A NEW APPROACH FOR PROJECT SELECTION IN SERVICE ORGANIZATIONS CONSIDERING WORKFORCE STRUCTURE

by

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ÖZET

HİZMET KURUMLARINDAKİ PROJE SEÇİMİNE DAİR İNSAN KAYNAKLARI EKSENİNDE YENİ BİR YAKLAŞIM

Günümüz iş dünyasında şirketler için verimlilik ve esneklik eskiye nazaran daha çok önem kazanmakta ve bu da kaynaklar üzerinde sıkı kontrol sağlayan bir idari uygulamayı gerekli kılmaktadır. Özellikle Ar-Ge, Bilişim Teknolojileri ve danışmanlık şirketleri gibi proje yönetimi yapan kurumlarda işgücü yapısının çapraz eğitimli çalışanlardan oluştuğu ve insan kaynaklarının sistem üzerinde bir kısıt meydana getirdiği görülmektedir. Dolayısıyla böyle şirketlerde kısıtlı kaynakların eşzamanlı projelere atanması somut bir yöntem gerektirmektedir. Bu çalışmada biz, bu gibi kurumların kaynak dağıtma sorunları için proje seçimi ve çalışanların atanması temel kararlarını kapsayan matematiksel modeller kurmayı amaçladık. Proje seçimi kararlarında insan kaynaklarını temel bir yapı taşı olarak kabul ederek dört eniyileme modeli ve bir de sezgisel yöntem önerdik. Temel olarak proje seçimi ve çalışan atamalarının hem çalışan becerilerinin hem de çalışanların birbirleriyle etkileşimlerinin göz önünde bulundurularak gerçekleştirilmesini sağladık. Ayrıca, bu çalışmada daha önceki proje deneyimlerinde aynı takım içinde olan farklı görev birimlerinden çalışanların aralarındaki iletişimin birbirlerinin nasıl çalıştıklarını bilmeye ve diğer görevlere tanıdık olmaya sebep olduğunu ve bunun da ileriki projelerde performanslarının gelişmesine sebep olduğunu kabul ettik. Bu olguyu çalışmamızda etkileşim terimiyle ifade ettik ve etkileşimin modellerdeki etkisini talep tahmini ihtilafları, proje özellikleri, bütçe kısıtları ve lider seçimi gibi önemli proje yönetimi konularıyla birlikte biçimlendirdik. Bütün olarak bu çalışma, proje bazlı kurumlarda insan kaynaklarının önemini vurgulamakta ve proje seçimi literatürüne proje yönetimine özgü önemli konuları çalışmak ve modellemek suretiyle katkıda bulunmaktadır.

ABSTRACT

A NEW APPROACH FOR PROJECT SELECTION IN SERVICE ORGANIZATIONS CONSIDERING WORKFORCE STRUCTURE

In the current business environment, organizations rely more on efficiency and flexibility, and this necessitates a management practice having a firm control on resources. Especially in companies where project management is the main activity, such as R&D, consulting, law or IT firms, there is typically a common pool of resources, and allocation of these resources to simultaneous projects requires a concrete methodology. In these companies, typically, workforce structure consists of cross-trained employees and human resources constitute a constraint on the system. In this study, we aim to develop sound mathematical models for the resource allocation problem of these companies based on two major decisions, project portfolio selection and employee allocation. By considering human resources as a major building block in project selection decisions, we propose four optimization models and a heuristic approach to construct project portfolios. Basically, we perform selection of projects and assignment of employees concurrently taking into consideration employee skills and interactions. Interaction is a term used to describe the communication between team members that stems from acquaintance and familiarity with each other's task and results in performance improvement in future projects. We formulate the effect of interaction in the models together with a number of significant project management issues such as demand estimation disagreements, project attributes and budget constraints, and leader selection. Overall, this study highlights the importance of human resources in project-based settings and extends the literature on project selection by studying and modeling specific issues in project management.

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NOMENCLATURE

i	worker index, $i = 1, \ldots, E$
E	number of employees
j	project index, $j = 1, \ldots, J$
J	number of projects
k	function index, $k = 1, \ldots, K$
K	number of functions
H	standard working capacity of each employee in a period (days/hours)
LT	lower bound for the number of employees assigned to a project
UT	upper bound for the number of employees assigned to a project
LC	lower bound for the number of projects an employee can be assigned to
UC	upper bound for the number of projects an employee can be assigned to
L	weight assigned to the effect of leader assignment in the overall project selection
PL	minimum required level of leadership for projects
f_{ik}	functional skill level of employee i in function k
n_{jk}	interaction of employee i with function k
l_{ij}	leadership score of employee i in project j
v_j	weight of project j
c_j	cost of project j
B	available budget
d_{jk}	demand for function k of project j (total days/hours required)
d^1_{jk}	demand for function k of project j according to first demand scenario
d^2_{jk}	demand for function k of project j according to second demand scenario

R^1	objective function value of the first model with estimated demand parameters $d^1{}_{jk}$
R^2	objective function value of the first model with estimated demand parameters $d^1{}_{jk}$
x_{ij}	indicator variable for employee *i* in project *j*
z_j	indicator variable for project *j*
$z^1{}_j$	indicator variable for project *j* according to first demand scenario
$z^2{}_j$	indicator variable for project *j* according to first demand scenario
a_{ij}	indicator variable for leadership of employee *i* in project *j*
y_{ijk}	contribution of employee *i* to function *k* in project *j*
w_{jk}	total interaction for function *k* in project *j*
B_i	breakpoint *i*
s_i	slope in the i^{th} region
nbemployee	number of employees
nbproject	number of projects
nbfunction	number of functions
nbgroup	number of functional families
DC	Total demand/Total capacity
CV	coefficient of variation
DF	demand distribution among functions

Chapter 1

INTRODUCTION

The intensity of global competition in today's markets forces business organizations to re-evaluate their structural decisions with the objective of creating operations that are more efficient and flexible. Currently, organizations compete on many dimensions such as cost, customization, quality, delivery time, and product variety, which heightens the need to have more efficient operating practices and strategies. Flexibility on the other hand, is mostly defined as providing rapid response to customer demand, developing customized products or services, and/or managing the internal changes effectively. Currently in many industries, one of the ways through which firms deal with efficiency needs and adapt themselves to the environment has become focusing more on their most valuable asset, the workforce (Belout, 1998). Especially in labor-intensive service companies, where employee structure constitutes an important part of the system and skilled labor is in short supply, workforce management becomes vital for the overall strategy and operations.

Today, in business environment, there are complex links between companies, which are controlled by project driven operations, and people. According to Turner (1993), a project is "an endeavour in which human, material and financial resources are organized in a novel way, to undertake a unique scope of work, of given specification, within constraints of cost and time, to achieve beneficial change defined by quantitative and qualitative objectives" (Turner, 1993, p.355). As the main activities of the organizations are realized through projects, project management, which is defined by Harvard Business School's Project Management Manual (2002) as "a formal management discipline whereby projects are planned and executed according to a systematic, repeatable, and scaleable process" (p.4) becomes a new kind of business practice with its own rules and dynamics.

Furthermore, in the global economy, organizations increasingly use project management practices while companies working only on projects grow in number. Project Management Institute (PMI), which is a non-profit organization that develops professional standards, provides certification for project management professionals, supports research on project management, and produces publications in the related areas. Today, PMI works with over 100,000 members in 125 countries worldwide while it started with 71 in 1969 and had almost 5,000 members in 1984.

With increasing interest in project management and the benefits it can provide, significant attention is given to project selection because of limited resources. Usually there are more projects available than can be undertaken with the available resources, thus it is crucial to select the projects to work on within existing constraints. This causes project management firms to make a great effort to choose the best project portfolios. Also, selection of projects in project management attracts the attention of a significant number of scholars and most of the studies take financial constraints as the basis for project selection (Badiru, 1993; Dickinson et al., 2001; Eben-Chaime, 2000; Graves et al., 2000). However, as the definition of project implies, allocation of human resources is an important element of project management since projects are operated by employees. Therefore, to be competitive in today's environment with improved efficiency and flexibility, companies organized around projects should choose project portfolios considering the current state of their employee structure. Although there are studies specific to employee issues in project management companies, the literature on project selection based on workforce structure and characteristics is limited. With this study, we aim to fill this gap and bring up major human resources issues in project selection.

In our study, we focus on service settings such as R&D, consulting, law or IT firms where project management is the main activity and the key resource is human capacity. Typically, there are more projects than can be completed and multiple projects running in parallel require the same resources at the same time. The organization has a number of project alternatives with known demand and each project necessitates skills in different functions. Besides, employee skills are scarce and not interchangeable, thus human resources constitute a constraint on project selection. In this setting, the workforce structure is identified with employees who belong to specific functional families and work in cross-functional teams that consist of employees from different functions. A functional family can be described as a specific area in which an employee is educated and skilled and it contains different functions grouped around a specific job type or specific skills. Functions, on the other hand, are different task types that an employee is capable of and/or experienced in performing under this functional family. Our investigations revealed that it is not common for employees to work in more than one functional family in practice. Therefore, it is not allowed for an employee to work outside his/her functional family, which means that it is not possible to make employees of a functional family perform the specific tasks of another family. However, employees are usually cross-trained in several functions within a family and can work in one or more of these functions according to requirements.

Using cross-trained employees has become a promising practice that can make employees, and potentially firms, more flexible. Cross-trained employees can be informally defined as individuals who are trained or skilled to work on more than one task type in an organization. Employee task types can be very distinct from each other in terms of requiring different basic training or they may necessitate the same basic education but different specializations. Since cross-trained workers may perform multiple tasks, the organization can utilize them in many ways and can achieve increased adaptation capabilities. For example, a financial consultant, whose primary task is corporate accounting, may also be skilled to work in taxing; an IT specialist, who is an expert on ERP, can work on CRM solutions too; an R&D employee in a durable goods firm whose expertise is on soundproofing may work on design of air-conditioning devices or refrigerators. There may be several more examples, but in all of the situations with these cross-trained employees the organization can achieve cross-utilization which is defined as the practice of using workers outside their primary skill to satisfy labor requirements in case of time varying demand (Brusco et al., 1998). The situation where employees are equipped with additional skills outside their primary skill also brings assignment and scheduling flexibility for the organization. Furthermore, by means of cross-training, employees develop a better understanding of the system in which they operate, and their broadened set of capabilities help them develop problem solving skills. Use of cross-trained employees is common in manufacturing and service companies. Besides, project management firms have been increasingly using cross-trained employees to survive in the environments where multiple projects are operated concurrently with limited number of employees. Therefore, we assume that employees are cross-trained in our setting.

Moreover, we introduce the concept of interaction which is not studied before in a mathematical modeling context. Interaction is used to describe the communication between team members based on acquaintance and familiarity with each other's task arising from previous project experiences and resulting in performance improvement in future projects. We assume that when individuals from different functional families work together in a project, they form a contact and exchange knowledge about their tasks. Consequently, the people learn what other functions do and how they work, and this causes better performance in a project team where they meet these functions again. In this study, we assumed that interactions between employees are quantified beforehand and we represent the effect of interaction in our models using interaction parameters.

In this context, we investigate some major questions regarding project selection and employee allocation with mathematical models. We review and examine a broad range of literature and encounter a lot of studies on either project selection techniques or employee allocation. Although some mathematical models have been developed for the assignment of manufacturing industry workers, service companies rely on the experience of the managers. Consequently, it is not common to use analytical systems or quantitative decision tools in case of human resource allocation in service companies. Moreover, there are not many studies on this issue in the literature. In this research, we attempt to make a contribution by structuring mathematical models that combine project selection and employee allocation considering the competencies and interactions of employees in project selection decisions. We encountered a similar approach in an independent work by Yoshimura et al. (2006) though they did not use a similar methodology. They worked on human resource allocation decisions in product development projects and considered human resource related issues while selecting a subset of projects. Their study deals only with product development projects and does not consider how employee qualifications are assessed or how interaction between employees affect their performance, while they use two separate models for project selection and employee allocation with genetic algorithms. We examine that study in detail in the problem definition part to compare it with our study in terms of similarities and differences.

The main goal of this study is to construct the optimal project portfolio and an assignment plan considering the available human resources and their characteristics in detail. With a basic optimization model, we provide a rough-cut capacity planning where projects are selected and employees are assigned to specific functions in these projects at once. The basic model is also used in the analysis of the factors used for problem generation. Alternative models are presented to develop robust plans in case demand estimates may not be exact. The robust model selects projects and assigns employees considering uncertainties in demand estimation based on scenarios. The heuristic method works for the same purpose but it is proposed for situation where robust model causes computational challenges and becomes inefficient. For the implementation of these models, we discussed some issues such as eliminating functional family limitations on employee cross-training and allocation, effects of team size, limiting the number of projects an employee can be assigned to, and computation of model parameters. Furthermore, we introduce extensions of the basic model, where different managerial objectives are incorporated into project selection. The first extended model includes additional parameters and constraints related to project attributes and budget considerations. We incorporate project leader selection into the basic model and construct the second extended model. Throughout the study, we work on a detailed example that is on the project selection problem of an hypothetical IT company. Using this example, we aim to illustrate the outcomes of all the proposed models and the significance of introducing human resources constraints into the selection decisions. In addition, we provide a comparison between a classical project selection model and our first extended model in the last chapter.

This study is organized as follows. In the following chapter, there is a broad review of the literature related to project selection, cross-functional teams in multi-project management, assignment of cross-trained employees, and leadership in project management organizations. In the third chapter, we talk about the place of our study in the literature, give a detailed investigation of the work of Yoshimura et al. (2006), and explain the overall problem we study in detail. The fourth chapter deals with the modeling of the problem and the findings from the computational analysis of the mathematical models proposed. This chapter also includes implementation issues regarding the mathematical models. The last chapter gives a brief summary of the study and the findings together with suggestions for further studies.

Chapter 2

LITERATURE REVIEW

Studies relevant to present research come from a broad spectrum, but we outline the most relevant research to provide an extensive review of the literature for further background on issues such as project selection, cross-functional teams in multi-project settings, assignment of cross-trained employees, and project leadership. Project management problems have received attention in both the Operations Management (OM) literature and the Human Resources (HR) literature. Studies in OM literature mostly deal with operational issues such as evaluation and selection of projects and assignment of employees. The HR literature on the other hand, focuses on some topics on employee characteristics, formation of teams and evaluation of employees.

2.1 Project Selection

There are always more projects available than can be completed in a given period. As Turner (1993) states, one of the basic concerns of project management is to choose the projects to work on, thus selection of the project portfolio is an important issue in project management. There is a vast amount of studies focusing on project selection and there are various project evaluation and selection methods discussed. Most of the studies talk about project selection methods based on various criteria such as economic return, possible risks or meeting the strategic objectives. Some of these techniques are used in practice although most of them are found to be unfeasible since they are too complex or do not include all the necessary elements. Apart from Yoshimura et al. (2006), we have not encountered any project selection technique that gives special attention to the characteristics of the available human resources. In this section, we give a brief review of the literature to cover different criteria used in project selection and to construct a solid ground for our mathematical models.

According to Project Management Manual (2002), every project should be assessed in terms of benefits and risks it possesses and this should be done before project selection is initiated. Most of the studies on project selection focus on evaluation of projects in terms of risks and returns. There can be different risks for projects such as problems with management, not meeting the strategic objectives, failure in implementation of the projects, possible financial and legal problems, and so on (Merkhofer, 2006). These risks can be put into different categories. For example, Merkhofer (2006) suggests that risk consists of two parts, internal and external risk. Internal risk emerges when problems and failure arise in the project operating phase and external risks are associated with risks that are outside project team's control. According to him, both of these risk components should be determined and quantified to select the best project portfolio. Quantifying project risks is vital for the organization since it gives an opportunity to assess the risks of alternative project portfolios and choose the optimal portfolio. According to Merkhofer (2006), enumerating project risks and selecting projects accordingly provides an opportunity to understand external risks, to get higher level management to take ownership of project risks, and to determine the overall risk of the project portfolio beforehand. Therefore, the only way to estimate accurately the risks of alternative project portfolios, and thereby choose projects that collectively produce maximum value at minimum risk, is to quantify these project risks.

Similarly, Archer and Ghasemzadeh (1999) point out that project selection should be done based on the stated objectives of the organization and internal and external business factors should be considered carefully. According to their view, projects should be evaluated in an organized way to simplify the project selection. Therefore, possible contributions and risks projects possess should be analyzed in a systematic manner. The study of Archer and Ghasemzadeh (1999) is significant in project selection literature since it gives a brief review of project evaluation and selection methods and proposes a way to perform effective portfolio selection. They divide project evaluation techniques into four categories and state that any evaluation method falls into one of these categories: 1) economic return (e.g. Net Present Value (NPV), Internal Rate of Return (IRR), Return on Original Investment (ROI), Return on Average Investment (RAI), Pay-Back Period (PBP), Expected Value (EV), and Capital Asset Pricing Method (CAPM)), 2) benefit/cost techniques, 3) risk, 4) market research. The authors state that each situation necessitates a different evaluation method but measurement should be done in an organized way to provide an equal comparison base when projects are selected. They also talk about five different portfolio selection technique classes which are ad-hoc approaches, comparative approaches, scoring models, portfolio matrices, and optimization models. As they state, projects can be selected with any of the methods, but the essence is to choose most desired projects according to the elements considered. Archer and Ghasemzadeh (1999) also point out that a post-selection process, where decision makers have the opportunity to evaluate and modify the components of selected project portfolio, is necessary to provide that selected projects meet the overall objectives without violating other constraints. This is also important for our study since we aim to conduct portfolio selection based not only on strategic objectives but also on available resources with the model (M_S).

Burke (1993) gives a different classification scheme than Archer and Ghasemzadeh (1999) for portfolio selection techniques. Burke (1993) divides project selection methods into numerical and non-numerical selection models and briefly explains the most popular ones used in each area. Numerical models consist of financial models and scoring models. Financial models are used extensively considering diverse measures such as payback period, return on investment, and discounted cash flow techniques based on Net Present Value (NPV) and Internal Rate of Return (IRR). Scoring models are based on different criteria determined according to the strategic objectives the organization has and the characteristics the projects own.

Scoring tools are popularly used in project selection and there are various studies in project selection literature that examine these tools. For example, Henriksen and

Traynor (1999) propose a scoring tool that is based on scoring and ranking of projects by relevance, risk, reasonableness, and return. In another study by Rengarajan and Jagannathan (1997), R&D projects are scored based on different criteria related to company image, available space, social objectives, patenting and so on. Both of these studies aim to rank projects and select the ones that best suit the overall objectives and constraints.

