1	2.000 2	2.000 1	2.000 1		
Aerospace & Defense	2.222 9	3.000 1	2.333 3			3.000 1		1.000 2
Financial Services	2.333 3	2.000 1						
Agriculture	2.250 4		2.000 1					
Telecommunications & Media	2.000 1	2.000 1			2.000 1		2.000 1	
Pharmaceuticals & Biotechnology	2.000 1							
Manufacturing	2.000 4	2.000 1	2.000 1			2.000 1		
Food & Beverage	2.000 1		2.000 1					
Chemicals	2.000 1							
Transport & Logistics	2.000 2	1.000 1						

Table 4-2 | Average PPM Proficiency Given Company Size and Industry

We have sorted the industries in descending order of average proficiency score. Moreover, we have indicated the number of responses below the mean score to assist the reader in ascertaining the significance of the data. For example, four participants belong to the Consumer Goods and Services industry, and each of them selected a different company size. Interestingly though, all four indicated that their companies had highly effective PPM practices. We cannot establish, however, whether this specific industry does have highly effective PPM practices or if the sample size is misleading. The Energy industry was the second most represented industry in the survey, second to Aerospace and Defense, followed by Healthcare. When calculating average proficiency after mapping company size to industry, we see the Energy industry had the highest proficiency among the top three most represented industries, followed by Healthcare and Aerospace and Defense. We do not feel that the bottom performers as shown in Table 4-2 are an accurate representation of the truth, especially the Pharmaceuticals and Biotechnology, and the Chemicals industries.

4.3. Types of Projects

Survey participants were asked if their companies combined internal and external projects in a portfolio. We were anticipating a correlation between this management decision and proficiency; since these two types of projects have vastly different communication and coordination needs. As such, we expected companies that do not combine these two categories to be more proficient. Participants were also asked whether their portfolios were comprised of a combination of new development and sustaining (or upgrade) projects or if they were separated. These variations have disparate technical risks, which may translate into different management and planning techniques. Therefore, if these variations were combined, proficiency results may begin to diverge. The summary of this analysis is shown below in Table 4-3. An overwhelming majority of participants signified that their companies tend to combine new development and sustaining projects in the same portfolio. Furthermore, as expected, companies tend not to mix internal and external projects. The previous result is rather surprising; however, according to the data, it is not uncommon. Consider a fictional project, where an automaker is working on the yearly upgrade of one of its models. The automaker may initiate a new project to design a new air intake system. As seen earlier in Table 4-1, proficiency still exhibits the same distribution that is largely centered on mediocre practices. Therefore, we cannot conclusively identify any correlations between project types in a portfolio and proficiency.

New Development vs. Upgrade Projects	Proficiency		
	Nonexistent	Mediocre	Highly effective
Both types make up the portfolio	1	32	17
New developments	2	6	3
Sustaining (or upgrade) projects		3	3
The types above are not usually in the same portfolio	1	4	

Combining Internal vs. External Projects?	Proficiency		
	Nonexistent	Mediocre	Highly effective
No		32	20
Yes	4	13	3

Table 4-3 | Mapping Different Project Types to PPM Proficiency

We were seeking a relationship between project types (internal vs. external and new developments vs. upgrades) and proficiency. In similar fashion to the preceding analysis, we mapped the types to each other and calculated average proficiency as seen in Table 4-4 below. There is a noticeable decrease in perceived proficiency when internal and external projects are combined regardless of the project type. Furthermore, we cannot conclusively determine a similar correlation when changing project type and holding combining internal and external projects constant. With that being said, almost an equal number of participants have indicated that new development and upgrade projects are standalone. The data points to upgrade projects having a higher perceived proficiency of PPM practices.

A possible explanation for this finding could be that organizations implement lessons learned from parent projects during subsequent upgrade projects.

New Development vs. Upgrade Projects	Combining Internal & External Projects? No	Combining Internal & External Projects? Yes
Both types make up the portfolio	2.389 36	2.143 14
New developments	2.429 7	1.500 4
Sustaining (or upgrade) projects	2.600 5	2.000 1
The types above are not usually in the same portfolio	2.000 4	1.000 1

Proficiency Score	
Highly effective	3
Mediocre	2
Nonexistent	1

Table 4-4 | Average PPM Proficiency Given Different Project Types

4.4. Number of Concurrent Projects and Portfolios

Participants were asked to identify the average number of projects in a portfolio and the number of simultaneous portfolios their companies manage at any one time. We hypothesized that companies strive to minimize the number of projects within a portfolio and maximize the number of portfolios. The reason being that projects in a portfolio would have many complex interdependencies, and thus managers attempt to minimize the quantity and complexity of these interdependencies. As usual, we have mapped the responses of these two questions to the responses of the proficiency question, as seen in Table 4-5 below. In agreement with our hypothesis, the vast majority of participants indicate that their companies aim to combine ten projects or less into a single portfolio. Most participants indicate that the number of concurrent portfolios is at least five. Over 50% of participants, however, indicate that their companies maintain at least ten simultaneous portfolios.

No. of Projects in a Portfolio	Proficiency Nonexistent	 Mediocre	 Highly effective
<5		15	10
5-10	1	17	7
>10	1	10	4

No. of Simultaneous Portfolios	Proficiency Nonexistent	 Mediocre	 Highly effective
<5	1	9	5
5-10	1	13	2
>10		20	14

Table 4-5 | Mapping Number of Projects and Portfolios to PPM Proficiency

This data begged the same question previously posed. Is there a relationship between the ratio of projects-to-portfolio and proficiency? We mapped the number of projects to the number of portfolios. Moreover, we averaged the proficiency score for a given number of projects and portfolios. Table 4-6 presents the results of the analysis. **There is strong proof that improved proficiencies are achieved by minimizing the number of projects in a portfolio and maximizing the number of portfolios (RH2)**. Said another way, companies may consider reducing the number of projects managed by an individual. Conversely, Table 4-6 shows the opposite is true – proficiency decreases as the number of projects increases and the number of portfolios decreases.

No. of Projects in a Portfolio	No. of Simultaneous Portfolios <5	 5-10	 >10
<5	2.375	2.250	2.462
5-10	2.167	2.125	2.364
>10	2.000	1.750	2.400

Proficiency Score	
Highly Effective	3
Mediocre	2
Nonexistent	1

Table 4-6 | Average PPM Proficiency given Number of Projects & Portfolios

4.5. Corporate Functions in Central Planning Entity

Firstly, participants were asked if their companies had a central planning entity, synonymous to a Project/Program Management Office (PMO). If they responded, "Yes," they were asked if the participating corporate functions are equally represented within said planning entity. If they responded, "No," they were finally asked to rank the representation of each function using a 1-5 scale, where 1 indicates the most represented. The functions were as follows: engineers/employees, program managers, analysts, and executives. The participants were also given two empty slots to enter other corporate functions not included in the above list. We combined the responses and mapped them to proficiency. Moreover, we summed each corporate function's ranking to sort them from most to least represented, as shown in Figure 4-2 below. We hypothesized that equal representation would correspond to improved proficiencies. Exactly half of the participants indicated that this central planning entity does not have equal representation of all corporate functions. **The responses failed to support our hypothesis that equal representation ensures improved proficiency of PPM practices (RH3).** As the bar chart depicts, program managers and executives, respectively, are the most represented corporate functions at the participants' companies' central planning entity. These results begged the following question. How do the rankings differ between highly effective and mediocre proficiencies? As seen in Figure 4-3, the glaring distinction is the ranking of engineers/employees and executives. The ranking of the remaining functions is unchanged. Despite the fact that there are substantially fewer data points for highly effective proficiencies compared to mediocre proficiencies, there is a correlation between the level of involvement of engineers/employees and the effectiveness of a company's PPM practices.

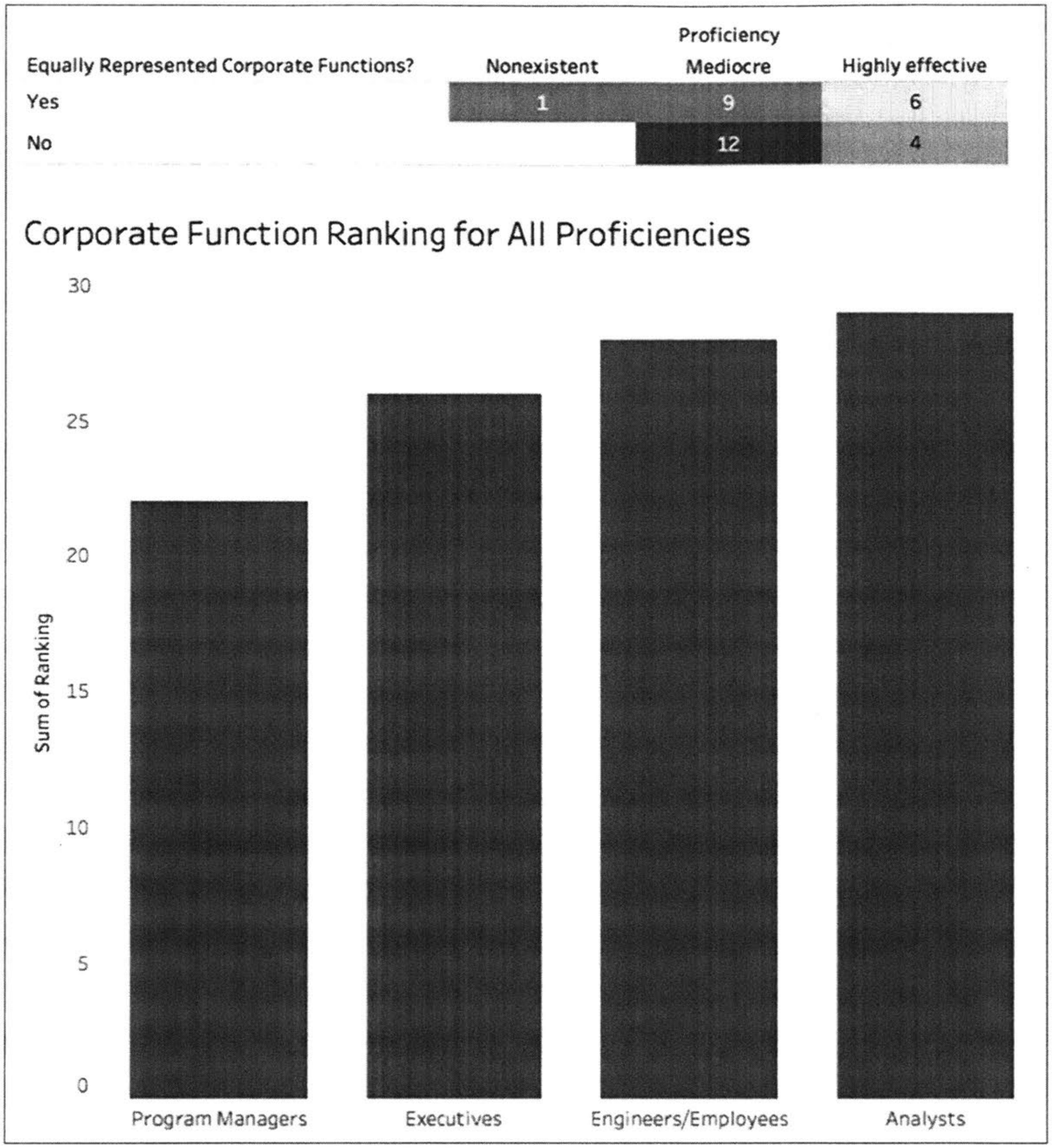

Figure 4-2 | Mapping Corporate Function Representation to PPM Proficiency

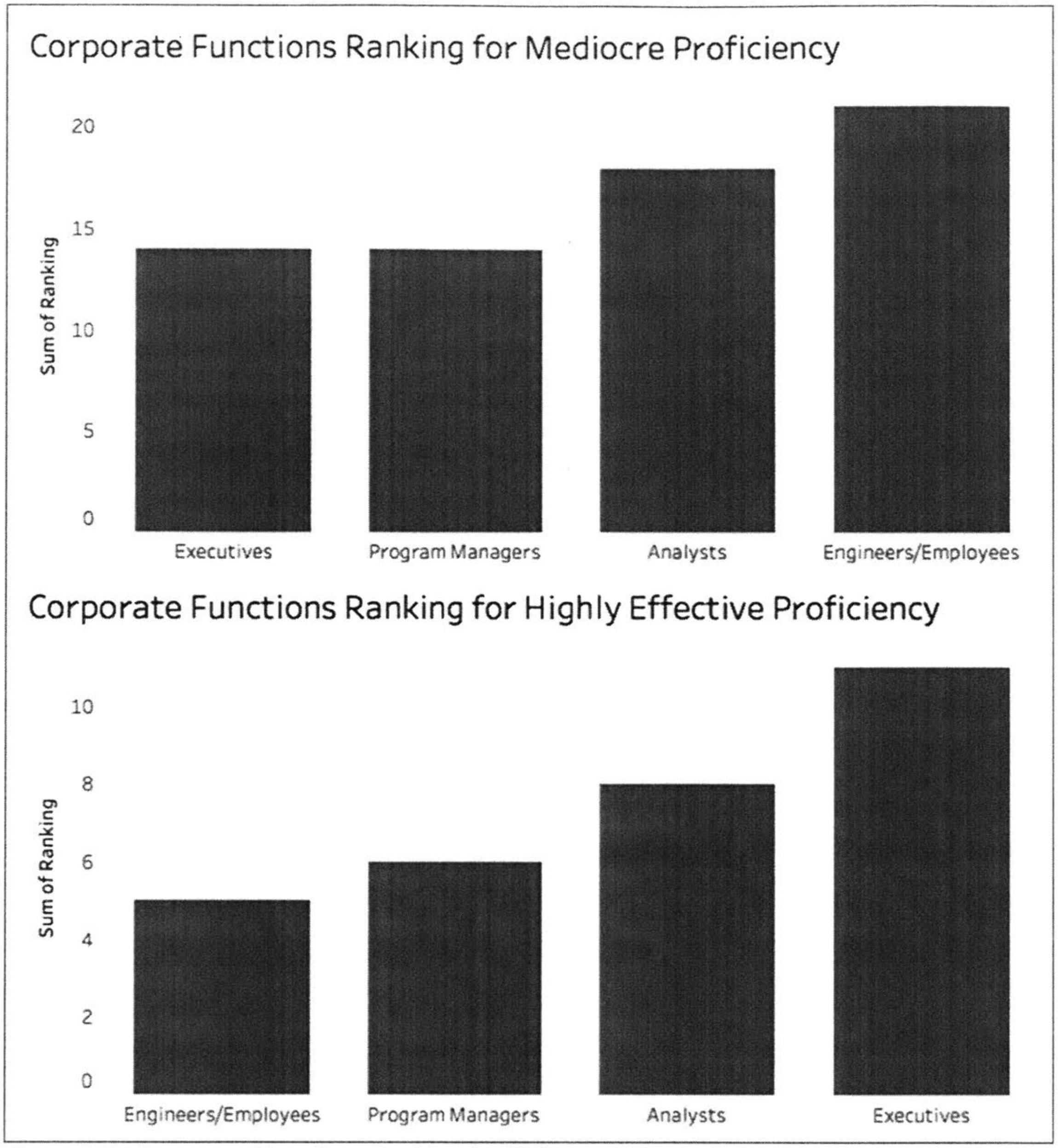

Figure 4-3 | Corporate Functions Ranking for Different PPM Proficiencies

4.6. Size and Budget of Central Planning Entity

For those participants whose companies had a central planning entity, they were asked to indicate the size of the entity, as well as its budget relative to the portfolios' baseline budgets. We hypothesized that smaller, more centralized groups would exhibit higher proficiencies. Eric Honour attempted to find a relationship between systems engineering budgets and project success. He concluded that a systems engineering budget of roughly 15% had yielded the highest number of project successes (Honour 2013). Similarly, we investigated the existence of a sweet spot for the entity's budget. The logic being that if the budget is too low, proficiency will drop and if the budget it too high, the group becomes inefficient and becomes overly bureaucratic. We have compared each of these variables to the participants' perceived proficiency, as seen in Table 4-7 below.

	Proficiency		
Size of Central Planning Entity	Nonexistent	Mediocre	Highly effective
<5			2
5-10		10	5
11-20	1	4	3
>20		10	2

	Proficiency		
Ratio of Central Planning Entity's Budget to Portfolios' Baseline Budget	Nonexistent	Mediocre	Highly effective
<10%		9	8
10%-20%	1	10	4
21%-30%		2	
>30%		3	

Table 4-7 | Mapping Size and Budget of Central Planning Entity to PPM Proficiency

The data neither supports nor refutes our hypothesis about the size of planning entity, as the distribution closely follows the pervasive proficiency distribution and is evenly spread across the top size tranches (RH4). However, there seems to be a relationship between budget and proficiency. The data is heavily skewed towards smaller budgets. Additionally, participants, who had earlier indicated a budget of less 10% of the portfolios' baseline budget, were evenly distributed among highly effective and mediocre proficiencies. Furthermore, the ratio of mediocre to highly effective responses increases as the budget increases. In keeping with our previous approach, we mapped entity size to budget and calculated the average proficiency score using our standardized scoring method as seen in Table 4-8. We have also indicated the number of responses below the respective average proficiency. Excluding the single responses in the left-hand side of the table, we can see a trend developing. Greater proficiencies are expected as long as the size of the planning entity is below 20 individuals while the entity's budget is 10% of the total budget; as seen by the significant drop in average score. As the entity grows beyond 20 individuals, expected proficiency stays constant as long as the group's budget is 20% of the total budget. The increase in budget is most likely proportional to the size of the entity.

	Size of Central Planning Entity			
Ratio of Central Planning Entity's Budget to Portfolios' Baseline Budget	<5	5-10	11-20	>20
<10%	3.000 1	2.500 8	2.500 4	2.250 4
10%-20%	3.000 1	2.143 7	2.000 4	2.333 3
21%-30%				2.000 2
>30%				2.000 3

Table 4-8 | Average PPM Proficiency Given Size and Budget of Central Planning Entity

4.7. Project Delays

Participants were asked to indicate the average project delay, as a percentage of baseline duration, in their companies' portfolio(s) due to what they would consider inefficacies in their PPM practices. We match their responses to the latter question to their responses to the proficiency question. Table 4-9 summarizes the findings.

Proficiency	Average Project Delay <10%	10%-20%	21%-30%	31%-40%	41%-50%	>50%
Nonexistent	1					1
Mediocre	6	16	11	1	3	
Highly effective	1	8	3	3	1	2

Table 4-9 | Mapping Average Project Delay to PPM Proficiency

The results are skewed toward the left side of the distribution; which peaks at the 10%-20% delay marker. What is most intriguing is participants who perceive their PPM practices to be highly effective, continue to experience delays at the project level. This result is both saddening and disturbing. It is saddening because participants have rated their companies' PPM practices as highly effective even though they are experiencing significant delays in their projects. Why have they tolerated these delays? Why does it seem that participants have accepted delays to be "a fact of life"? The result is disturbing because it may imply that current PPM practices do not provide practitioners with suitable methods to manage and execute portfolios. Recall the literature review summarized in Section 2.1 above, PMI and some academic researchers define PPM as the evaluation, analysis, and balancing of portfolios. Only a select few indicate that PPM should also include management and execution of the portfolio. Consider the following survey results. 51% of survey participants have indicated that their companies simultaneously manage ten or more portfolios. Approximately 40% of participants have indicated that their portfolios are comprised of five to ten projects. And nearly 70% of participants have indicated that a single portfolio's budget will fall between $100k and $100M; with half of that population indicating a budget in the range of $1M to $10M. These numbers translate to significant financial burdens on the order of tens of millions of dollars.

4.8. Portfolio Rebalancing Frequency

One of the main pillars of project portfolio management is balancing and rebalancing the portfolio. That is why we inquired of the participants about their companies' portfolio rebalancing frequency. Participants were asked to choose from a list of five possible frequencies; quarterly, semi-annually, annually, as needed or rebalancing when a project is inserted or taken out of the portfolio. We postulated that more frequent rebalancing would exhibit higher proficiency. First, we mapped rebalancing frequency to proficiency. The results are shown in Table 4-10. **Similar to previous proficiency maps, we cannot establish a correlation between these two variables (RH5).** Additionally, the previously observed distribution of proficiency responses is persistent.

		Proficiency	
Portfolio Rebalancing Frequency	Nonexistent	Mediocre	Highly effective
As needed	1	14	6
Quarterly		8	2
Semi-annually		5	4
Annually		8	4
When a new project is inserted into or removed from the portfolio	1	2	2

Table 4-10 | Mapping Portfolio Rebalancing Frequency to PPM Proficiency

We observe that most participants have indicated that their companies do not have a set schedule to rebalance their portfolios. The observation should be an alarming finding to practitioners since portfolio rebalancing is one of PPM's foundational tasks. This outcome led us to map rebalancing frequency to schedule delays (previously discussed in Section 4.7) while calculating the average proficiency score. Unfortunately, there were several responses of a single highly effective proficiency in the map, which may distort the analysis. Therefore, we present the map first including all responses then we exclude the single responses. As can be seen in Table 4-11 below, we cannot identify a conclusive trend in this data. Similar to Table 4-9, the distribution of delay responses is clear and centered around 10-20% average project delay.

	Average Project Delay					
Portfolio Rebalancing Frequency	<10%	10%-20%	21%-30%	31%-40%	41%-50%	>50%
As needed	2.000 4	2.364 11	2.200 5		2.000 1	
Quarterly	2.000 2	2.333 3	2.000 2	2.500 2	2.000 1	
Semi-annually		2.500 4	2.333 3	3.000 1	2.000 1	
Annually		2.000 5	2.250 4	3.000 1	3.000 1	3.000 1
When a new project is inserted into or removed from the portfolio	2.000 2	3.000 1				2.000 2

	Average Project Delay				
Portfolio Rebalancing Frequency	<10%	10%-20%	21%-30%	31%-40%	>50%
As needed	2.0000 4	2.3636 11	2.2000 5		
Quarterly	2.0000 2	2.3333 3	2.0000 2	2.5000 2	
Semi-annually		2.5000 4	2.3333 3		
Annually		2.0000 5	2.2500 4		
When a new project is inserted into or removed from the portfolio	2.0000 2				2.0000 2

Table 4-11 | Average PPM Proficiency Given Portfolio Rebalancing Frequency and Average Project Delay

4.9. Survey Conclusion

When we designed and implemented the survey discussed in this chapter, we had two objectives. Firstly, we hoped to evaluate the proficiency of current PPM practices. We asked participants to rate their companies' proficiency as highly effective, mediocre or nonexistent. We did not, however, define proficiency for participants or ask them to define it. As such, we believe this ambiguity may have induced incoherent survey responses. Secondly, we sought to find correlations between proficiency and several organizational and managerial variables. With that said, we should add that correlation is not causation. Correlation is a statistical measure, and it simply measures the degree of interdependence between variables, which may be completely random. For example, we do not mean to suggest that if organizations minimized projects in a portfolio while maximizing the number of portfolios, they would succeed more often. On the contrary, we are saying that based on our survey's sample size, which one could argue is not representative, we found a statistical relationship between the number of concurrent projects and portfolios and proficiency. Finally, we conclude that the lack of correlations is not an unfavourable result. We believe it is indicative of the complexity of PPM, in that proficiency does not simply rely on a single variable.

Admittedly, the survey is limited in breadth and it may not be representative of the entire project management community. Thus, it is recommended that a broader survey should be considered as a follow up to this thesis. The findings uncovered in the survey are not universal, since it did not reveal any industry-specific patterns. Nonetheless, the findings obtained were eye opening. Once again, these findings are not dogmatic. One cannot forget that project and portfolio management are comprised of a set of decisions and trade-offs. Organizations would approach said decisions and tradeoffs to maximize benefit while being conscious of internal processes and culture. For example, allowing engineers to become part of the human resource allocation process may be easily achievable in a start-up or a small company; however this method may be cost prohibitive in large, multi-national organizations. As such, these organizations may elect to follow a multi-tier process; wherein executives allocate projects to business units or regional offices, then local employees pick from the shortened list of projects.

Below are some noteworthy findings from the survey:

- 62% of participants indicated their PPM practices were mediocre, while 33% indicated they are highly effective.
- 70% of participants indicated their companies do not distribute internal and external projects to the same program or portfolio.
- Proficiency seems to improve when internal and external projects are not combined (correlation factor = 0.353).
- Proficiency seems to improve when number of concurrent portfolios is maximized and number of projects within a portfolio is minimized (correlation factor = 0.225).
- Proficiency seems to improve when engineers/employees are the most represented corporate function in the central planning entity and executives are the least represented.
- Proficiency seems to improve when size of planning entity is between 5 and 20 individuals (correlation factor = 0.284).
- All participants who indicated their companies have highly effective PPM practices have all indicated that projects are delayed on average 10-20%.

5. System Requirements

5.1. Stakeholders

Any honest and objective system (i.e., project or product) development requires eliciting requirements to assess various designs. The system's users would levy these requirements. However, a comprehensive requirements writing phase does not end with there. We adopted the term stakeholders and defined it as any and all parties affected by the system (Crawley, Cameron, and Selva 2016). As such, we generated a list of three stakeholders. They are the organization that is planning to adopt a human resource allocation system, the manager and the employee who are the primary system users. Next, we relied on our industry experience to conceive the list of requirements from the stakeholders mentioned above. We present the stakeholders and their requirements in Figure 5-1, using the notation proposed by (Crawley, Cameron, and Selva 2016)

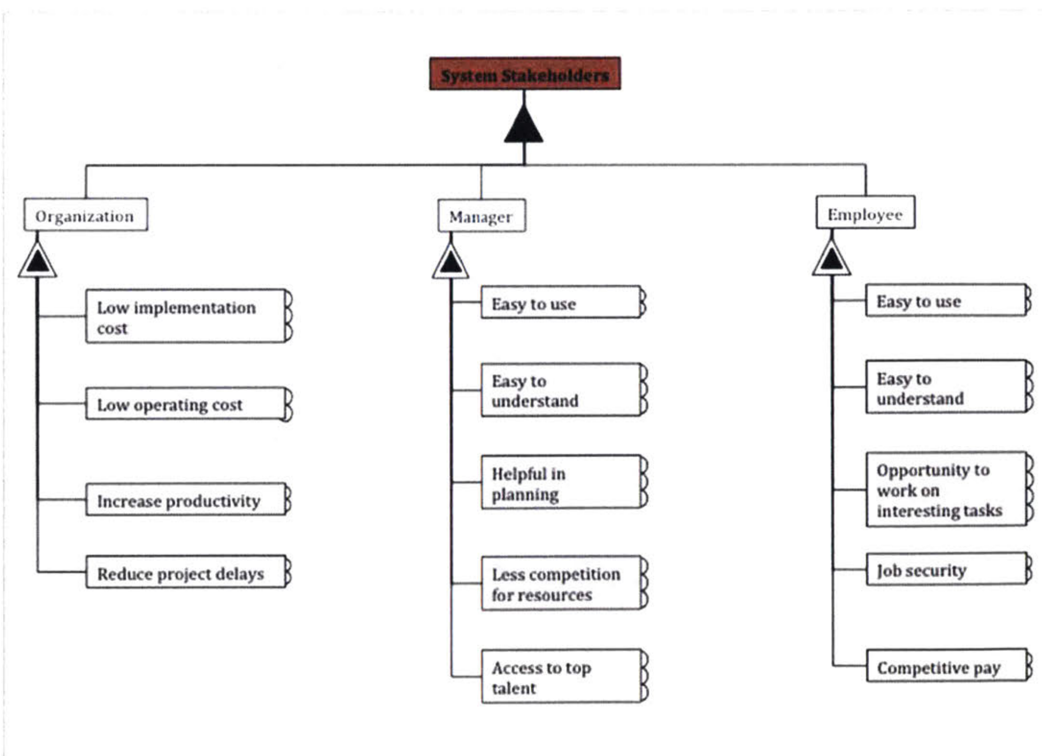

Figure 5-1 | System Stakeholders and Their Requirements for H-RAS

This notation builds on the work of (Dori 2011) and should be read as follows. System stakeholders are an abstraction and are decomposed to the three groups we identified earlier. Each stakeholder imposes requirements on the system, which are shown vertically below the stakeholder. The black triangle inside the white triangle signifies a characterization. In this context, it symbolizes that each stakeholder exhibits several characteristics, which are requirements. Next, we present and discuss each stakeholder's requirements. Note that we have purposefully used the same language any of these stakeholders would have used during a requirements gathering process. As always, the onus is on the system architect to translate the stakeholder's statements into measurable and verifiable requirements.

5.2. An Organization's Requirements

The organization is also an abstraction. Realistically, vice presidents or executives would levy the following requirements. The proposed H-RAS architecture shall have low implementation and operating costs. Furthermore, the proposed architecture shall increase a resource's productivity. Finally, the proposed architecture shall reduce project delays. Generally speaking, delays can be caused by a multitude of reasons and can have many adverse effects on the organization. For example, if the organization's contracts were performance or outcome based, it would forego additional revenue streams. Alternatively, if ongoing internal projects are delayed, the organization cannot proceed with its future planned projects as desired.

5.3. A Manager's Requirements

The manager is one of the system's primary users. In the context of this thesis, the manager may be referred to as a project, program or portfolio manager. Naturally, the proposed architecture shall be easy to use and easy to understand. Put differently; the manager would like the system to be as simple as possible. As system designers, we perceive this requirement as a need to balance simplicity and functionality. Most importantly, the proposed system shall be helpful in planning. As we have seen in Section 2.1 above, many of today's PPM methods and tools perform resource allocation activities a priori. Therefore, the manager would like an effective tool to be added to her arsenal of planning tools while offering flexibility in the face of unforeseen circumstances. The proposed system shall manage inter-project competition for scarce resources. It is important to realize that the system would never reduce competition since it is a function of the number of available resources. The proposed system shall provide the manager access to top talent. Any manager would like her organization's best and brightest employees to work on her projects; however, that is not always possible. Therefore, the manager would like the proposed system to increase the number of instances when this requirement is realized.

5.4. An Employee's Requirements

The employee is also one of the system's primary users. Similar to the manager, the employee would like the proposed system to be easy to use and easy to understand. The proposed system shall provide the employee with an opportunity to work on interesting and challenging projects. Employees are always looking to sharpen and upgrade their skills. Experiencing a variety of tasks and projects is one strategy to achieve that goal. Additionally, the employee is looking to maintain job security once the system is implemented. The employee may worry the H-RAS architecture may optimize the size of the workforce; leading to downsizing and layoffs. Finally, as usual, the employee is looking to secure competitive pay for the services provided.

In Table 5-1 below, we have assigned key performance indicators to each requirement along with an objective to either maximize or minimize the indicator. These will prove to be helpful to validate and verify the H-RAS architecture has met its design intent. We would like to point out that the primary users', manager and employee, requisite for an easy to understand system can be realized by eliciting more detailed requirements from them and by increasing their active participation during the design development process.

Stakeholder Requirement	Key Performance Indicator	Objective
Low implementation cost	Capital cost	Minimize
Low operating cost	Operating cost	Minimize
Increase productivity	Resource utilization factor	Maximize
Reduce project delays	Number of days behind schedule	Minimize
Easy to use	User's level of proficiency after training session	Maximize
Easy to understand	User's participation in system development	Maximize
Helpful in planning	Manager satisfaction	Maximize
Less competition for resources	Manager satisfaction	Maximize
Access to top talent	Rework due to errors Manager satisfaction	Minimize Maximize
Opportunity to work on interesting tasks	Employee satisfaction	Maximize
Job security	Employee satisfaction	Maximize
Competitive pay	Employee salary	Maximize

Table 5-1 | System Requirements, Features and Objective Functions

6. Human Resource Allocation System (H-RAS)

6.1. H-RAS Hypotheses

In response to the research questions shown in Figure 1-4 above, we augment the previously listed hypotheses in Section 4.1 with the following. Any findings that either support or refute the research hypotheses will be **bolded** throughout the thesis.

RH6. A human resource allocation process where decision-making privileges reside with a small, centralized group is desired.

RH7. Penalties are required to reprimand cancellations in the human resource reservation and brokering system.

6.2. Context Description

First, we present several useful definitions of the basic building blocks of a project organization. These are in line with the Project Management Institute's (PMI) definitions ("PMI | Glossary of Project Management Terms" 2016). A project is the rudimentary element of form within an organization. Next, a program is comprised of two or more projects. PMI defines programs as "...projects managed in a coordinated way to obtain benefits and control not available from managing them individually. Programs may include elements of related work outside of the scope of the discrete projects in the program." Common features among projects in a program may include the following: the client, the product or site, the types of projects (e.g., new developments vs. upgrades), the size of projects, among other features. Finally, the highest level of abstraction is a portfolio. It may consist of several projects and/or programs. PMI differentiates between programs and portfolios as follows "a portfolio is a collection of projects or programs and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives." Moreover, PMI adds, "projects or programs of the portfolio may not necessarily be interdependent or directly related."

Zooming in on the anatomy of a single project, we ascertain it is composed of two distinct elements of form: task and agent. A task is a well-defined project activity and it has been traditionally described using the three vertices of the Iron Triangle as seen in Figure 6-1 below. The agent is an abstraction, which includes a requester of a service and a provider of a service. The use of the term agent in this specific context is different from that used in Agency Theory as discussed in Section 2.4 above (Eisenhardt 1989). Both the requester and the provider can be characterized using attributes that are aligned with project management; such as labour cost, slack (Cheng and Kesner 1997), resource utilization factor, number of project delays, severity of project delays, among others.

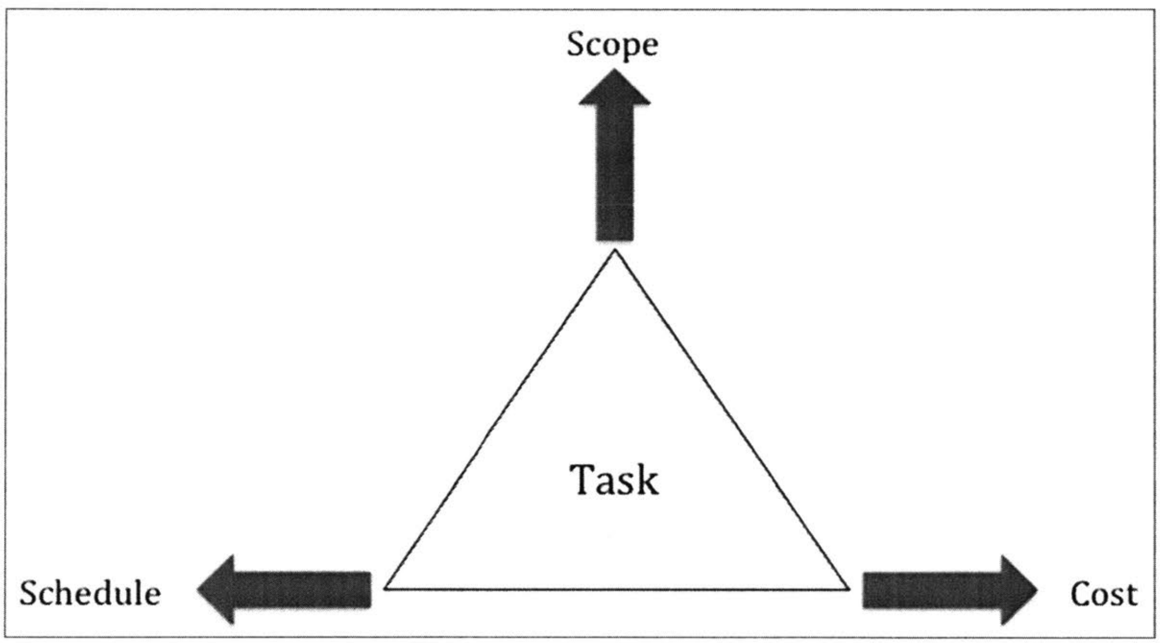

Figure 6-1 | The Iron Triangle

We recognize a new category of tasks not defined by PMI. We identify a service level agreement (SLA) as a task that is analogous to a service contract. The requester places a claim on a certain percentage of the provider's time for a specific duration of time. The requester may or may not require support from the provider per to the agreed-upon commitment. However, when the need does arise, the requester's obligations become the provider's foremost priority.

We have used Dov Dori's Object Process Methodology (OPM) (Dori 2011) to diagrammatically describe an organization using its portfolios, programs, projects, tasks and agents as seen in Figure 6-2 below. The thesis' system boundary is depicted using a dotted red line, and it encompasses a single portfolio, its programs, projects, and agents. Although tasks are not within the scope of this thesis, they are worthy of a brief discussion. Note a task's attributes in Figure 6-2, which are more detailed than the Iron Triangle. The scope is now characterized by its complexity while the schedule is described by its risk and uncertainty, which is fundamentally different from common definitions of schedule. It has been established that a task's schedule (primarily its end date) is dependent on its complexity and risk, and on the provider's attributes (B Moser, Kimura, and Suzuki 1998), as shown in Figure 6-2.

That is a drastic departure from today's notion of estimating schedules, wherein practitioners rely on mental models that are deeply anchored in historical performance, which disregard important exogenous variables such as the specific provider who completed the same task in the past. For example, consider a printing press that is marketing its services to local newspapers, and it quotes a print time of 12 hours. However, the printing press does not specify which of its presses will be utilized. It may have multiple presses, each with different speed, quality, and cost. Consider another example where an automotive product manager is writing her project plan. She notes a new air conditioning system could be designed within three months since that is the average duration that task has required in the past. However, she may not have confirmed if the resident air conditioning expert will have spare time to take on her project. She is now left with that expert's protégé, who is perfectly capable of completing the task but will need four months instead of three. Therefore, a task's duration only emerges as a skilful provider or team of providers is mapped onto the task's scope. Put differently; the schedule or task duration is an output, not an input, of the planning activity.

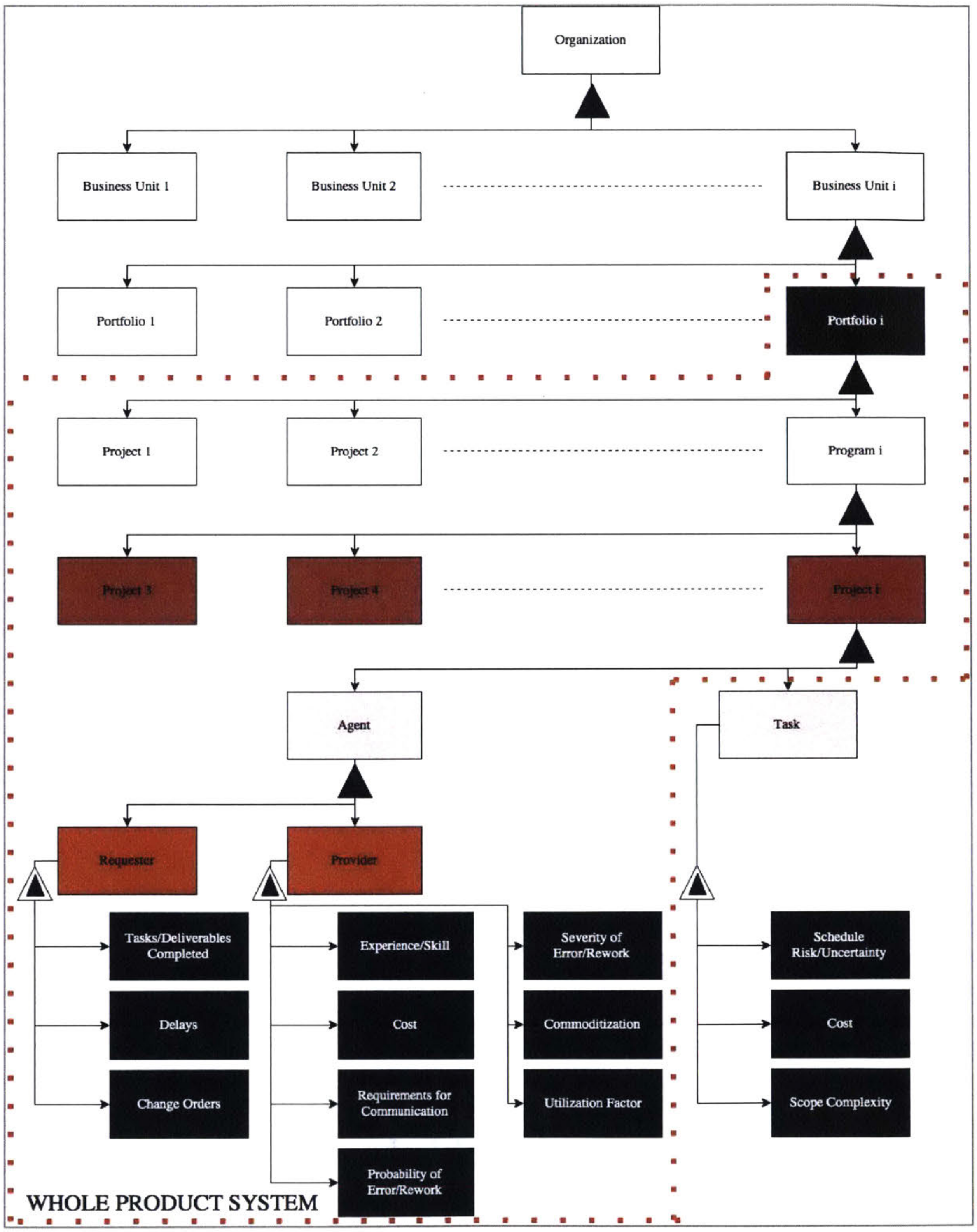

Figure 6-2 | High Level Context Description

Requesters and Providers, as agents, are the central focus of this thesis. These terms have been purposefully chosen to be industry-agnostic because the resource allocation system is intended to be reusable in any industry and with human and non-human resources. Requesters are agents who need their tasks to be completed. Providers are agents who possess the necessary skills to complete these tasks. Requesters continually search for appropriate providers to complete said tasks. Providers can be further described using seven attributes as shown in Figure 6-2 above.

"Experience/skill" denotes a provider's area of expertise and her level of competence. For example, a mechanical engineer may be classified by her organization as an intermediate pressure vessel engineer. "Cost" represents the provider's hourly wage or salary. "Requirements for communication" can be measured either at the provider level or the functional level. The attribute signifies the percentage of time this provider (or provider's function) has historically needed to communicate with other providers to complete a task. A requester worries about communication as it directly affects the task's end time.

"Probability of Error/Rework" can also be measured either at the provider or functional level. It indicates the probability at which said provider (or provider's function) has historically committed errors that resulted in rework. "Severity of Error/Rework" measures the gravity of these errors. For example, a provider, or her function as a whole, may only commit errors 10% of the time however these errors will result in change orders that are 50% of the task's baseline cost or duration.

"Commoditization" ultimately refers to the number of providers with a specific "Experience/Skill." For example, most oil and gas EPC companies have droves of 3D CAD modellers but only a handful of gas turbine experts. Finally, "Utilization Factor" (RUF) is colloquially known as the ratio of hours worked divided by the total possible number of work hours (typically 8 am to 5 pm). In this context, RUF is a measure of a provider's busyness. The common, underlying theme among these attributes is the provider's ability to accurately and productively complete a task. Similarly, requesters can also be described using three attributes that reflect their management abilities. Firstly, "Tasks/Deliverables Completed" measures the requester's past ability to meet milestones. Secondly, "Delays" is another historical performance indicator, and it conveys the requester's average delay in meeting milestones. Thirdly, "Change Orders" indicates the ratio (in dollars) of the requester's past change orders to baseline budget. The caveat is that these change orders cannot be generated from client-originated changes in scope.

This thesis is primarily focused on the interaction among requesters and between requesters and providers. Figure 6-3 depicts the different structural relationships among requesters, between requesters and providers and between providers and tasks; per the methodology employed by (Crawley, Cameron, and Selva 2016). The scenario pictured in the figure is an ordinary occurrence in the life of a portfolio manager, as it contains both resource and schedule dependencies. There are two projects, 1 and 2, each with a dedicated manager or requester. In this case, each project has t Tasks, which follow a typical Gantt chart notation. For example, T_{11} is expected to finish after T_{21} and T_{2t} is expected to start before and finish after T_{1t}. Next, these projects share a common set of resources P_1, P_2, P_3, and P_p. Figure 6-3 contains four types of structural relationships. Sequential relationships serve to show sequence among the project tasks. For example, T_{11} needs to be completed before T_{12} and T_{1t} could start. Similarly, T_{21} needs to be completed before T_{21} could start; and T_{21} needs to be completed before T_{2t} could start. Membership relationships signify belonging to an organization, group or, in this case, a project. As such, requester R_1 belongs to project 1 and requester R_2 belongs to project 2. As a virtue of working on its tasks, the providers also exhibit membership relationships to projects 1 and 2 respectively. Please note that these relationships are not shown to avoid further cluttering the figure.

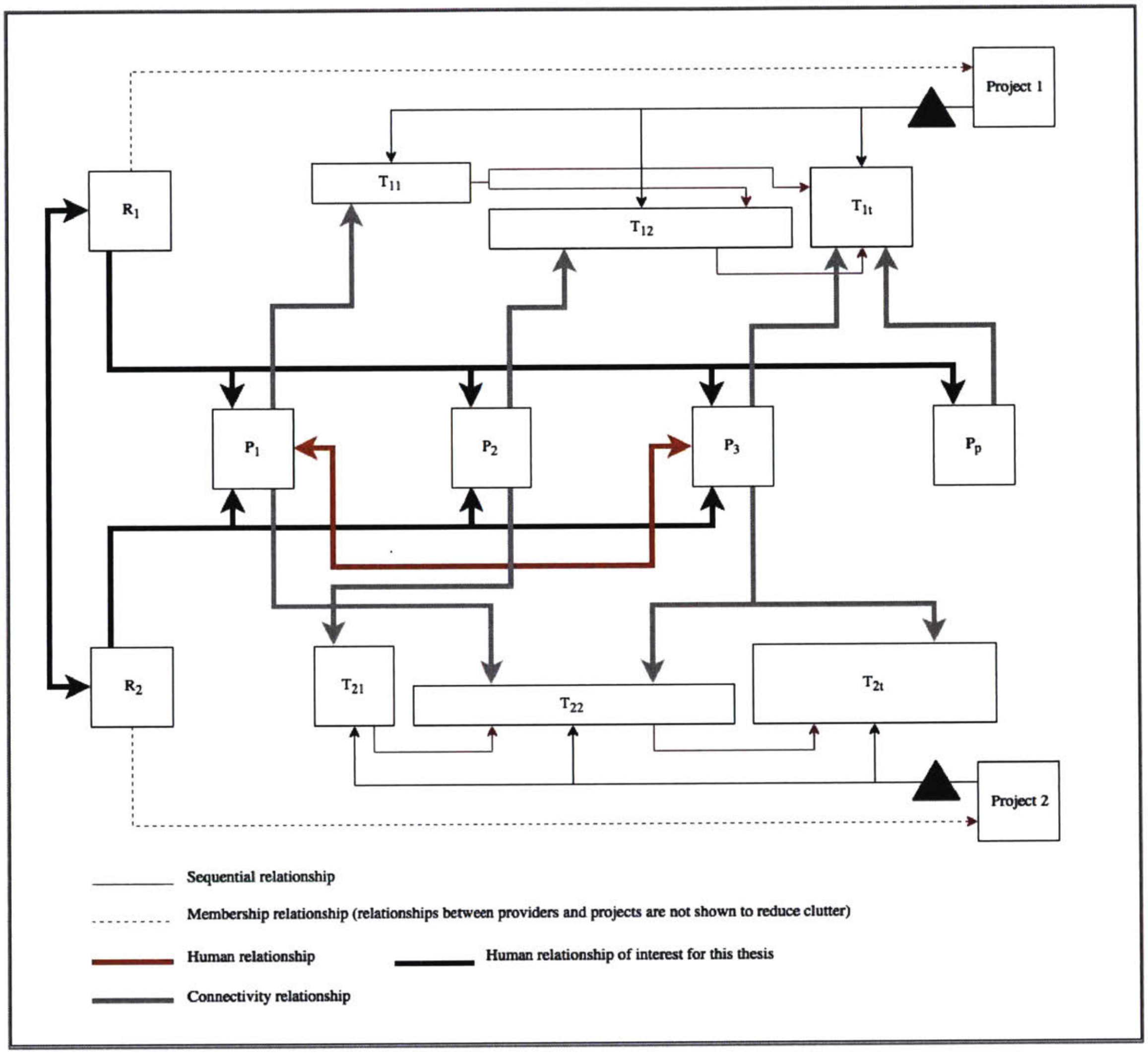

Figure 6-3 | Structural Relationships Within a Portfolio

Next, we identify human relationships, which embody relationships between the agents in the system. These exist between requesters and their respective providers, and among providers working on the same project. The bold black arrows are of particular interest as they are the focus of this thesis. These represent the relationships among requesters and between requesters and providers. Finally, we characterize the mapping of providers to their tasks using bold grey arrows to represent connectivity relationships.

Albeit fictional, Figure 6-3 raises several critical, real-world questions:

1. Providers P_1, P_2 and P_3 are working on projects that have different requesters. Which project has priority?
2. How do the providers split their time between both projects?
3. Have the requesters and providers agreed upon a required level of commitment or effort?
4. What happens if a task is delayed and its provider is required to work full time on another task? For example, T_{21} is delayed, and P_2 is needed on T_{12}?
5. Should requesters R_1 and R_2 be coordinating with each other since they are sharing providers? If so, how?
6. How would downstream providers and requesters be affected if a task were to start 1-2 days later than anticipated?

6.3. Reverse Engineering Resource Allocation Systems

This thesis is concerned with the dynamics of human relationships in the context of project portfolios. More specifically, we are interested in the interactions among requesters and between requesters and providers. The type and quality of information exchange in these bi-directional interactions have a direct impact on the cost and accuracy of project and portfolio plans. Therein lies our system.