The studies of Graves et al. (2000), Dickinson et al. (2001), Badiru (1993), and Eben-Chaime (2000) are examples of project selection based on financial criteria. Graves et al. (2000) study portfolio selection specific to R&D settings and use optimization for project selection. They structure a simple linear program that has the objective of minimizing risk for a given level of return. Iteratively solving the model, they construct an efficient frontier, find portfolios that are on this frontier, and find the most desired ones that can be chosen by the decision maker. Although their model is simple to solve, it only considers risk and return of projects without any attention to cost or other constraints. Dickinson et al. (2001) overcome this shortfall and take project cost into consideration in addition to risk and return factors. This study makes another contribution and constructs an optimization model where project interdependencies are quantified and incorporated into the decision making process. The aim is to find the optimum project portfolio that maximizes the potential return subject to cost-benefit, risk and overall objectives. Although it is specific to situations where projects are interrelated and start time of projects differ, the model is an interesting optimization approach for project selection.

Financial models are also popular in project selection literature. The project selection method given in Badiru (1993), which is called as capital rationing, is an example of financial models that is based on return on investment. The linear programming formulation for capital rationing is given below:

$$\max \quad z = \sum_{j=1}^{J} v_j z_j$$

subject to:

$$\sum_{j=1}^{J} c_j z_j \leq B$$

J: number of projects

v_j: measure of performance for project j (related to return on investment)

c_j: cost of project j

$$z_j : \begin{cases} 1, & \text{if project } j \text{ is chosen} \\ 0, & \text{otherwise} \end{cases}$$

B: budget availability level

This formulation illustrates a classical project selection model that is based on project performance and cost. The project performance parameter, v_j, which is the measure of return on investment, is used to show the importance of the project. However, a similar model where project performance is shown with two separate parameters, such as risk and return, can be seen in most of the financial models. Eben-Chaime's (2000) model for project selection is an example of such financial models. This model is described below:

$$\max Z(\alpha) = \max\left[\alpha \sum_{j=1}^{J} p_j z_j - (1-\alpha)\sum_{j=1}^{J} r_j z_j\right]$$

subject to:

$$\sum_{j=1}^{J} s_j z_j \leq B \quad \text{and} \quad z_j = \{0,1\}$$

Similar to the model given in Badiru (1993), the first period expected cash-flow of project j is shown with s_j that is parallel to the cost item in Badiru (1993). The objective function includes p_j and r_j that show the expected worth value of project j and the risk associated with project j respectively. While the previous model use a single parameter, Eben-Chaime (1999) illustrates project performance with two separate components and provides control on risk and return components of projects.

At this stage, the selection of α is important, since α is the measure of decision maker's risk aversion (the smaller the α, the more risk-averse the decision maker).

As explained above, a variety of tools and methods are available for project selection, but especially in environments where human resources constitute an important constraint and employee skills are scarce, a method that includes employee related constraints can work in favor of the organizations. Yoshimura et al.'s work (2006) is distinctive since it presents a model that selects projects according to human resources limitations and also profitability and strategic importance of projects. Yoshimura et al. (2006) develop a decision support system where project selection and human resource allocation are presented together. According to their method, a project selection algorithm is used with the objective of maximizing the total expected profit and potential future profits. The constraints of the algorithm assure that the available skills of the existing workforce satisfy the required amount of skills for the projects. Then, human resources motivations are incorporated into the decision making process and optimal employee allocation is provided with selection of leaders for each project. This study is specific to product development setting but it is significant since they emphasize employee skill constraints in project selection.

2.2 Cross-functional Teams in Multi-project Settings

In our problem setting, we assume that all the activities are operated by multi-projects where project teams are structured from employees of different departments and interaction between team members affect the performance. Therefore, studies specific to multi-project management situations with employee allocation dynamics and communication-performance issues in cross-functional teams deserve special attention.

Engwall and Jerbrant (2003) work on dynamics of multi-project settings and the coordination of project portfolio, and they search for operational problems that are specific to multi-project environments. They examine the resource allocation syndrome, which is used to define the problem of allocating resources from a common pool to simultaneous projects, and accept this as the basic problem in multi-project management. The resource allocation issue is a popular issue in project management and is also studied in Leus et al. (2003) and Hendriks et al. (1999). In their working paper, Leus et al. (2003) study the literature on planning in multi-project settings and focus on uncertainties available in such situations. They discuss multiple techniques on eliminating uncertainties and affirm that capacity planning is crucial to deal with uncertainties. The study of Hendriks et al. (1999) on human resource allocation in multi-project situations is important for our research because it deals with a similar organizational structure and makes similar allocation decisions. Hendriks et al. (1999) study an R&D environment where multiple projects are running concurrently, project results and project timing are very uncertain, knowledge is scarce and this necessitates almost everybody to provide his small specific contribution to every project, and motivation and involvement are important. With medium term allocation in their study, they try to determine contents of the project portfolio, decision rules to resolve resource conflicts and a rough cut capacity planning. Our work is also about choosing projects for the portfolio, but different from their study, we consider portfolio creation and rough cut capacity allocation simultaneously using mathematical modeling. Moreover, we do not work on short term resource allocation which is identified in Hendriks et al. (1999) as the daily allocation of resources.

The organizational structures where each employee is associated with a functional department but individuals from different departments come together for a common purpose are typically called matrix structures (Dunn, 2001). Although each functional area works separately and passes the activity completed to the next department in traditional functional organizations, matrix structures are identified with cross-functional teams, where each team member is associated with a functional department (functional family in our setting) but teams are structured from employees of different departments. There are studies examining difficulties in cross-functional team structures. Nurick (1993) investigates some of the major problems faced by teams in matrix organizations and notes that it is difficult to integrate people into an effective cross-functional team. He states that project team performance is affected by four important difficulties associated with group dynamics. Coming from different departments and disciplines, team members may suffer from different points of view. Secondly, multiple tasks may cause role conflict for an employee who is a member of more than one project team. Another problem in groups may be implicit power struggles that may cause resistances and low performance. The last behavior that may cause problems in teams is *groupthink* which is defined as a sense of separation and elitism members develop. Consequently, he relates the performance of the group to the interpersonal relationships of team members.

Bishop (1999) and Daft (1999) on the other hand, point out some advantages of cross-functional teams. According to Bishop (1999), when team members are from different backgrounds, needs and expertise, team structuring and communication becomes important for the performance of cross-functional teams. Because employees from different functions run the projects, cross-functional teams enhance the overall performance of the organization by reducing rework, eliminating sequential knowledge transfer activities between departments and improving the communication between different branches. Similar to Bishop's arguments, Daft (1999) talks about some benefits of teams structured with employees of separate functions. Cross-functional teams cause improvement in terms of information sharing between functions, coordination of the efforts of the departments, and development of new ideas and solutions since the teams consist of members from diverse functional departments that have different tasks, viewpoints and specializations. He also introduces the concept of interdependence which is related to how much "team members depend on each other for information, resources, or ideas to accomplish their tasks" (Daft, 2006, p.278). He analyzes three different kinds of interdependencies that are explained below:

- *Pooled interdependence*: team members are independent of each other.
- *Sequential interdependence*: team members depend on each other in case they have to exchange information and resources and because completion

of one job requires the completion of another one. Therefore, regular communication between members is necessary.

- *Reciprocal interdependence*: team members influence each other and the team as a whole does the job. Strong communication and coordination is needed since all the members have to interact with each other. This is the characteristic of most knowledge-based work.

Considering the setting we work on, it seems that our interaction concept is similar to interdependence as described above. Although we do not give a similar distinction, sequential and reciprocal interdependence are more relevant to what we mean by the importance of interaction.

The study of Patrashkova-Volzdoska et al. (2003) is significant in cross-functional teams literature since it is based on the relationship of team performance with team communication. As coherently described in Patrashkova-Volzdoska et al. (2003), some of the authors assume that there is a linear relationship between communication and performance indicating that performance would improve as communication increases. Some studies claim that there is no relationship between the two whereas some claim that communication negatively affects performance because with the greater information exchange between team members, such exchanges may overload capabilities of team members and inhibit their performance. On the other hand, Patrashkova-Volzdoska et al. (2003) examine communication frequency - team performance relationship for cross-functional teams and conclude that this relationship is curvilinear. According to their curvilinear team communication hypothesis, communication frequency improves team performance although both low and high communication frequencies inhibit team performance. Our assumptions of interaction concept is in line with the findings in this study. We assume that if an individual has been exposed to a functional area other than his own through past projects, his performance on a project assignment that involves this particular area improves. However, this improvement is limited and diminishes after a certain level.

In human resources literature that focuses on project teams, team size is seen an important factor that influences team performance (Burke, 1993; Daft, 1999; Hendriks et al., 1999). Burke (1993) talks about some factors affecting team size such as the variety of technical expertise required, number of people necessary to process all the project data and affordable rate of team conflict. Consistent with the arguments of Burke (1993), Daft (1999) and Hendriks et al. (1999) suggest that an ideal team should not have more than a specific number of members not to decrease devotion and efficiency of people.

2.3 Assignment of Cross-trained Employees

There is a vast amount of literature dealing with cross-training and assignment of employees in manufacturing and service settings. Even though our problem is not solely an assignment problem, we also study the literature on employee assignment in diverse settings to have a comprehensive review of available approaches and methods.

In various studies, the concept of cross-training has been addressed under a number of names, such as workforce flexibility (Felan and Fry, 2001; Hottenstein and Bowman, 1998; Riley and Lockwood, 1997), cross-utilization of the workforce (Brusco et al., 1998; Campbell, 1999), functional flexibility or multifunctionality (Cappelli and Neumark, 2004; Molleman and Slomp, 1999; Van Den Beukel and Molleman, 1998), and multi-skilled workers (Brusco and Johns, 1998). If a worker is cross-trained to work in more than one skill or function, s/he can be said to be multi-skilled or multifunctional. Equivalently, it is reasonable to use labels such as workforce flexibility or functional flexibility since cross-trained workers represent flexible capacity as they are able to work in more than one task. Because cross-training means utilizing a worker in different tasks simultaneously, cross-utilization is also an equivalent term. Consequently, all the scholars referenced study cross-trained workers, who are skilled to do more than one task, and identify them as a source of workforce flexibility.

Cross-training has become a widely-used practice in manufacturing industries, and there exist various studies examining cross-training strategies. Van Den Beukel and Molleman (1998) study driving forces of multifunctionality and constraints on it. They find that multifunctionality is crucial in unstable markets where demand for labor fluctuates over time. In another study, Bokhorst et al. (2004) work on the problem of development and evaluation of cross-training policies for teams particularly in production environments. They develop alternative flexibility structures with an integer goal programming model and assess effectiveness of these structures with simulation. Their findings are specific to three different manufacturing structures: parallel, serial and job shop. Hottenstein and Bowman (1998) review sixteen published studies on the use of cross-trained workers in production and analyze the findings in a few dimensions, such as extent of cross-training, worker efficiencies and queue characteristics. Although the studies they examine are based on manufacturing workers, some of the findings are noteworthy for cross-training in general. These findings are described below:

- Cross-training improves the performance of workers but it is not effective beyond a level,
- Cross-training costs make this practice less valuable for firms,
- Cross-training is also useful in systems where workers are not perfectly interchangeable.

Ebeling and Lee (1994) make a cost-benefit analysis of cross-training for assembly workers and reach the conclusion that these workers are crucial for companies having just-in-time manufacturing systems. Felan and Fry (2001) examine flexibility specifically in a job shop structure. They study the situations where workers have different levels of training in each department and unequal efficiency levels in each task and find that cross training configuration, which specifies whether all workers are cross-trained or workers are trained in equal number of departments or have same level of proficiencies, affects the overall performance. Likewise, Hopp et al. (2004) study serial production systems in terms of workforce cross-training and agile workforce policies. They focus on two cross-training strategies, cherry picking, an approach that picks cross-trained workers from other lines to balance bottleneck capacities, and skill chaining, which means to cross-train not all but some of the workers to be able to shift the work from a heavily loaded worker to a less loaded worker. Skill chaining is found to be more robust and efficient in serial production systems.

Although most scholars focus on workforce flexibility in production, there are studies specific to service settings and some that are applicable to both service and manufacturing organizations. Brusco et al. (1998) analyze cross-utilization in services considering two-skills and develop a model to find a relationship between workforce staff size and cross-training depth. In another research done by Brusco and Johns (1998), different cross-training structures are compared. Campbell (1999) develops a model on allocating cross-trained employees and analyzes the relationship between the level of cross-training and demand variability. He experiments with various factors that affect the value cross-utilization presents and finds that demand variation and extent of cross-training are most significant. The findings are in line with Hottenstein and Bowman (1998) in terms of stating that cross-training does not bring significant improvements beyond a certain amount although it is beneficial even in low levels. Similarly, the study of Slomp and Molleman (2002) on impacts of cross-training on team performance supports this finding. In this study, which is relevant not just for production but also services, authors examine impacts of cross-training on team performance with a detailed comparison of four cross-training policies by an assignment heuristic. Their analyses show that level and extent of cross-training should be decided carefully in assignment decisions because different policies affect team performance distinctively. A planning and scheduling model that is applicable specifically to nurse-staffing was presented by Abernathy et al. (1973). In addition, Hopp and Van Oyen (2004) look at different approaches for evaluating cross-training structures and their suitability with different manufacturing and service systems. They assess cross-training in both strategic and tactical ways, classify workforce agility structures and worker coordination policies, and review the related literature focusing on workforce agility. In a recent study on cross-training, Sayın and Karabatı (2006) study assignment of cross-trained workers with a two stage optimization model considering departmental utilities and improvements in worker skills at the same time. Departmental utilities are linked to labor shortages in departments and skill improvements of workers are analyzed with the help of learning curves. This study is applicable both in manufacturing and service settings. Their results indicate that skill improvement may cause a decrease in total utility; however, the magnitude of the decrease is usually tolerable.

There are research articles in cross-training literature that give special attention to the relationship of cross-training with organizational strategy. In their study, Hopp and Van Oyen (2004) evaluate organizations in terms of their suitability for use of cross-trained workers. They analyze how cross-training can support organizational strategy and describe a tactical framework for selecting a workforce structure. Riley and Lockwood (1997) define four different types of workforce flexibility and state that functional flexibility, one of the types of workforce flexibility, is a good way of dealing with situations of high variance in demand. They relate functional flexibility to labor substitutability since it causes the movement of multi-skilled employees between tasks.

In line with the appreciation of the benefits of cross-training in different organizational systems and strategies, the attention has been given to significance of cross-training in team structures. Molleman and Slomp (1999), for example, focus on impact of cross-training in team-based work structures. In their paper, they examine the relation between functional flexibility and team performance. This study mainly looks at distribution of workforce flexibility among workers and how this distribution affects team structure. The study of Slomp and Molleman (2002) is also significant for cross-trained teams and the changes in performance according to different cross-training practices. Cannon-Bowers et al. (1998) conduct an experimental study to see the impact of cross-training together with workload on team performance. One of the results is that the efficiency of cross-training is related to the nature of the task, thus tasks the employees run should be considered in deciding how cross-training is conducted.

Since we develop mathematical models for the assignment of cross-trained employees, we also review mathematical modeling approaches regardless of whether they are specific to manufacturing (Stewart et al, 1994; Bokhorst et al., 2004), services (Brusco et al., 1998; Brusco and Johns, 1998; Campbell, 1999), or applicable to both of the settings (Sayın and Karabatı, 2006).

The paper of Stewart et al. (1994) is an important study that develops four mathematical models that have different objectives based on worker flexibility. At first, they try to minimize training cost by assigning workers to machines with the constraints of available production hours, production requirement and the budget. Then, another model with the objective of maximizing worker flexibility (number of skill levels workers hold) is built with similar constraints. The third model aims at minimizing training time while the fourth model is developed to combine the objectives of minimizing training time and maximizing flexibility. Overall, they look at planning cross-training in a manufacturing setting with various possible objectives. These four models are important because they are tools to find optimal training policies when different managerial objectives are present. The model of the previously marked study by Bokhorst et al. (2004) is applicable to production firms where workers are assigned to machines. They study multifunctionality of the workers and machine coverage, which is defined as number of workers who are able to operate a machine. Ebeling and Lee (1994) perform a cost-benefit analysis of the employee cross-training process on a mixed-model assembly line. First, they simulate the manufacturing process to demonstrate savings from cross-training, and then a linear integer programming model is developed to make cost-effective cross-training assignments. Next, they examine profitability of these assignments with using a mathematical programming environment. They show that cross-training is not profitable in the short term, but it is profitable to cross-train workers for long term plans.

Besides the studies specific to production industries, there are models developed for service organizations or that can be relevant for both services and manufacturing. For example, Brusco et al. (1998) study cross-training as the basic program for deploying cross-utilization of the labor in terms of service firms. To analyze the effects of cross-training depth on workforce staff size they looked at two-skilled workers. Their model is constructed to find how many workers are needed in each skill class and has the objective of minimizing total number of workers in both of the skill classes. Evaluation of the model with an experimental study shows that even low levels of cross-training leads to considerable workforce savings. Likewise, Brusco and Johns (1998) focus only on service firms. They form a workforce staffing model with the objective of minimizing staffing costs in a single work shift with the satisfaction of minimum labor requirements. In their experimental studies, they use the model to evaluate eight cross-training patterns with a workforce structure consisting of employees who have different skill levels. The same workforce structure consisting of workers who have different proficiencies in multiple work categories is also used in Campbell (1999). In this paper, a nonlinear programming model for allocation of cross-trained employees, who are not fully or equally qualified in different tasks, to departments in a multidepartment service setting is studied. The model has an objective that maximizes departmental utilities with worker assignments and is used to analyze the relationship between the level of cross-training and demand variability. Because this model is a variant of the general assignment problem which is hard to solve to optimality, he uses a heuristic that was developed in one of his previous papers to test the model. Moreover, another assignment heuristic is developed in Campbell and Diaby (2002) for the same problem. Sayın and Karabatı (2006) work on a mathematical model for worker assignment that is applicable to both manufacturing and service employees. The model they propose also addresses how to cross-train workers.

Although all of the models described are developed deterministically, there is a line of research using stochastic models, goal-programming or heuristics. Abernathy et al. (1973) present a stochastic workforce planning and scheduling model particular for nurse-staffing. They develop a three stage model consisting of decisions of operating policy, staff planning and scheduling. They use an iterative solution procedure and conclude that the model is beneficial in a labor intensive organization facing demand uncertainties and where timeliness is important to deliver services.