From this point forth, we will be using an architectural nomenclature scheme developed by (Crawley, Cameron, and Selva 2016). The methodology serves to describe system architecture by writing phrases such that an *instrument object* carries out a *process* on an *operand* thus changing its state. More formally, the authors offer the following three definitions:

- Instrument object: has the potential for stable, unconditional existence for some period of time.
- Process: a pattern of transformation undergone by an object. Processes generally involve creation of, destruction of, or a change in an operand.
- Operand: also an object and therefore has the potential for stable, unconditional existence for some period of time. Operands are objects that need not exist before the execution of functional and are in some way acted

upon by the function. Operands may be created, modified, or consumed by the process part of the function.

For example, if we were to describe thesis writing using this nomenclature, we would say, *"the author (instrument object) is writing (process) a thesis (operand)."* The thesis' state changes from being incomplete to complete. Additionally, we will be making use of the system modeling language developed by (Dori 2011) to visually represent system architecture.

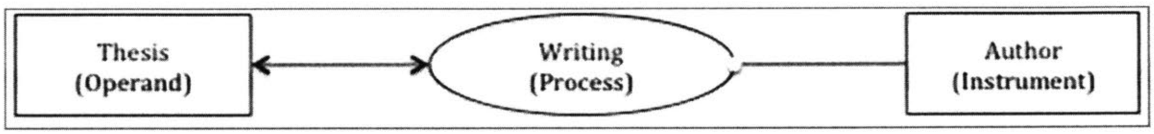

Figure 6-4 | OPM Notation

We, first, sought to reverse engineer three different non-human resource allocation systems. Then, we posed various probing questions to underscore these systems' basic building blocks, any common features they may share and their differences. These systems are an airline travel system, a hotel room reservation system and a financial options exchange. The airline travel system is adapted from an air transportation service example developed by (Crawley, Cameron, and Selva 2016). Table 6-1 summarizes the results of the reverse engineering exercise of the airline travel system using the architectural nomenclature described earlier. As the name implies, this architecture is built around the traveller and her belongings. It serves to define the process from the moment the traveller purchases a ticket, checks in at the airline's desk until she arrives at her destination.

AIRLINE TRAVEL SYSTEM		
Operands	Processes	Instruments
Ticket, traveller, baggage, reservation, travel program database	Purchasing, checking in, loading, transporting, nourishing, entertaining, unloading, checking out,	Reservation system, check-in system, baggage system, gate system, flight crew/aircraft, cabin

	crediting, linking, learning, reserving, amending	crew system, reward system, credit card, travel program database, schedule database, reservation engine

Table 6-1 | Reverse Engineering an Airline Travel System

Some examples of architectural descriptions that could be used to describe the airline travel system are as follows:

- *Check-in system is checking in a traveller*
- *Baggage system is transporting baggage*
- *Cabin crew system is nourishing a traveller*
- *Reservation engine is amending a travel program database*

In some scenarios, an instrument may also be an operand and vice versa. Consider, for example, the following description: *traveller is reserving a ticket.* In this case, the traveller is the instrument that is carrying out the process of reserving. Table 6-2 below summarizes reverse engineering the hotel room reservation system using the previously described architecture methodology and is based on our personal experiences. The reservation system described below is a process where the guest reserves a hotel room online, directly from the hotel's website.

HOTEL ROOM RESERVATION SYSTEM		
Operands	Processes	Instruments
Reservation, hotel website, reservation system, room, guest, credit card, schedule, dates (check-in & check-out), personal	Accessing, searching, optimizing dates, booking/reserving, confirming, cleaning, checking-in, sleeping/lodging,	Guest, front desk staff, housekeeping staff, reservation system, hotel

information, confirmation email	checking-out, showing, selecting, filling out, receiving	

Table 6-2 | Reverse Engineering a Hotel Room Reservation System

Similar to the airline travel system above, Table 6-2 contains examples where the instrument becomes an operand. For example:

- *Guest is accessing hotel website*
- *Guest is booking/reserving a reservation*
- *Front desk staff is checking in guest*

Whenever instruments become operands or operands become instruments; there exists a timeline or sequence of events in the system. In the case of the hotel room reservation process, the guest must first access the hotel website; then she must book the reservation and only at that point, can the front desk staff check her in. Lastly, Table 6-3 presents our personal interpretation of a financial options exchange process. Note that this description is not meant to be an exhaustive representation of this complex system. The description below is written from the investor's perspective when she makes use of the services of an online broker.

FINANCIAL OPTIONS EXCHANGE		
Operands	Processes	Instruments
Online brokering system, stock ticker, option (several characteristics such as, calls/puts, last quoted price, strike price, expiration date, open interest, etc.), quantity, security code, order,	Accessing, inputting, sorting, selecting, entering, confirming, finalizing, taking, paying, doing nothing, exercising, transferring, selling, paying, obtaining	Investor, broker, online brokering system, stock holding entity

brokerage fee, profits		

Table 6-3 | Reverse Engineering a Financial Option Exchange

Now that the reverse engineering process is complete, we began to compare and contrast the three systems to distil important information to support the next step of architecting our human resource allocation system. The investigative process consisted of asking and answering ten questions from each of the three systems' perspective as seen in Table 6-4 below.

	Airline Travel	Hotel Room	Financial Option
1. Percent of payment when contract is written	100%	100%	100%[1]
2. Is there a cancellation policy?	Yes	Yes	No[2]
3. When can one cancel and receive full amount paid?	First 24 hours	Up to last 24 hours	N/A
4. Do you have to use service after payment?	No	No	No
5. Who is the requester?	Traveller	Guest	Investor
6. Who is the provider?	Airline[3]	Hotel[3]	Another Investor[4]
7. Do providers know what other providers are offering?	Yes	Yes	Yes
8. Do requesters know what other requesters are searching for?	No	No	Yes[5]
9. Can the contract be transferred to another requester before the reservation date?	No	No	Yes[2]
10. Does the requester know exactly what she is getting?	Yes but only flight & seat	Yes but only hotel &	Yes

	type[6]	room type[7]	

Table 6-4 | Comparing and Contrasting Three Resource Allocation Systems

Notes:

[1] The option price is substantially lower than the price of the underlying security.

[2] The option cannot be cancelled; however, the contract can be sold to another investor.

[3] Although the requester dealt directly with the provider, there are architectures where there is an intermediary between requester and provider, otherwise known as a booking agent.

[4] The ultimate provider of the option contract is another investor, and the intermediary is the broker.

[5] The embodiment of the stock market, especially Level 2 trading information where an investor can see how many trades are open as well as their quantities and bid prices.

[6] Traveller would have to pay an extra fee for other information such as seat number.

[7] Guest would have to pay an additional fee for other information such as room location or floor.

With our human resource allocation system in mind, we analyzed the information in the table above. The resource in contention in the airline travel system is a flight ticket, whereas the resource is a hotel room in the hotel reservation system. Finally, an option contract is the resource being allocated in an options exchange system. In these three systems, the requester approaches the provider directly (airline and hotel) or through a third-party broker (options exchange). Therefore, the requester initiates communication hoping for a transaction to take place.

Another common feature between the three systems is the requesters' decision-making process. The three requesters have a need for a resource, possess a list of requirements or constraints that should be met by the resource and value the resource based on the benefit gained. For example, an investor is seeking an options contract to gain exposure to an otherwise expensive stock (e.g., Berkshire Hathaway Inc. Class A stock valued at over $250,000 on the New York Stock Exchange as of March 27, 2017). The investor would only be willing to purchase the contract if the option's risk measures are deemed acceptable. Finally, the investor has already allocated a monetary budget to this purchase, and therefore she is searching for the optimum contract that fits within her constraints.

The sample systems above require the requesters to pay 100% of the reservation's value upfront. However, it is not uncommon for a resource allocation system to require periodic payments leading up to the reservation date (e.g., paying a contractor to remodel a kitchen). One must wonder why none of the three systems above employs a periodic payment scheme. We believe there are two reasons. Firstly, the low uncertainty associated with receipt of the resource. In other words, when a traveller books a flight ticket, she can be nearly 100% certain she will use the ticket. Secondly, the provider owns the resource at the time of the reservation. The airline already owns and operates the aircraft on which the traveller will fly on the date of the reservation.

Next, we find that the options exchange system does not have a cancellation policy per se; the investor can sell the contract to another willing investor. The remaining two systems have different cancellation policies, and the requester stands to lose 100% of the payment if the reservation is cancelled beyond the terms of the policy. Interestingly, none of the requesters are obliged to use the resource after the reservation takes place. The traveller does not have to use the ticket she booked, the guest is not obligated to check-in to the room nor is the investor required to exercise the option and obtain the underlying securities.

An important similarity between the three systems is the near-perfect transparency of providers' offerings. Competing airlines, hotels or brokers can very easily find their competitors' products and prices. However, not all requesters have that luxury.

Stock exchanges list all open trades while including information such as trade volume and bid/ask prices. However, the traveller and the guest are not privy to their fellow requesters' plans. If that information were in the public domain, the traveller might elect to change her trip dates to coincide with a period of low demand.

Lastly we asked if the contracts could be transferred after the reservation takes place, which is only true in the case of options exchanges. On the other hand, the guest cannot sell her room reservation whose price has suddenly increased. We then wondered about the causal link between the similarities and differences in Table 6-4 and the value delivered to both requesters and providers. With that in mind, we created a list of architectural decisions.

6.4. Architectural Decisions

(Crawley, Cameron, and Selva 2016) have said, "In the design of complex systems, many of these early architectural decisions are made without full knowledge of the system's eventual scope. These early decisions have an enormous impact on the eventual design." On a different occasion, they explained, "Architectural decisions are the subset of design decisions that are most impactful. They relate to form-function mapping, they determine the performance envelope, they encode the key tradeoffs in the eventual product, and they often strongly determine cost." More generally, they have stated, "Architectural decisions lead to architectures that are fundamentally different from each other." Each architectural decision has several, mutually exclusive options, which may be thought of as concepts or solutions to that decision. For example, an important architectural decision in automotive design is engine location. The decision's options may be: front, mid or rear mounted. The option selected strongly impacts the car's handling and weight balance. Different combinations of decision options yield substantially distinct architectures that may have drastic variances in performance. As such, we have codified nine architectural decisions as shown in Table 6-5 below.

The first decision deals with the requester' or providers' visibility to each other. Naturally, there are three options: no visibility, similar to the airline and hotel systems described above; or complete visibility, similar to the financial option (i.e., brokering) system also described above. The third option is a combination of these and can be created by providing an opportunity for the parties to pay an additional fee for greater visibility. This decision applies to both requesters and providers, depending on which party initiates the reservation. In the case of human resource allocation and portfolio management, the "visible" option may offer improved communication and information exchange among requesters. On the other hand, an option of no visibility may be cheaper to implement and operate; which is beneficial to the organization. In the spirit of cooperation, we anticipate that reservation initiators may negotiate and exchange information to create mutual benefits. Having said that, we feel that a word of caution is necessary at this juncture. As with any stock market exchange scheme, the market is considered "efficient" when all market agents have access to the same information (Ang 2014). Therefore, we worry that with a brokering system, agents will become selective with whom they share information. That should not, however, detract from the utility of brokering. Any unwanted behaviour could be easily curbed using the proper control measures.

The second decision addresses cancellation policies. Can agents cancel reservation requests after an agreement or contract is already in place? That is a vital decision considering the foremost objective of H-RAS is to facilitate and streamline a manager's planning activities, given human resource scarcity and interdependence. If there are no cancellation policies, agents will become excessively risk-averse and will not enter into any contracts until uncertainty is unusually low, or practically zero. This behaviour may induce short bursts of agreements (synonymous to an illiquid, volatile security) punctuated by long periods of inactivity.

ARCHITECTURAL DECISION	OPTION1	OPTION 2	OPTION 3
1. Requesters'/provider's visibility to each other	No	Hybrid	Yes
2. Cancellation policy	None	Near beginning of contract	Up to end of contract
3. Cancellation penalty	None	Function of remaining duration	100% of amount "paid"
4. Cancellation refund (if within contract)	None	Function of remaining duration	100% of amount "paid"
5. Requester/Provider specificity	No	Hybrid	Yes
6. Resource allocation decision making privilege	Requester	Hybrid – matching system	Provider
7. Contract confirmation frequency	None	Once – at beginning of contract	Frequently
8. Task end date confirmation	None	Once – at beginning of contract	Frequently
9. Reservation value	Value set arbitrarily by central planning entity (ie. PMO)	Systematic method rooted in agents' attributes	

Table 6-5 | Morphological Matrix of Architectural Decisions of H-RAS

On the other hand, if there were reasonable cancellation policies in place, agents would take on calculated risks and attempt to plan in advance, considering the available information and its uncertainty.

The third decision pertains to the magnitude of the cancellation penalty. If the system were not designed around a cancellation policy, the cancellation penalty decision would become null. However, if there is a cancellation policy, an appropriately scaled penalty should be assessed. One may choose to impose a penalty equivalent to 100% of contract amount; regardless of elapsed or remaining time. Or, impose a penalty commensurate to the remaining contract period. Or, elect not to impose a penalty altogether. The "no-penalty" option will enable extreme risk-taking behaviour, which will inevitably increase the number of cancelled contracts, and negatively affect the planning process. On the other hand, the "100% penalty" option will sway the pendulum in the other direction and cause agents to become risk averse.

The fourth decision answers the question about a refund policy. If a contract is created then cancelled, should the cancelling party be entitled to a refund less the cancellation penalty? We list three options: a no refund policy, one that is proportional to the remaining contract duration, or a "100%" refund of the amount paid. Similar to the "100% penalty" option above, the "no refund" policy will detract away from the intent of the human resource allocation system. We aim to improve the planning process by encouraging planning ahead while creating backup plans. If an agent stands to lose its entire payment, it will not enter into any future contracts unless it could guarantee that risk and uncertainty are nearly zero. Alternatively, we could refund a portion of the payment, proportionate to the remaining contract duration. The relative magnitude of the cancellation penalty and cancellation refund will increase and decrease respectively, so as to discourage any cancellations closer to the contract date. Lastly, we could consider a refund policy where the cancelling party receives 100% of the amount spent. However, special care should be exercised if this option is chosen to assess the expected agent behaviour. If a late cancellation occurs and a provider is not fully utilized (i.e., RUF $\sim$ 1.0), the organization is practically paying the provider to be idle.

The fifth decision addresses requester/provider specificity. Should requesters be allowed to ask for certain providers "by name" and vice versa, or should they simply attempt to find a provider that meets the minimum performance attribute thresholds they have set out? We are aiming to eliminate any favouritism in organizations, and instead urge managers to select providers solely based on performance, and enable providers to select challenging tasks regardless of their managers. We have added a hybrid option to this decision; wherein agents may elect to pay extra to gain greater visibility. That is similar to the traveller paying additional fees to guarantee her seat's number and location on the plane. She is paying to reduce future uncertainty and possible discomfort that may arise if she has a window seat on a long-haul transoceanic flight.

The sixth architectural decision presents an intriguing variable. Who makes the resource allocation decisions? In other words, who gets the final say? Is it the requester, provider or both based on a matching system? Recall the lesson learned from Figure 4-3. Based on the data provided by survey participants; we found a positive correlation between PPM proficiency and the employees' role in planning. The hybrid decision-making system is one where requesters select providers and vice versa. Then, they are matched in such a way to maximize the number of instances where both agents have selected each other. One could argue that this decision offers the most utility; in that it allows requesters to choose the most suitable providers and in turn providers select the tasks or assignments they deem to be interesting or beneficial.

The seventh decision sets the contract confirmation frequency. We are envisioning a reservation system where, for example, a requester could be required to confirm their need for a specific provider at pre-agreed-upon intervals. We believe this is a beneficial feature in that it allows requesters to reduce their exposure to risk and uncertainty; especially considering that a requester is at the mercy of their planned provider's on-going task. If that task is delayed, it would affect all requesters and tasks downstream. At these confirmation intervals, we expect an information exchange to occur wherein the preceding requester confirms that the provider in question will indeed finish the task at hand as previously planned. Alternatively, there does not have to be a contract confirmation period, which is essentially similar to the airline and hotel reservation systems previously discussed.

The eighth decision asks a simple question. Should requesters be continually updating their ongoing tasks' end times so as to assist their fellow requesters with their planning activities? One may feel the answer to this question is "yes." However, the desirable frequency and accuracy of the estimate may diminish the manager's ability to manage and to execute the task. In other words, the reporting frequency and granularity should not be so regular that the manager's time is completely consumed with meeting the requirements of H-RAS.

The ninth, and final, architectural decision deals with bid points. Should these be a function of the provider's/requester's attributes? Or, should they be arbitrarily defined? Even though arbitrarily defined bid points do not require any setup, analysis or updates; they may not effectively reflect the agent's performance. On the other hand, points that are deeply rooted in historical performance can accurately forecast future performance. But again, these performance attributes must be selected wisely so as to accurately represent the agent's proficiency and skill while utilizing already available information to construct.

To reiterate, this list contains those decisions that have an enormous effect on the outcome and performance of the human resource allocation system. It is up to the system architect, designer or manager to develop the most suitable system architecture by combining decision options.

6.5. Tradespace Exploration

As can be seen by the stakeholder requirements presented in Chapter 5, some scenarios may arise where stakeholders have conflicting requirements. In the context of this thesis, the Organization would like to maximize its resource utilization factor, whereas the Employee would like to maintain a healthy work-life balance. Similarly, the Manager would like to reduce competition for human resources, yet the Organization would like to maximize RUF. How could the system designer appease all stakeholders? One such method is the architectural tradespace. As its name implies, this method can be employed by the system designer to depict a set of architectures using two or more metrics, and embark on a trade study to find the most desired set of solutions. To accomplish this goal, we first produced a list of metrics as seen in Table 6-6 below. The metrics are created by first selecting a representative set of quantifiable stakeholder requirements, then assigning weights and finally combining the requirements up into utility functions.

REQUIREMENT	WEIGHT	METRIC
1. Implementation Cost	20%	Utility to Organization
2. Operating Cost	40%	
3. Productivity	40%	
4. Planning Assistance	50%	Utility to Manager
5. Access to Top Talent	50%	
6. Opportunity for Interesting Tasks	50%	Utility to Manager
7. Job Security	50%	

Table 6-6 | Architecture Evaluation Metrics

Next, we created a scoring system using a Likert Scale as presented in Table 6-7 below.

REQUIREMENT	CHEAPEST	MID POINT	MOST EXPENSIVE	NO EFFECT / NO CHANGE

Implementation Cost	3	2	1	0
Operating Cost	3	2	1	0
REQUIREMENT	BEST	MID POINT	WORST	NO EFFECT / NO CHANGE
Productivity	3	2	1	0
Planning Assistance	3	2	1	0
Access to Top Talent	3	2	1	0
Opportunity for Interesting Tasks	3	2	1	0
Job Security	3	2	1	0

Table 6-7 | Architectural Decision Likert Scale

Now, we could evaluate each of the architectural decision options using our scoring system; to assess the utility of each option as perceived by the stakeholders. The result of the scoring exercise is shown in Table 6-8 below. The seven columns shown on the right-hand side of the table represent the seven variables that constitute the utility functions. At this point, we would like to add some comments about this process. It was extremely useful to explicitly define each requirement to ensure consistency throughout the scoring activity. Also, we implemented the approach described by (Sterman 2000) wherein he suggested first creating reference modes to conjecture variables' behaviour. Likewise, we developed a square matrix of the requirements and qualitatively speculated the sign of the correlation between each pair of requirements. This process helped us eliminate any preconceived notions about the expected results.

Scoring was assigned to mimic each stakeholder's responses closely. For example, requesters would like to obtain as much information as possible before their tasks begin (i.e., architectural decision 7). However, they may not be as keen to confirm their task end date once it has begun. Next, we created a full enumeration of the architectural tradespace using the nine architectural decisions and their options. There are 13,122 possible combinations. Only 11,664 architectures are feasible since the combinatorial space may include architectures that do not have a cancellation policy but select a cancellation penalty. The options that scored highest across all stakeholders are: 13 (mean score = 2.43), 92 (2.43), 21 (2.29) and 91 (2.29). Interestingly, both decision 9's options (91 and 92) obtained high scores, which led us to conclude that there is a need for an attribute-based evaluation methodology in lieu of today's ad hoc approaches. Furthermore, we were astonished to discover the no-penalty option obtain a high score.

Once the architectural space is fully enumerated, and each architecture's utility functions are computed; we were ready to create two-dimensional tradespaces. We produced three tradespaces, one for each pairwise comparison as shown in Appendix B: Pairwise Tradespaces. Each tradespace illustrates the Utopia Point, the Pareto Front, and the feasible and non-dominated architectures. Additionally, each tradespace shows the feasible and dominated, infeasible and dominated, the top and bottom architectures as measured from the Utopia Point, as well as the current resource allocation architecture, and an architecture that shall be further described in Section 6.6 below.

It is evident that there is a negative correlation between the Manager and the Employee's utilities and the Manager and Organization's utilities, thus recreating the agency problem. There is a positive correlation between the Employee and Organization's utilities, which was quite surprising to us, yet makes sense mathematically. Below is a summary of the correlation factors:

- Employee and Manager Utilities – correlation factor = -0.54
- Employee and Organization Utilities – correlation factor = 0.26
- Manager and Organization Utilities – correlation factor = -0.41

We analyzed the distribution of each stakeholder's utility to improve our understanding of the architectural space. Utility to the Organization had a standard deviation of 0.86 with a median value of 17.6. Utility to the Manager had a standard deviation of 1.83 with a median value of 24.0. Finally, Utility to the Employee had a standard deviation of 1.77 with a median value of 10.5. The results are plotted in Figure 6-5 below.

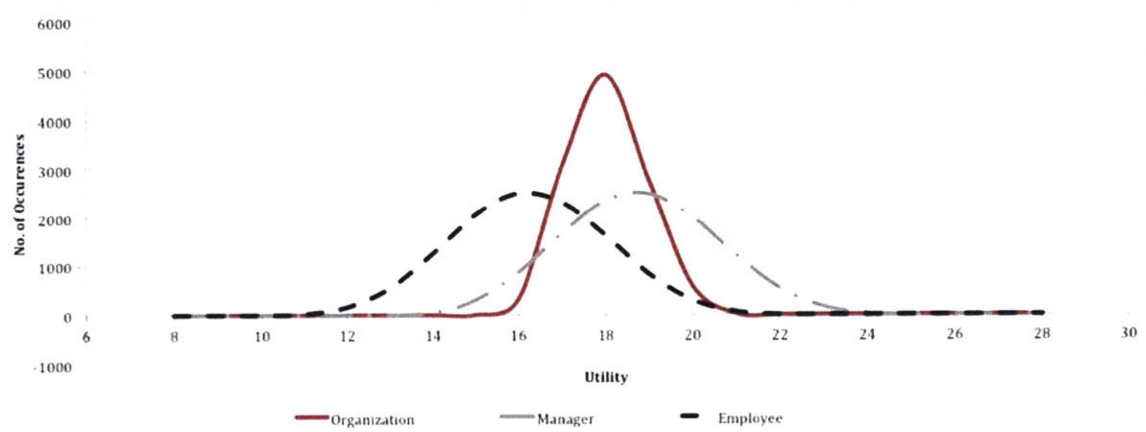

Figure 6-5 | Distribution of Utility to Organization, Manager and Employee

The heat map (Table 6-9) lists the Employee utility across the columns and the Manager Utility down the rows. Further, the map shows the mean Organization Utility for every pair of Employee and Manager utilities. The results of the heat map closely mimic the calculated correlation factors. For instance, at the maximum Manager utility, both Employee and Organization utilities are at their minimum values. The opposite is also true as can be seen from the dark maroon colors in the heat map. This depiction, however, is misleading since it does not differentiate between non-dominated and dominated architectures.

Consequently, we produced the three-dimensional tradespace in Figure 6-6. Similar to the two-dimensional tradespaces previously discussed; this tradespace illustrates the Pareto Front using a three-dimensional surface facing the Utopia Point. This point can be informally described as the most optimal, yet currently unavailable, architecture, where all three utilities are at their maximum values. We found 42 non-dominated architectures on the Pareto front using the software. We sought to understand the options behind this reduced list of architectures better. Furthermore, we wished to compare this list against the top and bottom architectures, as measured from the Utopia Point. We calculated the distribution across the different decision options, and we calculated the mean requirement for each stakeholder using the Likert Scale mentioned previously. The results are available in Table 6-10 below.

Beginning with the non-dominated architectures, there are three important observations. First, the entire group has option 13 in common, which allows all agents initiating a reservation to be visible to each other. In other words, these architectures are analogous to a marketplace where all participants are known to each other. **Second, when it comes to cancellation penalties, the architectures are evenly split between options 31 and 33, where there is either no penalty at all or penalty equivalent to 100% of the amount paid regardless of remaining period, respectively; which refutes our hypothesis (RH7).**

Third, these architectures did not select a hybrid matching system wherein the requester and provider have to agree to work together. **The majority of the architectures (83%), however, have option 63 where the provider alone makes the decision to work on a task. While this result is aligned with the survey results previously discussed in Chapter 4, it refutes our hypothesis (RH6).** Additionally, there is a noteworthy remark to add to the analysis. The majority of these architectures have selected option 92 (74%). Option 92 calls for the reservation value to be based on a systematic evaluation of the agents' performance. The latter is no surprise to us since it has many benefits both to the Organization, Manager and in some cases, the Employee.

ARCHITECTURAL DECISION	OPTION DESCRIPTION	1	2	3	4	5	6	7
1. Requesters'/providers' visibility to each other	11. No	3	2	1	1	3	1	1
	12. Hybrid	1	1	2	2	2	2	2
	13. Yes	2	2	3	3	1	3	3
2. Cancellation policy	21. None	3	3	0	3	3	1	3
	22. Near beginning of contract	2	2	2	1	2	2	2
	23. Up to end of contract	2	2	3	2	2	2	1
3. Cancellation penalty	31. None	3	3	0	3	3	0	1
	32. Function of remaining duration	1	2	2	2	2	0	2
	33. 100% of amount "paid"	2	2	3	1	1	0	3
4. Cancellation refund (if within contract)	41. None	3	3	0	1	1	0	3
	42. Function of remaining duration	1	2	3	2	2	0	2
	43. 100% of amount "paid"	2	2	2	3	3	0	1
5. Requester/Provider specificity	51. No	3	2	3	1	1	2	2
	52. Hybrid	1	1	2	2	2	3	2
	53. Yes	2	2	1	3	3	2	2
6. Resource allocation decision making privilege	61. Requester	2	2	0	3	3	1	1
	62. Hybrid – matching system	1	1	2	2	2	2	2
	63. Provider	2	2	2	1	1	3	3
7. Contract confirmation frequency	71. None	3	3	0	3	1	1	1
	72. Once – at contract creation	2	2	2	2	2	2	2
	73. Frequently	1	1	3	1	3	3	3
8. Task end date confirmation	81. None	3	3	0	3	1	1	1
	82. Once – at beginning of contract	2	2	2	2	2	2	2
	83. Frequently	1	1	3	1	3	3	3
9. Reservation value	91. Value set arbitrarily by central planning entity (ie. PMO)	3	3	2	2	2	2	2
	92. Systematic method rooted in agents' attributes	2	2	3	3	3	2	2

Table 6-8 | Architectural Decision Option Scoring

	Utility to Employee																						
Utility to Manager	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5
13.5										18.8		18.8		18.9		19.0		19.1		19.2		19.4	
14									19.2		19.2		19.3		19.4		19.5		19.6		19.8		
14.5								18.2	18.7	18.3	18.5	18.4	18.6	18.5	18.5	18.6	18.5	18.8	18.5	19.0	18.5	19.2	18.2
15							18.6	19.1	18.7	18.9	18.8	18.9	18.9	18.9	19.0	18.9	19.2	18.9	19.4	19.0	19.6	18.9	
15.5						18.0	18.1	18.3	18.1	18.2	18.1	18.3	18.1	18.3	18.1	18.3	18.2	18.3	18.2	18.3	18.2	18.2	18.0
16					18.4	18.5	18.7	18.4	18.6	18.4	18.7	18.4	18.6	18.5	18.6	18.5	18.6	18.6	18.5	18.7	18.4	18.7	18.0
16.5					17.9	18.0	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	18.0	18.0	18.0	18.0	18.0	
17				18.3	18.4	18.3	18.3	18.2	18.3	18.2	18.2	18.2	18.2	18.2	18.2	18.3	18.2	18.3	18.2	18.4	18.1	18.3	17.8
17.5				17.8	17.8	17.7	17.6	17.6	17.5	17.6	17.5	17.6	17.6	17.6	17.6	17.7	17.7	17.7	17.8	17.8	17.9		
18			18.2	18.2	18.1	17.9	18.0	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	18.0	17.9	18.1	17.9	18.1	17.9	18.1	
18.5			17.7	17.7	17.3	17.3	17.2	17.3	17.2	17.3	17.2	17.3	17.3	17.4	17.3	17.5	17.4	17.6	17.6	17.9			
19		18.1	18.1	17.7	17.8	17.6	17.7	17.6	17.6	17.6	17.6	17.6	17.7	17.7	17.7	17.7	17.8	17.8	17.8	17.8	17.9		
19.5		17.6	17.5	17.1	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.1	17.1	17.2	17.3	17.3	17.4	17.4	17.8				
20	18.0	17.9	17.5	17.4	17.4	17.3	17.3	17.3	17.3	17.4	17.3	17.4	17.3	17.5	17.4	17.6	17.4	17.6	17.5	17.7			
20.5		17.4	16.6	16.8	16.6	16.8	16.7	16.8	16.7	16.9	16.8	17.0	16.9	17.1	17.1	17.3	17.2	17.8					
21	17.8	17.1	17.2	17.0	17.1	17.0	17.1	17.0	17.1	17.1	17.1	17.1	17.2	17.2	17.3	17.2	17.4	17.3	17.6				
21.5		16.6	16.4	16.6	16.4	16.7	16.5	16.7	16.6	16.8	16.7	16.9	16.8	17.1	17.0	17.2							
22	17.0	16.9	16.8	16.8	16.8	16.8	16.7	16.8	16.8	16.9	16.8	16.9	16.9	17.1	16.9	17.2	17.0	17.6					
22.5		16.4		16.4		16.5		16.6		16.7		16.8		17.0									
23	16.8	16.4	16.6	16.4	16.6	16.5	16.5	16.5	16.6	16.6	16.6	16.7	16.7	16.9	16.8	17.0							
24		16.2		16.2		16.3		16.4		16.5		16.6		16.8									

Table 6-9 | H-RAS Architectural Space Heat map

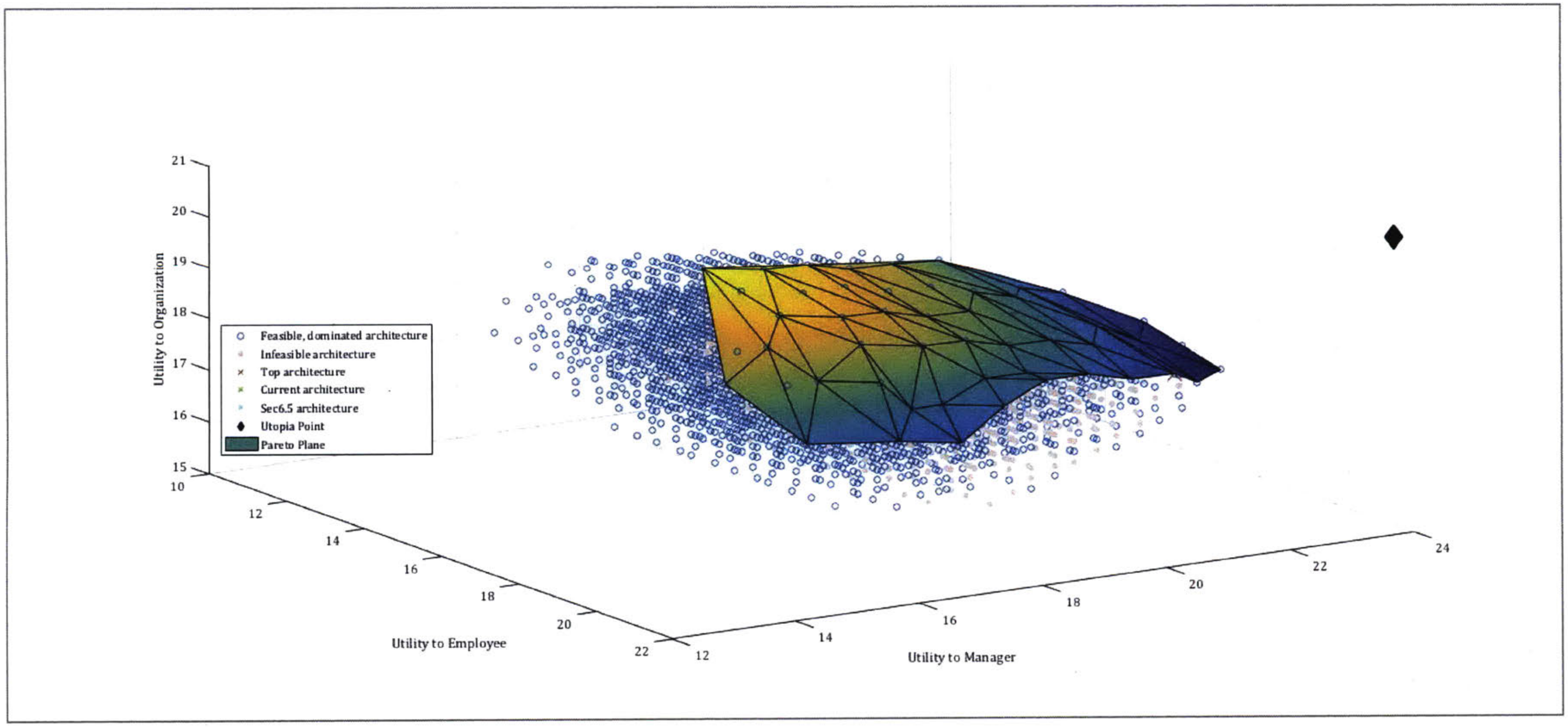

Figure 6-6 | H-RAS 3D Architectural Tradespace (bottom architecture is hidden)

When analyzing the difference between the non-dominated architectures and the top architecture, we find some similarities but a few glaring differences. For instance, when it came to cancellation penalties, the top architecture does not employ penalties, while it allows cancellations to occur until the start of the reservation. Therefore, this architecture provides more flexibility than the population of non-dominated architectures. Moreover, the top architecture assigned the decision-making privilege solely to the provider.

Finally, as we compare the top and bottom architectures, we find that they do not share any similarities. For example, the bottom architecture favoured that contract-initiating agents are not visible to each other, akin to a hotel reservation system. It, also, wished that cancellations only be limited to the front-end of the contract. It opted for an anonymous agent specificity option, wherein the requester can only "see" the providers' performance attributes and vice versa. Lastly, the bottom architecture chose that reservation value should be determined arbitrarily as opposed to being rooted in the agents' performance attributes. The bottom architecture lacks flexibility, and it seems to emulate a more centralized decision-making structure. On the other hand, the non-dominated architectures encourage transparency, and they are akin to a decentralized decision-making structure. The same can be inferred from the average requirement scores shown in Table 6-10.

The Organization is the biggest beneficiary of the bottom architecture whereas the Employee receives the lowest utility. As we move from the bottom to the top architecture, the Manager's utility remains constant while the Organization utility slightly drops and the Employee's utility increases by 8%. Likewise, the same pattern is observed when comparing the bottom architecture and the population of non-dominated architectures. However the Employee's utility increases by 45%! We can conclude, therefore, that active participation of providers in resource allocation activities would dramatically enhance the providers' utility; at the expense of an insignificant reduction of Organization and Manager's utilities.

As mentioned previously, we anchored our tradespaces with the current resource allocation architecture. This architecture places decision making exclusively with the requester, it does not have cancellation policies or penalties, and it does not require sharing information about task start and end dates. According to the mean requirement score, this architecture is more superior to the bottom architecture, but its chief beneficiary is the Manager. This result leads us to wonder which stakeholder, if any, should be the chief beneficiary in resource allocation systems. This question, however, may be difficult to answer. Therefore, the system designer may attempt to align the needs and requirements of stakeholders to facilitate the trade-off exercise.

A possible strategy would be to design inter-stakeholder contracts and incentive structures carefully. At this point, we draw on the previously discussed literature concerning agency theory presented in Section 2.4. (Jensen 1994) indicated that agents would negotiate to reduce the natural conflicts that would arise in a typical agency contract. Furthermore, (Mahaney and Lederer 2003) have found that employees value training and workplace perks more than monetary bonuses. As such, we believe organizations are presented with several alternatives. Firstly, modify the existing behaviour-based contracts to include a transparent outcome-based bonus. Or, completely transition to outcome-based contracts wherein incentives are evaluated using the agents' attributes previously presented in Section 6.2. Finally, organizations shall employ non-monetary incentives to reward top performers. For example, in reference to architecture decision 6 "Decision Making Privilege," a top performer may be allowed to select her tasks as a reward for exceptional performance. It is critical to realize that the H-RAS process presented in this thesis is both disruptive and is a radical departure from current resource allocation methods. Therefore, to maximize the system utility, an organization must adapt its strategies and procedures to encourage Manager and Employee buy-in.

In this section, we created and explored the architectural tradespace for a human resource allocation system. We have called out several architectures in the tradespace, one of which will be further described in Section 6.6 below. Note that we are not insinuating this architecture is the recommended solution; however, it helps demonstrate the mechanics of cancellations and refunds. The selected architecture exhibits characteristics that support the principle of uncertainty, the principle of alternatives and the principle of incentives. Uncertainty management is demonstrated by options 73 and 83, wherein task start and end dates shall be communicated and frequently updated to reduce risk, increase confidence interval and assist managers in planning. The principle of alternatives is demonstrated by option 92 where the reservation value is based on the agents' performance attributes. As such, managers can trade between cost, schedule and risk since different providers possess different characteristics. Lastly, the principle of incentives is also manifested by option 92. If the organization has invested in analyzing and updating performance attributes, agents' incentives can be more easily correlated and quantified.

OPTION	NON-DOMINATED	TOP	BOTTOM	CURRENT	SECTION 6.6
11	0%	0%	100%	0%	100%
12	0%	0%	0%	0%	0%
13	100%	100%	0%	100%	0%
21	57%	0%	0%	100%	0%
22	10%	0%	100%	0%	0%
23	33%	100%	0%	0%	100%
31	43%	100%	0%	100%	0%
32	0%	0%	0%	0%	100%
33	57%	0%	100%	0%	0%
41	14%	0%	100%	100%	0%
42	36%	0%	0%	0%	100%
43	50%	100%	0%	0%	0%
51	52%	0%	100%	100%	0%
52	14%	0%	0%	0%	0%
53	33%	100%	0%	0%	100%
61	14%	0%	0%	100%	100%
62	2%	0%	0%	0%	0%
63	83%	100%	100%	0%	0%
71	0%	0%	0%	100%	0%
72	29%	100%	0%	0%	0%
73	71%	0%	100%	0%	100%

81	0%	0%	0%	0%	0%
82	31%	100%	0%	0%	100%
83	69%	0%	100%	100%	0%
91	26%	0%	100%	100%	0%
92	74%	100%	0%	0%	100%
REQUIREMENT SCORE	NON-DOMINATED	TOP	BOTTOM	CURRENT	SECTION 6.6
Organization	2.07	2.07	2.11	2.07	1.89
Manager	2.07	2.00	2.00	2.17	2.00
Employee	2.10	1.56	1.44	1.72	1.83

Table 6-10 | Comparison of Non-Dominated, Top, Bottom, Current and Section 6.6 Architectures

6.6. System Architecture

So far, we have described the system context in Section 6.2; then we reverse engineered three distinct reservation systems; each with a different resource in Section 6.3. In Section 6.4 we defined our system's architectural decisions. Finally, in Section 6.5, we explored the architectural tradespace and selected a candidate architecture that will serve as the topic of discussion moving forward. It is important to realize that the human resource allocation system we are architecting is a *process* rather than *a user interface* of a reservation system. We have constructed the system architecture diagram shown in Figure 6-7 using the description methodology by (Crawley, Cameron, and Selva 2016) and object process methodology by (Dori 2011).

Instantly, one can see that the diagram is divided into five columns. From left to right they are primary operands, primary value processes, primary value instruments, secondary processes and secondary operands. The system's main objective is the creation of reservation contracts and subsequent distribution of information to enable managers to plan regardless of uncertainty. Primary operands, value processes, and value instruments are directly related to the system's primary value delivery. If the system fails to carry out these processes and transform the primary operand, it is considered inadequate. Secondary processes and operands are, as the name implies, additional features that the system can perform. These may not need to occur, for example, withholding penalties due to cancellations.

After that, one will notice the system boundary. It encompasses all the processes required to fill a requester's need of a service provider. As such, the requester's need is the sole and primary operand. The primary operand's states change from "unfilled" to becoming "filled" as the system's processes are completed. The sequence of events can be deciphered by following the arrows between operands and processes. Unidirectional arrows indicate creation or consumption of an operand by a process. On the other hand, bidirectional arrows suggest that a process modifies an operand. In this case, an unfilled requester's need initiates a contract.

The reservation agent carries out the process of initiating the contract. Once the contract is created, it is also written and amended by the reservation agent. A contract contains valuable information such as boilerplate information (e.g., cancellation policy, cancellation refund, confirmation frequency, among others), as well as start time ($\mathbf{T_s}$) and end time ($\mathbf{T_e}$) data, reservation fee and collateral. The reservation agent may amend the boilerplate information and $\mathbf{T_s}$ and $\mathbf{T_e}$ data as more accurate information about task start and end times become available following reporting periods.

Additionally, the analytics agent acquires $\mathbf{T_s}$ and $\mathbf{T_e}$ data, which are used to update a resource allocation database and to display and disseminate R_i and P_i's latest scores and attributes. Once the request is filled, and P_i is working on R_i's task, the analytics agent receives information about $\mathbf{T_e}$ to update the database.

The contract also contains the required reservation fee and collateral. It is up to the collections agent to receive the reservation fee and collateral from the requester. Once the task has been completed and the provider released, the requester gets a refund of the reservation fee and collateral paid at the time of contract creation.

Finally, the reservation agent completes the contract, which turns into a filled requester's need.

The system also contains several secondary processes and operands. The collections agent refunds the reservation fee and collateral once a task is complete (less any penalties if not completed on time). The collections agent can act as an intermediary who transfers reparation payments. This form of payments is borne out of situations when the preceding requester, R_{i-1}, has to delay $\mathbf{T_{ei-1}}$ for any reason. Therefore, due to the increased risk and uncertainty faced by R_i because the planned provider, P_i, will not be available; R_{i-1} transfers the agreed-upon reparation payment to R_i. This payment can be added to R_i's balance or used by R_i to pool several providers to complete task T_i. We envision that reparation payments would be included in the boilerplate section of the contract. Lastly, the reservation agent may cancel contracts at which point the collections agent withholds penalty payments.

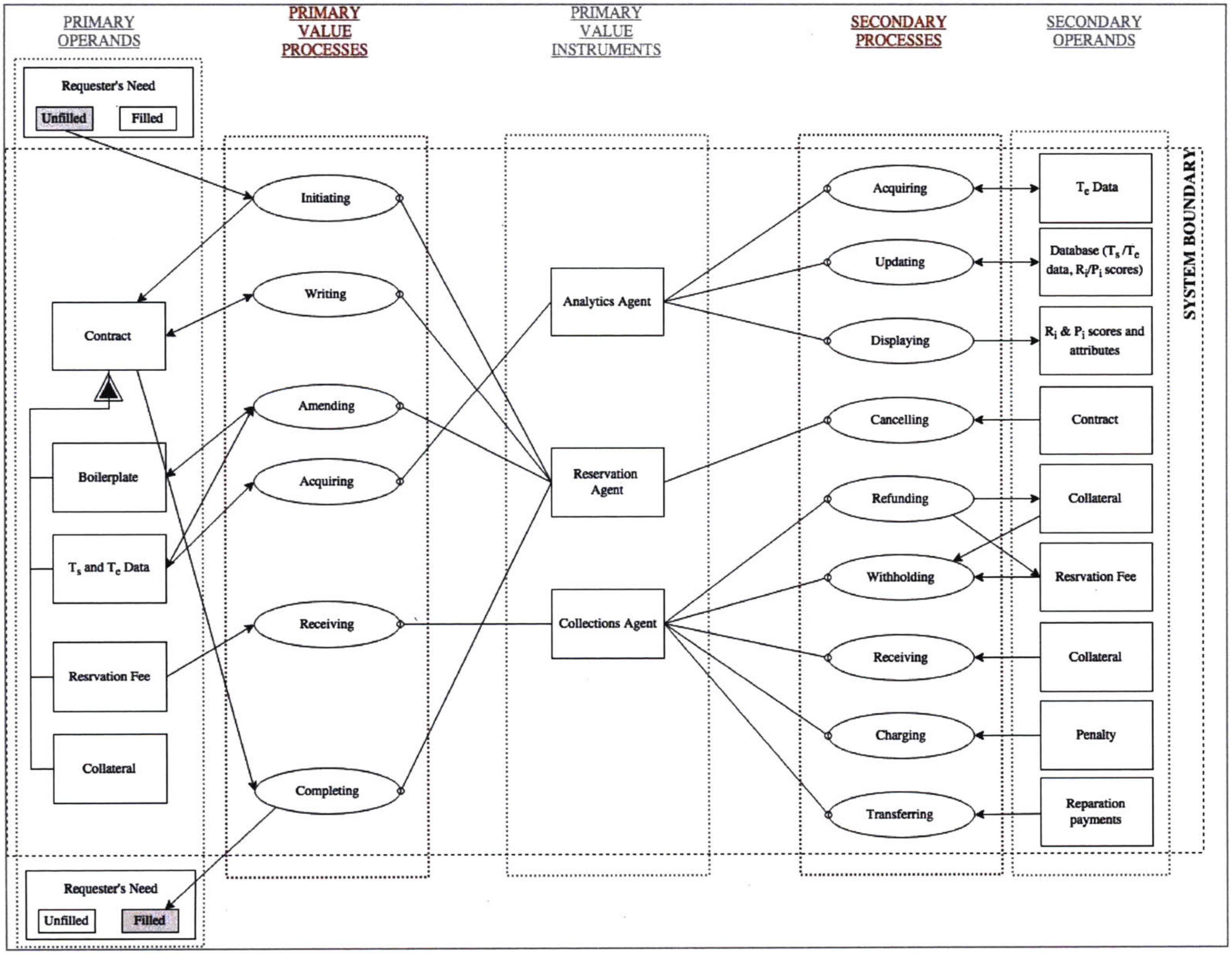

Figure 6-7 | Architectural Diagram of Candidate H-RAS Architecture

One may have noticed that requesters and providers are not shown in the architecture diagram. That is because the system's objective is the creation of contracts and distribution of information to allow planning when uncertainty is present. However, requesters and providers play equally important roles in the whole system (i.e., portfolio or organization) as shown in the context description in Figure 6-2. Since our candidate architecture places the decision-making privilege with the requester, we have developed several concept of operations (ConOps) diagrams to represent its actions over time. A concept of operations diagram is a versatile document that has many purposes, and that has many users. In fact, NASA (Scientific and Technical Information Program 2007) and INCOSE (Walden et al. 2015) use ConOps extensively. ConOps diagrams serve to describe a proposed system by visualizing different operational cases; typically one diagram is created for each case and user perspective (Thayer and Bjorke 2002).

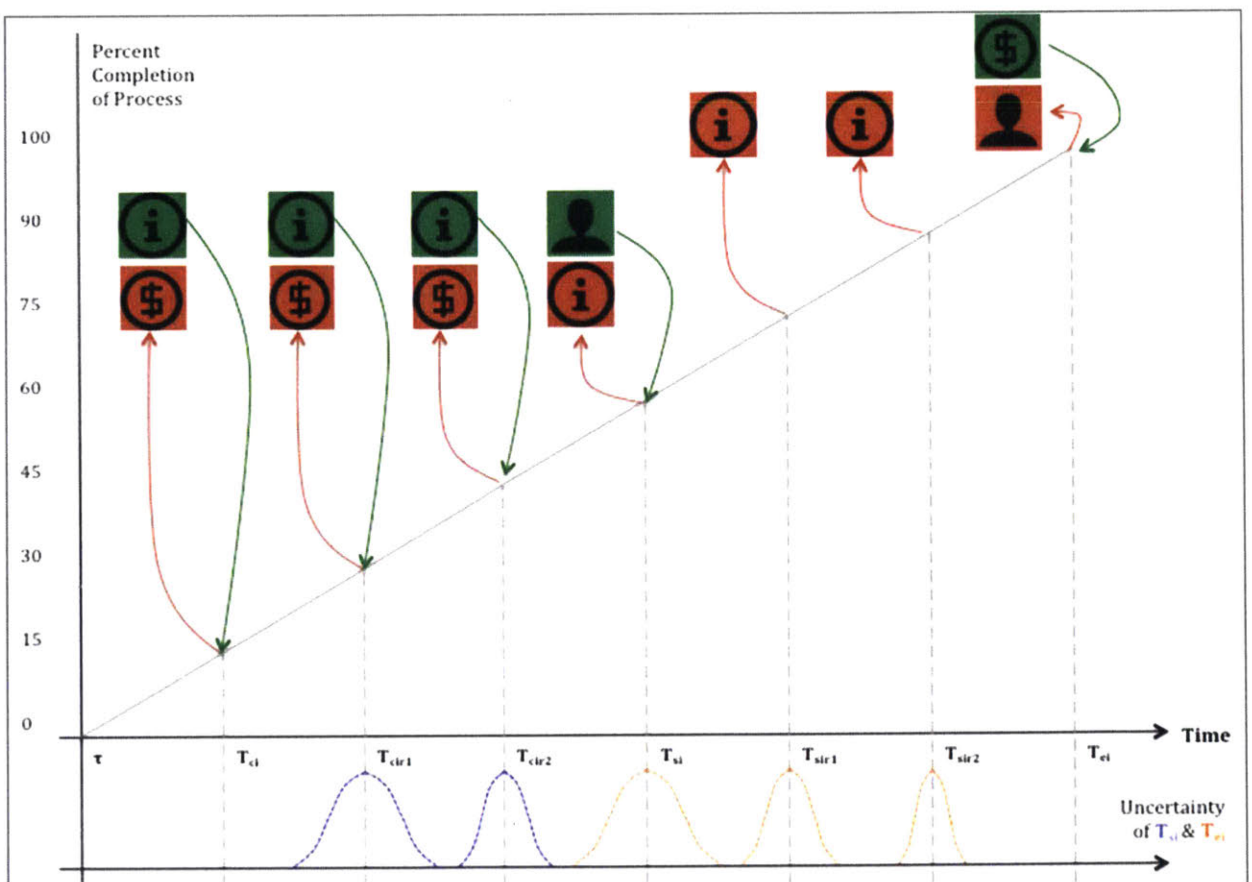

Figure 6-8 | ConOps: Normal Case from Requester's Perspective

Figure 6-8 is a simple depiction of the human resource allocation system from the requester's perspective, using the candidate architecture as a guiding example. In this thesis, any bolded **T** variables signify an instance in time. First, let us define the top x-axis, which is time.