In addition, Agnihothri and Mishra (2004) use a queuing framework to analyze cross-training efficiency with respect to costs in a field service system. The extent of cross-training, which is based on the number of workers cross-trained, the number of secondary skills taught, and the efficiency of workers in secondary skills, are studied in a system where three job types are available. Their results on cost-effectiveness of different cross-training configurations in field services are presented. The study of Jordan et al. (2004) can be accepted in this branch of literature since it is a queuing framework that is used to examine chaining in a manufacturing setting. Molleman and Slomp (1999) study a linear goal-programming model to assign workers to tasks. They assume that distribution of skills within teams is the basic issue to be considered. In another study by the same authors, a hierarchical procedure for assigning workers to tasks is developed (Slomp and Molleman, 2002). This research is important since it demonstrates the same findings on distribution of cross-training among workers. For example, the authors say that after a level cross-training provides a diminishing positive effect on team performance. They also suggest that cross-training is valuable when it is equally distributed among workers.

2.4 Performance Evaluation and Project Leadership

Leadership is a critical element of project management since it has a direct impact on team performance. As project management gets more attention, project leadership also becomes more visible. The project leader and skill evaluations of employees are important in our study since projects are key to our framework. We take project leader assignment into consideration (in Chapter 5) concurrently with project selection and employee allocation, thus we investigate the literature on project leadership. Also, we present a brief review on performance evaluation literature that is related to the parameters we use in our mathematical models.

Even though some of the studies such as Hebert (2002), Turner (1993), and Katz and Allen (1985) define the project manager as the person who can manage all the projects, we accept project leader as the one who is specifically assigned to one or a few projects and who works closer to his project teams. Therefore, in our study, project leader is assigned to one or a few projects and his job is to coordinate the team members and to organize and control the work to be done. In line with this definition, we accept that project leaders are selected when projects are chosen and their job is to communicate within the team and with upper level management about the projects they lead.

In the literature, it is agreed that leaders' abilities are vital for the performance of teams and success of projects. According to Hebert (2002) project leader is similar to an orchestra conductor in terms of coordinating the projects, determining the tasks of team members, and creating harmony between the team members to do their job considering the strategic objectives of the company. The study of Dunn (2001) on project and functional managers in matrix organizations is notable because it shows the importance of relationship between project team and project manager in matrix-type organizations. Dunn (2001) conducts a survey with 222 individuals from different organizations and finds that project leaders have a significant influence on team performance. According to Nurick (1993), performance of project teams depends on project leader who has the ability to persuade and influence the people. He notes that a project leader should have the authority to direct the team, s/he should manage team members, but s/he should leave autonomy and freedom within the team. In addition, he suggests that a project leader should create a bond between the team and outside people. Similar to Nurick (1993), Hirst and Mann (2004) state some hypotheses about the relationship between team leader and team communication. Their evaluations show that the important factor affecting project performance is related to how team leader understands and communicates objectives, requirements, and information transmission. Henderson's work (2004) is a relevant analysis where a strong relationship between communication abilities of the project leader with the team performance is observed.

Consistent with the studies remarked above, the survey conducted by Ammeter and Dukerich (2002) with members and leaders of project teams from different organizations show that team leaders are the important actors who affect the overall performance of project and team performances. The authors also point out that the important team leader roles are communicating the objectives of the team to members and to inform the team about the progress of the project. Moreover, Ammeter and Dukerich (2002) show a relationship between finances and leadership. They suggest that budgeting performance is related to team leaders in a way that better leader behaviors are associated with projects coming under budget. Similar to this study, Katz and Allen (1985) states that project leaders have an important role in external relations and the overall outputs of the projects. Therefore, it is important for project managers to understand the profit and use of different functions. In addition, Katz and Allen's (1985) study is useful since it examines the effect of project and functional managers on team performance in R&D settings and find similar conclusions.

Most of the studies support that project leaders are important actors to manage all the projects smoothly and make team members understand the organizational and project-specific considerations. For that reason the study of El-Sabaa is significant since it focuses on essential project leader skills. El-Sabaa (2001) refers to the required skills Robert Katz (1991) defines for an effective project manager. According to Katz, there are three basic skills for effective management:

- Human skill: the ability of a leader to understand his/her team members and outsiders.
- Conceptual and organizational skill: the ability of a leader to see the project and the organization as a whole, recognize the interdependence of functions and act in a way to advance for both the organization and the project objectives.
- Technical skill: technical ability and knowledge of a leader related to the tasks his/her project requires.

In his research specific to Egypt, El-Sabaa (2001) examines these skills and concludes that the most important leadership skill is human interaction while conceptual and organizational skill is second and technical skill is the last.

According to his findings, project leaders should also know and understand the basic needs of the functions other than his/her own.

Different from El-Sabaa, Wysocki et al. (2000) and Turner (1993) imply a different set of managerial skills. Wysocki et al. (2000) determine following skills to be crucial for project managers: background and experience in project management, leadership and strategic expertise (must get the cooperation and support of team members), technical expertise, interpersonal competence, and managerial ability (related to skills such as strategic planning, budget planning, staff planning, quality management, business process reengineering, personal development). Besides that, Turner (1993) proposes that problem solving ability and result orientation, energy and initiative, self-assurance, broader perspective, communication, and negotiating ability are the most important skills of effective managers. The authors do not overrate one of the skills, but they point out that all of them are necessary for successful project management.

The evaluation of employees in terms of management abilities requires a sound understanding of employee skills and abilities. There are various techniques on evaluation of employee skills and there are some only for leadership assessment. As Gillespie (2005) points out, in the last years, many organizations, most of the Fortune 500 companies, use 360º feedback as a major assessment tool. 360º feedback was initiated as a method for reviewing managers' performance. Nowadays, it is used for assessment of employees in all levels. This tool is used in different ways by many organizations, but it typically involves performance evaluation of a person by many of the people who work with that person on a project or in that organization by a multi-item survey (Toegel and Conger, 2003). 360º assessment method is a significant tool for employee assessment since evaluations from all the people a person works with, and sometimes from his/her customers, are collected, the competencies are quantified and a rating for any predetermined skill set can be found for each person. Since 360º assessment quantifies the interpersonal, technical and leadership abilities of the employees, it shows the compatibility of a person for a position, which may be a management position. The results it conveys are important to visualize the basic parameters we use in the modeling of the problem.

Chapter 3

PROBLEM DEFINITION

3.1 Links to Literature

Closely examining Chapter 2, it is evident that we study an issue that has strong links to HR and OM fields. Since the main elements of the study are project management and employee allocation, research considering human resources in project management are as important as OM literature on employee assignment and project portfolio selection. Different from the previous chapter on the related literature (Chapter 2), this section presents a review where we locate our study in the available literature and give a detailed description of a study conducted by Yoshimura et al. (2006) that focuses on a similar problem.

In the current business environment, organizations rely more on efficiency and flexibility, and this necessitates a management practice having a firm control on resources. Especially in situations where several projects are managed concurrently, allocation of resources becomes a major operational problem (Engwall and Jerbrant, 2003; Leus et al., 2003; Hendriks et al., 1999). In such settings, there is typically a common pool of resources and allocation of these resources to simultaneous projects requires a concrete methodology to minimize uncertainties and manage strategic objectives (Merkhofer, 2006). Therefore, selection of projects according to existing resources becomes a crucial managerial task. In this study, we establish a project selection and employee allocation method that takes employee structure into consideration as a crucial factor in decisions.

Diverse branches of the literature we looked at show that in a methodology aiming at an extensive approach for project selection and simultaneous employee assignment, five important factors should be evaluated carefully. These factors are valuation of projects in terms of performance and cost, implications of cross-training, team formation and communication, leadership, and modeling of employee allocation.

In this work, we do not give any methodology for the evaluation of projects or how to quantify risks, but we assume that, before selection is started, a project evaluation process is conducted in a systematic approach. This approach is said to include strategic objectives, internal/external risks and benefits, and budget constraints that are stated to be crucial by Archer and Ghasemzadeh (1999) and Merkhofer (2006). We use these parameters in the problem formulation phase assuming that they are quantified. We investigate papers such as Archer and Ghasemzadeh (1999) and Burke (1993) that include an outline of available project evaluation and selection methods. Some articles on project selection based on scoring tools (Henriksen and Traynor, 1999; Rengarajan and Jagannathan, 1997) and some others that use financial criteria and optimization method (Badiru, 1993; Dickinson et al., 2001; Eben-Chaime, 2000; Graves et al., 2000) are also examined in detail. Although we do not follow the methods offered in these studies directly, we incorporate the formulation of Badiru (1993) where we extend our model to include constraints related to project characteristics which may be risk, return, or strategic importance.

Since the setting we study comprises of cross-trained employees working for diverse projects, introducing human resources into the modeling necessitates a close review of studies that take account of characteristics of cross-trained employees, team formation in project management and communication activities. We assume that characteristics of employees, structure of project teams, and interaction of team members have a substantial impact on performance of projects. The studies we inspect support the notion that cross-trained employees bring flexibility in unstable demand situations (Riley and Lockwood, 1997; Van Den Beukel and Molleman, 1998). As Hopp and Van Oyen (2004) point out cross-training is beneficial when it supports the overall strategies of the organization. Therefore, cross-trained employees can be accepted as a source of flexibility for project management companies where diverse projects are operated with a limited number of employees and project portfolios change over time.

Even though we have not encountered any study that includes interaction in our terms, the assumptions on this concept do not conflict with the available studies focusing on communication in team settings. As stated by Nurick (1993), cross functional teams may suffer from different points of views they hold because of different functions or departments they are associated with. Communication is the way of getting rid of these differences, and the research of Bishop (1999) and Patrashkova-Volzdoska et al. (2003) show that communication is a crucial factor that has a positive impact on team performance. Daft's (1999) interdependence concept and his ideas on cross-functional teams support the notion that information sharing between functions and coordination of the efforts of diverse departments improve by communication. In addition, the study of Patrashkova-Volzdoska et al. (2003) gives hints about communication in cross-functional teams. Particularly, Patrashkova-Volzdoska et al. introduce a curvilinear team communication hypothesis that says communication frequency in teams improves team performance while both low and high frequencies inhibit team performance. Their hypothesis is in line with our assumptions because we also say that communication has an impact on team performance. However, we look at this impact in a different context and examine the effect of previous communication on future performances. We assume that when individuals from different functional families work together, they form a contact and exchange knowledge with others. Henceforth, the people learn what other functions do and how they work, and this causes performance improvement in a project team where they meet these functions again. Therefore, we use interaction to describe the acquaintance of employees with outside functions that stems from previous project experiences and results in performance improvement in future projects. However, the effect of interaction is limited since this acquaintance cannot be expected to improve performance beyond a threshold.

In studies focusing on team structures, team size and leaders are found to be important elements that affect team performance and communication (Burke, 1993; Daft, 1999; Hendriks et al., 1999). As studies suggest, determining a limit for team size would be useful because more than a specific number of people may cause decrease in devotion and efficiency while small teams may decrease the possibility of diverse opinions or may result in dominance of one person. There are a lot of studies implying that leaders are important actors in project management (Nurick, 1993; Ammeter and Dukerich, 2002; Dunn, 2001; Hebert, 2002; Henderson, 2004; Hirst and Mann, 2004; Katz and Allen, 1985). A significant result that can be reached from the available studies is that project leaders are the ones who are important in coordinating the projects according to the overall strategic objectives since they are bridges between team members and the external actors. Therefore, evaluation of leadership skills of people is important and leader selection is an important part of employee assignment (El-Sabaa, 2001; Turner, 1993; Wysocki et al., 2000). We do not give a methodology for employee evaluation but we review studies on leadership theory and determine which characteristics are important for this role to construct a sound modeling environment.

The branch of literature that is based on algorithms developed for assignment of cross-trained employees is significant for our study since we base project selection on employee assignment. Stewart et al. (1994) present four mathematical models that serve as tools to find optimal training policies when different managerial objectives are present. The model Campbell (1999) develops aims to allocate cross-trained employees, who are not fully or equally qualified in different tasks, to departments in a multidepartment service setting is studied with the aim of maximizing departmental utilities. Similarly, Sayın and Karabatı (2006) propose an assignment algorithm that considers departmental utilities and improvement in worker skills concurrently. Even though our methodology is different, these studies are important to see which criteria are used in assignment decisions and how employee skills are considered in an assignment problem.

This current study extends the literature on workforce planning analysis by examining cross-trained employees in multi-project structures and by studying specific issues such as the effect of interaction and demand uncertainty in assignment of cross-trained employees in such settings. We develop a project selection algorithm where selections are based on employee skills and interaction, at the same time we assign employees to tasks. Unlike the classical project selection studies that concentrate on risk, return and/or cost of projects (Merkhofer, 2006; Archer and Ghasemzadeh, 1999; Henriksen and Traynor, 1999; Graves et al., 2000; Dickinson et al., 2001; Eben-Chaime, 2000), attention to employees necessitates a human resources orientation in this study.

We use an exceptional point of view that aims to structure the problem of project selection and employee assignment in a systematic way and develop a decision support tool. At that stage, not only examples of employee assignment and project selection work in the literature but also theories on employee communication and team formation become important. The three models we present in different sections, M_R, M_S, M_L, are variants of the basic model, M_B, where we construct a project selection algorithm based on satisfaction of demand and assignment of employees. M_B serves for our basic purpose which is to include human resources as a major building block in project selection decisions. The aim of the robust model, M_R, and the heuristic is to include effects of demand variation and/or estimation disagreements into the problem analysis. For M_S, where we include weights and insert cost constraints for the projects, we use the capital rationing model of Badiru (1993). Hence, we expand our basic model in a way to include human resources together with project-specific attributes and strategic objectives. M_S selects projects considering weights together with available human resources constraints, thus it provides an extensive approach that is desired by the scholars who support the notion that selected projects should meet the overall strategic objectives without violating any constraints (Archer and Ghasemzadeh, 1999; Merkhofer, 2006; Yoshimura et al., 2006). With this model, we aim to show the implications of a selection process that includes a wide range of factors related to project features. M_L, which is a variant of M_B, is structured to illustrate a widely held issue in project management literature, leadership. With this model, we intend to include leader selection in the decision system where projects are selected and employees are assigned to specific tasks. As stated, the line of the literature on such focus is weak and the only example we encounter is Yoshimura et al (2006), which proposes a different methodology with similar assumptions.

Yoshimura et al (2006) work on the problem of project selection and employee allocation in product development settings considering employee skills, motivation and career goals and also leader selection. According to their method, a project selection problem is solved at first, and then a project leader for each project is chosen. Consequently, the human resource allocation algorithm is used to allocate workers to the chosen projects. They use two genetic algorithms, one for project selection and the other for human resource allocation, and leave leader selection to decision makers. A project portfolio is selected at first where they use an algorithm to choose the project set that maximizes the total expected profit and potential future profits. In this algorithm, required amount of skills for the projects are satisfied with the available skills of the allocated employees. Then, as the second step, a leader for each project is chosen based on two important factors. The first factor is the satisfaction of the core skill, which is the skill the leader should have expert knowledge on and is one of the most important skills for the given project. The second factor for leader selection is leadership ability parameter that should be greater than a specific value for the person to be a leader. The authors use an allocation algorithm to assign human resources to selected projects for the last stage of their method.

The allocation algorithm Yoshimura et al. (2006) propose includes three objective functions that are described below:

1. Satisfaction of required skills: this function maximizes total allocated skill of workers who are assigned to chosen projects.

2. Career path satisfaction levels: this function maximizes the satisfaction level of the managers considering their workers' career paths.

3. Worker motivation: this function consists of two weighted parts, one is to maximize the level of desire to work on a given project for each worker, and the other is to maximize compatibility level between different workers allocated to the same projects.

As stated, the study of Yoshimura et al. (2006) is significant since they use employee characteristics in the decision support system they develop and work on a similar problem to ours. Although their methodology is different and they use a three stage heuristic method based on genetic algorithms, their general approach and goals are similar. They do not treat humans as uniform entities but take into consideration their skill levels and compatibility with the external environment. Even if it is not explained in detail, the compatibility concept in Yoshimura et al. (2006) takes the relationship between employees into consideration but it is not similar to our interaction concept. A compatibility measure is used to consider the desire of the employees for working in the same projects and is a factor considered in assignment decisions. On the other hand, our interaction concept shows how much an employee worked with a functional family in the previous projects and how much s/he knows about another function and if s/he is familiar with what that function does. Thus, interaction is used in the model as a factor that affects the overall performance of the team. In Yoshimura et al. (2006) leader selection is not a part of the algorithm, instead it is a decision taken considering some constraints related to the core skills. Unlike this, we incorporate leader selection into our optimization model where projects are chosen and employees are assigned. Also, in our method, we can solve a single optimization method that does project selection, employee allocation and leader assignment simultaneously while Yoshimura et al. (2006) reach these decision in three stages done consecutively. A brief comparison of our study and Yoshimura et al. (2006) can be seen in the Table 3.1.

	Yoshimura et al. (2006)	*Our study*
Methodology	Genetic algorithms (Heuristic method)	Mixed-Integer Linear Programming
Solution approach	Three consecutive stages	One stage
Organizational structure	No functional family concept	Functional families restrict cross-training
Team structure	Cross-functional teams	Cross-functional teams
Employees	Cross-trained	Cross-trained
Objective of project selection	Expected profit, strategic importance, human resources	Financial and strategic constraints, and human resources considerations
Human resources related considerations	Satisfaction of required skills, compatibility and motivation of employees	Satisfaction of required skills, interactions between employees
Selection of project leaders	Not explained in detail	Maximize leadership scores

Table 3.1: Comparison of Yoshimura et al. (2006) and this study.

3.2 Problem Setting

In this study we investigate some major questions regarding allocation of employees in project-based service organizations or organizational units. In these structures, employees belong to specific functional families, which may be thought almost as departments, and each employee can run one or more function, task or task type, under this family. An employee cannot run the tasks of another family because each functional family is different from the other by means of the basic skills and/or education that is required. However, for employees who are cross-trained in several functions in each family, they can do the jobs of more than one function when necessary.

Figure 3.1 displays a sample workforce structure that we study. In this setting, a functional family can be accepted as a specific area that an employee is educated/skilled in and functions are different task types that an employee is capable/experienced in. Thus, cross-training in our framework is limited to functions in each family. Since we restricted the basis of our study to service companies working on projects, the situation of working outside the particular functional groups is not common because of the exclusive skills or experiences involved in each group. Even though employees of different functional families have similar skill sets, there is a difference in terms of tasks they run. This assumption is also supported by the interviews we made with two professionals, the director of the R&D branch of a multinational durable goods company and a senior partner of a worldwide consulting firm. They suggested that it is not a common practice that an employee of a functional family is shifted to another family or is assigned to tasks of the other family. However, it is worth mentioning that this assumption is not binding in modeling of cross-training. In some companies, manufacturing or service, there may be no functional families and workers may be cross-trained to work in any function. Even the case of availability of functional branches may not restrict cross-training to each branch but a cross-trained worker can work in different functions from different groups. Studies of Brusco et al. (1998), Brusco and Johns (1998), Slomp and Molleman (2002), and Yoshimura et al. (2006) are examples that do not use such a limitation on cross-training.