τ denotes the start of the H-RAS process	T_{si} denotes start time of task i
T_{ci} denotes contract formation for task i	T_{sir1} denotes task i's reporting period #1
T_{cir1} denotes contract reporting period #1	T_{sir2} denotes task i's reporting period #2
T_{cir2} denotes contract reporting period #2	T_{ei} denotes end time of task i

Table 6-11 | Time Variables in H-RAS

The y-axis denotes the percent completion of the resource allocation process, whereas the bottom x-axis denotes the resulting uncertainty of T_{si} and T_{ei} as a result of uncertainty in T_{ei-1}. Between τ and T_{ci}, the requester is looking for a suitable service provider. At T_{ci}, the reservation agent creates the contract between the requester, Ri, and the provider, Pi. The requester pays the reservation fee denoted by the red dollar sign in the ConOps diagram in Figure 6-8. Also at contract creation, R_i receives information about the preceding task's end time, T_{ei-1}. At this point, R_i, tentatively forecasts T_{ei} based on T_{ei-1} and the intended provider's attributes (e.g., requirement for communication, probability of error/rework, among others). We have elected to add two reporting periods before T_{si} and two periods afterward. The intent is for R_i to report on the status of T_{ei} for the sake of R_{i+1}. If there are no significant changes, the contract does not need to be amended by the reservation agent. Then, R_i pays the first of two collateral payments, which is held by the collections agent within H-RAS. At this instance, the variance associated with T_{si} is rather large, and is depicted by the blue distribution shown under T_{sir1}. At T_{sir2}, R_i receives information from R_{i-1} about the status of T_{ei-1}, for which there are no significant changes. Therefore, R_i pays the second collateral payment to the collections agent. Consequently, T_{si}'s variance has shrunk as shown by the blue distribution under T_{sir2}. At T_i, R_i receives P_i and it begins to forecast T_{ei}, which at this point has a significant variance. As previously mentioned, R_i also communicates that information to the succeeding requester, R_{i+1}. At

T_{sir1} and T_{sir2}, R_i continues to forecast T_{ei} and communicates that information to R_{i+1}. All is according to plan, and T_{ei}'s variance continues to shrink. In the end at T_{ei}, R_i releases P_i and receives the previously paid reservation fee and collateral.

ConOps diagrams are particularly useful in visualizing how users get affected in abnormal operational cases. We have identified four broad abnormal cases, where there are two variables at play. First is the source of cancellation, which could either be R_i or R_{i-1}. Second is the timing of cancellation, which could either be before or after T_{si}. We held the first variable constant at R_i and varied the timing. Figure 6-9 depicts the ConOps of a requester-initiated cancellation before T_{si}.

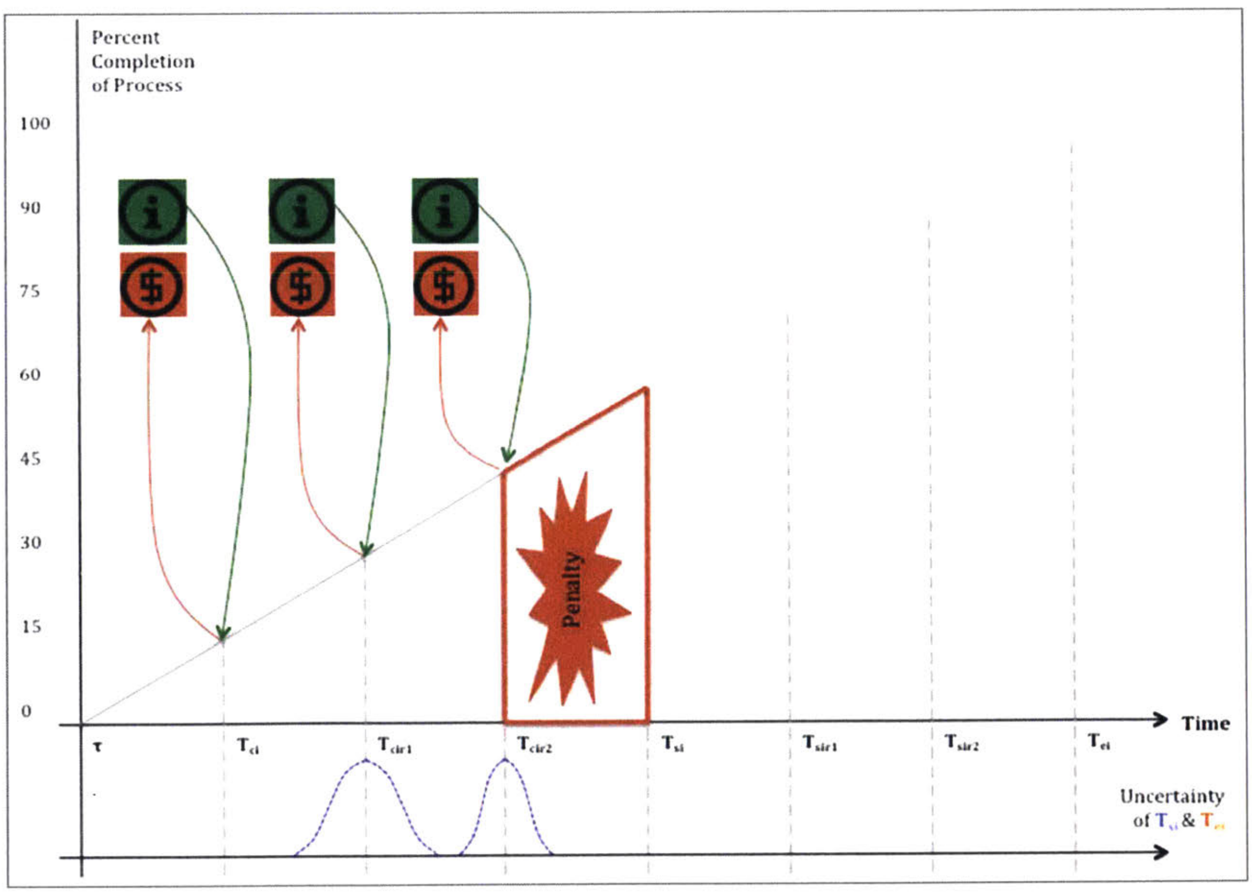

Figure 6-9 | ConOps: Abnormal Case from Requester's Perspective – Requester Initiated Cancellation Before T_{si}

At first glance, one can see that T_{ei-1}'s variance has not changed compared to the normal case in Figure 6-8. If R_i were to cancel the contract before T_{cir1}, it would lose the reservation fee. Similarly, if the cancellation occurred before $\mathbf{T_{cir2}}$, the requester would lose the reservation fee and the first collateral payment. Generally speaking, if R_i initiates a contract cancellation, it will forego all prior payments. Additionally, if the cancellation were to happen between $\mathbf{T_{cir2}}$ and $\mathbf{T_{si}}$, the requester would incur an additional penalty. Therefore, the closer the cancellation is to $\mathbf{T_{si}}$, the more severe the penalty. This strategy serves as a deterrent from late cancellations since providers would not be staffed on projects and their utilization factors may be excessively low for prolonged periods of time.

Next, we evaluate requester-initiated cancellations after $\mathbf{T_{si}}$, as seen in Figure 6-10 below. This abnormal case can be decomposed into two scenarios as shown in the inset illustration.

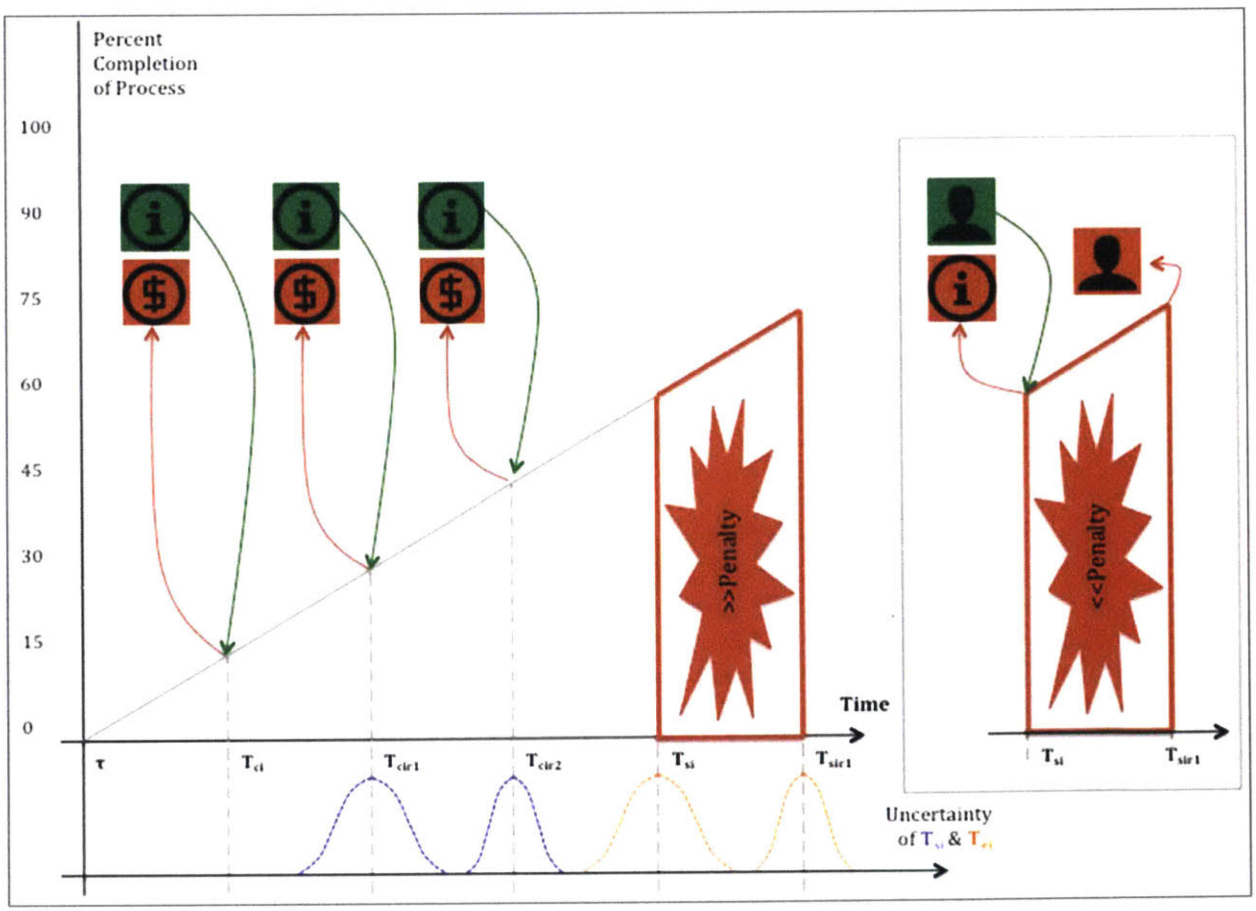

Figure 6-10 | ConOps: Abnormal Case from Requester's Perspective – Requester-Initiated Cancellation After T_{si}

Since this cancellation case occurs after $\mathbf{T_{si}}$, the preceding reservation fee and collateral payments proceed per the normal case. However, after the task has already begun, the requester decides to cancel the contract. At this moment, the requester is faced with two options. Incur a severe penalty that is significantly larger than the penalty incurred when cancelling before $\mathbf{T_{si}}$. Or, retain P_i for a period of time until another requester picks it up. At which point, the reservation agent cancels the contract, withholds the reservation fee and collateral payments and charges a reduced penalty. We should note that contracts cannot be transferred to other requesters or providers.

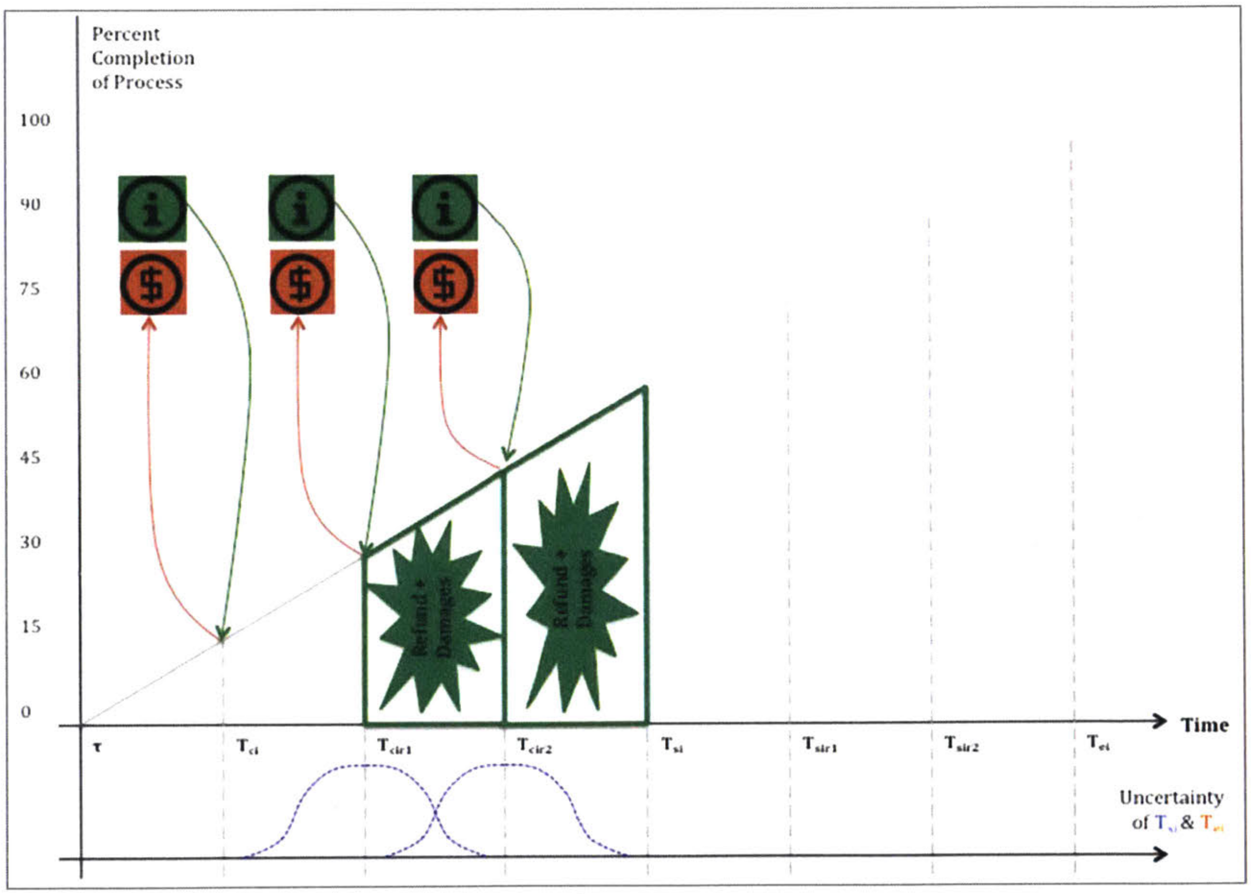

Figure 6-11 | ConOps: Abnormal Case from Requester's Perspective - Requester R_{i-1} Induced Cancellation Before T_{si}

Figure 6-11 represents a cancellation induced by the preceding requester before $\mathbf{T_{si}}$. As such, the cause of the cancellation is manifested in the $\mathbf{T_{ei-1}}$'s variance; which has substantially increased in comparison to the normal case. Therefore, R_{i-1} will pay R_i

reparatory damages. Furthermore, R_i will receive a refund of the reservation fee and any collateral already paid. One of the contract's boilerplate statements specifies the threshold at which a contract can be cancelled due to a delay in the preceding task. Figure 6-12 illustrates the fourth abnormal case wherein a cancellation is induced by R_{i-1} after the planned $\mathbf{T_{si}}$. That is the most severe scenario because $\mathbf{T_{ei-1}}$ crept past its threshold during its closing stages, which caused R_{i-1} to hold onto P_i longer than expected. In this case, R_{i-1} would pay R_i reparatory damages as well as a risk premium since its task is now delayed. Similar to the third abnormal case, R_i would get its reservation fee and collateral refunded due to this unforeseen cancellation.

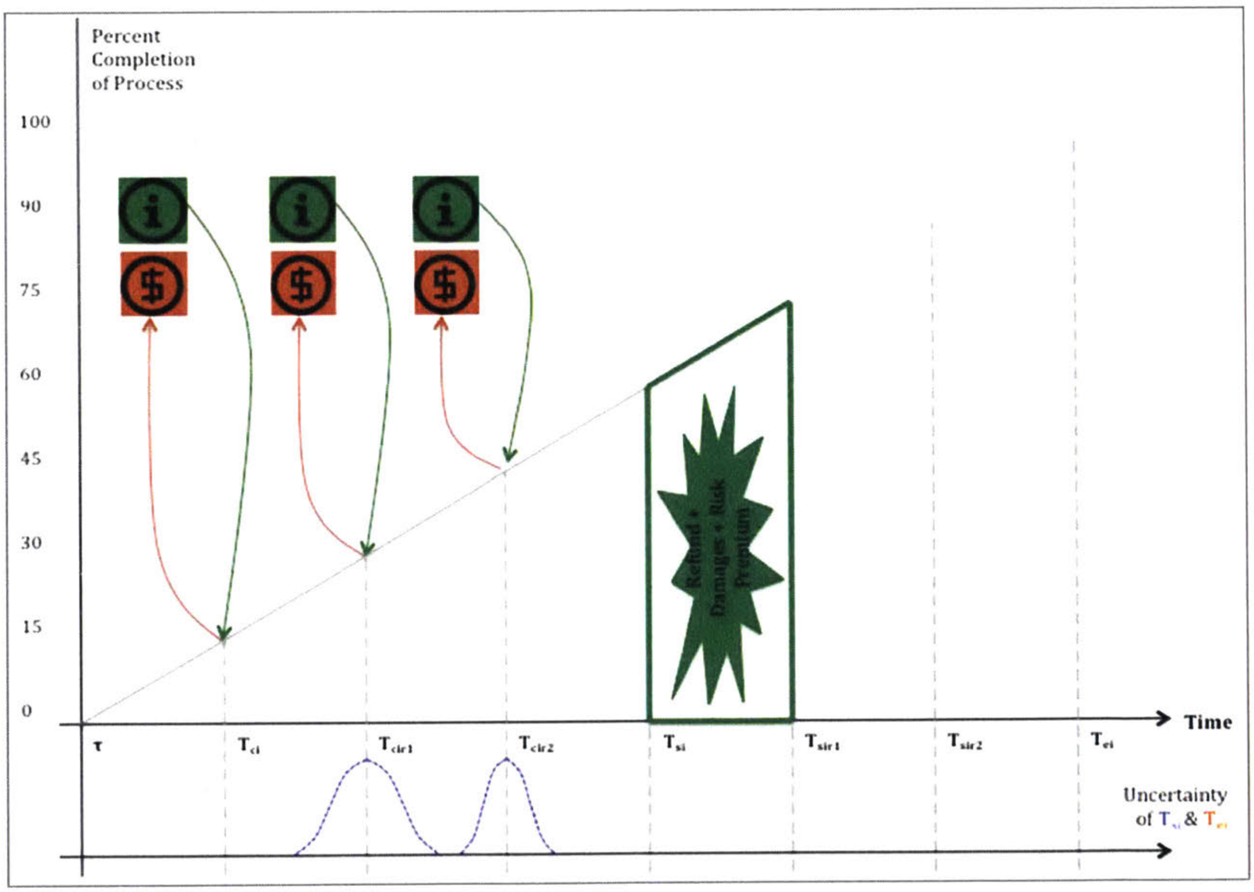

Figure 6-12 | ConOps: Abnormal Case from Requester's Perspective - Requester R_{i-1} Induced Cancellation After T_{si}

Our Human Resource Allocation System (H-RAS) bares some similarities to the grid resource broker backed by an economic analysis engine (GRACE) proposed by (Buyya, Abramson, and Giddy, n.d.). There are, however, two key distinctions worth mentioning. Firstly, our providers are neither decision makers nor optimizers. The GRACE system allowed the grid's resources to optimize their own loading and jobs. The setup is akin to an H-RAS architecture where both requesters and providers bid for each other and are subsequently matched. In that architecture, the provider is optimizing its own schedule based on interests, skills or perhaps even vacations. The provider may purposefully choose not to bid to free up time for vacations. The second key distinction is that our system is used entirely by humans who either behave irrationally or are prone to errors. As such, we have introduced the penalty feature. This feature may be thought of as the "bad" incentive previously mentioned by (Jensen 1994).

7. Conclusion

7.1. Summary of Research

The overarching objective of this thesis is to develop a process of allocating human resources, to facilitate and to streamline planning and execution activities given resource scarcity and interdependence. As such, we introduced two work streams. Firstly, we sought to assess the current state of project portfolio management (PPM) practices, to understand the qualities of successful organizations better. Secondly, we sought to explore key process design decisions, to create distinct process architectures, and to evaluate the architectures against the stakeholder requirements.

We chose to roll out a survey to evaluate the current state of PPM practices. The survey participants hail from many industries, such as Aerospace and Defence, Energy, Healthcare, Manufacturing, and many others. We were especially interested in the participants' opinion of their organizations' PPM practices, and they were asked to qualitatively classify the proficiency of these practices as highly effective, mediocre or non-existent. Next, participants were asked to indicate the number of simultaneous portfolios and projects their organizations manage. Then, we arrived at the resource allocation and planning methods currently employed in practice. We asked participants if corporate functions were equally represented in a central planning entity, analogous to a program management office (PMO). Next, we asked participants to indicate the average schedule delay at their organizations. Finally, we inquired about the organizations' portfolio rebalancing frequency. The survey and its results paved the way for the second work stream, codifying process design decisions for an improved human resource allocation method.

To ensure wide acceptance of the proposed method, it was imperative to elicit requirements from all stakeholders. Hence, we began by describing the stakeholder requirements for the process design. We are recommending that organizations should strive to empower their employees and to allow them to participate in decision-making. Yes, the requirements may be conflicting at times; however, we firmly believe that the final solution would garner added interest and support from all stakeholders. The system stakeholders have added requirements such as ease of use and simplicity. We were not able to assess the degree to which the non-dominated architectures satisfy these requirements. However, we have listed the key performance indicators that may be monitored to validate these requirements.

First, we abstracted the typical organizational fabric into requesters (i.e. managers) and providers of a service (i.e. employees). At this point, we reverse-engineered three different reservation systems, those of a hotel, an airline, and a financial options exchange. We compared and contrasted these systems to emphasize their performance and utility. For example, a hotel reservation may be cancelled without penalty up to the last 24 hours, whereas the airline only allows free cancellation within the first 24 hours (for an economy fare).

In response to the overarching objective of this thesis and its research questions, we identified nine crucial architectural decisions. Each decision is comprised of several options, which when combined yield distinct system architectures. These architectures are situated on a continuum where one extreme is a reservation system akin to hotel reservations, and the other extreme is a brokering system similar to a stock exchange. Once the architectural space was fully enumerated, we had 13,122 possible architectures of which 11,664 were feasible. The architectures were evaluated based on their constituent options, plotted in pairwise tradespaces to compare utility to each stakeholder group (Appendix B: Pairwise Tradespaces) and a three-dimensional tradespace combining all stakeholders (Figure 6-6). The scoring was completed using a Likert Scale and determined by relying on our prior experience as employees, managers, and executives.

7.2. Insights and Findings

Sixty-two percent of survey participants indicated their current PPM practices to be mediocre while 33% reported that they were highly effective. We did not find any correlation between proficiency and organization size or industry. Participants were also asked if their organizations combine internal and external projects in the same program or portfolio, as well as new development and iterative projects. We mapped these responses to the proficiency responses, and we found that segregating internal and external projects yields higher perceived PPM proficiency (Table 4-4). It also seems that iterative or upgrade projects also experience higher perceived PPM proficiency. We conjecture that is due to learning effects.

Survey results also showed that organizations strive to minimize the number of projects in a portfolio, which in turn maximizes the number of concurrent portfolios. We found strong evidence to support the effect of this strategy on PPM proficiency (Table 4-6). The majority of participants indicated that program managers are the most represented group in the central planning entity, while analysts are the least represented. We filtered the results using PPM proficiency, and we were astonished at the findings. Executives are the most represented group, and employees are the least represented at organizations with mediocre PPM proficiency, while the opposite is true (Figure 4-3).

We stumbled upon another critical finding. Nearly half of the respondents indicated average delays of 10-20%. Interestingly though, participants who perceive their PPM practices as highly effective still experience project delays. We can offer two possible conclusions. First, today's prescribed PPM practices are not sufficient to stem schedule delays and cost overruns. Second, these participants' organizations must employ unusual, yet clearly successful, PPM practices that conciliate their employees.

We hypothesized that more frequent balancing would yield higher PPM proficiencies. The results we obtained and analyzed were inconclusive (Table 4-11). The lack of correlations is not an unfavourable result. We believe it is indicative of the complexity of project portfolio management, in that proficiency or success are not affected a single variable.

Two key findings from the first work stream are underlined as follows. Employee engagement and participation in resource allocation and planning may yield superior project and portfolio results. Additionally, today's process centric PPM practices are not sufficient to ensure projects and portfolios are completed in a timely and cost effective manner.

The stakeholder utility calculations yielded an unexpected result. We anticipated that the utility to the Organization and Manager would be positively correlated, and they would be negatively correlated to the Employee's utility. However, we found that the utility of the system from the perspectives of the Organization and Employee are positively correlated; whereas the utility to the Manager is negatively correlated with the other stakeholders. This result is a classic manifestation of the agency problem. Organizations and executives should be aware of this conflict. Research in agency theory indicates that all agents' incentives shall be aligned to minimize these types of conflicts. Furthermore, we reiterate that organizations shall empower and involve their employees in their decision-making processes to ensure acceptance and support of strategic initiatives.

We isolated 42 non-dominated architectures in the three-dimensional architectural space. There were four common features among these architectures. All architectures valued visibility among active agents in the system, as opposed to the anonymity in a hotel reservation system. Furthermore, 83% of the non-dominated architectures assigned the resource allocation decision to the provider. In other words, the employee selects his/her tasks and projects. Additionally, roughly 70% of these architectures opted for frequent task start and end date confirmations to ensure information accuracy and relevance. Finally, the majority of the architectures valued the importance of coupling the contract or reservation value to the agent's performance attributes. We foresee tremendous value in calculating and maintaining these performance attributes since they could be used to assess bonuses and incentives in a transparent, objective manner.

Some may argue that the results and findings presented in this thesis are radical. As discussed in Chapter 2, contemporary project portfolio management practices rely on numerical methods rooted in financial portfolio theory. Most recently, some organizations and academics have made use of optimization algorithms to solve the highly complex human resource allocation problem. While these methods are organization-centric, they still treat the problem as static. The benefits of the proposed, non-dominated H-RAS architectures are twofold. Firstly, they aim to immerse the employee in the planning and allocation process. Secondly, the contract or reservation feature enhances the flexibility of the planning experience through cancellations, refunds, frequently updated start and end times, among others. The bottom line is that we are looking to redefine PPM proficiency. It is no longer only a balancing act of the Iron Triangle constraints. Practitioners and organizations should not forget that project portfolio management is concerned with managing stakeholders, their needs, and their expectations as much as it is concerned with managing cost, budget, and risks. Project portfolio management should not be a rigid, bureaucratic process. Practitioners and organizations should be cognizant of the sociotechnical context in which projects and portfolios are managed. System agents, managers and employees, should be not completely abstracted by numbers and attributes.

Furthermore, any organization strives to maximize the resource utilization factor. We feel that the transparent nature of the system's reservation and contract creation mechanics may lead to brokering behaviour among agents. As such, we believe this allocation heuristic would maximize the resource utilization factor as agents, especially employees, become involved in choosing their tasks and projects.

With that being said, the proposed architectures constitute a paradigmatic shift in today's human resource allocation activities. As such, organizations must modify internal processes and procedures, as well as incentives to encourage widespread adoption of an H-RAS architecture. The importance of the latter undertakings cannot be overstressed enough!

7.3. Future Work

Academics have noted that 50-60% of new product development projects fail due to mismanagement of resource and technology interdependencies (Rungi 2009). While others have found that projects fail due to human resource deficiencies in key areas (Blichfeldt and Eskerod 2008). We are confident in the groundwork and research developed in this thesis. However, this is only the beginning of revolutionizing project portfolio management and particularly human resource allocation. At this stage, there exist several work streams to refine H-RAS further, test the system, and implement it. The work presented in this thesis may be thought of as an empirical endeavour to conceive and design a human resource allocation system. While we have confidence in the work and results, we do not mean to apply a single brushstroke by inferring all organizations would arrive at the same set of non-dominated architectures. As such, recommend the following work streams.

Firstly, the stakeholder list shall be expanded as needed and a formal requirements gathering exercise shall be undertaken. Next, stakeholder requirements shall be translated into actionable design objectives and ranked to determine priority and criticality. Finally, the stakeholders shall participate in scoring the utility of different architectural decision options against the system requirements.

Secondly, the proposed H-RAS architectures are only concerned with contract creation. However, that is only one facet of a valuable human resource allocation system. We did not address contract execution and evaluation. How would requesters or managers evaluate if the employee completes a task satisfactorily?

How would agents be rewarded or penalized for their performance? Are the incentives set out in individual contracts, or are they a corporate standard?

Thirdly, we have assumed that all agents are rational. Organizations may be interested in educating and building up their workforces. Therefore, situations may arise where requesters would reserve less than ideal providers to train them. How does this behaviour affect the value of H-RAS?

Finally, the simplicity and ease of use of the system shall be tested. This may be accomplished using surveys, or stakeholder participation in the system architecture, or by creating social experiments or simple games to evaluate the utility of different decision options. Considering the allocation process becomes a heuristic that is driven by humans, system designers shall be aware that agents may take advantage of ambiguities to advance their personal positions. Hence, the process shall be tested in any organization it would be implemented in. We expect the organizational culture to play a major role in the success of the human resource allocation system.

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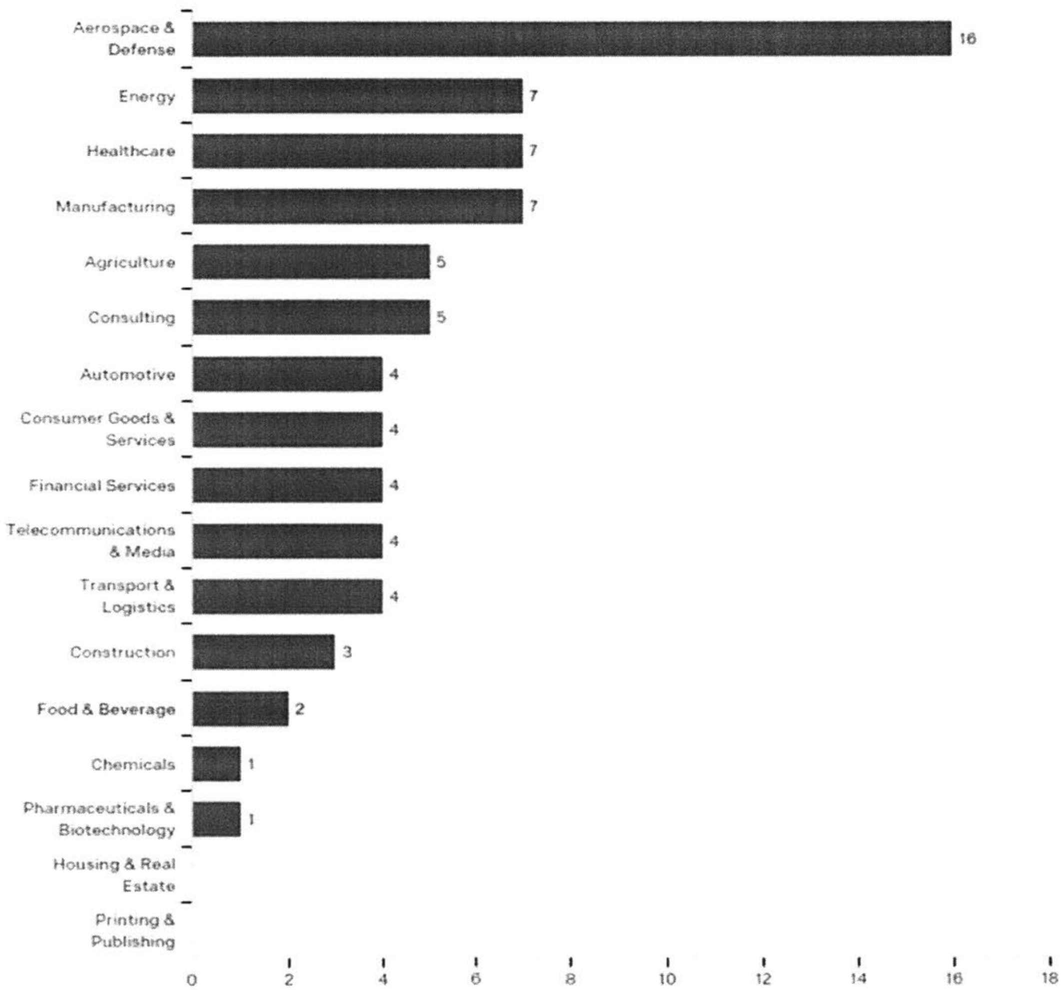
Appendix A: Survey Results

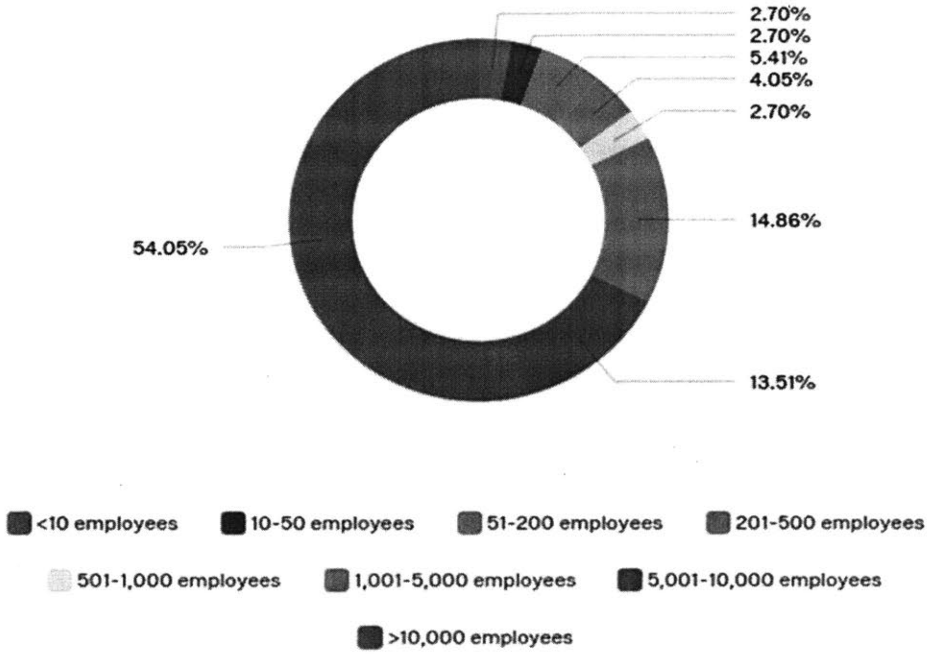
Default Report

Mina's Thesis Survey - Project Portfolio Management
March 20th 2017, 8:58 pm MDT

Q1 - What industry do you work in, or have most recently worked in? Choose the most relevant answer.

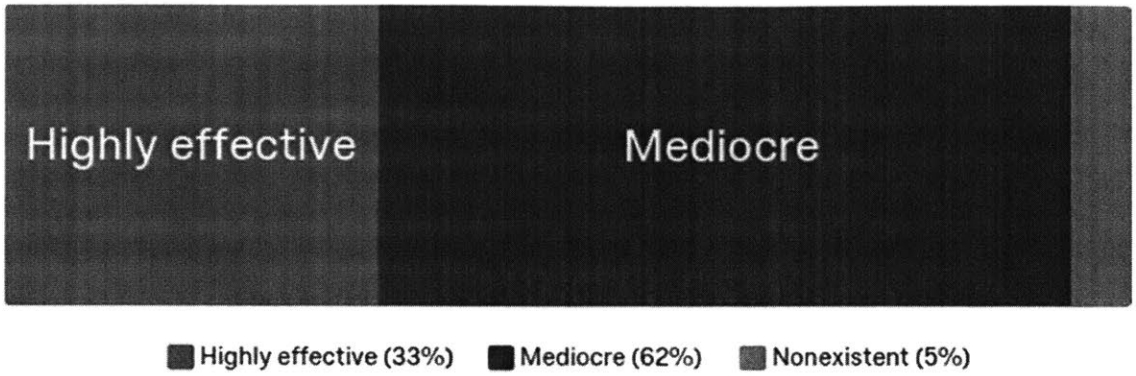


Q2 - What is the size of your firm?

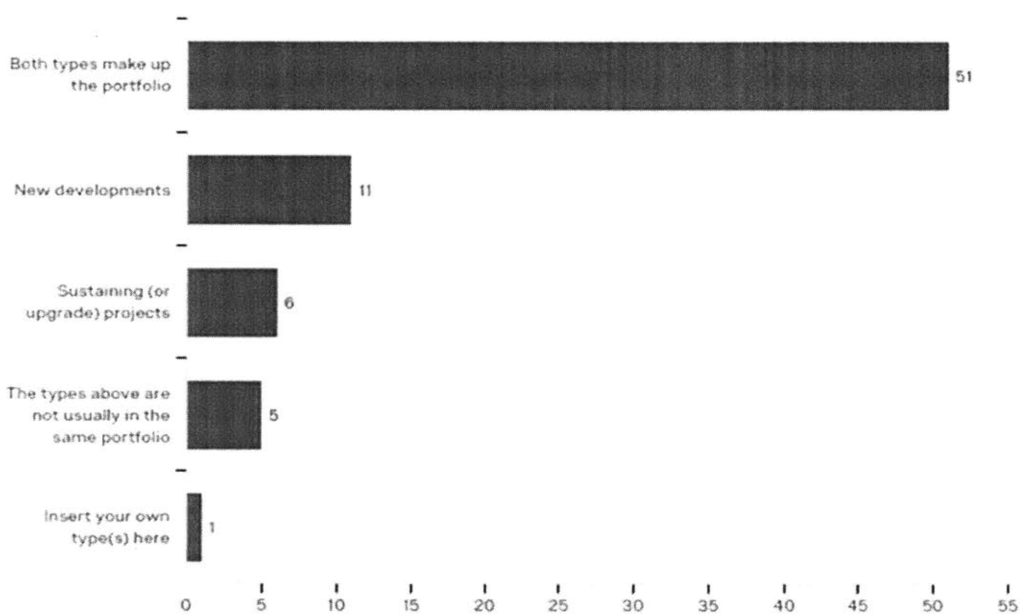


Q3 - What is your current or most recent job title?

Q4 - How would you categorize your firm's Project Portfolio Management (PPM) practices?



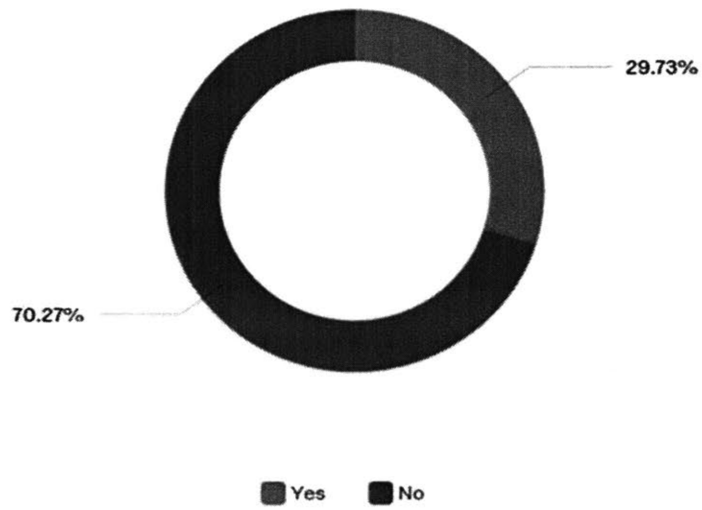
Q5 - What types of projects are included in your portfolio(s)? Choose the most applicable answer.



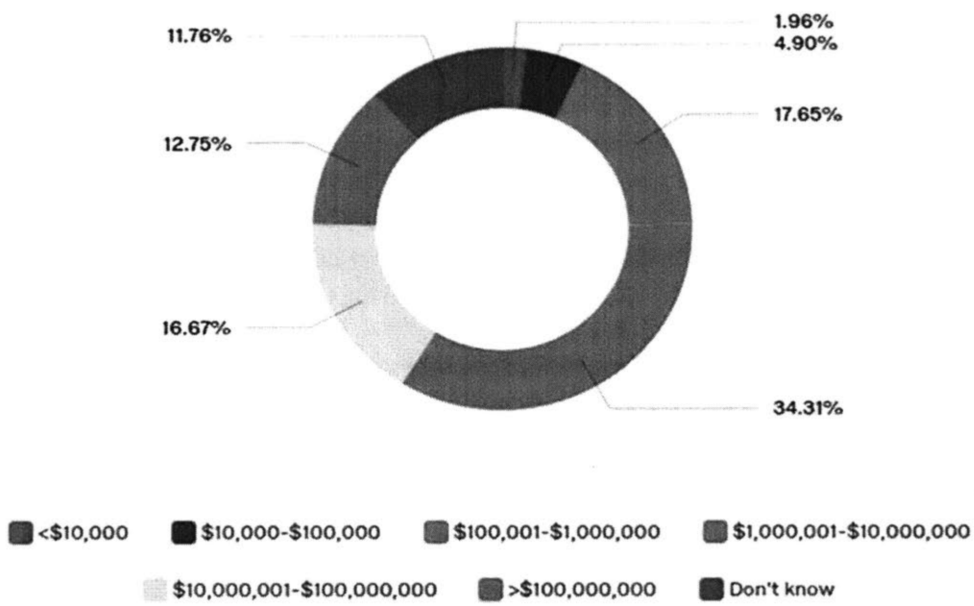
Q5_5_TEXT - Insert your own type(s) here

Insert your own type(s) here
Innovation

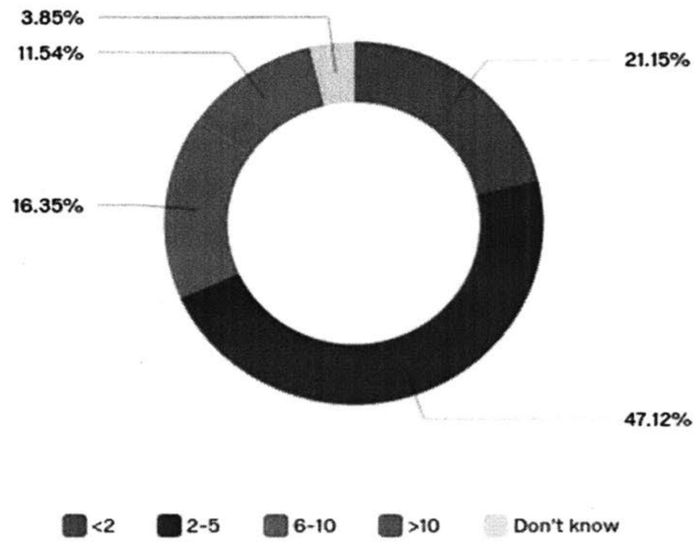
Q6 - Does your firm combine internal and external projects in the same portfolio?



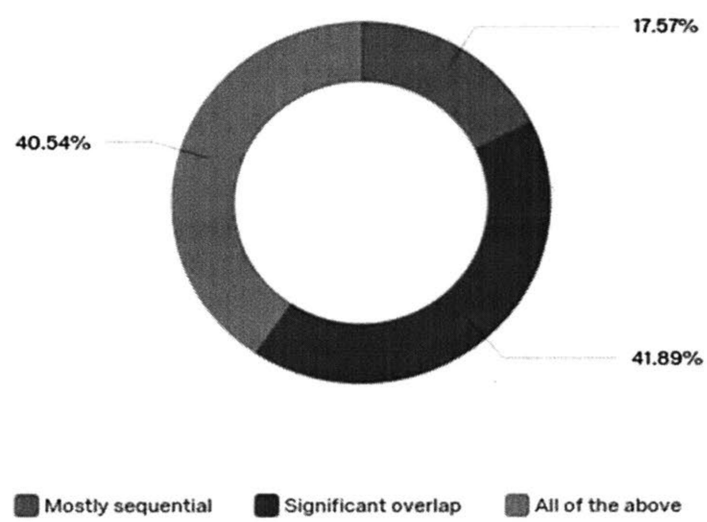
Q7 - What is the average order of magnitude of your firm's portfolios' budgets? You may choose multiple answers.



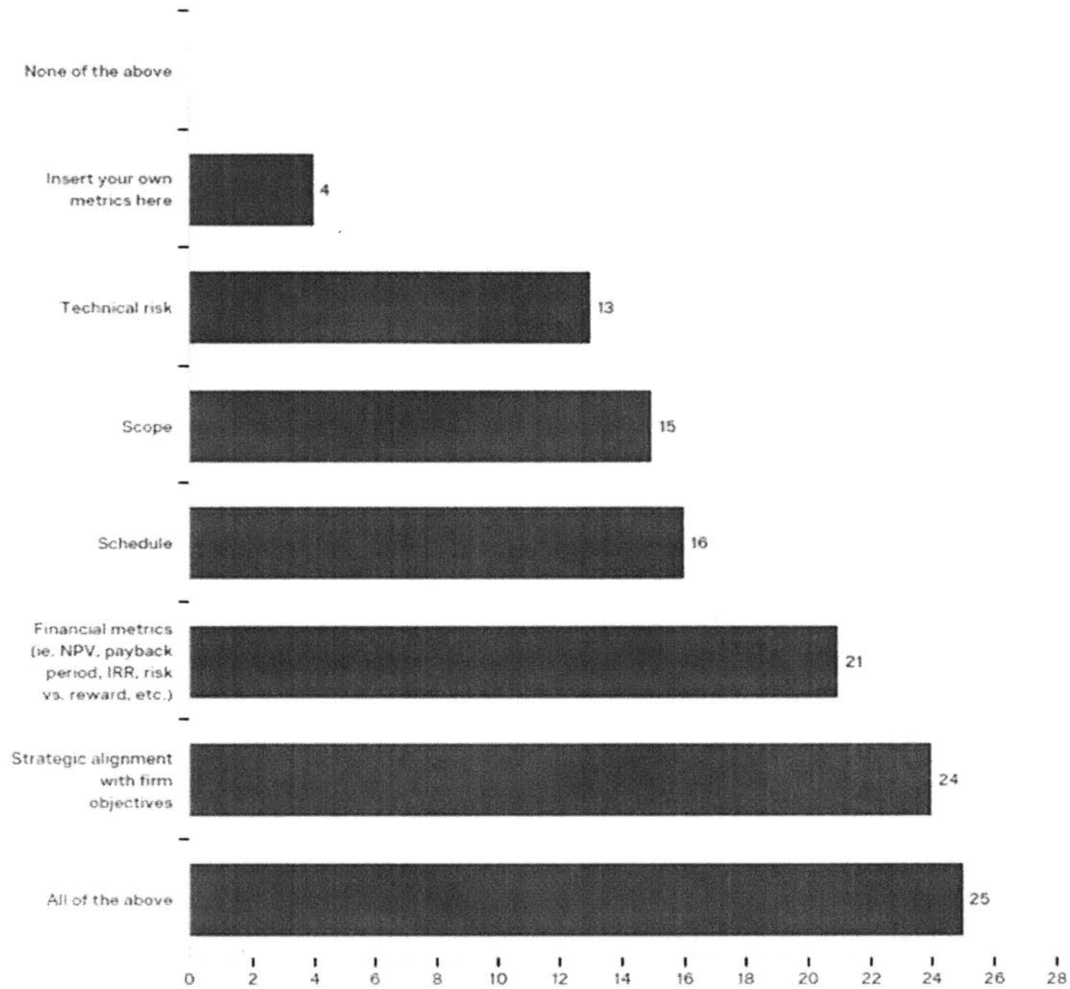
Q8 - What is the planned length (in years) of your firm's portfolio(s)? You may choose multiple answers.