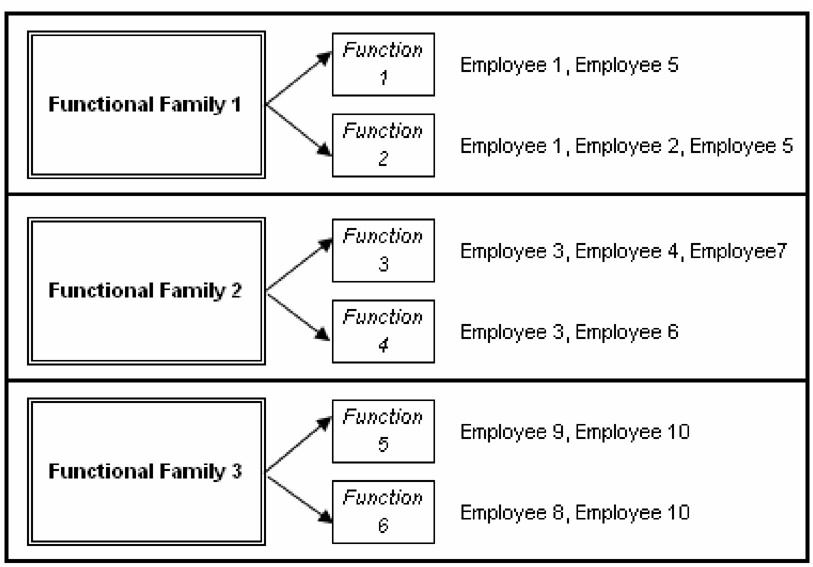

Figure 3.1: Workforce structure.

	Functional Family 1		Functional Family 2		Functional Family 3	
	Function 1	Function 2	Function 3	Function 4	Function 5	Function 6
Project 1	10	40			30	
Project 2		30	20	50		90
Project 3	100				[illegible]	40
Project 4						20
Project 5	100					50
Project 6	70		30	80	40	
Project 7			50	20	50	
Project 8		30		40	10	10

Employees out of different functional families are assigned to projects according to specific requirements each project has

Figure 3.2: Multi-project situation where each project has different requirements.

Our framework consists of companies specialized in project management. According to our basic assumptions, there are more projects available in a given period than that is possible to be done and we primarily need to choose the project portfolio for the period. We do not emphasize financial aspects of project selection in the basic model, instead we select projects that are optimal with the available workforce. To choose which projects will be in the portfolio, we look at the workforce structure which is identified with available employee time, employee skills and interactions among them. We also assume that specific tasks required by the projects and how much standard employee time each function in each project requires is known. In our setting, projects require various tasks and it is hard to estimate these requirements realistically. However, this is a common assumption in the relevant literature and most of the models we encountered assume that demands of projects are estimated deterministically before selection is conducted. Figure 3.2 illustrates an example where there are eight candidate projects requiring different tasks from different functions. In this structure, we select the best group of projects and conduct employee assignment with the aim of satisfying the demands without overtime working or allocation outside the skilled functions. Both of the decisions are carried out concurrently to optimize the project portfolio and to allocate employees accordingly.

One of the basic contributions of our study is the interaction concept which is not studied before in a mathematical modeling context. In this study, we use interaction to describe the communication and teamwork realized in previous projects that affect current performances of project teams. We assume that if an employee works with people from other functional families in a project, s/he gets accustomed to functions of these families and learns what they do. Therefore, if s/he works again with these functions, his/her efficiency increases because of familiarity gained before. To add interaction into the mathematical models and to analyze its significance, we use an **interaction coefficient (n_{ik})** that is related to *how much/how many times* employee *i* has worked with function *k*. A higher interaction coefficient means the worker worked more with the other function in earlier periods and when s/he works again with that function, her/his efficiency increases more compared to the case of lower interaction coefficient. In addition, we assume that interactions between employees of the same functional family are zero. The effect of this concept is incorporated into the formulations by an adjustment to the functional demand values. To facilitate the quantification of interactions in a simple way and to contain them in the mathematical models, we determine adjustments based on total interactions in a team. As discussed in detail in Section 4.1, we use an additive method to find total interactions. Also, we formulate piecewise linear constraint sets to illustrate diminishing rate of improvement interaction brings about. This is because we assume that even though total interaction value is large, improvement it causes cannot be more than a specific ratio. This limitation comes from the definition we use for interaction. It is possible to think interaction as a concept parallel to “learning” in service/production settings. However, what takes place is not exactly learning but facilitating the tasks since challenges decrease when a basic knowledge of other function is present. Therefore, we develop a rough method using breakpoints to express this notion.

One important factor that should be considered in making assignment decisions is skill levels of available employees. Hence, we use varying levels of skills across different functions, which is consistent with the literature (Brusco et al., 1998; Brusco and Johns, 1998; Campbell (1999). As expected, we assume these skill levels are calculated beforehand. Also, an employee can be assigned to different functions in a project or in more than one project since each worker works in one family but is cross-trained in different functions in this family. Thus, we do not restrict the whole time of a worker to a specific function or a project, instead we assign part of his/her time to functions of different projects.

Our basic problem is to choose projects and assign employees to functions in these projects together with only one restriction: employees should be assigned to functions, which they are skilled in, and they should work without overtime. The aim of constructing the basic model is to understand how different parameters may affect a model where employee skills and interactions are crucial for project selection. The second model, which we call the robust model, is an expanded version of the basic model where two different demand scenarios are considered. Introducing a second scenario on project demands, the robust model aims to construct a solid selection and allocation even when the estimations are allowed to deviate. A heuristic procedure is introduced to cope with the deviations with an easier solution approach that lessens the computational burden. A way of dealing with more than two demand scenarios is also feasible with this heuristic.

The basic model is constructed to illustrate the problem mathematically with overall objectives and to examine factors that are significant for the structuring and evaluation of the problem. The objective of this model is to maximize number of projects selected and we use it to analyze the effects of various factors in our numerical experiments. Seven factors are investigated in this model. The four factors are the numbers of workers, projects, functions, and functional families.

These factors are used to analyze if the size of the organization, its functional structure, or available project choices affect the results. We use three factors for demand variation. The first one is the number of work days projects require in total relative to available capacity in a period. We used coefficient of variation for allocating the total demand to each project, which may be thought of as how much employee time each project demands, as another factor and looked if it affects the model performance. The factor related to functional allocation of demands is used to investigate the effect of how demand spreads out in each project meaning that in how many functions a project requires work on average. For the robust model and also for the heuristic, a last factor is introduced. This factor is called demand range and it is used to examine deviations from the realized demand. According to the specifications that demand range presents, a second demand scenario is built.

The second model, which we call the robust model, helps us analyze how we can carry on the projects with the available employee structure when there are deviations from demand estimations determined before. In this second model, the objective is to analyze an efficient employee allocation in case demand realizations become different from the estimations. This model is not different from the basic one in the sense that it allocates employees according to demand constraints and their skills. However, it makes an assignment considering both of the demand possibilities, thus generating a robust assignment plan. One of the scenarios is the one that is used in the basic model and the other scenario involves a given range of possible estimation deviations from the first one.

Since it is not computationally efficient to consider a large number of demand scenarios with the robust model, we propose a simple heuristic approach. For the heuristic, the maximum of available demand estimations for each function of projects are taken, and then the basic model is used to allocate employees and select projects on the basis of these maximum values. The heuristic gives an easier way of dealing with deviations in demand estimations and it is computationally affordable to work with more than two scenarios with this method.

After these two models and the heuristic are presented and examined in detail, a new investigation on the problem is started with Chapter 5. In Chapter 5, we examine extensions of the models with incorporating human resources constraints into the classical project selection methods and leader selection into our basic problem. Our approach is not common in the literature where classical selection procedures based on risk, return, strategic importance, and cost are popular while there are not many studies considering employees in handling of project selection. With a new linear programming model, we merge our basic model with a classical project selection method and reach an expanded solution methodology. As the studies we review argue, leaders are important for the performance of project teams. Therefore, we add leader selection decision into the modeling in the extensions part.

Chapter 4

THE MODELS

Assume that a fixed set of employees is available to be allocated to multiple projects at the beginning of a period. Each employee has a primary function where s/he is skilled in and also possibly secondary functions that s/he is cross-trained in the same functional family. Employee capabilities are described by f_{ik} values which denote functional skill level of employee i in function k, $i = 1, \ldots, E$; $k = 1, \ldots, K$. In the literature, Brusco and Johns (1998) focus on workers having different productivity levels ranging from 0 to 100%, and they accept that productivity levels in secondary skill classes may be 100% or 50%. Similarly, Brusco et al. (1998) use productivity level in the range of 0 and 100% in their study on cross-utilization. In his study on allocation of cross-trained workers, Campbell (1999) considers capabilities between 0 and 1 where capability of 1 means that the worker is fully qualified. In this work, we accept that a standard employee has skill level of 1 for a task, and employees have functional skill levels between 0 and 1.2 implying that any employee may work at most 20% better than a standard employee. Interaction of employees with other functional families, on the other hand, is captured by n_{ik} values representing how many times employee i was involved in a project that required function k. We assume that interaction of employee i with the employees in his/her own family is zero. In addition, each employee works a standard number of days/hours in a period. Thus, the models do not incorporate overtime working. Finally, we assume that for each candidate project, workforce requirements of its tasks are known.

We develop two mixed-integer programming models, which are presented in Section, 4.1 and 4.2 respectively, and a heuristic approach that is in Section 4.5. The basic model solves the employee assignment problem with the objective of maximizing the number of projects that can be completed in a given period. The aim of the robust model is to conduct selections and find an allocation when two different scenarios on workforce requirements of a project's tasks are present. The heuristic method is parallel to the robust model since it works in the situations where two scenarios are present, but it is more efficient and can be used for multiple scenarios.

4.1 The Basic Model (M_B)

For the basic model, the following notations are used:

i: worker index, $i = 1, \ldots, E$,

j: project index, $j = 1, \ldots, J$,

k: function index, $k = 1, \ldots, K$.

Parameters:

K: number of functions

J: number of projects

E: number of employees

d_{jk}: demand for function k of project j (total days/hours required)

f_{ik}: functional skill level of employee i in function k

n_{jk}: interaction of employee i with function k

H: standard working capacity of each employee in a period (days/hours)

B_i: breakpoint i

s_i: slope in the i^{th} region

Variables:

$$x_{ij}: \begin{cases} 1, & \text{if employee } i \text{ is assigned to project } j \\ 0, & \text{otherwise} \end{cases}$$

$$z_j: \begin{cases} 1, & \text{if project } j \text{ is chosen} \\ 0, & \text{otherwise} \end{cases}$$

y_{ijk}: contribution of employee i to function k in project j

w_{jk} : total interaction for function k in project j

M$_B$:

$$\max \quad \sum_j z_j \tag{4.1}$$

subject to:

$$y_{ijk} \le H * x_{ij} \qquad \forall i, j, k \tag{4.2}$$

$$y_{ijk} \le H * f_{ik} * M \qquad \forall i, j, k \tag{4.3}$$

$$\sum_j \sum_k y_{ijk} \le H \qquad \forall i \tag{4.4}$$

$$x_{ij} \le z_j \qquad \forall i, j \tag{4.5}$$

$$\sum_i x_{ij} n_{ik} = w_{jk} \qquad \forall j, k \tag{4.6}$$

$$\sum_i \ y_{ijk} f_{ik} H \ge d_{jk} * P - (1 - z_j) * M \qquad \forall j, k \tag{4.7}$$

$$\sum_i \ y_{ijk} f_{ik} H \le d_{jk} * P + (1 - z_j) * M \qquad \forall j, k \tag{4.8}$$

$$P = \left\{ \begin{array}{ll} 1 + w_{jk} * s_1 & \text{if } w_{jk} \le B_1 \\ 1 + B_1 * s_1 + (w_{jk} - B_1) * s_2 & \text{if } B_1 < w_{jk} \le B_2 \\ 1 + B_1 * s_1 + (B_2 - B_1) * s_2 + (w_{jk} - B_2) * s_3 & \text{if } B_2 < w_{jk} \le B_3 \end{array} \right\} \forall j, k \tag{4.9}$$

$$x_{ij} = \{0,1\} \qquad \forall i, j \tag{4.10}$$

$$z_j = \{0,1\} \qquad \forall j \tag{4.11}$$

In the above formulation, M is a sufficiently large number.

The objective function (4.1) maximizes total number of projects that can be completed in the period. Constraint set (4.2) ensures that an employee's contribution cannot be more than the standard working days/hours if s/he is assigned to a project; (4.3) requires that in order to be assigned to a function of a project the employee should be skilled in that function, and (4.4) specifies that no overtime working is allowed. In addition, constraint set (4.5) says that if a project is not chosen, then there should be no employees assigned to that project. In the basic model, the constraint sets (4.6)-(4.9) are related to demand satisfaction and include the effect of interaction.

With constraint set (4.6), we compute the total interaction in each function in a project (w_{jk}) that affects project tasks accordingly. We use a rough method where interactions of project team members with a specific function are added up to find the total interaction in that function of the project. Since interaction of employees in their own functional family is 0, w_{jk} is the sum of interactions of all employees assigned to that project except the interactions of employees whose functional families include function *k*. We pursue this scheme because it does not include complex calculations while the essence of interaction can be captured in a reasonable way. Given that interaction between employees has a significant but limited impact on overall performance of the projects, constraint set (4.9) also helps us control the possible problems resulting from the additive characteristic of this method. The left-hand-sides of the constraint sets (4.7) and (4.8) show the overall contribution of all employees to a specific function in a project while requirements are shown in the right-hand-sides. With these two sets, we ensure that when a project is selected, employee day/hour requirements of its tasks are met. However, the requirements are discounted with the appropriate interaction factor (*P*). This factor incorporates the effect of total interactions. Constraint set (4.9) shows how *P* is computed. Demand of a function in a project decreases according to *P* which is the sum of interaction coefficients of all employees assigned to the project, and a percent decided before. Figure 4.1 helps clarify what breakpoints and slopes mean in the calculation of *P*.

Consequently, constraints (4.10) and (4.11) place nonnegativity and integer restrictions on the decision variables of the model.

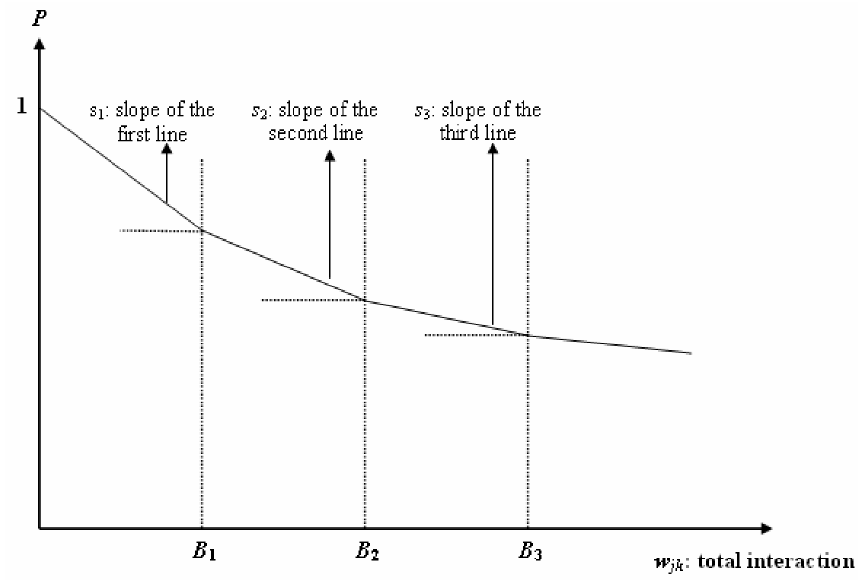

Figure 4.1: Effect of total interaction on the computation of interaction factor.

As Figure 4.1 presents, total interaction has a diminishing effect on project performance. The *x* axis of the graph shows the total interaction realized by assignments and *y* axis represents the interaction factor *P*. In this representation and in the formulation, we use three breakpoints. Total interaction up to B_1 decreases total demand by a rate computed by $w_{jk} * | s_1 |$. When total interaction is between B_1 and B_2, total demand reduces by $B_1 * | s_1 |$ plus the remainder which is $(w_{jk} - B_1) * | s_2 |$. Because $| s_1 | > | s_2 |$, there is less reduction for total interaction values between $(w_{jk} - B_1)$ than for interaction values up to B_1. The impact of total interaction decreases further for the values larger than B_2 in a similar fashion. While doing computational experiments, we worked with one breakpoint and accepted that B_1 is 10, s_1 is -0.01 and s_2 is -0.0001 as seen in Figure 4.2.

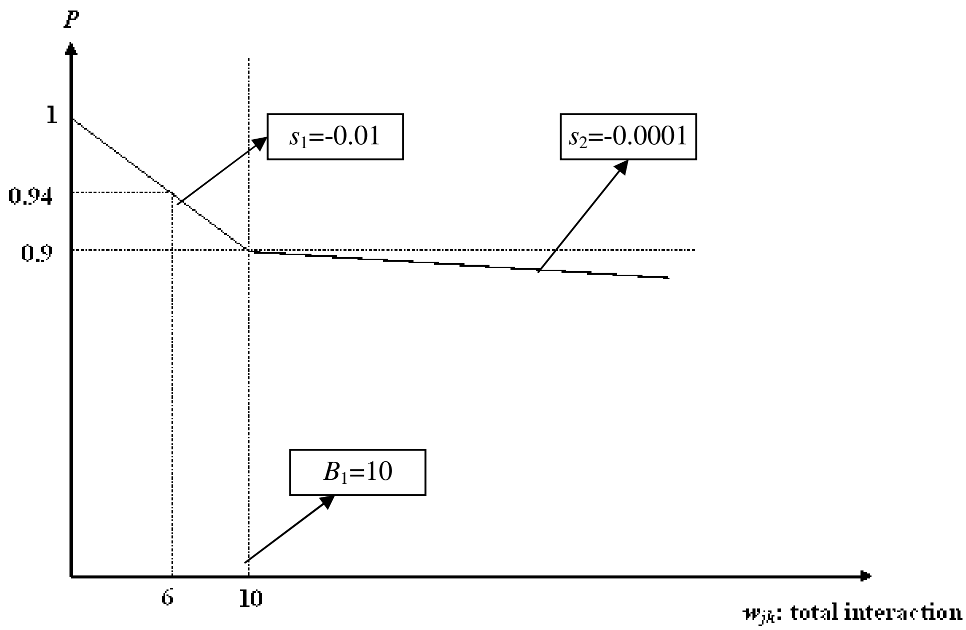

Figure 4.2: An example for computing the interaction factor *P*

Figure 4.2 shows a simple example where one breakpoint is used. It is seen that, if the total interaction in function *k* of project *j*, w_{jk}, is 6, then *P* is 0.94. Therefore, we see the effect of interaction on a reduction in demand by rate of 0.06 and total demand becomes d_{jk} *0.94.

With M_B, we find which projects to select together with the optimal employee allocation. Our aim is to analyze the significance of factors that are anticipated to be critical in assignment decisions. We investigate the model and the factors extensively in computational analysis part and use this basic model in heuristic development stage again.

4.2 The Robust Model (M_R) with Two Demand Scenarios

To capture uncertainties in demanded employee days/hours of projects, which may result from estimation difficulties, we introduce demand scenarios and develop a robust model to analyze the effects of multiple demand scenarios. This model uses the same parameters that the basic model uses, however, it has two separate demand parameters, $d^1{}_{jk}$ and $d^2{}_{jk}$, and constraints. We also introduce two additional parameters, R^1 and R^2: R^1 stands for the objective function value of M_B with estimated demand parameters $d^1{}_{jk}$'s and R^2 is the objective function value of M_B when it is solved with demand parameters $d^2{}_{jk}$'s. The decision variables of the model (M_R) are:

Variables:

x_{ij}: $\begin{cases} 1, & \text{if employee } i \text{ is assigned to project } j \\ 0, & \text{otherwise} \end{cases}$

$z^1{}_j$: $\begin{cases} 1, & \text{if project } j \text{ can be completed in case of demand scenario 1} \\ 0, & \text{otherwise} \end{cases}$

$z^2{}_j$: $\begin{cases} 1, & \text{if project } j \text{ can be completed in case of demand scenario 2} \\ 0, & \text{otherwise} \end{cases}$

y_{ijk}: contribution of employee i to function k in project j

w_{jk}: total interaction for function k in project j

M_R:

$$\max \quad z \tag{4.12}$$

subject to:

$$\frac{\sum_j z^1{}_j}{R^1} \geq z \tag{4.13}$$

$$\frac{\sum_j z^2{}_j}{R^2} \geq z \tag{4.14}$$

$$y_{ijk} \leq H * x_{ij} \qquad \forall i, j, k \tag{4.15}$$

$$y_{ijk} \leq H * f_{ik} * M \qquad \forall i, j, k \tag{4.16}$$

$$\sum_j \sum_k y_{ijk} \leq H \qquad \forall i \tag{4.17}$$

$$x_{ij} \leq z^1{}_j + z^2{}_j \qquad \forall i, j \tag{4.18}$$

$$\sum_i x_{ij} n_{ik} = w_{jk} \qquad \forall j,k \qquad (4.19)$$

$$\sum_i \ y_{ijk} f_{ik} H \geq d^1{}_{jk} * P - (1 - z^1{}_j) * M \qquad \forall j,k \qquad (4.20)$$

$$\sum_i \ y_{ijk} f_{ik} H \geq d^2{}_{jk} * P - (1 - z^2{}_j) * M \qquad \forall j,k \qquad (4.21)$$

$$\sum_i \ y_{ijk} f_{ik} H \leq \max(d^1{}_{jk}, d^2{}_{jk}) * P + (1 - z^1{}_j) * M \qquad \forall j,k \qquad (4.22)$$

$$\sum_i \ y_{ijk} f_{ik} H \leq \max(d^1{}_{jk}, d^2{}_{jk}) * P + (1 - z^2{}_j) * M \qquad \forall j,k \qquad (4.23)$$

$$P = \left\{ \begin{array}{ll} 1 + w_{jk} * s_1 & if \ w_{jk} \leq B_1 \\ 1 + B_1 * s_1 + (w_{jk} - B_1) * s_2 & if \ B_1 < w_{jk} \leq B_2 \\ 1 + B_1 * s_1 + (B_2 - B_1) * s_2 + (w_{jk} - B_2) * s_3 & if \ B_2 < w_{jk} \leq B_3 \end{array} \right\} \forall j,k \quad (4.24)$$

$$x_{ij} = \{0,1\} \qquad \forall i, j \qquad (4.25)$$

$$z^1{}_j = \{0,1\} \qquad \forall j \qquad (4.26)$$

$$z^2{}_j = \{0,1\} \qquad \forall j \qquad (4.27)$$

Solving the problem with the basic model results with higher number of selected projects, relative to the results of the robust model, because M_B considers only one demand scenario. However, M_R considers two different demand possibilities and determines the optimal assignment plan that is applicable under both demand realizations. The constraint sets (4.13) and (4.14) provide the ratio of number of projects that can be completed when both scenarios are considered together versus number of projects that can be done considering the scenarios independently. Thus, the ratio $\sum_j z^1{}_j / R^1$ can be considered as the percentage of the projects that can be completed when the robust plan is in action as opposed to a plan that uses the first demand scenario alone. Therefore, (4.12) is a max-min objective where $z = \min\{\frac{\sum_j z^1{}_j}{R^1}, \frac{\sum_j z^2{}_j}{R^2}\}$.

Most of the constraints have the same functionality as in the first model with some exceptions. Demand constraints double in this model with a slight difference, which can be seen in constraint sets (4.20)-(4.23). These constraint sets guarantee that all demands are satisfied for selected projects and assigned employee contributions do not exceed maximum numbers required in each project of functions. Constraint set (4.24) serves the same purpose as (4.9) does in the basic model. The last constraints (4.25)-(4.27) are used to ensure that decision variables are nonnegative and integer.

4.3 An Illustrative Example

Throughout the study, we will work on the hypothetical company explained below.

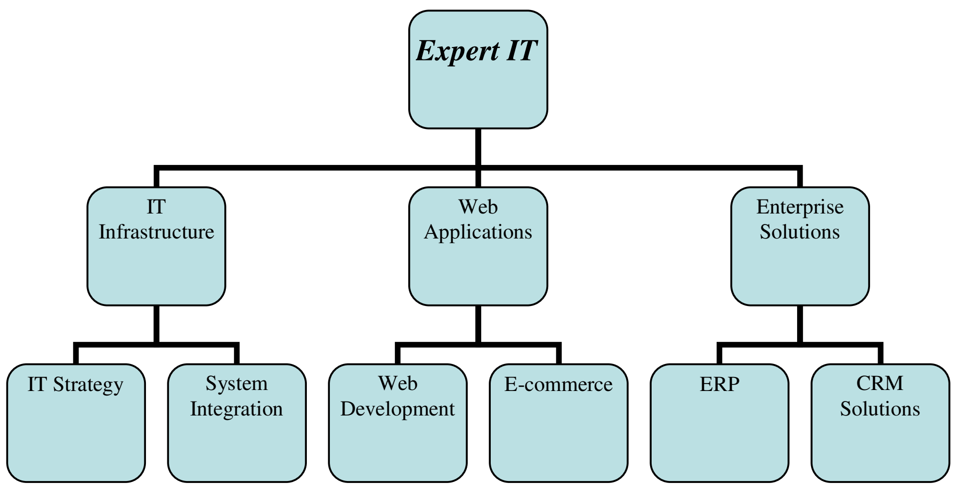

Figure 4.3: Organizational structure of Expert IT.

Expert IT is a small company specialized in giving IT services to outside companies in three main areas, which are IT Infrastructure, Web Applications and Enterprise Solutions. Figure 4.3 shows the organizational structure of the company where there are three main areas and two divisions under each area. The workforce structure of this firm consists of 8 employees who are specialists in their areas. Besides, we know that each employee has at most 200 days available in a year for the projects. All the projects due 2005 were completed and the company evaluates the offered projects for 2006.

In Expert IT, how employees are distributed among the functions and their skill levels are shown in Table 4.1, and Table 4.2 shows the interactions between the employees. Table 4.1 presents the workforce structure of the company with functional families the employees belong to and skill levels of each employee. For example, Employee 1 belongs to Web Applications department and has skills in both Web Development and E-commerce. Interpreting the given skill scores, we can say that he is not an experienced employee since he has scores less than 1, but he is better in Web Development than in E-commerce. However, Employee 4, who works in IT Infrastructure department, is good both in IT Strategy and System Integration.

Skill	***IT Infrastructure***		***Web Applications***		***Enterprise Solutions***	
	IT Strategy	***System Integration***	***Web Development***	***E-commerce***	***ERP***	***CRM Solutions***
Employee 1	0	0	0.8	0.4	0	0
Employee 2	0	0	0.3	1	0	0
Employee 3	0	0	1	0.5	0	0
Employee 4	1.2	0.8	0	0	0	0
Employee 5	0.5	1	0	0	0	0
Employee 6	0.2	1.1	0	0	0	0
Employee 7	0	0	0	0	1.2	0.2
Employee 8	0	0	0	0	0.4	0.9

Table 4.1: Employee structure of Expert IT.

The concept of interaction is used in this study to explain the effects of communication and prior experiences of employees on their current performance. As stated, interaction is related to *how much/how many times* an employee has worked with a functional family other than his family in the previous projects. Table 4.2 shows interaction scores of employees, which are computed according to the number of times an employee worked with a functional family in previous projects. For example, we can see that Employee 1 has worked with the other three functions in only one project before, but Employee 4 worked almost 3 or 4 times with the functions in Web Applications and Enterprise Solutions. When Table 4.1 and Table

4.2 are interpreted together, we can reach the conclusion that Employee 1 is new in Expert IT, while Employee 4 is a senior employee.

Interaction	***IT Infrastructure***		***Web Applications***		***Enterprise Solutions***	
	IT Strategy	***System Integration***	***Web Development***	***E-commerce***	***ERP***	***CRM Solutions***
Employee 1	1	1	0	0	0	1
Employee 2	2	0	0	0	3	0
Employee 3	2	2	0	0	2	1
Employee 4	0	0	3	4	4	1
Employee 5	0	0	4	1	0	4
Employee 6	0	0	4	2	3	0
Employee 7	3	1	2	1	0	0
Employee 8	2	3	1	1	0	0

Table 4.2: Employee structure of Expert IT.

In the beginning of 2006, Expert IT is offered 10 projects and the requirements of the projects are estimated (Table 4.3) based on the analyses and interviews with the customers.

Demand(1)	***IT Infrastructure***		***Web Applications***		***Enterprise Solutions***	
	IT Strategy	***System Integration***	***Web Development***	***E-commerce***	***ERP***	***CRM Solutions***
Project 1	100	30	80	50	90	0
Project 2	60	0	20	20	60	40
Project 3	60	30	60	20	0	100
Project 4	80	0	40	90	0	0
Project 5	0	80	30	0	0	100
Project 6	50	40	30	30	0	60
Project 7	40	0	10	0	60	0
Project 8	0	50	0	0	20	100
Project 9	30	100	80	0	30	0
Project 10	0	20	100	0	80	100

Table 4.3: Projects available for the year 2006.

Table 4.3 shows how much standard employee days each project requires and how these demands are distributed among functions. For example, we see that Project 4 requires 80 standard employee days from IT Strategy, 40 days from Web

Development, and 90 days from E-commerce. In total, 210 standard employee days are required for Project 4.

When the partners of Expert IT came together to examine the available projects, some of the departments raised objections about the estimations. Therefore, a second demand scenario, which is shown in Table 4.4, was constructed to display the changes these departments propose.

Demand(2)	***IT Infrastructure***		***Web Applications***		***Enterprise Solutions***	
	IT Strategy	***System Integration***	***Web Development***	***E-commerce***	***ERP***	***CRM Solutions***
Project 1	100	30	70	60	100	0
Project 2	70	0	30	20	60	40
Project 3	60	30	60	30	0	100
Project 4	80	0	50	90	0	0
Project 5	0	70	30	0	0	120
Project 6	60	40	40	30	0	80
Project 7	30	0	10	0	80	0
Project 8	0	60	0	0	20	110
Project 9	30	100	90	0	30	0
Project 10	0	20	90	0	80	100

Table 4.4: Demand estimations for the available projects.

If we accept that each employee can work 200 days in a year without overtime, the total demand, sum of demands of ten projects, in the first scenario is almost 42% more than the available capacity while the second scenario gives an excess around 46%. Therefore, some of the projects should be eliminated. For this selection, we used our mathematical models and found that it is optimal to work on six projects considering the skills and interactions of the employees. If the first scenario is realized, the projects 1, 4, 5, 6, 7, and 9 can be completed. When the objections raised about demand estimations are taken into consideration, the project portfolio should consist of the projects 1, 2, 4, 5, 7, and 9. However, the robust model helps us to consider both of the scenarios and gives the optimal projects to be completed as 1, 4, 5, 6, 7, and 9, which is the same set obtained under scenario 1. This shows that although demand requirements change as in the second scenario, the first selection is optimal. It is useful to remind that, for this problem, we used the additional limitation that an employee can work in at most 4 projects.

Overall, these results show the significance of employee structure in our method and illustrates how this structure influences project selection. It can be seen in a simple analysis of the results. According to Table 4.1, the third functional family, Enterprise Solutions, has only two employees while there are three employees in the other families. In addition, the employees of CRM Solutions function in this family have skill levels under 1. Besides, projects 3, 5, 8, and 10 has a lot of requirements in CRM Solutions. Together with the requirements of these projects in other functions, this situation causes the model not to satisfy the demands of projects 3, 8, and 10 while project 5 is selected. Therefore, we can reach the conclusion that restrictions workforce structure cause should be incorporated into the decisions while project selection is conducted.

In the next section, we explain the computational issues regarding the basic and robust models.

4.4 Computational Experiments

To analyze the models, we generated test problems with ILOG OPL Studio 3.6.1 IDE for OPL modeling and solved them with ILOG CPLEX 9.1. The test problems were created with the OPL Script language and solved with a 1.5 GHz mobile Pentium M with 256 MB RAM operating under MS Windows XP Professional. We generated random data using the scheme that is described below. Then, we solved the problems first with the basic model (M_B) to analyze the significance of the factors we used in problem generation. Next, we used the robust model (M_R) to solve problems with demand variations. For both models, we carried out experiments to determine limits on problem sizes that can be solved efficiently.

We designed a $2^5 x 3^2$ full-factorial experiment with the factors and treatment levels described in the next page:

Factor	**Levels**
Number of Employees (nbemployee)	10, 25, 50
Number of Projects (nbproject)	10, 25
Number of Functions (nbfunction)	6, 10
Number of Functional Families (nbgroup)	3, 6
Total Demand/Total Capacity (DC)	0.75, 1.25, 1.75
Coefficient of Variation (CV) in demand	0.1, 0.5
Demand Distribution Among Functions (DF)	0.5, 0.9

Table 4.5: Factors and treatment levels.

The following parameters are created sequentially in problem generation phase:

- Each function is allocated to a functional family, thus every functional family has at least one function.

- A primary function is specified for every employee, and there is at least one employee primarily skilled in each function.

- An employee has a primary function that s/he is skilled in and may have one or more secondary functions of the same family. We use employee skill levels as percentages of a standard employee skill level that ranges from 0 to 1.2. For example, a skill level of 1.2 means the employee may complete 20% more work compared to a 100% qualified employee does in a standard time. Likewise, an employee having the skill level of 0.5 is equivalent to 50% of a fully qualified one in terms of performance. These f_{ik} values are uniformly distributed in the interval 0.8-1.2 for primary functions and 0.1-0.5 for secondary functions.

- We create interaction parameters that are denoted by n_{ik}, which show how much/how many times employee i worked with function k in previous projects. We assume that interaction of an employee is zero for the functions belonging to his/her functional family and is same for all the functions in a functional family. These coefficients are uniformly distributed between 0 and 5.

- All project demands are created according to the total workforce capacity. DC factor shows the rate of total demand of all the available projects over total workforce capacity. Total workforce capacity is computed by multiplying the number of employees with standard working time of an employee. Total demand of all projects is created according to the level of DC, which can be 0.75, 1.25, and 1.75. Then, total demand is distributed normally among projects according to coefficient of variation, CV, which is used in two levels, 0.1 and 0.5. With this method, we create projects having similar total requirements on average. On the other hand, demand of each project is distributed randomly between functions according to the DF factor, which indicates on average in how many functions each project require work. For example, DF = 0.9 means that projects require skills in 90% of all functions on average. When DF is 0.5, work of half of the functions is necessary for each project.

- The last parameters constructed are second demand scenarios that are used in the robust model. In line with its level, demands for functions of each project are increased or decreased by a percent distributed uniformly between 0% and 10%, or 0% and 20%. This makes second demand situations to be less or more than the first ones in a 10% or 20% range.

Our first aim was to examine the significance of the experiment factors. Therefore, we used a three stage framework which can be outlined as follows:

- Solve M_B with respect to the first demand scenario and find R^1.
- Solve M_B with respect to the second demand scenario and find R^2.
- Based on R^1 and R^2 and two demand scenarios, solve M_R.

20 problems for each treatment level (288 levels) were solved to optimality with all three models and results were observed for all of the 5760 problems. Since our

basic purpose was to test factors used, we did not consider solution times, which are less than 1000 CPU seconds for any problem.

4.4.1 Factor Analysis

For factor analysis, we used the optimal results found with the basic model. Initially, we conducted a simple analysis by MS Excel to investigate if our experiment factors are significant. Next, we examined the results statistically with Minitab and we found that all the experiment factors are statistically significant.

Factor	Levels	Number of projects done		
		min #	max #	avg #
nbemployee	**10**	2	25	13.012
	25	2	25	11.801
	50	2	25	12.595
nbproject	**10**	2	10	6.572
	25	5	25	18.367
nbfunction	**6**	2	25	12.389
	10	2	25	12.550
nbgroup	**3**	2	25	13.024
	6	2	25	11.915
DC	**0.75**	3	25	15.727
	1.25	2	23	12.142
	1.75	2	19	9.539
CV	**0.1**	2	25	11.907
	0.5	2	25	13.031
DF	**0.5**	2	25	12.620
	0.9	2	25	12.318

Table 4.6: Optimal number of projects selected with M_B.