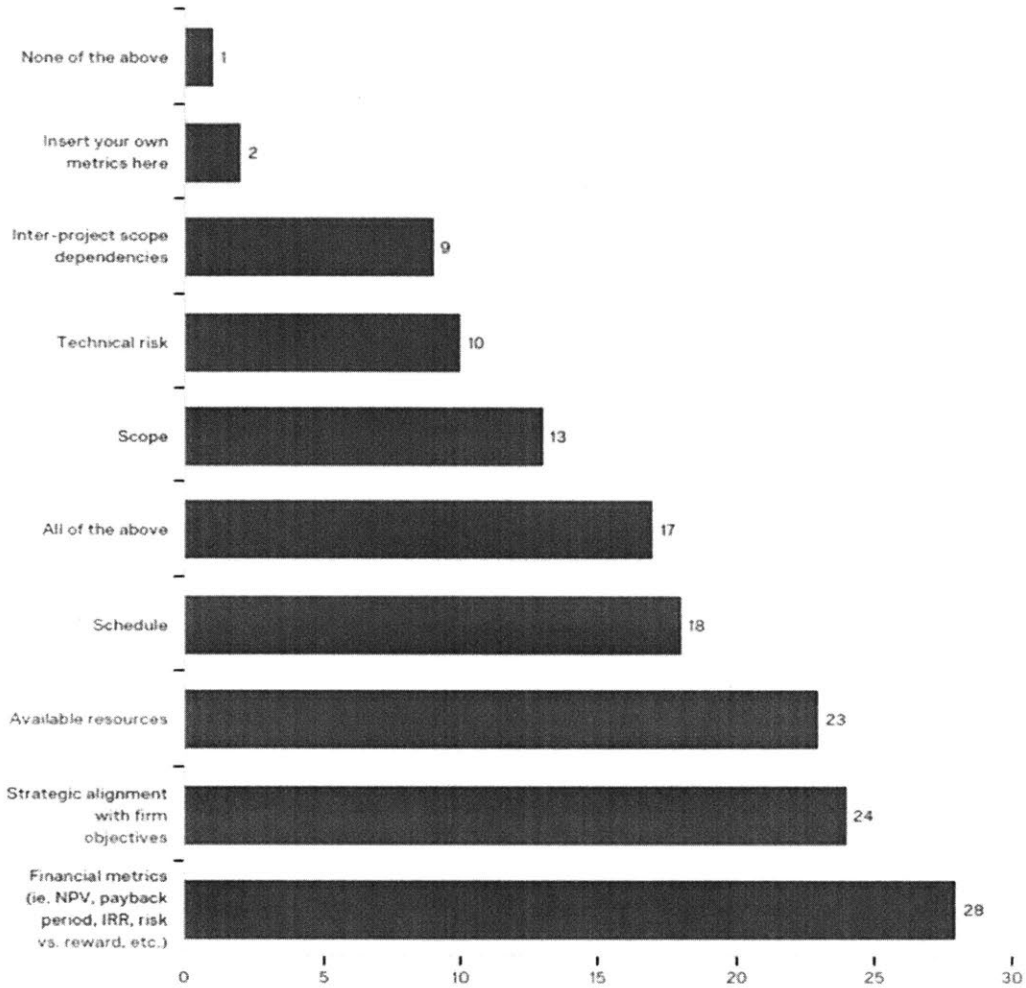
Q9 - What is the cadence of projects in your portfolio(s)? In other words, how are projects scheduled in the portfolio?



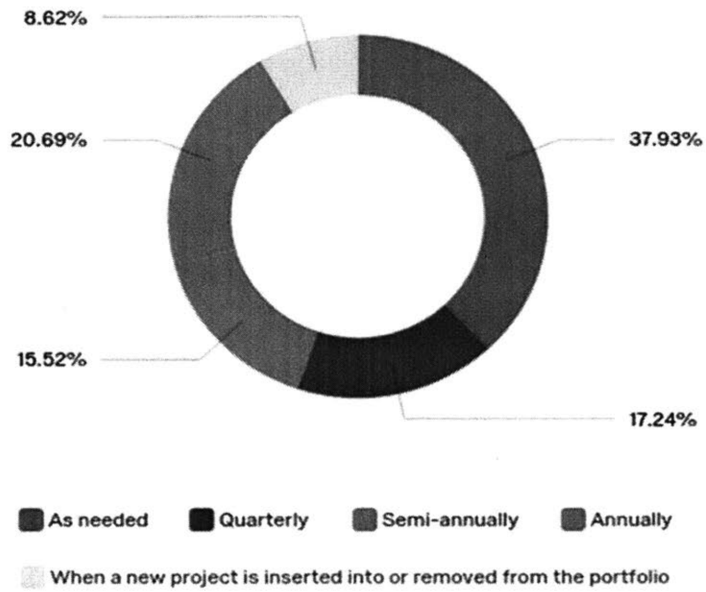
Q10 - How does your firm assess its prospective projects' feasibility? You may choose multiple answers.



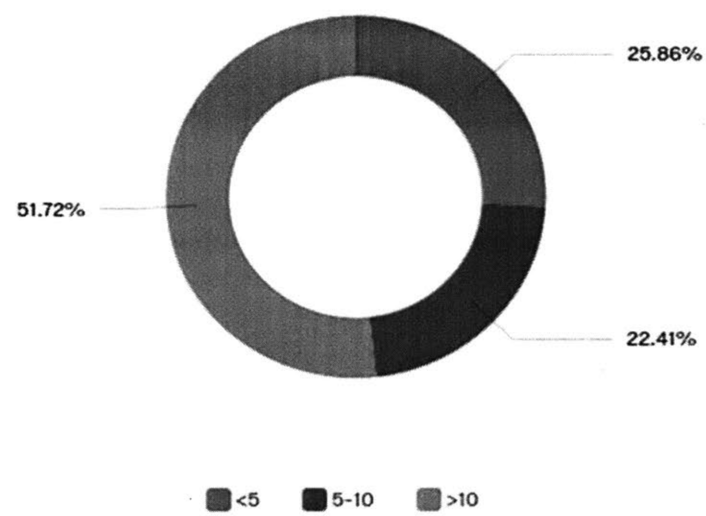
Q11 - How does your firm assess its prospective portfolios' feasibility? You may choose multiple answers.



Q13 - How often does your firm balance or analyze its current portfolios?

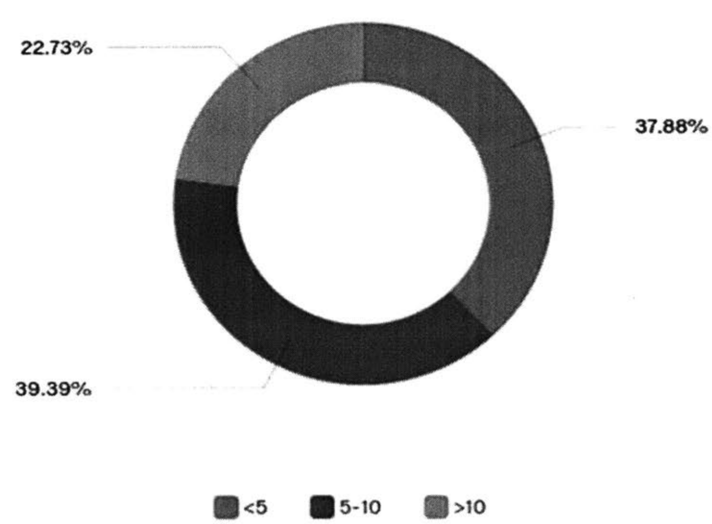


Q14 - How many portfolios does your firm maintain simultaneously?

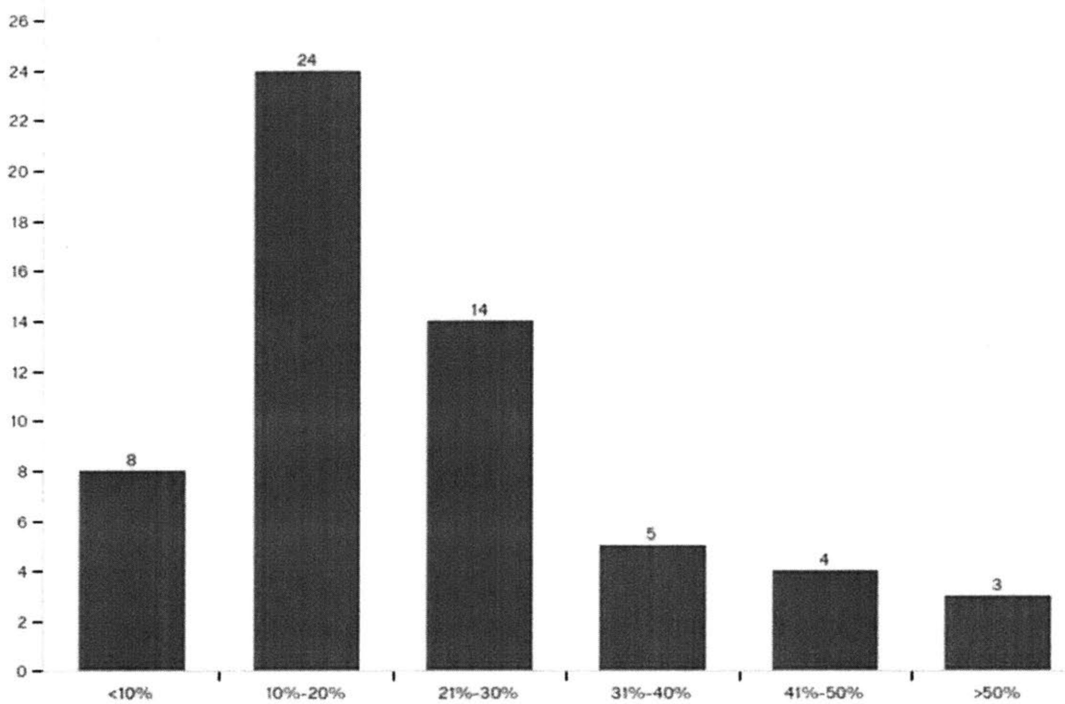


Q15 - What are the common features among projects in your firm's portfolio(s)? For example, a common feature may be responsible business unit, type of resource, etc. Use keywords only (less than 100 characters)

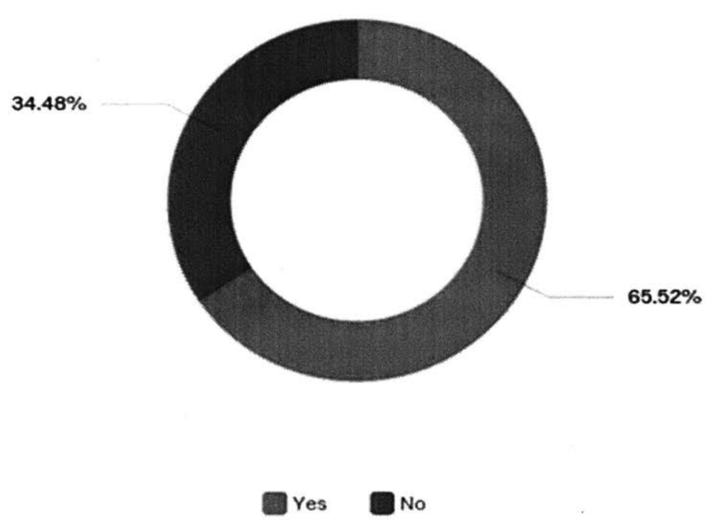
Q44 - How many projects does your firm typically combine into a single portfolio? You may choose multiple answers.



Q16 - What is the average project delay within your firm's portfolio(s) due to what you would consider inefficacy of your current Project Portfolio Management (PPM) practices? Delays are represented as a percentage of baseline portfolio duration.

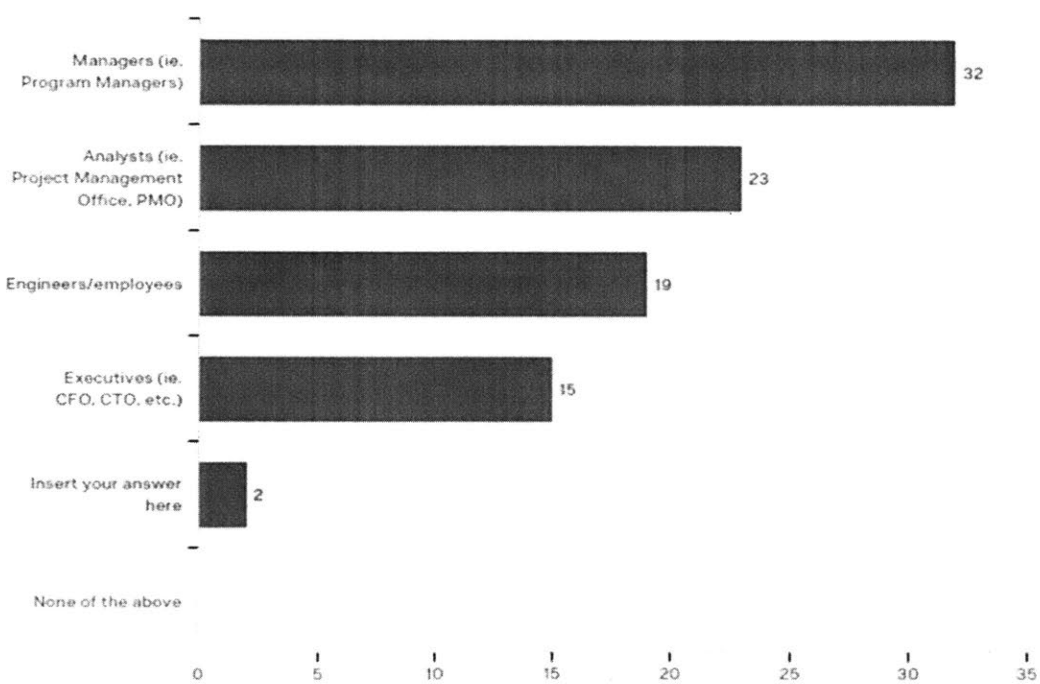


Q17 - Is there an official entity within your firm (ie. Project Management Office, PMO) that balances and analyzes the portfolio?



Q18 - What is this entity called?

Q19 - What functions is this entity comprised of? You may choose multiple answers.



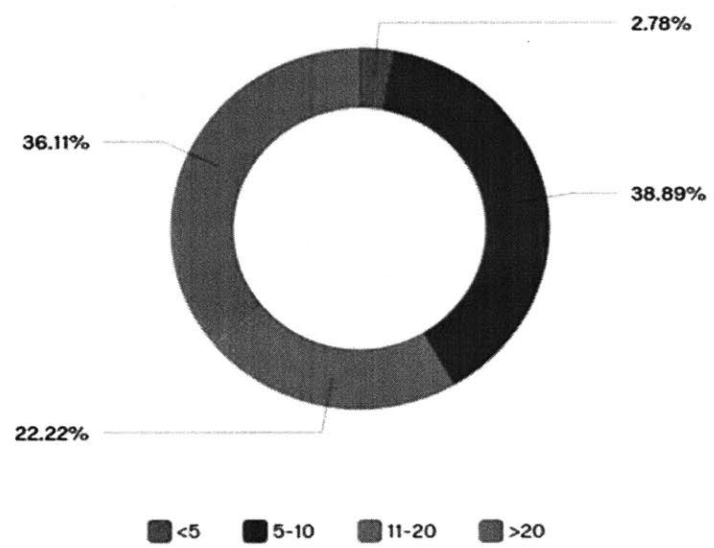
Q19_6_TEXT - Insert your answer here

Insert your answer here

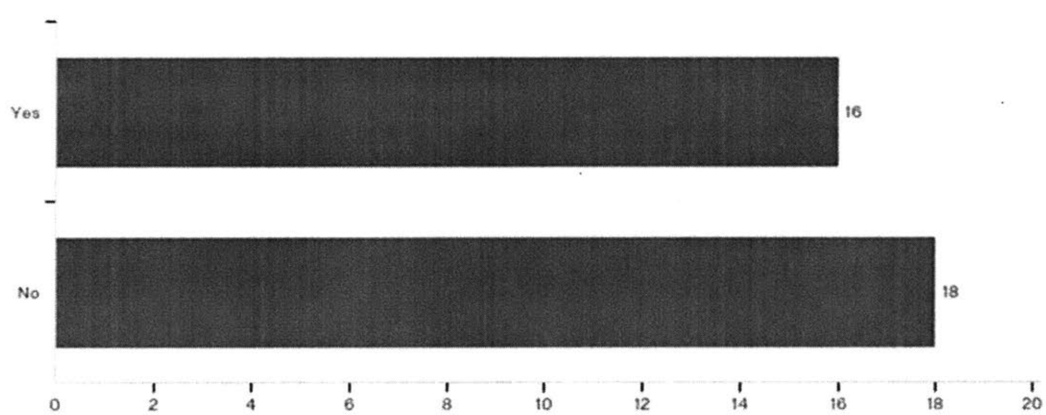
Current or former Operators

Product managers

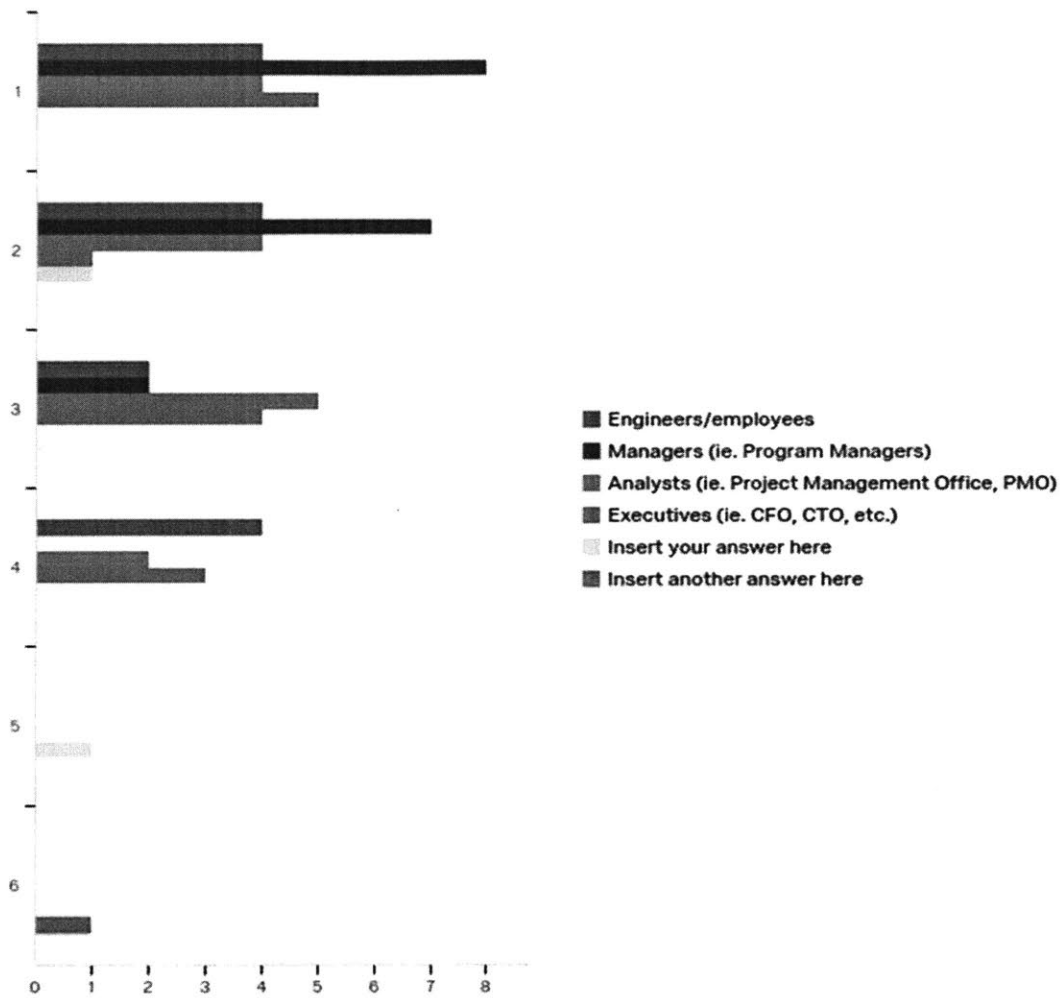
Q20 - What is the size (number of individuals) of this entity?



Q21 - Are the functions you previously selected equally represented in this entity?



Q22 - Rank each function's representation in this entity. Most represented should be ranked as "1". If you do not wish to enter any additional answers, add "0" in the ranking box.



Insert your answer here

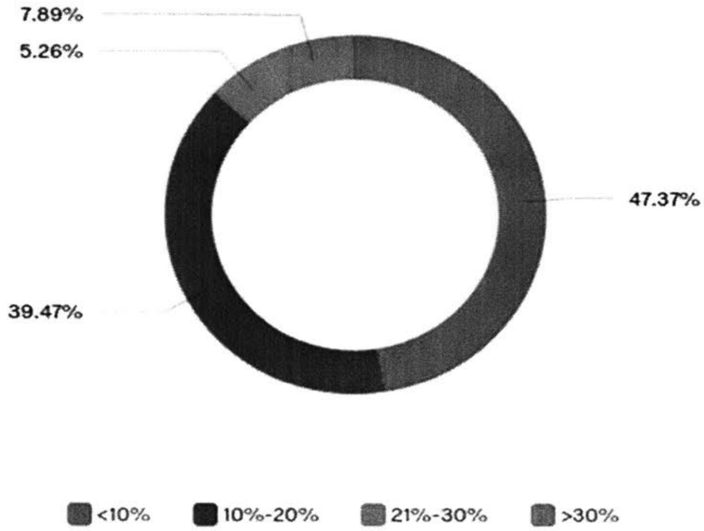
Insert your answer here

Product managers

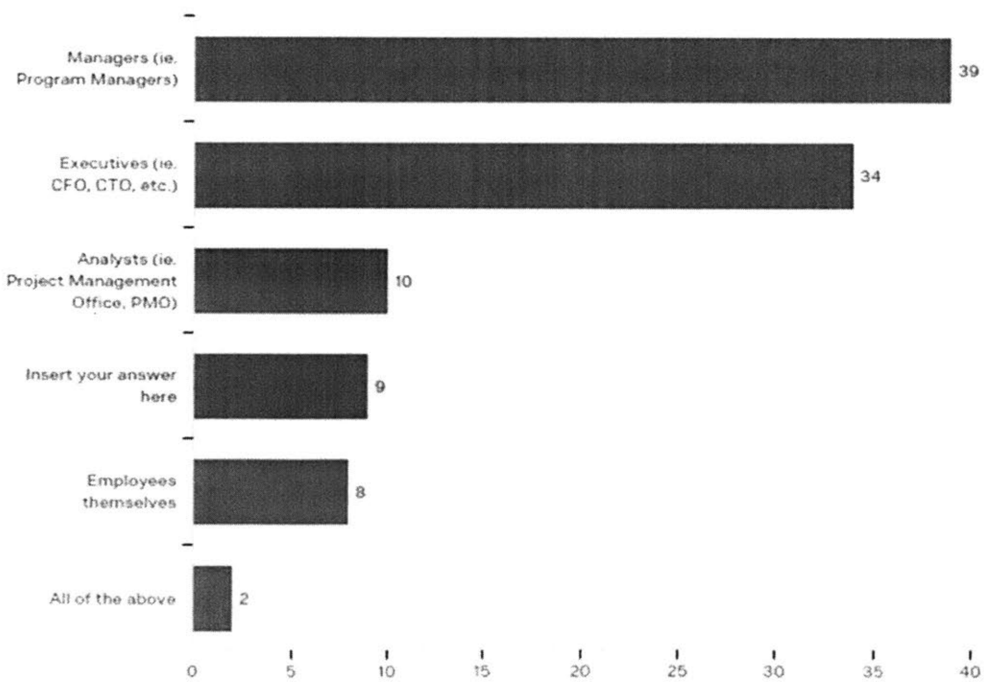
0

None

Q23 - What is the approximate ratio of this entity's budget to the portfolios' baseline budgets? You may choose multiple answers if your portfolios' budgets have varying orders of magnitude.

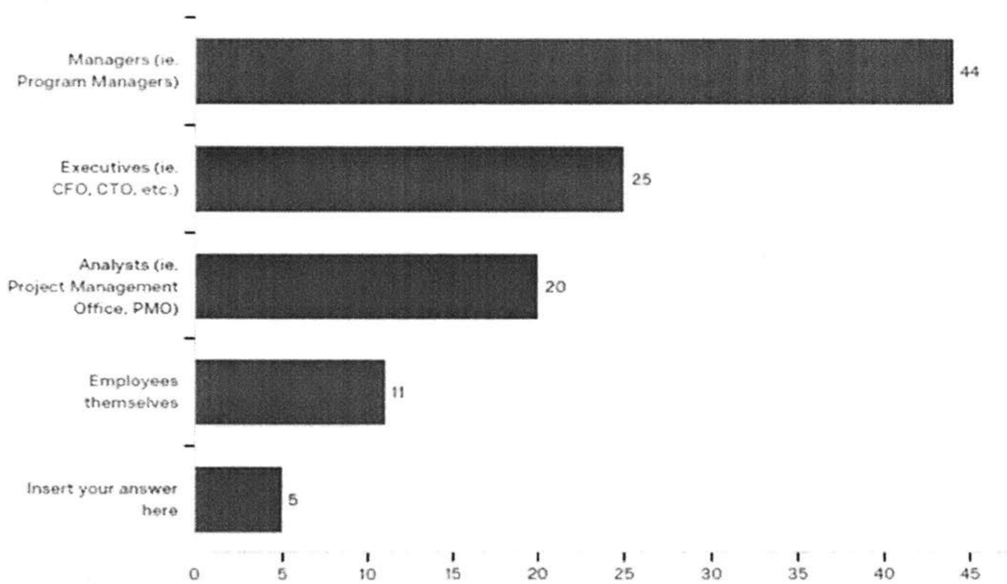


Q24 - Which of the following functions makes resource allocation decisions in your firm? You may choose multiple answers if these decisions are shared.