In Table 4.6, for each factor and for each treatment level, we report the minimum, maximum and average number of projects M_B selects. Number of functions and demand distribution among functions (DF) do not seem to affect the results while there are visible differences in different levels of the other factors. As expected, the optimal values are higher when there are more projects (number of projects is 25) in the pool of candidate projects. Similarly, there are fewer projects that can be completed in the situations where total demand is more than available capacity (DC = 1.25 and 1.75). According to our data generation scheme, projects become larger in size when DC increases. An interesting result can be observed regarding the factor nbemployee. The number of projects selected is largest when number of employees is 10. Again, this is the result of our data generation scheme, where total project demands are determined according to total workforce capacity and the demand is allocated across projects normally. When number of employees is 10, the project sizes are relatively small. Therefore, a larger number of them can be completed. As for number of groups we see that when there are 3 functional families, more projects are completed compared to the situation where there are 6 functional families. Similarly, there is difference between the two levels of standard coefficient of variation. It is seen that, performance is better when CV is 0.5. This might be due to the fact that a higher variety of project types are generated within this setting.

Predictor	Coef	SE Coef	T	P
Constant	7.6434	0.2041	37.45	0
nbemployee	-0.00613	0.001621	-3.78	0
nbproject	0.786366	0.003565	220.57	0
nbfunction	0.04019	0.01337	3.01	0.003
nbgroup	-0.36979	0.01783	-20.74	0
DC	-6.1875	0.0655	-94.47	0
CV	2.8099	0.1337	21.02	0
DF	-0.7543	0.1337	-5.64	0
R-Sq	**91.00%**			
R-Sq(adj)	**91.00%**			
The regression equation is Number of projects selected = 7.64 - 0.00613 nbemployee + 0.786 nbproject + 0.0402 nbfunction - 0.370 nbgroup - 6.19 DC + 2.81 CV - 0.754 DF				

Table 4.7: Regression results for the optimal number of projects selected with M_B.

The regression results conducted for all the factors are reported in Table 4.7. Since all the factors have *p* values less than 0.05, all the seven factors are statistically significant meaning that the optimal objective value of model (M_B) is sensitive to changes in values of the parameters we have introduced.

Source	DF	SS	MS	F	P
Nbemployee	2	1453.1	726.5	364.61	0
Nbproject	1	200352.2	200352.2	100545.9	0
Nbfunction	1	37.2	37.2	18.68	0
Nbgroup	1	1772.2	1772.2	889.38	0
DC	2	37061.9	18530.9	9299.67	0
CV	1	1819.1	1819.1	912.92	0
DF	1	131.1	131.1	65.79	0
nbemployee*nbproject	2	326.1	163.1	81.83	0
nbemployee*nbfunction	2	1572.7	786.4	394.64	0
nbemployee*nbgroup	2	162.1	81.1	40.69	0
nbemployee*DC	4	19.9	5	2.5	0.041
nbemployee*DF	2	133.9	66.9	33.59	0
nbproject*nbgroup	1	212.8	212.8	106.77	0
nbproject*DC	2	5987	2993.5	1502.28	0
nbproject*CV	1	338.8	338.8	170.04	0
nbproject*DF	1	185.3	185.3	92.97	0
nbfunction*nbgroup	1	20.7	20.7	10.37	0.001
nbfunction*DC	2	46.8	23.4	11.75	0
nbfunction*DF	1	55	55	27.62	0
nbgroup*DC	2	17.9	9	4.5	0.011
nbgroup*DF	1	13.5	13.5	6.78	0.009
DC*CV	2	690.4	345.2	173.24	0
DC*DF	2	41.6	20.8	10.43	0
CV*DF	1	10.8	10.8	5.4	0.02
nbemployee*nbproject*nbfunction	2	241.4	120.7	60.58	0
nbemployee*nbproject*nbgroup	2	43.7	21.9	10.97	0
nbemployee*nbproject*DF	2	27.8	13.9	6.97	0.001
nbemployee*nbfunction*nbgroup	2	65.2	32.6	16.36	0
nbemployee*nbfunction*DC	4	36.9	9.2	4.63	0.001
nbemployee*nbfunction*DF	2	44.6	22.3	11.19	0
nbemployee*nbgroup*DF	2	19.6	9.8	4.93	0.007
nbproject*nbfunction*nbgroup	1	8.2	8.2	4.1	0.043
nbproject*nbfunction*DF	1	9.3	9.3	4.65	0.031
nbproject*nbgroup*CV	1	9.1	9.1	4.57	0.033
nbproject*nbgroup*DF	1	8	8	4.03	0.045
nbproject*DC*CV	2	203.6	101.8	51.1	0
nbproject*DC*DF	2	57.2	28.6	14.35	0
Error	5472	10903.8	2		
Total	5759	264612.6			
R-Sq	95.88%				
R-Sq(adj)	95.66%				

Table 4.8: ANOVA results for the optimal number of projects done with M_B.

In line with the findings from the regression analysis, Table 4.8 shows the ANOVA results that illustrates the significances of the factors. In this table, only the significant interactions with up to three factors are presented while the whole table can be seen in Appendix A. Interpreting this table, we reach the result that there are significant interactions among factors.

In order to see how significant interactions might affect our previous interpretation of the main factors, we look at the interaction plots that depict two-way interactions between all the factors in Figure 4.4. As displayed in the figure, a majority of the plots contain lines with similar slopes meaning that interactions between these factors do not complicate our previous analysis. However, we can reach further conclusions with unparallel lines and understand how interactions between some factors may have significant impact on results.

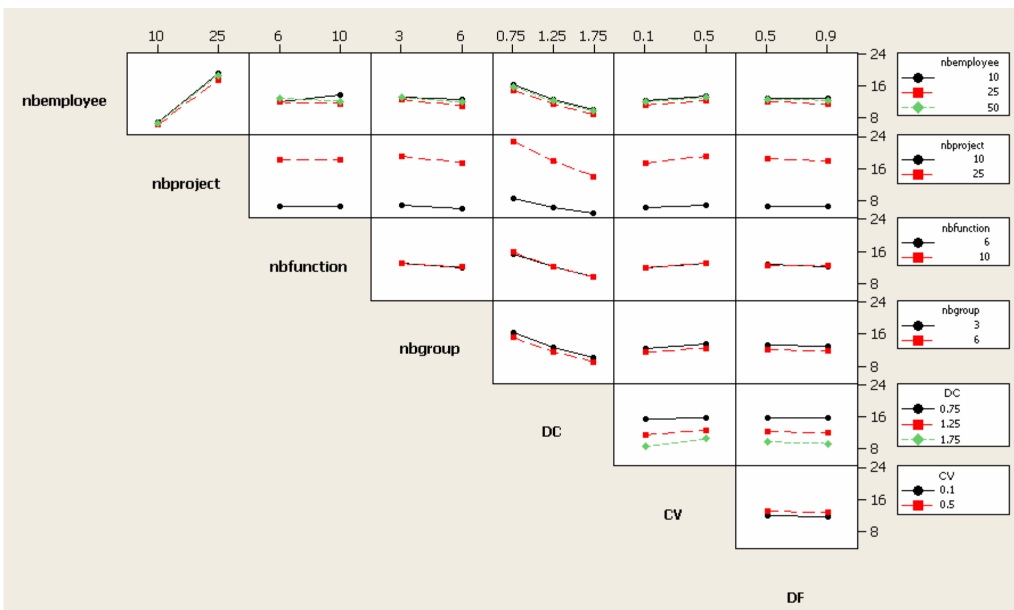

Figure 4.4: Two way interactions for all the factors used in M_B.

We present examples of two different situations in Figure 4.5 and 4.6. Figure 4.5 shows the interaction plot for the factors nbproject and nbfunction. Since the lines are flat and parallel, we can conclude that the interaction between these factors does not affect our interpretation of factors. On the other hand, another explanation is required for situations where we do not see parallel lines. As the unparallel lines in Figure 4.6 illustrate, levels of nbfunction factor have an impact on the results when number of employees is 10, unlike the cases where number of employees is equal to 25 or 50. Originally, we did not see any difference between the two levels of nbfunction. However, this analysis shows that interaction of nbfunction with nbemployee might lead to different interpretations depending on the level of nbemployee. The same explanation is also relevant for the interactions between nbgroup and nbemployee.

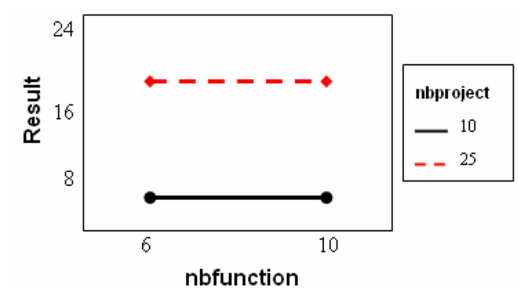

Figure 4.4: Two-way interactions between nbfunction and nbproject.

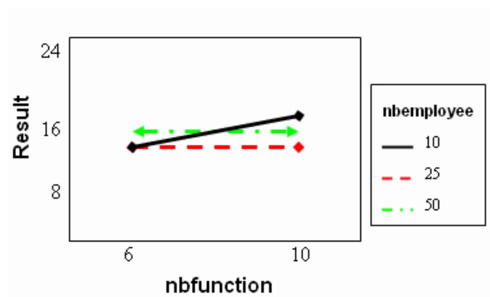

Figure 4.5: Two-way interactions between nbfunction and nbemployee.

Finally, we built confidence intervals to verify the preliminary observations we have made for the analysis of the main factors. The details of this analysis can be found in Appendix B. Overall, our conclusions can be summarized as follows:

- All the factors are significant and there are significant interactions among them.

- When the number of projects increases, the number of projects selected increases accordingly. This is an expected finding because of our data generation scheme.

- As expected, DC showing the total demand of all projects with respect to total capacity seems to be a very influential factor that affects optimal number of projects done. When DC is high, the number of projects that are done decreases. Because total demand is normally distributed between projects, when DC increases demand of all projects increase which may cause the shortage of enough capacity.

- In the situations where number of employees equals to number of functions, which is present when number of functions and number of employees are equal to 10, optimal number of projects done is at its highest level. This can be attributed to the symmetric feature of this situation. In data generation, project sizes (according to total requirements) are constructed according to the overall employee capacity and the size of projects is minimum when number of employees is 10. Besides, when nbfunction is also 10, there is only one employee who is primarily skilled in each function and there is a balanced distribution of primary skills. Therefore, this situation can be accepted to be more advantageous compared to situations where nbemployee is higher or nbfunction is smaller.

4.4.2 Analysis of the Basic Model (M_B)

nbemployee	100	200	300	100	200	300	100	200	100	100	200	500	200
nbproject	25	25	25	40	40	40	100	100	25	25	50	25	100
nbfunction	10	10	10	10	10	10	10	10	20	20	25	10	25
nbgroup	6	6	6	6	6	6	6	6	6	10	10	6	10
Average solving time (seconds)	< 10	< 10	< 50	< 10	< 10	< 100	< 50	< 700	< 10	< 10	< 100	< 150	< 550

Table 4.9: Maximum problem sizes solved efficiently with M_B.

We investigated the efficiency of the basic model according to maximum problem sizes that are solved within the computational environment we use. The results, which can be seen in Table 4.9 (constructed by solving 12 problems for each situation), illustrate that it is efficient to use M_B for maximum problem sizes consisting of 200 employees, 50 projects, 25 functions and 10 functional families. The model is also efficient when there are 500 employees or 100 projects but the efficiency decreases when all the factors are increased to higher numbers altogether.

4.4.3 Analysis of the Robust Model (M_R)

Factor	Levels	Number of projects done		
		min #	max #	avg #
nbemployee	**10**	0.75	1	0.978
	25	0.667	1	0.974
	50	0.667	1	0.981
nbproject	**10**	0.667	1	0.973
	25	0.833	1	0.983
nbfunction	**6**	0.667	1	0.977
	10	0.667	1	0.979
nbgroup	**3**	0.667	1	0.978
	6	0.667	1	0.978
DC	**0.75**	0.75	1	0.983
	1.25	0.75	1	0.974
	1.75	0.667	1	0.976
CV	**0.1**	0.667	1	0.976
	0.5	0.667	1	0.979
DF	**0.5**	0.667	1	0.978
	0.9	0.667	1	0.978

Table 4.10: Analysis of the objective values of M_R according to all factors and treatment levels.

How the robust model works can be seen in Table 4.10. Since we look at the ratio of number of projects that can be finished when the two demand scenarios are considered independently versus number of projects that can be done considering both demand cases together, the results are between 0 and 1. It is seen that the minimum ratio we reach is 0.667, which means that the optimal number of projects selected with the robust model is at least 66% of the optimal number of projects selected when only one scenario is considered. This minimum value is seen only when the number of projects is 10, which is because only one or two projects that are not completed cause large deviations in this situation. On the other hand, on average, number of projects selected by different demand scenarios separately can be reached by M_R, which is illustrated by the average values that are around 0.97. Overall, we can reach the conclusion that the robust model performs well and optimal number of projects does not change much even when we use M_R that considers two different demand possibilities.

4.5 The Heuristic Method

The robust model poses computational challenges when the problem size is increased beyond the levels we used in our experiments. Therefore, we develop a heuristic method to be used for larger problem sizes. The heuristic works in a simple way such that:

- First, we look at d_{jk} values in each scenario and find the maximum considering all of the scenarios.

- Then the basic model is used to make portfolio selection and employee assignment according to these demands (max{ d^1_{jk} , d^2_{jk} , d^3_{jk} , …, d^n_{jk} }).

As it is seen in Table 4.11, which is constructed comparing the heuristic and optimal results for 5760 problems, the heuristic performs well and there is statistically insignificant deviation from the optimal results in all cases. It is useful to state that the maximum differences always occur in cases when there are 10 projects, which is because the numbers are small in this situation and even a deviation of one project shows a high percentage. Excluding this effect, the analysis illustrates that the heuristic performs well with 0.3% deviation from the optimal result on average and 33% deviation at most, which is the situation where the number of projects is small.

Factor	Levels	Difference between optimal and heuristic results		
		Min	max	Avg
demand range	**10%**	0	0.333	0.004
	20%	0	0.333	0.004
nb employee	**10**	0	0.250	0.004
	25	0	0.333	0.005
	50	0	0.250	0.002
nb project	**10**	0	0.333	0.007
	25	0	0.091	0
nb function	**6**	0	0.333	0.004
	10	0	0.333	0.004
nb group	**3**	0	0.333	0.002
	6	0	0.333	0.005
DC	**0.75**	0	0.167	0.001
	1.25	0	0.333	0.004
	1.75	0	0.333	0.006
CV	**0.1**	0	0.333	0.003
	0.5	0	0.333	0.004
DF	**0.5**	0	0.333	0.005
	0.9	0	0.333	0.003

Table 4.11: Difference between the M_R results and the heuristic results.

Factor	Levels	Difference between optimal and heuristic results		
		min	max	avg
demand range	**50%**	0	0.25	0.014
nb employee	**10**	0	0.25	0.014
nb project	**10**	0	0.25	0.016
	25	0	0.09	0.011
nb function	**6**	0	0.25	0.015
	10	0	0.25	0.011
nb group	**3**	0	0.25	0.013
	6	0	0.25	0.015
DC	**0.75**	0	0.13	0.006
	1.25	0	0.2	0.017
	1.75	0	0.25	0.018
CV	**0.1**	0	0.25	0.014
	0.5	0	0.25	0.013
DF	**0.5**	0	0.25	0.018
	0.9	0	0.2	0.010

Table 4.12: Difference between the M_R results and the heuristic results (demand range is 50%)

Since we used small demand range factors in the previous analysis, there could be a possibility that the heuristic may not perform well when the demand range becomes wider. Therefore, we introduced a third level for the demand range factor, which is 50%, and tested the method for 825 problems created with this factor and the level of 10 for the number of employees factor. The heuristic performance for these tests can be seen in Table 4.12. Analyzing the differences, it can be concluded that the heuristic performs well, with 1% difference on average, even when the estimations deviate in a 50% range. It is also evident that, maximum percentage difference is higher in case there are 10 projects, which is because of the same fact that is explained in the previous paragraph.

Examining Table 4.11 and 4.12, we can conclude that our heuristic method performs well and it is also more efficient than the robust model since more than two demand scenarios can be incorporated into it without bringing computational difficulties. The problem does not become harder when solved with the heuristic when number of demand scenarios increases because we take the maximums and solve the model based on the satisfaction of one unified scenario constructed as such.

4.6 Example (Cont.)

When we use the heuristic method to solve the project selection problem of Expert IT, the resulting portfolio includes the projects 1, 2, 4, 5, 7, and 9. Although the number of projects selected does not diverge, this result is different from what we find with the robust model. However, this portfolio is similar to the result found by the second demand scenario solved with the basic model. This is because the method conducts the selection according to the maximum demands and the second scenario has more requirements compared to the first one.

4.7 Implementation Issues

When our approach is used in real life settings, some implementation issues may appear. We present some of these issues in this section considering the approach we set up.

- In the setting we studied, it is not a common practice that employees are cross-trained or allowed to work in distinct functional families, but we can remove this limitation without any modification in the model. Since we used this assumption only in our data generation phase and our model is not restricted in this fashion, the model can be used when employee cross-training is not limited.

- In addition, team size seems to be an important issue that may affect the performance of and communication between the employees. According to Burke (1993), some factors affect team size such as the variety of technical expertise required, number of people necessary to process all the project data and affordable rate of team conflict. In case of conflict, he notes that more people cause conflict to increase but few people bring the dominance of one person. According to his study, an ideal team consists of between five and ten people. Daft (1999) suggests that an ideal team consists of seven people, although a team of 5 to 12 people can also be successful, which is consistent with the arguments of Burke (1993). As studies suggest, determining a limit for the number of people assigned to each project would be useful. Therefore, we may add a simple constraint to the models to limit the team sizes, which is represented below:

  $$TL \leq \sum_i x_{ij} \leq TU \quad \forall j$$

  where TL and TU are the lower and upper bounds on the number of employees assigned to a project respectively.

– Similar to team size restrictions, lower and upper bounds can be used for the number of projects each employee can be assigned to. If the aim is to increase motivation of employees in the projects, there can be a limit on the number of projects each employee is assigned to. With this limitation, the distraction that may be caused by various tasks of different projects or communication problems caused by more people can be decreased. In the case where the motivation is to increase interaction between employees, there can be a lower bound for the number of projects each employee is assigned to and the communication possibilities among employees would be improved accordingly. Using *LC* and *UC*, which are lower bound and upper bound on the number of projects an employee can be assigned to respectively, we can add a simple constraint in our models:

$$LC \leq \sum_{j} x_{ij} \leq UC \quad \forall i$$

These controls can be used in different ways in practice. For example, in the R&D department of Arçelik, which is one of the biggest durable goods companies in Turkey and has operations globally, there are around 500 employees and 90 active projects in a year and one employee works in four projects on the average (Arçelik, 2006).