Q24_6_TEXT - Insert your answer here

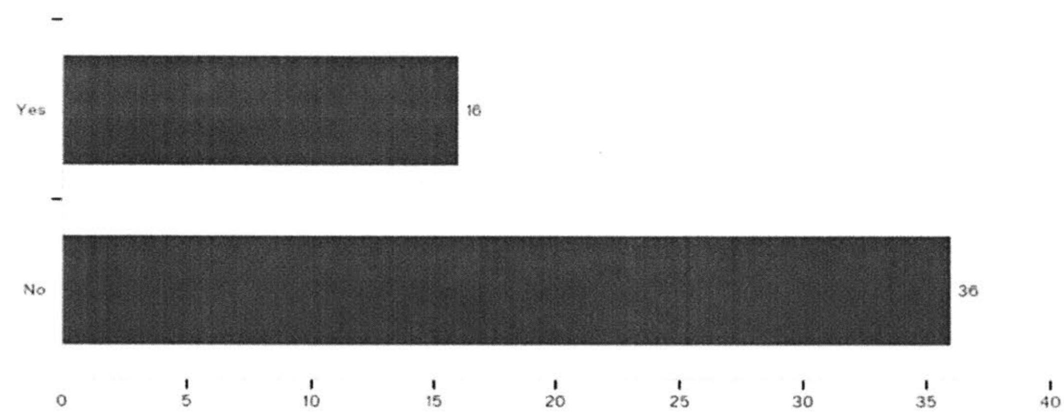
Q25 - In your opinion, which function(s) should be making resource allocation decisions? You may choose multiple answers.



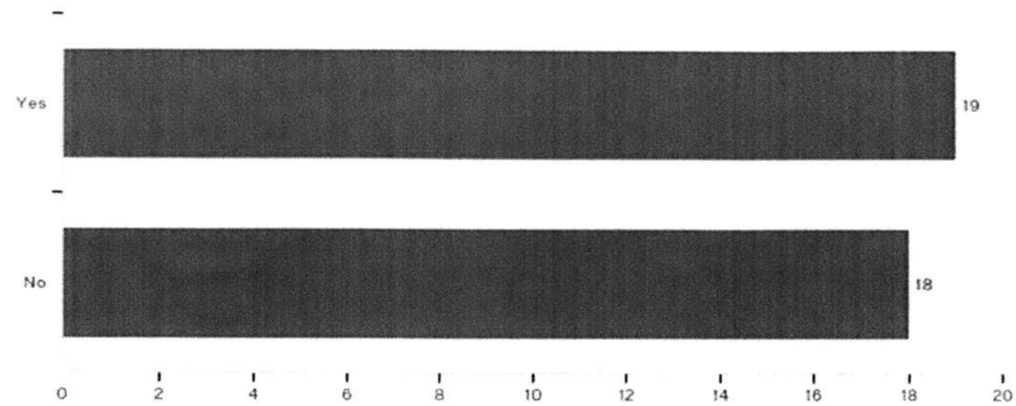
Q25_5_TEXT - Insert your answer here

manager

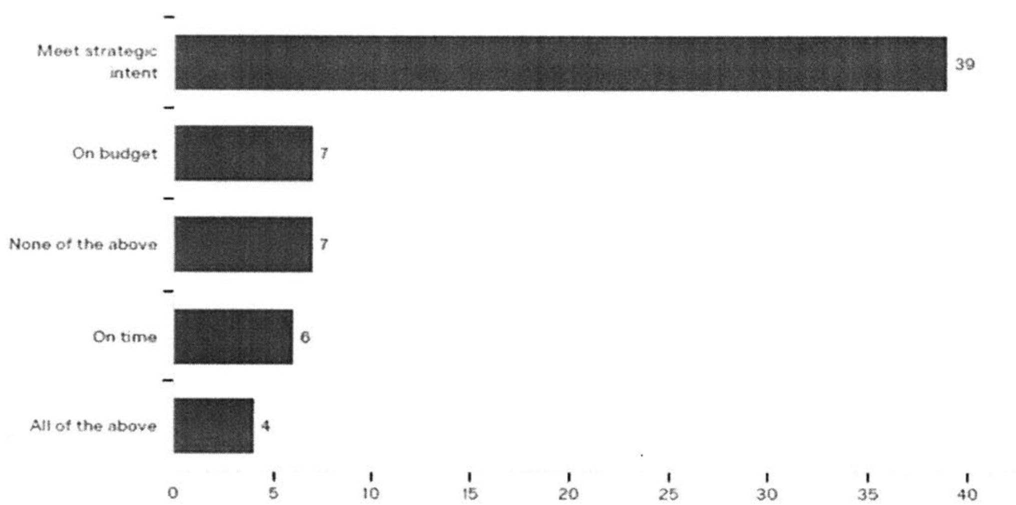
Q26 - Does your firm have backup portfolio plans?



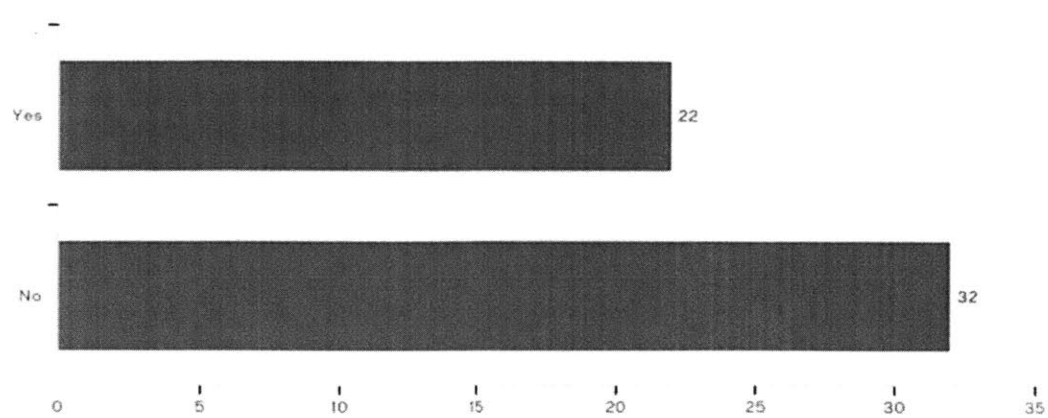
Q27 - Should your firm have backup portfolio plans?



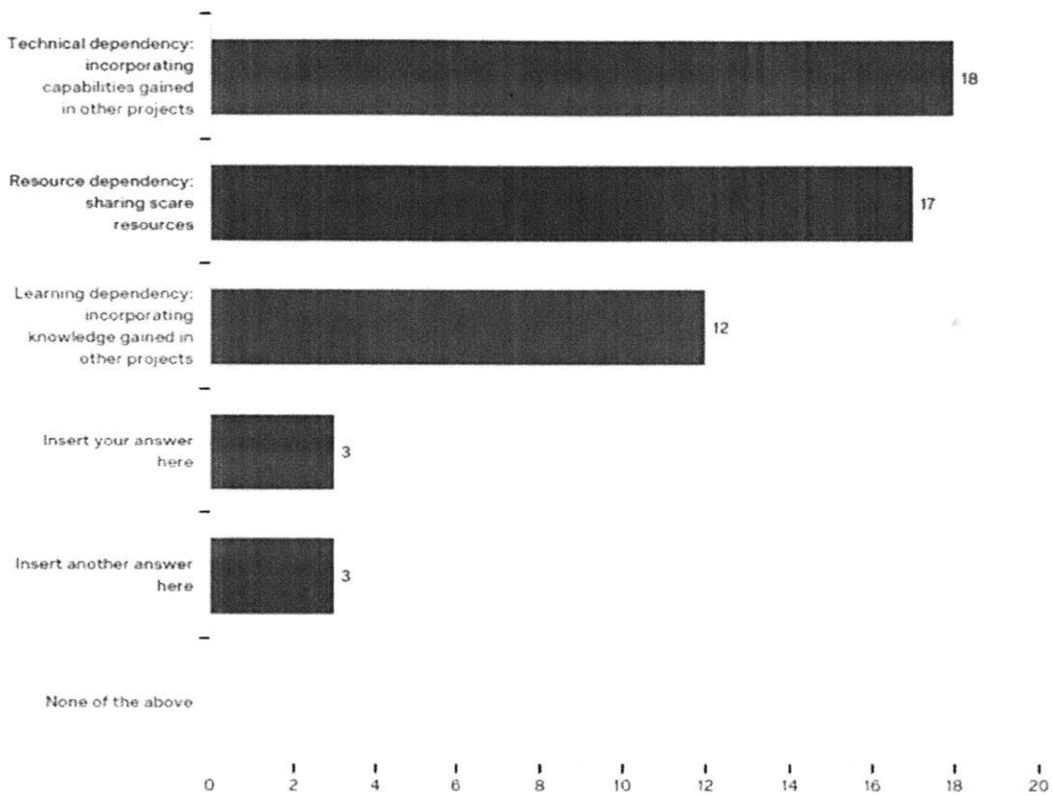
Q28 - Based on your current Project Portfolio Management (PPM) practices, would you say the majority of projects and portfolios in your firm are: (You may choose multiple answers)



Q29 - Does your firm model and evaluate any inter-project dependencies?



Q30 - What types of inter-project dependencies does your firm model and evaluate? You may choose multiple answers.



Insert your answer here

Insert your answer here

Requirements overlap

Location dependency

Sharing human and instrument resources

Insert another answer here

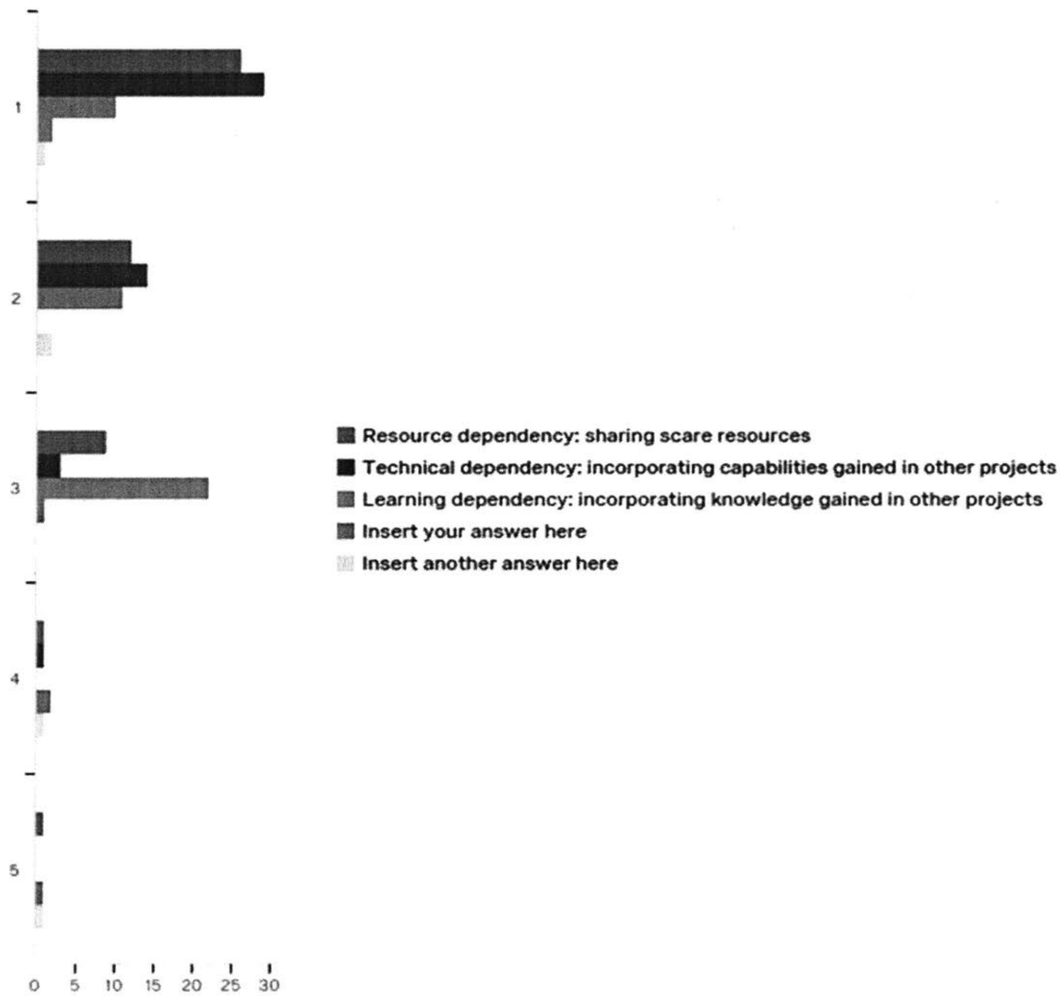
Insert another answer here

Location Dependency

Data dependency: essential data to a program being derived from another program

Sharing external resources. I aerospace some components come from a well known vendor and there may not be an alternative vendor

Q31 - How do you perceive the effect of the below inter-project dependencies on project and portfolio success? Highest effect should be ranked as "1". If you do not wish to enter any additional answers, add "0" in the ranking box.



Q31_4_TEXT - Insert your answer here

Insert your answer here

Requirements overlap

Leverage existing solutions

Co-Locatoin of teams

Schedule

Customer dependency: Same or similar customer in other projects

0

Location dependency

Q31_5_TEXT - Insert another answer here

Insert another answer here

Location Dependency

Data dependency: essential data to a program from another program

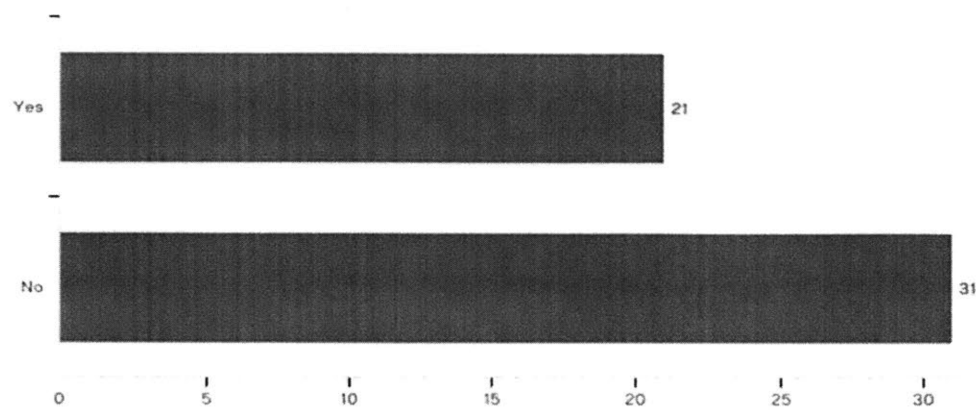
Just filling to move to next page

Number of skilled resources

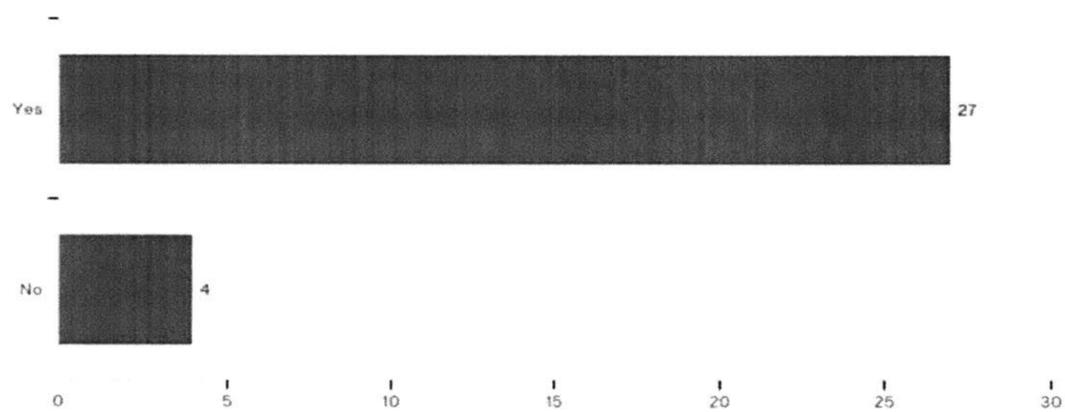
Technical Dependency: Integration and interface management

0

Q32 - Does your firm model and evaluate scope uncertainty? This uncertainty could be due to technologies used, other technical risks, errors, rework, etc.

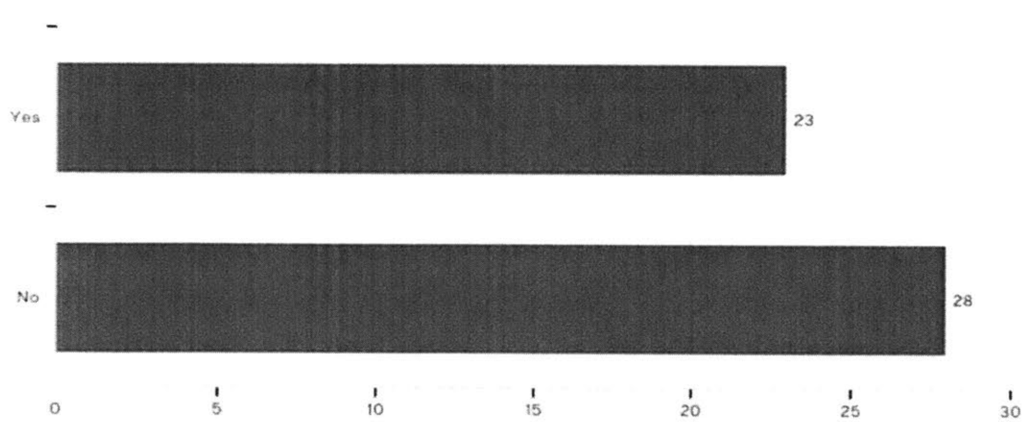


Q33 - Should scope uncertainty be modeled and evaluated?

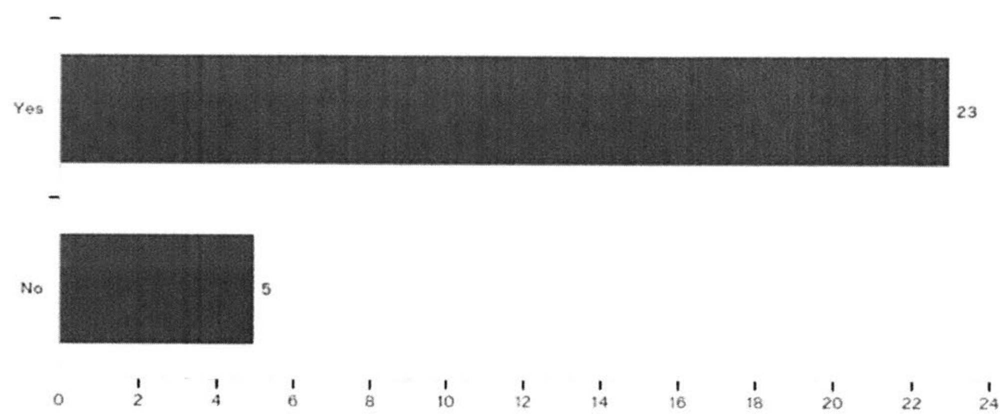


Q34 - What methods or tools does your firm use to model scope uncertainty? (less than 100 characters)

Q35 - Does your firm model and evaluate resource uncertainty? This uncertainty could be due to resource availability, skill, cost, etc.



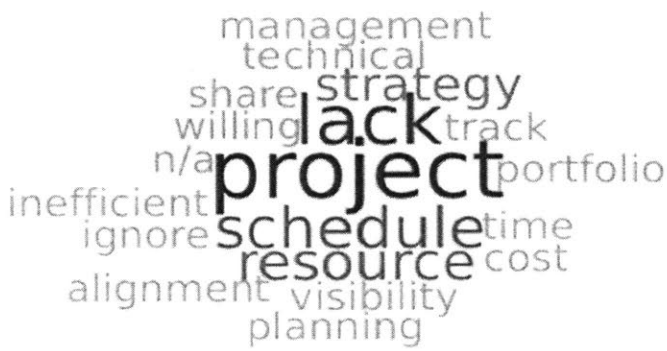
Q36 - Should resource uncertainty be modeled and evaluated?



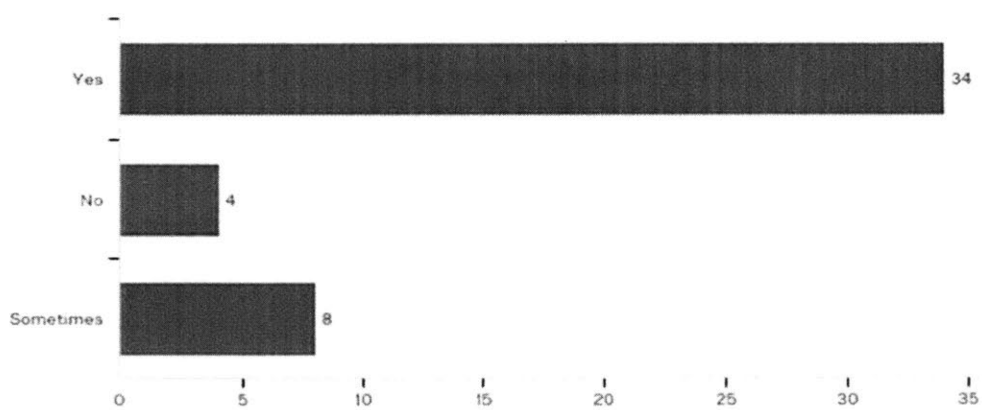
Q37 - What methods or tools does your firm use to model resource uncertainty? (less than 100 characters)

Q38 - What are the key enabling features that contribute to the success of your firm's current Project Portfolio Management (PPM) practices? Use keywords only (less than 100 characters)

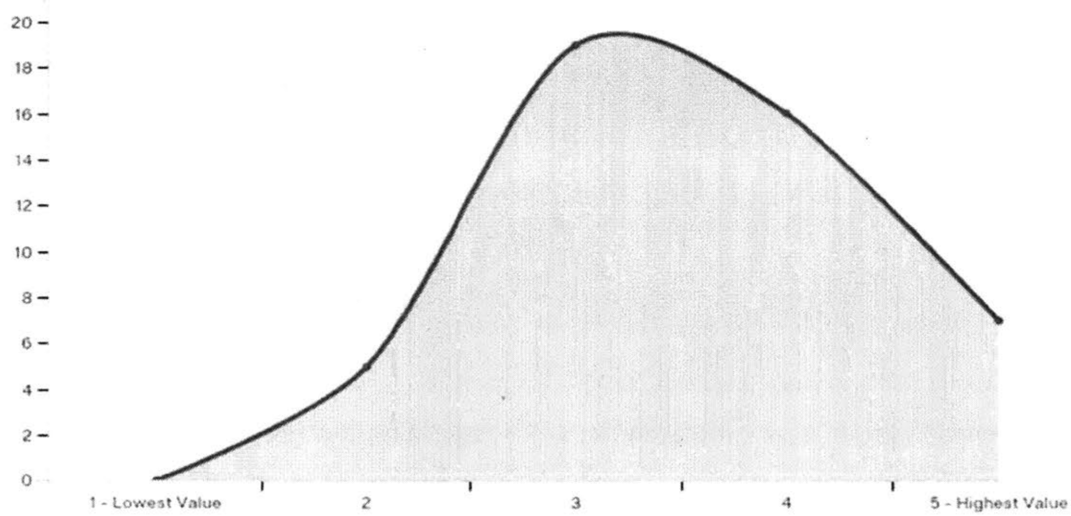
Q39 - What are the major weaknesses of your firm's current Project Portfolio Management (PPM) practices? Use keywords only (less than 100 characters)



Q40 - In your opinion, do you think modeling and evaluating inter-project dependencies is positively correlated to project and portfolio success rates?



Q42 - What marginal value would you place on modeling and evaluating inter-project dependencies?



Q44 - Would you like to include any other comments?

Would you like to include any other comments?

Good luck with your thesis!

I found it challenging to frame the scope of my answers. At such a large company, each business unit may operate differently...some more effective than others.

None.

My responses were in reference to the US Air Force Space Enterprise. This is comprised of multiple portfolios that each cover a specific mission areas (ground-based space control, space situational awareness, battle management command & control, early warning satellites, communications satellites, etc.)

All the best!

I worked in a software company, but I had to select "Consumer Goods/Services" for first question. Please let me know if you have any question, I will be glad to meet to provide any additional info. Mojdeh

Portfolio management at my company varies across many different market segments and multiple answers could have been provided depending in what part of the organization is being considered. I have tried to put a consumer perspective on the survey diluted with influences from other market segments.

I mainly answered for my Business Unit, which has 5-10 portfolios, answering for the company as a whole would result in 10x higher number of portfolios and I am not close enough to the other BUs to answer fairly for them. Good luck with this!

I believe the marginal value of modeling and evaluating inter-project dependencies varies depending on the size of the portfolios. For small companies it might not be needed.

Thanks and good luck for your thesis!

Would be helpful to include a category from public service/governments since that touches a wide spectrum of industries.

I do this survey based on non-ferrous metal and mining industry in China and Africa. I hope it helps to some extent.

Portfolio management is only as good as the ease of collecting project data, this is the hard part.

I don't know the correlation or how to estimate the benefits of modeling since the company hasn't done it.

Appendix B: Pairwise Tradespaces