– How to quantify the parameters used is also important for the mathematical models proposed. As we briefly talk about in the literature review part, there are a lot of techniques used for the evaluation of employee skills. Although we do not give a detailed description, we assume that functional skills may be computed and updated by a learning curve based approach or the available skill scores of employees can be normalized in a way to be used in our methodology. Interactions, on the other hand, can be calculated in a simple way. For example, number of projects an employee worked with projects requiring tasks of a specific function, which is out of his/her functional family, can be the interaction parameter for this employee as was displayed in our example in Section 4.3.

Chapter 5

EXTENSIONS

We study project selection and assignment of employees to the projects simultaneously but in the previous chapter we only analyzed project selection based on skill satisfaction and interaction concepts. The aim of the previous analysis is to construct mathematical models for project selection on the basis of human resources considerations. In this chapter, we introduce the so-called financial constraints to the project selection approach we built up and incorporate leader selection issue into our models.

5.1 Project Selection with Project Attributes and the Budget

Project selection is a popular issue since it is not possible to work on all the available projects because of limited resources such as people, money and time. Therefore, it is crucial to evaluate projects considering project scope, objectives, required resources, possible risks and returns. For this evaluation, it is essential to analyze if the project outputs are relevant to the markets the company operates in, if it is possible to provide the required employee structure with the existing workforce and if the budget requirements of the projects can be covered with the available resources. Thus, selection procedure should include the project characteristics and their compatibility with overall company objectives, markets targeted, and available resources. Upper level management should perform risk evaluation before project selection because external project risks and some of the internal ones cannot be captured or tackled in project execution stages (Project Management Manual, 2002). In this section, we introduce a new project selection model where new parameters that represent project characteristics such as project performance and cost, and available budget are included.

To evaluate and compare the projects and select among them, companies should measure or forecast project risks and returns. Different criteria can be used to evaluate project characteristics. Some of the techniques on project evaluation are presented in the literature review chapter, but we do not give a methodology for this. Instead, we accept that project assessment is performed beforehand and parameters are quantified, thus we conduct selection considering these parameters. For this decision, a method different from the classical methods is used. Project portfolio selection in the classical sense is conducted mostly through a procedure based on financial analysis of projects. Two optimization models for project selection are presented in Chapter 2 to show the classical approach that comprise of risk, return and cost factors. The capital rationing model in Badiru (1993) aims to maximize return on investment considering project cost and available budget. On the other hand, the approach of Eben-Chaime (2000) is based on parametric weighing of project risks and returns in project selection. Our method includes the budget constraint both of these models have and possesses a similar objective Badiru proposes, but the parameter we use for project characteristic is not the same as what he uses. The motivation behind changing the meaning of this parameter is to include a broader analysis that may include a wide range of project features that are risk and return, or strategic importance of the projects in the classical selection literature. Because the aim of this study is to involve benefits and constraints human resources may cause in a decision making system, the optimization model, which is explained in the next section, is constructed by inserting Badiru's model into the basic model with some modifications in the definition of the parameters.

5.1.1 The Selection Model (M_S)

The additional parameters we introduce for M_S are :

v_j: expected value of project j

c_j: cost of project j

B: available budget

The objective of this model is:

$$\max \quad \sum_j v_j * z_j$$

Although Badiru (1993) specifies v_j as a parameter related to return on investment, v_j is assumed to be the weight of project j determined through a project evaluation stage. The evaluation may include an analysis of project's risks, returns, and/or strategic importance and should determine a weight for each candidate project. On the other hand, the constraint set of Badiru, which is given below, has a similar function in our model. Given that, project costs are known or estimated, adding (5.2) into the constraint sets of the basic model, we ensure that selected projects do not violate budget constraints.

$$\sum_j c_j * z_j \leq B$$

Thus, model M_S becomes:

$$\max \quad \sum_j v_j * z_j \qquad (5.1)$$

subject to:

$$\sum_j c_j * z_j \leq B \qquad (5.2)$$

(4.2) – (4.11).

We reconsider the project selection problem of Expert IT in the next section with a new approach where M_S is used.

5.1.2 Expert IT – Project Selection

At this stage, we look at the problem of Expert IT considering the project selection model we develop here. We also compare the results found with our model and the results Badiru's model produces.

We know that, Expert IT allocates $40,000 for the overall project budget in 2006 and has project evaluations and costs presented in Table 5.1.

Projects	***Weights***	***Costs ($)***
Project 1	10	10000
Project 2	9	6000
Project 3	10	3000
Project 4	8	2000
Project 5	6	8000
Project 6	8	10000
Project 7	5	15000
Project 8	8	5000
Project 9	4	2000
Project 10	9	6000

Table 5.1: Project characteristics based on the evaluations

Solving the selection problem with M_S gives the project portfolio consisting of projects 1, 2, 3, 4, 6, and 7. On the other hand, Badiru's method, where the model consists of only (5.1) and (5.2), selects eight projects which are 1, 2, 3, 4, 7, 8, 9, and 10. This gives us a simple representation of what our model brings into the project selection process with the introduction of the employee constraints. If the project selection is conducted without considering the human resources, such as Badiru's model does, resulting selection may not be possible to implement. When skills, interactions and capacity of employees are considered, our method provides a more realistic selection.

5.2 Project Leader Selection

In the literature review part, it is said that leadership is a popular concept in project management research. Although there are many studies on characteristics, skills and behaviors of leaders conducted by various scholars from behavioral sciences and industrial organization, we limit our scope to leadership in project management. There is not a consensus in project management studies about project leaders. Also, there are two kinds of leaders, functional and project leaders, in the structures we study in project management. However, our leadership approach is limited to project leaders who are specific to each project and has the responsibility of managing all the activities involved in this project.

As we reviewed studies on how project leaders should be and how to choose a leader for project teams, we found some basic leadership characteristics that are accepted by the majority. It is commonly accepted that project leaders should have some core skills about the projects they lead. According to El-Sabaa (2001), skills related to communication are more important than technical skills. This suggestion is based on the idea that a project leader, should communicate his ideas to high level management and his team members while he could understand their ideas and desires. Also, s/he should look at the project with a wide perspective that includes the features of the organization, the overall strategies, available resources and means, and the factors related to employee motivation. Therefore, it is better for her/him to have interaction with as many functions as possible. It is also ideal for a leader to have high skill scores. These issues are important to evaluate leadership abilities of leaders. However, we do not propose a method for the evaluation of these skills. Instead, we assume that all employees are assessed in terms of leadership abilities they possess according to a method similar to 360º assessment, which is briefly explained in Chapter 2. Therefore, we incorporate leader selection into the basic model accepting that leadership scores are known for each employee. The model in the next section is an extension of the basic model. It is constructed with some additional constraints and a modification in the objective function.

5.2.1 Leader Selection Model (M_L)

For M_L, we add the additional parameters that are described below:

l_{ij}: leadership score of employee *i* in project *j*

L: weight assigned to the effect of leader assignment in the overall project selection

We assume that leadership score can be zero for the employees who do not meet required criteria specified by the organizations and it is greater than 0 for the others.

We also introduce a new decision variable for this model, which is:

$$a_{ij} : \begin{cases} 1, & \text{if employee } i \text{ is assigned as the leader of project } j \\ 0, & \text{otherwise} \end{cases}$$

Model M_L can be expressed as:

$$\max \sum_j z_j + L * (\sum_i \sum_j a_{ij} * l_{ij}) \qquad (5.3)$$

subject to:

$$a_{ij} \le x_{ij} \qquad \forall i, j \qquad (5.4)$$

$$\sum_j a_{ij} \le 1 \qquad \forall i \qquad (5.5)$$

$$\sum_i a_{ij} = z_j \qquad \forall i, j \qquad (5.6)$$

$$a_{ij} \le l_{ij} \qquad \forall i, j \qquad (5.7)$$

(4.2) – (4.11).

The objective function (5.3) maximizes total number of projects done in the period and total leadership scores provided by assignments of the leaders. *L* is used to give a weight to the importance of leader selection according to the attributes projects have. The decision makers can decide an *L* value according to their priorities. If the projects require a high level of coordination and leaders are crucial for the sake of them, a large value of *L* can be chosen. In the situations where it is not so important who the leader is, *L* can be a small value.

Constraint set (5.4) requires that in order to be the leader of a project the employee should be assigned to that project. Constraint set (5.5) ensures that each employee can be the leader of at most one project; (5.6) guarantees every project has a leader; and (5.7) requires that in order to be assigned to a leadership position in a project the employee should have a leadership score in that function.

With this model, we select projects for the period and assign a leader for each project with the aim of maximizing total leadership scores. Here the aim is to incorporate leader selection into the decision system and to allocate the most favorable leader for each project together with conducting the optimal project selection.

The leader selection process can be modeled in alternative ways. Below we describe two such examples.

As a first alternative, the second part of the objective function, which shows total leadership score of all the leader assignments weighted with L, can be removed from the objective. Then, a new constraint set, which is presented below, can be introduced.

$$\sum_i a_{ij} * l_{ij} \geq PL \qquad \forall j$$

With this new constraint, we give a lower limit for the leadership scores, which is represented by *PL*, required for each project. *PL* can be determined by decision makers according to the significance of leader skills in the companies

As a second alternative, a 2-stage model can also be used for leader selection. At first, project selection and employee assignment can be conducted according to the previous models we introduced. Then, the employee who has the maximum leadership score for each project among all the employees assigned to that project can be selected as the leader. However, it should not be forgotten that this method does not guarantee that employees selected are suitable for leadership and some modifications may be required. Although there can be other alternatives, we leave it to future studies.

In the next section, the example we look at is reconsidered incorporating the leader selection into the problem and using the first model we proposed here.

5.2.2 Expert IT – Leader Selection

Projects	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Employee 1	7	0	3	6	0	2	7	2	2	0
Employee 2	3	1	4	0	4	10	6	5	1	2
Employee 3	7	5	3	0	0	2	4	8	10	3
Employee 4	1	3	7	9	2	5	2	6	2	8
Employee 5	2	1	4	3	0	6	10	0	8	9
Employee 6	5	6	7	2	0	3	4	0	6	0
Employee 7	9	6	1	4	10	0	9	7	5	5
Employee 8	5	4	6	8	9	0	9	0	5	5

Table 5.2: Leadership scores of employees.

We know that leader selection is not a crucial part of project selection in Expert IT, but they want to have a good leader assignment plan for the selected project portfolio. Therefore, they determine leader assignment weight as 0.001. To investigate how leaders are assigned, we need the leadership scores of employees in Expert IT, which are presented in Table 5.2.

The best leader assignment plan performed by the model is given in Table 5.3. Investigating the table, we see the same project set that we found with the basic model. This is because leader selection has a small effect on results since L=0.001.

Projects chosen	**Leader**
Project 1	Employee 7
Project 4	Employee 4
Project 5	Employee 8
Project 6	Employee 2
Project 7	Employee 5
Project 9	Employee 3

Table 5.3: Leader assignments.

Chapter 6

DISCUSSIONS AND CONCLUSIONS

In most of the project management firms, there is usually a pool of candidate projects that are available to work on in a given period. However, the resources are limited and a set of projects should be selected among the available ones evaluating all the resources and projects in harmony. In the scope of this thesis, we aimed to establish a modeling framework for project selection in such multi-project situations based on human resources considerations. The main objective of this study was to determine important issues and formulate the problem in a logical way, thus we first examined studies in HR and OM fields related to workforce management and project portfolio selection. Then, we intended to extend the literature on project selection and workforce planning by studying specific issues such as employee skills and interactions and demand uncertainty in a new project selection approach. For this purpose, we worked on a few project selection algorithms that perform project selection and employee assignment concurrently. Our approach is significant in the literature because it frames portfolio selection and employee assignment in one formulation and includes employee related constraints in project selection decisions. Besides, we attempt to make a contribution to the literature with the concept of interaction that has not been studied before. With interaction, we present the effect of familiarity of employees with outside functions on project performances.

In this thesis, we formulated our project selection problem in four mixed-integer optimization models and a heuristic method including different objectives in each one. At first, we proposed a basic model, M_B, to select projects for the portfolio and assign employees to specific functions in these projects including constraints related to human resources. M_B serves for our basic purpose which is to include human resources as a major building block in project selection decisions. The basic model is efficient for a wide range of problem sizes such as problems with 500 employees or 100 projects, but its efficiency decreases when the problems are increased to larger sizes. This model is significant since it is the basis for the other models that we present in different sections and is used to analyze the factors used. We experimented with different tools for factor analysis. Initially, we inspected the results in Excel. Then, we used Minitab for statistical analysis and applied the results found by regression analysis, ANOVA, interactions plot, and confidence interval analysis. Overall, we found that all the factors we introduced are statistically significant and ANOVA results support the notion that there are significant interactions between the factors. The most evident result found is that number of projects selected increases accordingly when available number of projects are increased. As expected, optimal number of projects selected is sensitive to variations in project demand. Consequently, optimal number of projects done found to be in its highest level in the situations where number of employees equals to number of functions, which is the result of our data generation scheme.

Different from the basic model, we included the effect of variations in demand estimations in the problem formulation with the robust model, M_R, and with the heuristic approach. The robust model selects projects and assigns employees based on two different scenarios that take account of uncertainties in demand estimations. This model performed well and optimal number of projects did not change much even when we solved the same set of problems with M_R. However, the robust model poses computational challenges when the problem size is increased beyond the levels we used in our experiments or when more than two demand scenarios are introduced. Therefore, a heuristic procedure was built to work on more than two demand scenarios in an easier way. Analysis of the heuristic showed that it performs well and there is statistically insignificant deviation, 0.3%, on average from the optimal results found with M_R in all the cases. On the whole, with these two methods, we formulated selection of projects with newly introduced human resources constraints when there are deviations in demand estimations.

After the two models and the heuristic approach are analyzed, we discussed some implementation issues to point out important topics that we see in diverse literature areas we reviewed and that are relevant for our models. In this part, we talked about and proposed recommendations on four major topics: unrestricted cross-training situations, limits on team size, limits on number of projects an employee can be assigned to, and how to quantify the parameters related to employee skills and interactions. In a possible extension of the study, constraints offered for team size and assignment restrictions can be attached to the basic model and investigated with computational experiments. Different approaches for quantifying employee characteristics and its effects on formulations can also be the subject of a further study.

In the last chapter, we built two models where we extended the basic model to cover two important topics, the effects of project attributes and project leaders in project selection. The first extended model, M_S, includes additional parameters and constraints related to project attributes and budget considerations. With this model, we presented a selection process that includes a wide range of factors related to project features together with human resources constraints. A future study may look at computation of project costs based on chargeable human resources costs. Project leaders, who occupy much of the studies in project management literature, are included in our thesis with the second extended model, M_L, that integrates project leader selection to our basic model. The alternatives presented for this model can be used according to the characteristics of the situation and preferences of the decision makers.

Considering all the work carried out during this study, there are some other promising future work directions. Although we could not work on real data in this study, it would be valuable if the models we presented here are applied to a real problem in a future work. The models we presented can be implemented within a decision support system structure that also integrates book-keeping facilities for our model parameters such as employee skill levels and interactions. In addition, a further study can be structured through the usage of functional skills of employees as experiment factors and evaluation of different cross-training structures based on this. This would provide valuable guidelines regarding cross-training policies to be employed by firms. Moreover, the impact of alternative organizational structures, such as the existence or lack of functional family definitions and restrictions, can be experimented with. We believe that our study constitutes a simple and basic representation of the project selection problem with human resources constraints. Therefore, our models can be used as building blocks in simulation experiments that are designed to explore how to select, train, organize, and assign this valuable resource. Finally, similar simulation experiments with the basic model might help develop some indices that relate the suitability of human resources with the requirements of the projects. These indices can be used to examine if there are visible patterns between the workforce structure and resulting selections. If some conclusions about the selections can be reached, heuristic methods for selecting projects might be developed.

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Appendix A

Source	DF	SS	MS	F	P
Nbemployee	2	1453.1	726.5	364.61	0
Nbproject	1	200352.2	200352.2	100545.9	0
Nbfunction	1	37.2	37.2	18.68	0
Nbgroup	1	1772.2	1772.2	889.38	0
DC	2	37061.9	18530.9	9299.67	0
CV	1	1819.1	1819.1	912.92	0
DF	1	131.1	131.1	65.79	0
nbemployee*nbproject	2	326.1	163.1	81.83	0
nbemployee*nbfunction	2	1572.7	786.4	394.64	0
nbemployee*nbgroup	2	162.1	81.1	40.69	0
nbemployee*DC	4	19.9	5	2.5	0.041
nbemployee*CV	2	9	4.5	2.25	0.106
nbemployee*DF	2	133.9	66.9	33.59	0
nbproject*nbfunction	1	7.2	7.2	3.59	0.058
nbproject*nbgroup	1	212.8	212.8	106.77	0
nbproject*DC	2	5987	2993.5	1502.28	0
nbproject*CV	1	338.8	338.8	170.04	0
nbproject*DF	1	185.3	185.3	92.97	0
nbfunction*nbgroup	1	20.7	20.7	10.37	0.001
nbfunction*DC	2	46.8	23.4	11.75	0
nbfunction*CV	1	0	0	0.01	0.933
nbfunction*DF	1	55	55	27.62	0
nbgroup*DC	2	17.9	9	4.5	0.011
nbgroup*CV	1	0.2	0.2	0.09	0.758
nbgroup*DF	1	13.5	13.5	6.78	0.009
DC*CV	2	690.4	345.2	173.24	0
DC*DF	2	41.6	20.8	10.43	0
CV*DF	1	10.8	10.8	5.4	0.02
nbemployee*nbproject*nbfunction	2	241.4	120.7	60.58	0
nbemployee*nbproject*nbgroup	2	43.7	21.9	10.97	0
nbemployee*nbproject*DC	4	9.1	2.3	1.14	0.338
nbemployee*nbproject*CV	2	1.4	0.7	0.36	0.696
nbemployee*nbproject*DF	2	27.8	13.9	6.97	0.001
nbemployee*nbfunction*nbgroup	2	65.2	32.6	16.36	0
nbemployee*nbfunction*DC	4	36.9	9.2	4.63	0.001
nbemployee*nbfunction*CV	2	7.9	3.9	1.97	0.14
nbemployee*nbfunction*DF	2	44.6	22.3	11.19	0
nbemployee*nbgroup*DC	4	17.7	4.4	2.22	0.065
nbemployee*nbgroup*CV	2	0.3	0.1	0.06	0.937
nbemployee*nbgroup*DF	2	19.6	9.8	4.93	0.007

Table A.1: ANOVA results for the optimal number of projects done with M_B.

Source	DF	SS	MS	F	P
nbemployee*DC*CV	4	2.2	0.5	0.27	0.895
nbemployee*DC*DF	4	7.5	1.9	0.93	0.443
nbemployee*CV*DF	2	3.1	1.5	0.77	0.462
nbproject*nbfunction*nbgroup	1	8.2	8.2	4.1	0.043
nbproject*nbfunction*DC	2	2.9	1.4	0.72	0.489
nbproject*nbfunction*CV	1	1.4	1.4	0.69	0.406
nbproject*nbfunction*DF	1	9.3	9.3	4.65	0.031
nbproject*nbgroup*DC	2	0.9	0.5	0.23	0.797
nbproject*nbgroup*CV	1	9.1	9.1	4.57	0.033
nbproject*nbgroup*DF	1	8	8	4.03	0.045
nbproject*DC*CV	2	203.6	101.8	51.1	0
nbproject*DC*DF	2	57.2	28.6	14.35	0
nbproject*CV*DF	1	0	0	0.02	0.889
nbfunction*nbgroup*DC	2	2.1	1.1	0.54	0.585
nbfunction*nbgroup*CV	1	1.3	1.3	0.66	0.417
nbfunction*nbgroup*DF	1	1	1	0.52	0.472
nbfunction*DC*CV	2	4.9	2.5	1.24	0.29
nbfunction*DC*DF	2	9.6	4.8	2.41	0.09
nbfunction*CV*DF	1	0	0	0.01	0.903
nbgroup*DC*CV	2	1.1	0.6	0.29	0.752
nbgroup*DC*DF	2	0.2	0.1	0.05	0.947
nbgroup*CV*DF	1	0.1	0.1	0.03	0.859
DC*CV*DF	2	4.1	2	1.03	0.359
nbemployee*nbproject*nbfunction*nbgroup	2	6.8	3.4	1.71	0.18
nbemployee*nbproject*nbfunction*DC	4	31.4	7.8	3.94	0.003
nbemployee*nbproject*nbfunction*CV	2	0.3	0.1	0.07	0.932
nbemployee*nbproject*nbfunction*DF	2	13.9	6.9	3.48	0.031
nbemployee*nbproject*nbgroup*DC	4	16	4	2.01	0.091
nbemployee*nbproject*nbgroup*CV	2	1.2	0.6	0.3	0.739
nbemployee*nbproject*nbgroup*DF	2	15.3	7.6	3.83	0.022
nbemployee*nbproject*DC*CV	4	2.8	0.7	0.36	0.84
nbemployee*nbproject*DC*DF	4	19.7	4.9	2.47	0.043
nbemployee*nbproject*CV*DF	2	2.4	1.2	0.61	0.545
nbemployee*nbfunction*nbgroup*DC	4	16.6	4.1	2.08	0.081
nbemployee*nbfunction*nbgroup*CV	2	7.6	3.8	1.9	0.15
nbemployee*nbfunction*nbgroup*DF	2	2.7	1.4	0.69	0.504
nbemployee*nbfunction*DC*CV	4	6	1.5	0.75	0.56
nbemployee*nbfunction*DC*DF	4	13.5	3.4	1.69	0.15
nbemployee*nbfunction*CV*DF	2	2.3	1.1	0.57	0.565
nbemployee*nbgroup*DC*CV	4	6	1.5	0.76	0.554
nbemployee*nbgroup*DC*DF	4	2.8	0.7	0.35	0.847
nbemployee*nbgroup*CV*DF	2	0.7	0.4	0.18	0.832
nbemployee*DC*CV*DF	4	19.3	4.8	2.42	0.046
nbproject*nbfunction*nbgroup*DC	2	2.2	1.1	0.54	0.58
nbproject*nbfunction*nbgroup*CV	1	3	3	1.5	0.221
nbproject*nbfunction*nbgroup*DF	1	0.5	0.5	0.24	0.621

Table A.1 (cont.): ANOVA results for the optimal number of projects done with M_B.

Source	DF	SS	MS	F	P
nbproject*nbfunction*DC*CV	2	3.1	1.6	0.78	0.458
nbproject*nbfunction*DC*DF	2	3.3	1.6	0.82	0.441
nbproject*nbfunction*CV*DF	1	0	0	0.01	0.918
nbproject*nbgroup*DC*CV	2	2	1	0.5	0.609
nbproject*nbgroup*DC*DF	2	2.4	1.2	0.6	0.551
nbproject*nbgroup*CV*DF	1	0	0	0.01	0.933
nbproject*DC*CV*DF	2	15.3	7.7	3.85	0.021
nbfunction*nbgroup*DC*CV	2	0.1	0.1	0.03	0.968
nbfunction*nbgroup*DC*DF	2	2.6	1.3	0.64	0.526
nbfunction*nbgroup*CV*DF	1	0	0	0	0.978
nbfunction*DC*CV*DF	2	1.9	0.9	0.47	0.625
nbgroup*DC*CV*DF	2	2	1	0.51	0.602
nbemployee*nbproject*nbfunction*nbgroup*DC	4	14	3.5	1.75	0.135
nbemployee*nbproject*nbfunction*nbgroup*CV	2	0.3	0.1	0.06	0.939
nbemployee*nbproject*nbfunction*nbgroup*DF	2	0.1	0.1	0.03	0.969
nbemployee*nbproject*nbfunction*DC*CV	4	1.7	0.4	0.22	0.928
nbemployee*nbproject*nbfunction*DC*DF	4	16.5	4.1	2.07	0.082
nbemployee*nbproject*nbfunction*CV*DF	2	0.4	0.2	0.09	0.912
nbemployee*nbproject*nbgroup*DC*CV	4	5.6	1.4	0.7	0.592
nbemployee*nbproject*nbgroup*DC*DF	4	3.8	0.9	0.48	0.753
nbemployee*nbproject*nbgroup*CV*DF	2	3.9	2	0.99	0.373
nbemployee*nbproject*DC*CV*DF	4	20.5	5.1	2.57	0.036
nbemployee*nbfunction*nbgroup*DC*CV	4	11.2	2.8	1.41	0.229
nbemployee*nbfunction*nbgroup*DC*DF	4	0.3	0.1	0.04	0.998
nbemployee*nbfunction*nbgroup*CV*DF	2	8.1	4	2.02	0.132
nbemployee*nbfunction*DC*CV*DF	4	5.6	1.4	0.71	0.588
nbemployee*nbgroup*DC*CV*DF	4	4.5	1.1	0.56	0.691
nbproject*nbfunction*nbgroup*DC*CV	2	3.7	1.9	0.94	0.392
nbproject*nbfunction*nbgroup*DC*DF	2	0.2	0.1	0.06	0.943
nbproject*nbfunction*nbgroup*CV*DF	1	0.3	0.3	0.15	0.702
nbproject*nbfunction*DC*CV*DF	2	8.1	4	2.03	0.132
nbproject*nbgroup*DC*CV*DF	2	6.8	3.4	1.71	0.181
nbfunction*nbgroup*DC*CV*DF	2	0.5	0.3	0.13	0.876
nbemployee*nbproject*nbfunction*nbgroup*DC*CV	4	7.9	2	0.99	0.412
nbemployee*nbproject*nbfunction*nbgroup*DC*DF	4	1.5	0.4	0.18	0.947
nbemployee*nbproject*nbfunction*nbgroup*CV*DF	2	2.3	1.1	0.57	0.567
nbemployee*nbproject*nbfunction*DC*CV*DF	4	11.2	2.8	1.4	0.23
nbemployee*nbproject*nbgroup*DC*CV*DF	4	5	1.2	0.62	0.645
nbemployee*nbfunction*nbgroup*DC*CV*DF	4	1.5	0.4	0.19	0.943
nbproject*nbfunction*nbgroup*DC*CV*DF	2	1	0.5	0.24	0.783
nbemployee*nbproject*nbfunction*nbgroup*DC*CV*DF	4	5.2	1.3	0.65	0.625
Error	5472	10903.8	2		
Total	5759	264612.6			
R-Sq	95.88%				
R-Sq(adj)	95.66%				

Table A.1 (cont.): ANOVA results for the optimal number of projects done with M_B.

Appendix B

CONFIDENCE INTERVAL ANALYSIS

To generate a more detailed statistical analysis, we have constructed confidence intervals for the means of optimal number of projects selected with M_B. Because minimum sample size required for confidence interval construction is 30, we have removed the effect of the coefficient of variation (CV) factor which was found to be significant but with a very small effect on R-square. This is also important since it facilitates the reporting of the results. The first regression model, which explains the dependent variable optimal number of projects completed as a function of all factors, turned out to be significant with R-square = 91%. Then, we conducted two other regression models, one that did not consider the coefficient of variation as an independent variable and resulted with R-square = 90.4% and the other with the coefficient of variation as the only factor that brought a very low R-square, which was 0.7%. With these tests, it was showed that the effect of this factor can be removed and the resulting situation was suitable for confidence interval computations since our sample size increased to 40 for each set. In addition, to remove the effect of this factor and to lead the analysis further, we used residuals of the last regression model that used coefficient of variation as the only independent variable. For the next step, we computed standard deviations of the optimal results with the help of these residuals and formed the confidence intervals that are shown below in Table A. Even though some of the results reached in the previous section are not proven, we achieved the following conclusions with the confidence intervals analysis:

		nbproject	ngroup	nbfunction	DF	nbemployee	mean	stdev	confidence	confidence interval	
DF	0.75	10	3	6	0.5	10	8.65	1.028	0.319	8.331	8.969
						25	8.85	1.031	0.320	8.530	9.170
						50	9.075	1.201	0.372	8.703	9.447
					0.9	10	8.7	0.968	0.300	8.400	9.000
						25	8.575	1.553	0.481	8.094	9.056
						50	9.2	1.430	0.443	8.757	9.643
				10	0.5	10	9.5	0.830	0.257	**9.243**	**9.757**
						25	8.85	0.858	0.266	8.584	9.116
						50	8.925	1.124	0.348	8.577	9.273
					0.9	10	9.95	0.656	0.203	**9.747**	**10.153**
						25	8.375	1.255	0.389	7.986	8.764
						50	8.975	1.101	0.341	8.634	9.316
			6	6	0.5	10	7.725	1.126	0.349	7.376	8.074
						25	7.8	1.592	0.493	7.307	8.293
						50	8.525	0.971	0.301	8.224	8.826
					0.9	10	7.925	0.817	0.253	7.672	8.178
						25	7.75	1.661	0.515	7.235	8.265
						50	8.175	1.396	0.433	7.742	8.608
				10	0.5	10	9.05	0.885	0.274	**8.776**	**9.324**
						25	7.575	1.235	0.383	7.192	7.958
						50	8.05	1.069	0.331	7.719	8.381
					0.9	10	9.8	0.656	0.203	**9.597**	**10.003**
						25	7.6	1.155	0.358	7.242	7.958
						50	7.75	1.331	0.413	7.337	8.163
		25	3	6	0.5	10	23.225	1.743	0.540	22.685	23.765
						25	23.575	1.915	0.593	22.982	24.168
						50	23.975	1.927	0.597	23.378	24.572
					0.9	10	23.1	1.185	0.367	22.733	23.467
						25	23.25	2.330	0.722	22.528	23.972
						50	24.325	1.318	0.409	23.916	24.734
				10	0.5	10	24.85	0.755	0.234	**24.616**	**25.084**
						25	22.6	2.139	0.663	21.937	23.263
						50	23.7	1.437	0.445	23.255	24.145
					0.9	10	25	0.569	0.176	**24.824**	**25.176**
						25	22.875	2.182	0.676	22.199	23.551
						50	23.925	1.674	0.519	23.406	24.444
			6	6	0.5	10	22.075	1.306	0.405	21.670	22.480
						25	21.25	2.373	0.735	20.515	21.985
						50	22.6	2.252	0.698	21.902	23.298
					0.9	10	22.05	1.483	0.460	21.590	22.510
						25	19.475	3.927	1.217	18.258	20.692
						50	22.6	3.065	0.950	21.650	23.550
				10	0.5	10	24.525	0.902	0.280	**24.245**	**24.805**
						25	21.1	2.083	0.646	20.454	21.746
						50	22.125	2.275	0.705	21.420	22.830
					0.9	10	24.85	0.711	0.220	**24.630**	**25.070**
						25	20.7	2.500	0.775	19.925	21.475
						50	21.775	2.731	0.846	20.929	22.621

Table B.1: Confidence interval analysis.

		nbproject	ngroup	nbfunction	DF	nbemployee	mean	stdev	confidence	confidence interval	
DF	1.25	10	3	6	0.5	10	6.475	0.780	0.242	6.233	6.717
						25	6.7	0.769	0.238	6.462	6.938
						50	6.9	1.047	0.324	6.576	7.224
					0.9	10	6.45	0.789	0.245	6.205	6.695
						25	6.6	1.243	0.385	6.215	6.985
						50	6.875	1.265	0.392	6.483	7.267
				10	0.5	10	6.875	0.597	0.185	**6.690**	**7.060**
						25	6.1	1.083	0.336	5.764	6.436
						50	6.55	0.726	0.225	6.325	6.775
					0.9	10	7.525	0.610	0.189	**7.336**	**7.714**
						25	6.125	0.973	0.301	5.824	6.426
						50	6.825	0.840	0.260	6.565	7.085
			6	6	0.5	10	5.75	0.846	0.262	5.488	6.012
						25	5.875	0.959	0.297	5.578	6.172
						50	6.175	0.984	0.305	5.870	6.480
					0.9	10	5.75	0.904	0.280	5.470	6.030
						25	5.625	1.008	0.313	5.312	5.938
						50	6.225	1.022	0.317	5.908	6.542
				10	0.5	10	6.85	0.729	0.226	**6.624**	**7.076**
						25	5.3	1.072	0.332	4.968	5.632
						50	5.625	0.834	0.259	5.366	5.884
					0.9	10	7.2	0.589	0.183	**7.017**	**7.383**
						25	5.125	0.901	0.279	4.846	5.404
						50	5.55	1.233	0.382	5.168	5.932
		25	3	6	0.5	10	19.125	1.539	0.477	18.648	19.602
						25	18.75	1.919	0.595	18.155	19.345
						50	19.95	1.236	0.383	19.567	20.333
					0.9	10	18.075	1.598	0.495	17.580	18.570
						25	17.675	2.651	0.822	16.853	18.497
						50	19.25	2.131	0.661	18.589	19.911
				10	0.5	10	20.1	0.906	0.281	**19.819**	**20.381**
						25	18.15	1.523	0.472	17.678	18.622
						50	18.825	1.277	0.396	18.429	19.221
					0.9	10	20.775	0.866	0.268	**20.507**	**21.043**
						25	16.875	2.066	0.640	16.235	17.515
						50	17.75	2.613	0.810	16.940	18.560
			6	6	0.5	10	16.95	1.641	0.509	16.441	17.459
						25	17.425	2.048	0.635	16.790	18.060
						50	18.825	1.573	0.488	18.337	19.313
					0.9	10	16.225	1.573	0.488	15.737	16.713
						25	15.55	2.564	0.794	14.756	16.344
						50	17.725	2.406	0.746	16.979	18.471
				10	0.5	10	19.55	1.236	0.383	**19.167**	**19.933**
						25	16.475	1.799	0.558	15.917	17.033
						50	17.125	2.066	0.640	16.485	17.765
					0.9	10	20.375	1.012	0.313	**20.062**	**20.688**
						25	14.575	1.856	0.575	14.000	15.150
						50	15.675	2.425	0.751	14.924	16.426

Table B.1 (cont.): Confidence interval analysis.

		nbproject	ngroup	nbfunction	DF	nbemployee	mean	stdev	confidence	confidence interval	
DF	1.75	10	3	6	0.5	10	5.075	0.600	0.186	4.889	5.261
						25	5.075	0.590	0.183	4.892	5.258
						50	5.525	0.679	0.211	5.314	5.736
					0.9	10	4.95	0.752	0.233	4.717	5.183
						25	5.15	0.793	0.246	4.904	5.396
						50	5.575	0.735	0.228	5.347	5.803
				10	0.5	10	5.3	0.526	0.163	**5.137**	**5.463**
						25	4.8	0.694	0.215	4.585	5.015
						50	4.875	0.719	0.223	4.652	5.098
					0.9	10	5.7	0.621	0.193	**5.507**	**5.893**
						25	4.725	0.805	0.249	4.476	4.974
						50	5.25	0.663	0.206	5.044	5.456
			6	6	0.5	10	4.4	0.947	0.294	4.106	4.694
						25	4.45	0.938	0.291	4.159	4.741
						50	4.975	0.646	0.200	4.775	5.175
					0.9	10	4.325	0.676	0.209	4.116	4.534
						25	4.075	1.185	0.367	3.708	4.442
						50	5.025	0.785	0.243	4.782	5.268
				10	0.5	10	4.9	0.656	0.203	**4.697**	**5.103**
						25	4.025	0.891	0.276	3.749	4.301
						50	4.4	0.684	0.212	4.188	4.612
					0.9	10	5.525	0.519	0.161	**5.364**	**5.686**
						25	4.025	0.734	0.227	3.798	4.252
						50	4.625	0.827	0.256	4.369	4.881
		25	3	6	0.5	10	15.1	1.352	0.419	14.681	15.519
						25	15.4	1.378	0.427	14.973	15.827
						50	16	1.237	0.383	15.617	16.383
					0.9	10	13.925	1.462	0.453	13.472	14.378
						25	13.875	2.519	0.781	13.094	14.656
						50	15.15	1.824	0.565	14.585	15.715
				10	0.5	10	15.9	1.311	0.406	**15.494**	**16.306**
						25	14.525	1.485	0.460	14.065	14.985
						50	14.7	1.484	0.460	14.240	15.160
					0.9	10	16.15	1.301	0.403	**15.747**	**16.553**
						25	13.775	2.010	0.623	13.152	14.398
						50	13.9	2.186	0.677	13.223	14.577
			6	6	0.5	10	13.975	1.235	0.383	13.592	14.358
						25	13.775	1.588	0.492	13.283	14.267
						50	14.975	1.584	0.491	14.484	15.466
					0.9	10	12.825	1.572	0.487	12.338	13.312
						25	11.225	2.471	0.766	10.459	11.991
						50	13.8	2.147	0.665	13.135	14.465
				10	0.5	10	15.5	0.922	0.286	**15.214**	**15.786**
						25	12.9	1.442	0.447	12.453	13.347
						50	13.5	2.035	0.631	12.869	14.131
					0.9	10	16	1.248	0.387	**15.613**	**16.387**
						25	11.525	2.200	0.682	10.843	12.207
						50	12.725	2.128	0.659	12.066	13.384

Table B.1 (cont.): Confidence interval analysis.

VITA

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